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DEVELOPING A LOW IMPACT DEVELOPMENT MODEL ORDINANCE IN NORTHEAST FLORIDA AND SOUTHEAST GEORGIA: PROTECTING THE ST. MARY'S RIVER

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Abstract

Low Impact Development (LID) is an emerging green infrastructure method implemented around the world to combat environmental impacts, especially stormwater runoff pollution. LID has been shown to be a cost-effective means to reduce stormwater runoff volume, nutrients and heavy metals in waterbodies by providing alternate routes for water to flow after interaction with urban and industrial materials. The Northeast Florida Regional Council, in partnership with the Southern Georgia Regional Commission and the Coastal Regional Commission of Georgia, developed the Water Beyond Borders initiative to create a bi-state effort to protect the St. Mary's River, the boundary between the states. The goals of this include a LID model ordinance for all municipalities in Northeast Florida and Southeast Georgia to implement. Water quality data Alligator Creek, Sarasota County, Florida with a completed LID project was statistically analyzed to determine if changes in water quality occurred pre-and post-LID construction to show benefits of this new infrastructure to local policy makers. Water quality analysis shows a decrease in nitrogen load at the outfall sampling site from a LID Stormwater Facility in Sarasota County. Cost-benefit analysis depicts that in most cases, use of LID compared to conventional stormwater management systems is less expensive. GIS analysis shows many areas within Northeast Florida and Southeast Georgia with high suitability to implement LID techniques. Policy recommendations are for each municipality in the Northeast Florida and Southeast Georgia region to adopt a LID ordinance, tailoring the model to their needs, which would require the use of LID in all new development and redevelopment projects.

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EXECUTIVE SUMMARY

Coastal communities throughout the United States have seen an increase in population as more people choose to relocate closer to the coast. As urban development near coastal ecosystems in Florida and the Southeast increases, impacts of humans to the natural environment increase as infrastructure alters the natural landscape. Stormwater systems divert water away from rainfall sites and move rainwater over impervious surfaces into stormwater drains and directly into waterbodies. Consequences observed of traditional stormwater infrastructure include increased nutrients from fertilizers, pollutants from automobiles, and large volumes of fresh water flowing into waterways without treatment. These issues cause nutrient overloading and increased algal blooms, poor water quality, and changes in estuarine ecological function that impact Florida's fisheries and tourism income.

Low Impact Development (LID) is a method first introduced in the 1990s that uses different infrastructure techniques to use or mimic the natural hydrology of an area. This allows for stormwater infiltration, evapotranspiration, or rainwater harvesting. LID techniques include bioswales, permeable pavement, rain gardens, rain barrels, and green roofs. Most techniques can be adapted for large-scale or small-scale projects.

The Northeast Florida Regional Council (NEFRC) created the Regional Community Institute of Northeast Florida, Inc. to study local policy issues. Determining that protecting the natural environment of the region was important for the future, the NEFRC started a collaboration with Southeast Georgia for the regions' shared ecosystems. A bi-state partnership focusing on the environment with representatives of both states saw the need for a joint effort on water. The NEFRC completed the Water Beyond Borders study, with the focus on the St. Mary's River as common ground between Florida and Georgia. The goals from this initiative included the development of a Low Impact Development model ordinance.

To determine the potential of LID legislation in the Northeast Florida and Southeast Georgia region, water quality analysis of a Sarasota County LID facility draining to Alligator Creek was completed. Mean water quality values for Total Nitrogen were calculated pre- and post-LID project construction and were compared using an analysis of variance test and Tukey Method test to determine if the means were significantly different.

Geospatial data were collected for Northeast Florida and Southeast Georgia, including layers on land use and soil hydrology. Parameters in each layer were selected based on potential for LID project construction success. These selected data layers were analyzed in ArcGIS using overlay geoprocessing to determine the best sites in the region for LID implementation.

An initial cost-benefit analysis was performed to give a framework for more in-depth future analyses. Costs for LID infrastructure and traditional infrastructure were found through the U.S. Environmental Protection Agency. Total costs were subtracted from total benefits in order to determine if LID infrastructure is financially beneficial for municipalities within the Northeast Florida and Southeast Georgia region.

Water quality analysis of Alligator Creek revealed that overall nitrogen load of the creek has increased significantly pre- to post-LID facility construction. Further investigation of an additional water quality sampling site directly at the LID Treatment Facility outfall to Alligator Creek was done to determine if the facility was achieving the intended goal to reduce nutrients. The outfall, situation between two original sampling sites, were compared to determine facility impacts. Total nitrogen values were compared from sites in 2011 (pre-LID construction) and 2017 (post-LID construction). The original sites significantly increased in nitrogen load from 2011 to 2017, but the outfall site decreased significantly over the same time, signifying the LID Facility is succeeding in reducing nutrient loads from the stormwater entering the facility.

Cost-benefit analysis looked at 12 case studies around the nation comparing costs of LID techniques to conventional stormwater methods. Of these projects, 11 were shown to have decreased cost for the LID methods, with a range of 14-80% reduction in price. This case study, conducted by the United States Environmental Protection Agency, can help shift mindsets away from the status quo of stormwater management systems to LID techniques, which are both environmentally and economically beneficial.

GIS Analysis of Northeast Florida and Southeast Georgia was completed to determine areas in the region that would be best suited for LID stormwater treatment systems. In Northeast Florida, data was available for land use and soil hydrology. GIS Analysis shows that areas in Northeast Florida most suitable for LID systems are residential areas on the coasts and larger urban areas. In Southeast Georgia, data was only available for land use. Southeast Georgia shows suitability for LID projects in small towns and near agriculture.

The goal of the Water Beyond Borders initiative is to create a model ordinance for LID that each municipality in Northeast Florida and Southeast Georgia can adapt, implement, and enforce. The St. Marys River Region LID Ordinance is modeled after the Los Angeles LID Ordinance, with relevant information from the Sarasota County LID Guidance Document. The main component of the St. Marys River Ordinance that differs from other Florida LID guidance documents is that LID will be a requirement for all new development and redevelopment projects. The ordinance is constructed as a framework that allows each municipality to tailor the regulations to individual community needs. The ordinance also includes sections where each municipality can input the required water quality standards for the region, which may differ between states and counties.

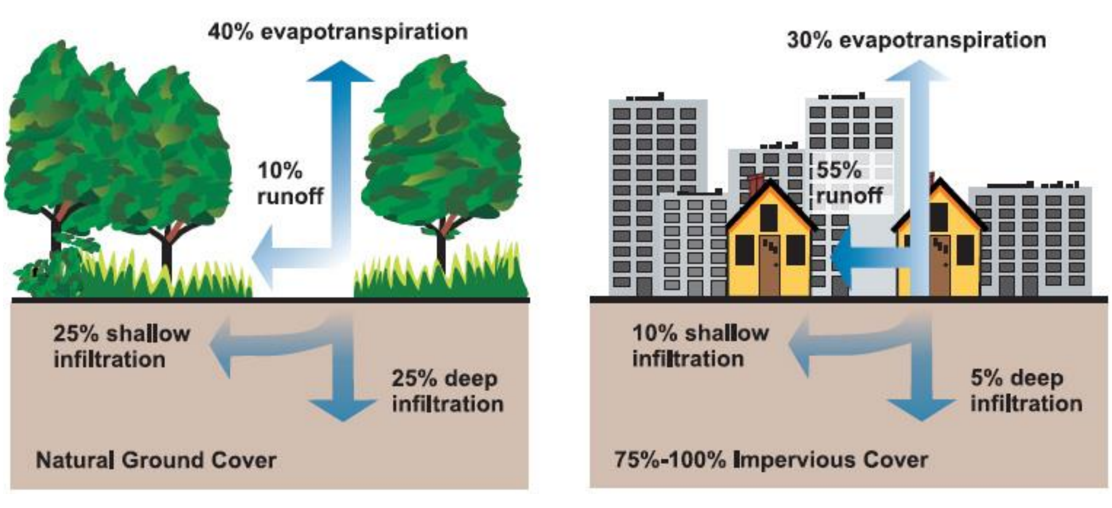
DEVELOPING A LOW IMPACT DEVELOPMENT MODEL ORDINANCE IN NORTHEAST FLORIDA AND SOUTHEAST GEORGIA: PROTECTING THE ST. MARY'S RIVER

I. Background

Coastal communities throughout the United States have seen a dramatic increase in population since the 1970s as waterfront and near water living became a desire for many people (NOAA, 2015). In 2010, 39% of the national population lived on the coast with expectations to increase to 47% by 2020 (NOAA, 2015). Increased human population on the coasts puts elevated stress on vulnerable lands as coasts receive direct influence from communities, including hydrology changes from infrastructure and stormwater pollution. In Florida, human impacts on coastal communities are even more prominent as Florida is the fourth fastest growing state in the nation since 2010 (World Population Review, 2019). Endless changes are made to the natural environment to accommodate human residence, work and recreation, and the results have been detrimental to Florida's most valuable resource.

In the past, urban development construction did not consider ecological changes or damage, simply because consequences were not observed or widely understood. In a natural system, only 10% of rainwater flows into waterways as runoff. As populations grew and coastal communities expanded rapidly, many consequences from the natural environment destruction, including increased flooding, came to light. This traditional, or grey, construction method removes natural vegetation, soils, and creates hard surfaces that does not allow for water filtration, altering the natural hydrology of the sites (Dhakal, K. et al, 2017). Rainfall in areas with this grey infrastructure is captured on impervious surfaces, gathers urban pollutants and runoff, and flows directly into stormwater runoff drains to waterways instead of filtering into the ground. Due to impervious surfaces, 55% of rainwater is now diverted into waterways as runoff. Figure 1 below illustrates the differences in rainwater sinks from a natural system to an urban system.

Figure I: Stormwater Sinks- Natural Systems and Urban Systems



Diversion of rainwater directly to stormwater systems causes numerous problems, both to the environment and to the coastal communities. Increased nutrients in waterbodies from stormwater runoff impair the water quality of the surrounding systems (Dhakal, K. et al, 2017). In Florida, increased nutrients from several sources has led to harmful algal blooms, both in freshwater rivers and lakes and Red Tide off the coasts in the ocean (Florida Sea Grant, 2019). Algal blooms can be toxic to fish and cause respiratory problems in humans, harming the environment and local economies by reducing fisheries and tourism (Florida Sea Grant, 2019). Stormwater runoff can also put toxic heavy metals from industry and automobiles such as zinc and lead into water systems, a community issue when human populations are then ingesting those metals through drinking water and seafood (Davis, A. et al, 2003).

Traditional infrastructure prohibits rainwater from infiltrating and recharging the groundwater supply (Dhakal, K. et al, 2017). This poses a big problem for both Florida and Georgia as the drinking water supply comes from the Floridan aquifer, which requires recharge from rainwater. This fresh rainwater, instead of seeping into the ground to the aquifer system, instead increases the volume flowing into streams and rivers. As Florida is a coastal community, this freshwater volume increase can alter the salinity in estuarine ecosystems, changing coastal species behavior, distribution, and biodiversity (Dhakal, K. et al, 2017).

Climate change, as seen already, will increase the consequences of traditional urban infrastructure expansion (Eckart, K. et al, 2017). Warmer oceans with the increased nutrients flowing into water systems will intensity harmful algal blooms (Florida Sea Grant, 2019). Hurricanes, already great forces of damaging winds and rain, are predicted to increase in intensity with the warmer ocean (NOAA, 2020). This increased intensity is especially likely to increase rainfall during hurricane events, releasing more freshwater into Florida's coastal communities. As hurricane intensity increases every 2 degrees Celsius, rainfall is predicted to increase by 10-15% (NOAA, 2020).

Urban development and grey infrastructure, in addition to environmental and economic impacts, can have negative social impacts (Dhakal, K. et al 2017). Conventional infrastructure deprives urban communities the benefits of clean air and water, natural flood control, and the beauty of nature (Dhakal, K. et al, 2017). While traditional infrastructure may provide some flood control in certain communities by diverting stormwater away, downstream communities could become more prone to flooding due to increased stormwater volume in upstream waterways (Dhakal, K. et al, 2017).

Conventional infrastructure can no longer successfully protect coastal communities from stormwater runoff due to increased freshwater, nutrients, and heavy metals impacting the environment, economy, and society (Eckart, K. et al, 2017). Wide-spread stormwater methods need to allow rainfall to follow a more natural path by removing impervious surfaces for stormwater to infiltrate, retain, or be harvested. A developing alternative to traditional infrastructure is Low Impact Development (Eckart, K. et al, 2017).

Low Impact Development

The foundation for environmentally friendly development began with Ian McHarg's book, "Design with Nature." Published in 1969, the landscape architect identified the best way to maximize the potential of the Earth is to purposefully plan human communities in harmony with the natural ecology (McHarg, I. 1969). His goal for developing a site was to understand the soil hydrology, land use, habitats, and other ecological parameters of the area and layer them together to promote healthy development. McHarg developed techniques for infrastructure and implemented them around the globe, many of which are still in practice today and inspiring the next generation of landscape planners.

Low Impact Development (LID) describes "systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration, or use of stormwater in order to protect water quality and associate aquatic habitat" (U.S. EPA, 2018). Compared to traditional stormwater infrastructure, LID methods manage, treat, or infiltrate rainwater close to the source and considerably reduce impervious surfaces that collect excess nutrients and pollutants, leading to better water quality potential in natural waterbodies (U.S. EPA 2018).

In the 1990s, alternatives to conventional stormwater management were found necessary in Prince George's County, MD to combat poor water quality (Penniman, D. et al., 2012). The method used in this area at the time for stormwater was to divert rainwater on impervious surfaces and pipe water directly into waterbodies without treatment. Prince George's County was the first area to introduce a LID centralized stormwater management system that allowed rainfall to infiltrate through the soil instead of polluting the streams and lakes (Penniman, D. et al., 2012). In 1998, the Low Impact Development Center, Inc. non-profit organization was formed to provide LID services and support to researchers and organizations in need of design or permitting assistance (LID Center, 2019). Since its inception, the LID Center has grown to provide up-to-date information and training on new stormwater techniques and provide grants nationally and worldwide.

LID practices can reduce nutrients, heavy metals, and other human-caused pollutants as well as stormwater runoff volume, both of which factor into water quality (Penniman, D. et al., 2012). Contributing to LID method success is the need to maintain natural soil hydrology of sites with well-draining soils (Penniman, D. et al., 2012). Disturbance of soil ability to filter rainwater reduces the amount of pollutants and runoff volume that can be absorbed and diverted from natural waterways. It is, therefore, important to select areas for LID that have the necessary hydrological functions to maximize absorption.

There are multiple LID methods that can be used to fit small-scale areas, such as a single-family home, or large-scale areas, such as an entire neighborhood (Penniman, D. et al., 2012). In urban areas, use of permeable surfaces, such as permeable pavement, provide an alternative to large parking lots that could collect automobile pollutants and flush them into stormwater drains. Raingardens provide retention and filtration areas for rainwater and compliment conventional retention ponds by adding vegetation to remove pollutants. Bioswales next to roads provide areas for water to flow off impervious surfaces and filter into the soil before reaching storm drains (Penniman, D. et al., 2012). Rain barrels collect rainwater for irrigation and green roofs can provide benefits of a rain garden in cities with limited green space (Penniman, D. et al., 2012). In most cases, a combination of several LID methods is used to maximize the reduction of stormwater runoff and pollutants (Penniman, D. et al., 2012). Illustrations of different LID methodology can be found in Appendix 1.

As seen since the 1990s, traditional infrastructure can no longer support healthy waterbodies in growing human communities. Changes, especially in vulnerable coastal communities in Florida, are necessary to protect fishery habitats and income from tourism. In a time when Florida needs to benefit from innovative and environmentally friendly decisions, Low Impact Development may be one solution to mitigating human impacts on the environment.

Client Information

The Northeast Florida Regional Council (NEFRC) formed in 1977 as "network of local governance" between seven counties in the Northeast Florida region – Nassau, Duval, Baker, Clay, St. Johns, Flagler, and Putnam counties (nefrc.org, 2019). The goals of the NEFRC is to coordinate inter-county activities at a regional level in order to "resolve issues and problems transcending their individual boundaries" (nefrc.org, 2019). Regional Councils are sanctioned by Chapter 163 of Florida Statutes and have a myriad of roles, including but not limited to emergency preparedness and evacuation, homeland security, community planning, regional coordination, economic data analysis, and geographic information systems analysis (nefrc.org, 2019).

The Regional Community Institute of Northeast Florida (RCI) was created by the NEFRC as a non-profit to study local policy issues (Water Beyond Borders, 2017). The RCI and NEFRC collaborated with the public to analyze the vision for Northeast Florida in the next 50 years and determined that protecting the natural environment was of the utmost importance (Water Beyond Borders, 2017). In 2015, the RCI was given water as the policy topic of importance for 2017 and assigned discussions to the Natural Resources Committee (Water Beyond Borders, 2017). The RCI Board of Directors agreed that water issues of the region go beyond the boundaries of Florida and successful protection of water resources requires collaboration between Northeast Florida and Southeast Georgia. This initiative was named Water Beyond Borders.

A bi-state partnership focusing on the natural environment was a novel event and representatives from both states saw the need for a joint effort on water. The common ground for both states is the St. Marys River and an opportunity arose for collaborative protection of this waterway (Water Beyond Borders, 2017). The main issue with two states sharing the river as a border is that one state may consider the waterbody impaired and will act accordingly but the other state may not, eliminating protection efforts of the acting state. The Natural Resources Committee saw this opportunity to create a comprehensive plan between Florida and Georgia to reduce inconsistent actions and maintain the health of the St. Marys River (Water Beyond Borders, 2017).

Led by Dr. Quinton White, Executive Director of the Marine Science Research Institute at Jacksonville University, the Natural Resources Committee brought together stakeholders, experts, and volunteers from both Florida and Georgia to the Water Beyond Borders initiative. The committee wanted to know how much water the states have, where it is, what the data collection methods are, the best practices for water quality, and how the states communicate (Water Beyond Borders, 2017). After eight meetings, the committee put together three recommended action items that were deemed doable.

First, to formalize this cooperation, the committee put forward the idea to draft a Florida-Georgia compact that would detail water quality testing, monitoring, and communication within the region (Water Beyond Borders, 2017). The second action item the committee felt necessary is a water quality data clearinghouse website accessible to both states. The data sharing would keep all stakeholders informed of the different water quality results found at multiple locations and start a conversation to standardize water quality monitoring (Water Beyond Borders, 2017). The last action item is to review best practices for LID and develop a LID Model Ordinance that each municipality within the region could implement. The LID Model Ordinance is the focus of this research project and will be completed in April 2020. The NEFRC will present this work at the next formal Water Beyond Borders meeting.

LID in Northeast Florida and Southeast Georgia

Low Impact Development methods may have different levels of success depending on the natural landscape parameters. Certain areas may have capabilities to implement infrastructure such as bioretention and other areas may not. In coastal Florida and Georgia, LID infrastructure construction must consider certain issues specific to the region such as proximity to estuarine ecosystems and high groundwater. The first major LID project in the state of Florida, the parking lot at the aquarium in Tampa along the Hillsborough River, aimed to reduce stormwater runoff and pollutants entering the river (Chang, N. et al, 2017). This case required specific knowledge Florida ecosystems to create a project best suited for the area.

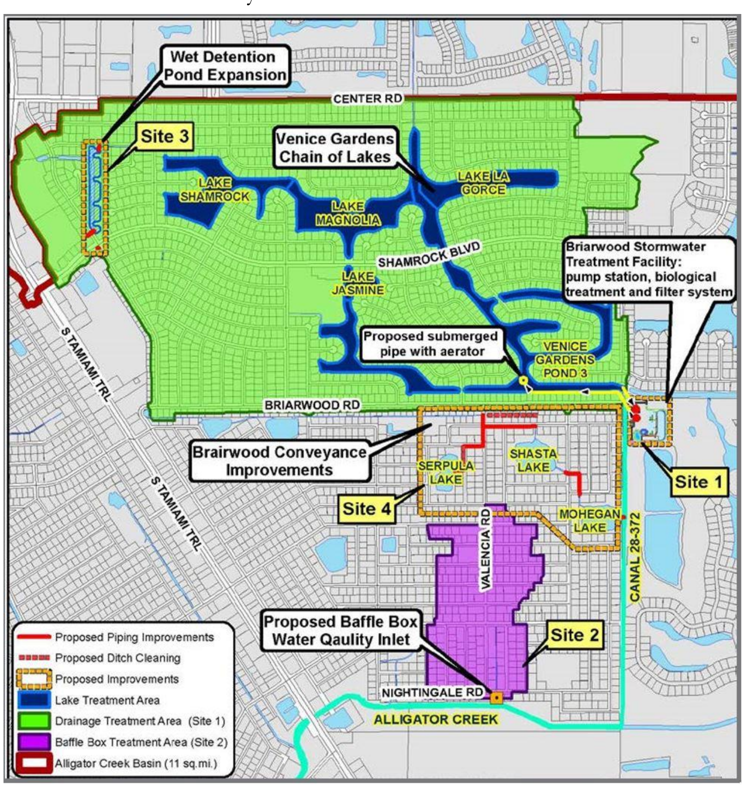
Bioretention ponds are the most popular and easiest LID method to implement. In Florida, bioretention ponds are difficult to permit and implement due to the high groundwater table (Chang, N. et al, 2017). LID, however, is especially important in Florida and Georgia to recharge the Floridan Aquifer with fresh drinking water. To implement LID in Florida, shallow bioretention ponds have been developed to overcome issues with high groundwater.

The permitting enforcement in Northeast Florida comes from the St. Johns River Water Management District's Regulatory Division. Regulatory officers working for the District are trained and able to work with permit applicants interested in including LID in projects (sjrwmd.com, 2019). LID systems can be properly reviewed with site-specific needs by District personnel and employees are also encouraging implementation of LID projects throughout the region (sjrwmd.com, 2019).

LID Facility in Sarasota County, FL

Alligator Creek in Sarasota County, FL flows through a heavily urbanized area and drains to Lemon Bay (Alligator Creek Final Report, 2016). In 1986, Lemon Bay was designated as an Aquatic Preserve and measures were taken to improve water quality in all waterways flowing into the Bay, including Alligator Creek. Because of the urban land use around Alligator Creek and proximity to residential areas, high amounts of stormwater pollutants were entering the creek after each major rainfall. A partnership between the U.S. Environmental Protection Agency, the Southwest Florida Water Management District, and Sarasota County pooled funds to construct a stormwater treatment facility to help protect Alligator Creek and, in turn, Lemon Bay Aquatic Preserve (Alligator Creek Final Report, 2016).

Figure II: Alligator Creek LID Treatment Facility Sites



The project was completed in two phases at four sites within the Alligator Creek drainage basin (Alligator Creek Final Report, 2016). Figure II above depicts the locations of all four sites in Sarasota County, proximity to residential parcels, and proximity to Alligator Creek. Phase I included construction of the stormwater treatment facility in an area that housed an abandoned wastewater treatment plant and placement of a baffle box at an outfall to Alligator Creek at Valencia Road to separate nutrients and sediment (Alligator Creek Final Report, 2016). This portion of the total project was completed in November of 2012. Phase II included expansion of a water detention pond with new piping to alleviate local flooding and connections of small lakes in the area to reduce flooding and improve water quality. This last project work was completed in February of 2013 (Alligator Creek Final Report, 2016).

The Alligator Creek Stormwater Treatment Trains Final Report published in 2016 detailed the impacts from Phase I on this project. Water quality analysis was done pre- and post-project to determine the effectiveness of the stormwater treatment facility and baffle box on nutrient reduction, the goal of this project (Alligator Creek Final Report, 2016). Figures III and IV below show an aerial photograph and on-ground photograph of the completed Alligator Creek Stormwater Treatment Facility. This project with complete a water quality analysis of Total Nitrogen in Alligator Creek to determine if the LID Facility is meeting the goal of reducing stormwater pollutants to the Alligator Creek.

Figure III: Aerial photograph of Alligator Creek LID Treatment Facility

Figure IV: Alligator Creek LID Treatment Facility

Waterways by Fletcher Davis: Richmond Hill, Georgia

Fletcher Davis construction company was founded in 1961 by brothers Paul and Jerome Fletcher and is based in St. Augustine, FL (Fletcher Davis). The underlying philosophy is to create "green" and "sustainable" living communities throughout the Southeast United States in order to protect the local natural environment. The four areas of focus for creating these sustainable neighborhoods are energy, water, waste, and food (Fletcher Davis). Through these focus areas, Fletcher Davis communities are developed to reduce carbon dioxide emissions, surface and ground water pollution and use of non-renewable products. These communities also aim to promote growth of native food-producing vegetation. Notable communities developed by Fletcher Davis include Old Brick Township in Palm Coast, FL and TPC Sawgrass in Ponte Vedra Beach, FL. The newest project, led by Fletcher Davis CEO Doug Davis, is Waterways in Richmond Hill, GA.

Waterways, like the previous communities developed by Fletcher Davis, takes great care to introduce a residential neighborhood with minimal disturbance to the natural ecosystem. For the neighborhood location and surrounding area, GIS layers for wetlands, soils, flood plains, wildlife habitat, and other factors were overlaid and combined to create a development site suitability map (Fletcher Davis). From these suitability maps, areas with very low scores were identified as development sites while areas with high scores were set aside as conservation areas. Development plans made sure that any new infrastructure built would not isolate wildlife in conservation areas by limiting movements or breaking habitats. Figure V below depicts the conceptual master plan for Waterways using the overlay of GIS maps.

Figure V: Waterways by Fletcher Davis

Construction of Waterways accounts for all the survey and suitability data to develop the neighborhoods sustainably. Rights-of-way were planned to follow the natural vegetation and requiring minimal tree removal. Deeper, double stacked sewer pipes were installed to minimize soil excavation and eliminate the need to raise housing lots for water flow slope requirements. Decreased removal and disturbance of soils and natural vegetation limits stormwater runoff. Housing lots are designed to limit tree removal for foundation construction. Tree preservation in lots reduces heat in the homes by providing shade. Driveways are constructed with pervious pavers or split concrete to increase groundwater filtration. Bioswales, bioretention, and hedge rows with natural vegetation are used to filter runoff and prevent flooding. A connected lagoon flows throughout Waterways, promoting water transportation between communities and enhancing habitats for wildlife. Fish feeders spaced throughout the lagoon are powered by solar energy, as well as the underwater aeration bubblers to limit algal buildup.

The sustainable construction techniques used by Fletcher Davis in their communities have ecologic, economic, and social benefits that will enable community long-term success. By limiting soil excavation, needs to raise housing lots and tree removal, construction costs are significantly less than clear-cut traditional neighborhoods. Decreased construction costs allow homes in Waterways and other Fletcher Davis communities to become more affordable for families who want to minimize their carbon footprint. Preserving conservation sites with high ecologic impacts around developed communities ensures wildlife will have ample space and mobility to continue thriving in their habitats. In developed sites, limiting disturbance of natural hydrology through permeable pavements and bioswales enhances the natural ecosystem and reduces flooding.

Quality of life in such communities increases when the surrounding area is natural and peaceful. Doug Davis, in surveys to new residents of Waterways, finds that people move there for the serenity of living close to preserved natural areas. The lagoon system and the conservation areas promote eco-tourism through birdwatching, hiking, and kayaking. Shaded trails and porches of the homes invite residents to enjoy the outdoors and meet others in the community.

The Fletcher Davis LID techniques show that development does not have to destroy natural ecosystems. On the contrary, preserving and protecting can save money and improve quality of life (Fletcher Davis). Doug Davis and other members of Fletcher Davis have reached out to the community to educate about sustainable development. They have presented their construction techniques and developed a book detailing their mission and LID methods. Such methods, already tested and practiced in Florida and Georgia, should be included in the Model Ordinance as required methods in future development throughout the region.

Florida and Georgia LID Manuals

Incorporation of LID methods within municipality plans is not a new practice in the states of Florida or Georgia. Several counties have already developed and implemented LID practices into county Stormwater Management Plans or Comprehensive Conservation and Management Plans. Three counties in Florida with such documents that will serve as models for Northeast Florida and Southeast Georgia LID practices are Alachua, Pinellas, and Sarasota Counties. One county in Georgia with a LID document is Augusta, GA. An additional reference for practice development will be the Duval County Low Impact Development Manual. The Model Ordinance for Northeast Florida and Southeast Georgia will consider the methodology outlined in the Duval County LID Manual to determine what regulations in the region are feasible. This Ordinance, called the St. Marys River Region LID Ordinance, will use information from these model manuals to create practices best for Northeast Florida and Southeast Georgia.

Alachua County

Alachua County introduces LID methodology in its Stormwater Treatment Manual, last updated in October of 2018 (Alachua County). The Florida Department of Environmental Protection (FDEP) sets maximum pollutant loads for waterbodies to preserve water quality and officials testing the waters within Alachua County determined that many waterbodies were not meeting FDEP standards. Changes to stormwater infrastructure were necessary to limit runoff nutrients, as well as heavy metals such as zinc and copper (Alachua County). To achieve maximum nutrient and heavy metal reduction in stormwater runoff, Alachua County identified a new goal of stormwater management is to "maintain the pre-development stormwater characteristics of a site or watershed after development" (Alachua County). In the updated Stormwater Treatment Plan, this goal can be achieved using suggested LID techniques to preserve and protect the natural hydrology of soils, slopes, groundwater, and local ecosystems.

The two categories for stormwater pollution prevention discussed in the Alachua County Stormwater Treatment Manual are structural and nonstructural (Alachua County). Nonstructural best management practices aim to reduce pollutant loads at the source through vegetation preservation, clustering development, and minimizing the amount and connectivity of impervious surfaces (Alachua County). Structural best management practices include bioretention, permeable pavements, swales, and other infrastructure designed to retain natural hydrology (Alachua County). In most cases, the developments with the highest rates of success in reducing stormwater runoff and preserving natural hydrology include a "Best Management Practice Treatment Train" of multiple structural and nonstructural steps.

Pinellas County

Pinellas County is the sixth most populated county in the state of Florida as of 2019, with nearly 1 million residents and a 6% growth since 2010 (World Population Review). As a coastal county, Pinellas officials became concerned about water quality, flooding, and the impacts of climate change on the community. Following the passage of Florida House Bill 7123, stating that all local governments building state-funding infrastructure must be developed sustainably, Pinellas County looked to be a model county for the state in environmental sustainability (Natural Resource Conservation). In addition to constructing new buildings to meet or exceed Green Local Government standards by 2008, Pinellas County also identifies LID methods to combat poor water quality and flooding.

Pinellas County has investigated incentives that would encourage developers to use LID methods, including fast-tracking permits and reducing fees (Natural Resource Conservation). Officials have also considered disincentivizing use of traditional stormwater techniques over LID methods. Increased use of LID methods throughout the county will improve knowledge of LID in Pinellas and determine which steps in a Treatment Train are most successful (Natural Resource Conservation).

Like Alachua County, Pinellas County incorporated LID practices into the Stormwater Manual, siting a need to reduce runoff nutrients and heavy metals through both structural and nonstructural methods. Included are vegetated buffers, permeable pavement, rain gardens and bioswales, as well as using Florida-friendly plants and fertilizers (Pinellas County). Two LID projects completed in the county are a bioswale system at an intersection and a no-curb system in a parking lot (Natural Resource Conservation). The University of Central Florida's Stormwater Management Academy is continuing to monitor and quantify impacts from these LID projects to determine the value of such technologies in Pinellas County.

Sarasota County

Sarasota County developed a LID Guidance Document which was implemented in 2012 (Sarasota County). Of all the county documents considered for the Northeast Florida and Southeast Georgia Model LID Ordinance, the Sarasota County LID Guidance Document is the most robust. As such, the LID Guidance Document has been featured by the EPA as one of the foremost documents on LID in the country (Green Infrastructure, U.S. EPA). Sarasota County officials have designed the LID Guidance Document to support and supplement stormwater standards and requirements set by the State and the Southwest Florida Water Management District (Sarasota County).

Stormwater Runoff contributed 62% of pollution in Sarasota Bay in 2014 (Sarasota County CCMP). This eye-opening information led the Sarasota Bay Estuary Program to make stormwater pollution prevention a top priority for the health of all waterbodies. The goals of the Sarasota County LID Guidance Document include preserving natural hydrology, collecting stormwater for retention, infiltration, or use at the point source, and minimizing runoff entering waterways and Sarasota Bay (Sarasota County). Suggested methods described in the Guidance Document appropriate for use in the county include shallow bioretention, permeable pavements, stormwater collection, green roofs, and detention with infiltration (Sarasota County).

Additionally, the LID Guidance Document discusses the proper process for evaluating a site chosen for development (Sarasota County). Traditional stormwater treatment systems would clear the site of vegetation and alter soil hydrology to divert rainwater away from the area. The Guidance Document, alternatively, suggests a site evaluation to take advantage of the environment's natural ability to capture, store, and infiltrate rainwater (Sarasota County). In many instances, a Treatment Train of LID methods can preserve natural hydrology and prevent stormwater pollution and flooding.

The Sarasota County LID Guidance Document does not require the use of LID techniques within county jurisdiction yet but has expanded the definition of stormwater management to include LID techniques where possible (Sarasota County). As more information is gathered, the LID Guidance Document can be edited to emphasis methods best suited for the county and work with local policy makers to make LID a requirement.

Augusta, GA

Augusta, GA is a consolidated city-county community on the Georgia- South Carolina border. A low-lying area, Augusta is prone to flooding and the hydrology of Augusta causes runoff to the Savannah River (Stormwater Management Program, 2017). City officials created the Green Infrastructure and Low Impact Development Program within the Stormwater Management Program in order to protect water quality and quantity flowing through Augusta and into the Savannah River.

Ground surveys of the Augusta area showed numerous hydrological systems and soil types, both of which impact water flow and ability to infiltrate into the ground. As such, the GI/LID Program sought to provide multiple alternatives for traditional stormwater systems that would encompass the broad landscape (Stormwater Management Program, 2017). Three action areas identified by the Program are early collaboration and communication, conservation of natural resources, and "build with the land" design methods (Stormwater Management Program, 2017).

Like the Florida LID Guidance Documents and Manuals, Augusta does not specifically require LID techniques in new development or redevelopment projects. Stormwater runoff standards must be met and shown that they are met, and LID techniques are suggested for runoff treatment in that area, but those LID techniques are not necessary if runoff is minimized or treated before entering the waterways.

Duval County

Jacksonville residents and visitors alike consider the St. Johns River flowing through downtown one of Duval County's greatest assets. High levels of nutrients from stormwater pollution, however, decrease the economic and aesthetic value of the river (Duval County). In 2008, a Management Action Plan for nutrient reduction throughout the Lower St. Johns River was implemented (Duval County). In addition to reducing point source reductions in nutrient pollution, policymakers developed the Duval County Low Impact Development Manual to expand stormwater treatment methods for nutrient reduction and river health (Duval County). This legislation was voted on by the Jacksonville City Council, which passed the manual. Implementation, however, has not moved forward since the vote.

The Duval County LID Manual was modeled after the Sarasota County LID Guidance Document (Duval County). While the state of Florida regulations and requirements for stormwater pollution and water quality are the same for both counties, parameters such as soil hydrology are different, causing the Duval County LID Manual to have different requirements for design (Duval County). Like Sarasota County, LID practices in Duval are not required but builders of new development and redevelopment projects are encouraged to consider LID methods (Duval County).

St. Marys River Region

The Model LID Ordinance for Northeast Florida and Southeast Georgia will take the best practices from the county LID manuals to create an ordinance framework for each municipality in Northeast Florida and Southeast Georgia to implement. While the original objective of such an ordinance is to protect the St. Marys River from stormwater pollution, municipalities may also find a reduced financial need for pollution clean-up, healthier coastal ecosystems, and reduced flooding. The model will expect that LID practices for stormwater pollution prevention are a requirement.

LID Ordinance Model

While LID design manuals and guidance documents are present in multiple Florida municipalities, LID has not yet been enacted through ordinance in the state. The City of Los Angeles, CA adopted the City of Los Angeles Low Impact Development Ordinance in 2012 to reduce stormwater pollution and includes many of the same goals of LID of municipalities in Northeast Florida and Southeast Georgia. Updated in 2015, this Los Angeles LID Ordinance requires use of LID practices in all development and redevelopment that causes land displacement and adds over 500 square feet of impervious surfaces to the landscape (LA City Sanitation).

The goals the City of Los Angeles hoped to achieve by enacted LID requirements were to control and beneficially reuse rainwater and urban runoff (LA City Sanitation). With the focus on water, the Ordinance encourages rainwater harvesting for irrigation and other reuses, groundwater recharge, and reducing all stormwater runoff to improve water quality and decrease erosion (LA City Sanitation). As a measure to help sway the public and local policymakers to support the ordinance, Los Angeles described the economic and aesthetic benefits of LID to the community.

In addition to the LID ordinance, the City of Los Angeles has a Low Impact Development Best Management Practices Handbook, like the LID Manuals and Guidance Documents for Sarasota, Alachua, Duval and Pinellas Counties. Within the Los Angeles LID Ordinance, the Handbook is referenced for specific LID methods and standards each new development or redevelopment project must adhere to. Each municipality in Northeast Florida and Southeast Georgia, along with tailoring the St. Marys River Region LID Ordinance to their local needs, should create a LID Handbook like that of Sarasota or Duval County to reference the appropriate LID methods and standards for that area.

To remain consistent with Northeast Florida and Southeast Georgia ordinance format, an ordinance from Beverly Beach in Flagler County, FL will be referenced when writing the St. Marys River Region LID Ordinance. After consideration of several ordinance formats from around the region, Beverly Beach was selected as the ordinance format that looked most like a typical Northeast Florida ordinance.

Relevant Literature

Several recent papers on Low Impact Development have been published around the globe on potential benefits and disadvantages of LID infrastructure techniques. Impacts of LID on stormwater pollution have been documented both in natural systems and in laboratory settings, considering factors such as nutrients, heavy metals, total suspended solids, and total runoff volume. GIS analysis of LID site suitability has been documented, detailing which types of areas have the highest potential benefit from LID methods, and if information about a site can auto select for best LID practices. Cost-benefit analysis and public opinion information is also discussed.

Nutrient, Volume and Heavy Metal Reduction

The largest issue that has caused municipalities to seek stormwater treatment alternatives is high levels of nutrients and heavy metals entering waterways through stormwater runoff (Davis, A. et al, 2003). Additionally, large volumes of stormwater can cause flooding at peak flow rates, increase suspended solids yielding poor water quality, and introduce copious amounts of freshwater than alter coastal ecosystem function (Gulbaz, S. and Alhan, C., 2015). In order to continuously promote the use of LID to reduce stormwater pollution, studies must be done to show that these techniques accomplish the intended objectives. Several scientific studies have been conducted to show the potential benefits as well as potential concerns with LID methods improving water quality.

A study in Central Oklahoma's Lake Thunderbird watershed evaluated LID practices in two ways. First, GIS analysis was conducted to determine the best sites for LID based on factors including land cover, impervious surfaces, elevation, and soil hydrology (Martin-Mikle, C. et al, 2015). Second, LID pilot projects using bioretention catchments near Norma, OK were assessed to determine impacts on total phosphorus, total nitrogen, and total suspended solids, all of which were reduced. This study also found that, when applying this single LID method on all suitable sites within the Lake Thunderbird watershed, total phosphorus could be reduced by up to 16%, total nitrogen up to 15%, and total suspended solids up to 17% (Martin-Mikle, C. et al, 2015).

Reducing the amount of stormwater that is directed over impervious surfaces to waterways yields healthier aquatic ecosystems and flood protection (Tredway, J. and Havlick, D., 2016). Colorado Springs, CO was the site of 9 damaging floods between 1864 and 1935, causing the construction of the Templeton Gap Flood Control, diverting normal water flow away from Colorado Springs and building a levee. Increased urban development near the levee has increased stormwater runoff and strain on that levee, which is no longer accredited to survive a 100-year storm (Tredway, J. and Havlick, D., 2016). This study used ArcGIS analysis to create a Stormwater Management Model (SWMM), calculating total impervious surfaces within subsections of the Templeton Gap watershed and modelling how changes in the amounts of impervious surfaces would alter stormwater runoff volume to the levee. The model used three treatments: permeable pavement, rain gardens, and stream naturalization (Tredway, J. and Havlick, D., 2016). The initial simulations found that, while each LID practice individually reduced total runoff volume, the highest potential reducing came from a combination of all three methods in a best management practice treatment train with 32.7% volume reduction. With this percentage of reduction, the peak flow rate results would fall below the capacity for the levee.

A second publication using a model to predict the impacts of different LID techniques was done in the Sazlidere Watershed in Istanbul, Turkey (Gulbaz, S. and Alhan, C., 2015). In addition to modelling total runoff volume, this study also considered impacts of the same techniques on total suspended solids as a measure of water quality. Rainfall data was collected between November 2009 and May 2010 and flow rate was measured during 5 storms (Gulbaz, S. and Alhan, C., 2015). The three types of LID methods considered in the model were bioretention, vegetated swales, and permeable pavements. This model predicted a 17.5% decrease in total runoff volume with combined LID implementation (Gulbaz, S. and Alhan, C., 2015).

At the College of Environment and Resources at Fuzhou University in China, researchers expanded on the idea of LID methods improving water quality and reducing water quantity over several modelled rainfall scenarios and different combinations of LID techniques (Peng, Z. et al, 2018). The LID methods considered were permeable pavements, vegetative swales, and green roofs. The modelled study site was in a high-density residential area of the Jiefangxi Watershed with 74.37% impervious surfaces (Peng, Z. et al, 2018). The model was run to predict the total runoff volume and accumulation of total suspended solids for each LID method separately and in combination while altering rainfall return periods, duration, and location of highest intensity. The best individual method for reducing total stormwater runoff volume and total suspended solids was permeable pavement due to the large surface area that could be converted to allow water infiltration (Peng, Z. et al, 2018). During small to moderate rainfall events, the combination of all three LID techniques gave the best potential success in stormwater pollution, reducing total runoff volume by 86% and total suspended solids by 97% (Peng, Z. et al, 2018). Next research questions already under consideration from this university will look at a combination of green and grey stormwater treatment infrastructure to find the best way to implement new green techniques to existing infrastructure (Peng, Z. et al, 2018).

In highly urbanized areas, stormwater runoff can contain increased concentrations of heavy metals from automobiles and other industrial sources (Ma, Y. et al, 2018). This study performed an experiment in Zhejiang, China to determine reduction in heavy metal concentrations in a retention basin. A pilot LID project was constructed along Jintang North Road. Grass swales were implemented along the road, followed by a graveled retention area before a discharge drain (Ma, Y. et al, 2018). Four water samples were collected for each rainfall event at the road, grass swale, gravel area, and discharge drain and were analyzed for heavy metal concentrations. Results quantified total heavy metal particle amounts and found that 685 kg of particles were collected on the road but only 2.85 kg of particles made it to the discharge drain, a reduction of almost 97% (Ma, Y. et al, 2018). This study provides evidence that even the simplest, cost-sensitive LID practices of grass swales and gravel can have significant impacts on heavy metal reduction in stormwater runoff.

A 2001 laboratory study by Davis, A. et al identified bioretention as a plausible LID technique for reduction of heavy metals, total phosphorus, and total nitrogen in stormwater pollution under fixed conditions. A follow up experiment conducted a few years later aimed to identify the potential for the same bioretention method to reduce heavy metal concentrations under varying conditions, such as different water pH, pollutant concentration, and flow intensity (Davis, A. et al, 2003). The objective of this study was to determine the long-term sustainability of bioretention with heavy metal buildup that would decrease the site's filtering potential. This experiment was performed both in the laboratory and as a field study, using the same measuring techniques for heavy metal concentration in each. Differences in water pH, pollutant concentration, and flow intensity did not have a significant impact on the reduction potential of the bioretention sites (Davis, A. et al, 2018). Additionally, heavy metal build-up was shown not to be a significant issue for 15 to 20 years of stormwater runoff filtration, and any minimal buildup can be easily tended through mulch or vegetation removal (Davis, A. et al, 2018).

Site Suitability

A review of LID methods and implementation outcomes in *Science of the Total Environment* discussed the importance of selecting sites for LID techniques with careful consideration to several factors, including anticipated runoff volume, soil hydrology, native vegetation and site topography (Eckart, K. et al, 2017). Any LID method that promotes the natural hydrology of an area will have a positive impact but selecting a site that is more suitable for LID will increase stormwater treatment success. The best areas for LID methods include those that have highly permeable soils that can filter significant volumes of water and flat areas with limited slope changes (Eckart, K., et al, 2017). The location of LID treatment sites makes a big difference in stormwater treatment success. By observing the flow rates and directional patterns of stormwater runoff, planners and engineers can determine the end location of most stormwater runoff and plan LID sites in those areas to retain and filter that water (Eckart, K. et al, 2017).

Numerous studies have been done that find the most suitable sites for LID practices based on soil hydrology, runoff volume, and peak flow rate. A study by Zhu, Z. et al from Sun Yat-sen University in China aimed to "evaluate and optimize the design parameters of different combinations of LID in areas limited by current land use" (Zhu, Z. et al, 2019). While other research has attempted to define the most suitable site for LID practices, this project aimed define the most suitable LID method for a site in a limited urban area. This study took place in the city of Guangzhou, China, where rainfall was measured and used in a stormwater management model to assess runoff. Results from this study found that the design of pervious pavements and bioretention ponds in these urban areas can be auto calculated through runoff models (Zhu, Z. et al, 2019). In highly urban areas with antiquated drainage where constructing new LID stormwater treatment systems is not cost-effective, small green infrastructure alternatives are now considered to improve water quality and prevent flooding events (Zhu, Z. et al, 2019).

Public Opinion

Public opinions of LID methods and green infrastructure are important factors to consider when implementing new policies. A study from Iowa State University used contingent value surveys in Ames, Iowa to determine participant's willingness to pay for LID (Bowman, T. et al, 2012). Surveys included questions on the opinions of clustered housing with surrounding conservation areas and LID methods. Most participants indicated a willingness to pay for clustered housing, rain gardens, and streams with a forested buffer. Previous knowledge of clustered housing and LID concepts had an influence on the responses that came out favorable to paying extra for green infrastructure techniques. This study concluded that more homeowners would be willing to pay for LID alternatives in neighborhoods if they were educated about these techniques and how they would improve water quality and reduce flood risk (Bowman, T. et al, 2012).

Policy Barriers

Although studies on the benefits of LID and green infrastructure have been published for twenty years, there has been relatively few implementations of LID projects (Dhakal, K. and Chevalier, L., 2017). LID methods not only improve stormwater quality and prevent flooding but also bring clean air, water, and natural beauty to urban areas. A 2017 study from Southern Illinois University Carbondale attempted to identify the underlying barriers to the construction of more LID projects (Dhakal, K. and Chevalier, L., 2017). The research explored policies in 10 US cities, as well as state and federal policies. Results identified 29 different barriers grouped into 5 categories and new policies were presented that would allow more LID projects at a faster pace. These 5 categories included federal or state policy barriers, city policy barriers, governance barriers, resource barriers, and cognitive barriers (Dhakal, K. and Chevalier, L., 2017). This study found that the most important barrier to overcome is cognitive barriers, which includes unawareness of stormwater pollution issues or LID alternatives and reluctance to change. Policy suggestions to alleviate these barriers include education and awareness of LID and other green infrastructure initiatives and to train personnel on green infrastructure techniques (Dhakal, K. and Chevalier, L, 2017).

Research Question

This project encompasses several aspects of researching and creating a Low Impact Development model ordinance for Northeast Florida and Southeast Georgia. As such, several questions need to be considered for the best policy outcomes.

1. Will the implementation of Low Impact Development policies in Northeast Florida and Southeast Georgia lead to improved water quality in the St. Marys River?
    a. Is there evidence of improved water quality from Low Impact Development stormwater systems in other Florida municipalities?
2. Are Low Impact Development stormwater systems a cost-effective alternative to traditional stormwater techniques?
3. What areas in Northeast Florida and Southeast Georgia are suitable for implementing Low Impact Development techniques?
4. What factors need to be included in a Low Impact Development model ordinance to ensure success?

II. Methodology

Data Sources

Florida water quality data are publicly available through the University of South Florida's Water Atlas website. This website allows interested parties to search for and downloaded data for specific waterways and identify all water quality sampling stations. Data collected varies by sampling station but include parameters such as salinity, dissolved oxygen, bacteria indicators, nutrients such as total nitrogen and total phosphorous, current and historic water levels and present vegetation.

Water quality data for total nitrogen were downloaded from three sampling stations collected by Sarasota Coastal Creeks in Alligator Creek and organized by sampling date. Water level data for Alligator Creek was also downloaded to determine if high values of nutrients corresponded to rain events. In addition to water quality values from the three Sarasota Coastal Creeks sampling sites, water quality data was collected from a sampling site directly at the Stormwater Facility outfall to Alligator Creek at Valencia Rd. and Nightingale Rd. This analysis was done to determine output of nutrients in Alligator Creek as a direct result of the LID Stormwater Treatment Facility by comparing nutrient values at the outfall sampling site to the nutrient values obtained for the upstream and downstream sampling sites.

The US Environmental Protection Agency completed a cost-benefit analysis of LID practices compared to traditional stormwater management practices to determine economic and environmental impacts (US EPA, 2007). The analysis comprises 17 case studies of LID projects around the nation with prices for conventional project practices and LID practices. All cost-benefit analysis data is publicly available through the EPA (US EPA, 2007).

Florida GIS data is publicly available through the Florida Geographic Data Library. Datasets downloaded include soil hydrology and land use. These layers were confined to Northeast Florida and used to analyze areas in the region most suitable for LID implementation. Suitability maps were created for Northeast Florida.

Georgia GIS data was provided by Erica McLelland at the Southern Georgia Regional Commission. Latest GIS shapefiles are maintained at the Regional Commission for Ware and Charlton Counties, two of the counties within this project's study area. Datasets provided include land use for Southern Georgia and were used to analyze areas in the region most suitable for LID implementation. Results from Southeast Georgia and Northeast Florida were kept on separate results maps due to differences in land use designation between Florida and Georgia

Water Quality Analysis

One major LID project site in Sarasota County was chosen for analysis. The Alligator Creek LID Stormwater Facility was constructed to reduce total nitrogen and total phosphorus entering the creek which drains into the Lemon Bay Aquatic Preserve. The facility was completed in 2013. Water quality data was collected from three sampling sites in Alligator Creek to have nutrient values reflective of the entire waterway. The specific parameter considered was Total Nitrogen In order to determine if the implementation of LID project significantly impacted the water quality of the drainage basin, water quality data was broken down for statistical analysis.

Four temporal times were selected to determine historical parameter values, pre-construction values, immediate impact values, and post-construction values.

- Before LID (2006-2008)
- Right Before LID (2009-2011)
- Right After LID (2013-2015)
- After LID (2016-2018)

Out of the monthly water quality samplings, the months representing hurricane season that see the most rainfall in Florida were chosen to analyze to understand impacts of stormwater runoff on the health of Alligator Creek. The 6 months chosen for water quality analysis were June through November.

The sampling sites analyzed were chosen as the three sites completed by the same sampling group, Sarasota Coastal Creeks. Choosing one sampling team minimized sampling error from differences in techniques, depth, and equipment. The three sites were spaced evenly throughout Alligator Creek as upper creek, middle creek, and lower creek. A fourth site directly at the outfall to Alligator Creek from the LID Facility was included.

- Site 1: ALL-1 (Alligator Creek middle)
- Site 2: ALL-2 (Alligator Creek upper)
- Site 3: ALL-3 (Alligator Creek lower)
- Stormwater Facility Outfall (Alligator Creek between ALL-1 and ALL-2).

Nutrient values were determined for each parameter at each temporal distinction, year, month, and site. Results were analyzed using an Analysis of Variance test to determine if there was any significant change in those means. Analysis of Variance uses the calculated results of the related water quality values to determine if the nutrient loads pre-and post- LID construction are statistically different. If significant change is found, a potential conclusion could arise that LID infrastructure played a role in reducing nutrients and pollutants in the studied waterbodies.

Water level data obtained was compared to the nutrient values from Alligator Creek site 3, the downstream sampling site. Nutrient levels should be highest when water level is the highest after rainfall events. Fluctuations of water level and nutrient values downstream can help determine pollutant sources.

To determine the exact impacts of the Stormwater Treatment Facility on the nutrient runoff to Alligator Creek from that site, water quality data was collected from an additional sampling site directly at the Treatment Facility outfall to the creek. Nutrient reduction at this sampling site would show the success of the LID Treatment Facility, even if the nutrient values for the entire creek remain unchanged or increased.

More research will be needed to be sure that any changes in water quality are directly caused by LID implementation rather than simply correlated with a direct cause coming from an outside factor. Factors that could impact water quality other than LID project construction could include abnormal weather events and other infrastructure construction with drainage into the same waterbody.

Cost-Benefit Analysis

An initial cost-benefit analysis was performed to give a framework for more in-depth future analyses. Costs for LID infrastructure and traditional infrastructure were found through a case study by the US Environmental Protection Agency of 17 LID projects nationwide. From the 17 cases, several were broken down into components of site preparation, stormwater management, paving and sidewalks, landscaping, and other costs (US EPA, 2007). Total costs were subtracted from total benefits in order to determine if LID infrastructure is financially beneficial for municipalities in Northeast Florida and Southeast Georgia. Percent of cost increase or decrease of LID techniques compared to conventional techniques were also calculated.

GIS Analysis

Geospatial analysis was performed using ArcGIS 10.6. Separate analyses were performed for Florida and Georgia due to differences in available data. Layers were clipped to the Florida counties in the study area, which are Nassau, Baker, Duval, Clay, Putnam, St. Johns and Flagler counties using county boundary shapefiles available through FGDL.

Both soil hydrology and land use datasets were converted to raster (gridded data), which allows for overlay analysis. Two different overlay analysis methods will be performed to provide the most information to the municipalities. The first will be a binary suitability model, which will determine which areas are suitable for LID infrastructure and which areas are not. The second will be a weighted overlay model, which will categorize the entire study area with a range of LID suitability possibilities from best suited to least suited.

Soil hydrology datasets are categorized based on drainage potential from excessively drained to very poorly drained. Drainage ability is an important parameter for LID infrastructure as only well-draining soils can filter water back into the ground. As such, areas with excessively drained soils, well drained soils, and moderately well drained soils will be the most suitable for LID.

Land use datasets are categorized based on zoning type. As LID is a means to reduce stormwater runoff pollution from areas of increased urban development, lands most suitable for LID infrastructure include retail, residential, right of way, and industrial areas. The amount of runoff pollution that is preventable is much higher in these areas than in natural areas with minimal human interactions.

The first GIS analysis performed was a binary overlay to determine which lands in the study area had all components desired for LID implementation.

- Excessive, Somewhat excessive, and well-drained soils: 1
- Residential, Commercial, Industrial, Right-of-Way, Retail: 1
- All other categories for land use and soil drainage: 0

Sites deemed suitable for LID implementation were those that had both the correct soil hydrology and land use, leaving all other sites depicted as unsuitable. Overall suitability was determined by using map algebra and multiplying the land use and soil hydrology layers together. The resulting values were 0 for sites that had unsuitable land use or unsuitable soil hydrology and 1 for areas with both suitable land use and soils.

The second GIS analysis performed was a weighted overlay, which would allow for visualization of a range of suitability for LID implementation. Different categories of soil hydrology were given different numerical values based on the suitability for LID.

- Excessively well-drained: 5
- Somewhat excessively drained: 5
- Well drained: 5
- Moderately well drained: 4
- Somewhat poorly drained: 3
- Poorly drained: 2
- Very Poorly Drained: 1

Different categories of land use were given also given different numerical values based on suitability for LID.

- Industrial: 5
- Retail/Office: 5
- Residential and Right of Way: 5
- Institutional: 4
- Agricultural: 3
- Public: 2
- Vacant and Recreational: 1
- Other: 1

This analysis gave each area of land a value between 2 and 10 for LID suitability, with higher values corresponding to a higher possibility of LID infrastructure success on reducing stormwater runoff pollution. These values were grouped together for better visualization and mapped. The condensed values are as follows:

- 8-10: Best suitable
- 6-7: Somewhat Suitable

- 4-5: Somewhat Unsuitable
- 2-3: Unsuitable

The same GIS analysis was performed for Ware and Charlton counties in Southeast Georgia. Only land use was provided by the Southern Georgia Regional Commission. Binary suitability and weighted suitability maps were created for Southeast Georgia based only on land use.

The binary overlay map is the most efficient guideline for where LID projects have the best chance for diverting the most runoff volume and pollutant away from waterbodies. This result map should be used by policymakers when determining which LID projects should move forward. The weighted overlay map is most useful for counties in the study area that may want to implement some LID infrastructure but have limited sites with both the correct land use and soil hydrology. The range of suitability given in the weighted overlay map shows the best and the worst places for LID projects.

III. Discussion and Analysis

Water Quality Results

In a joint effort between Sarasota County, the Southwest Florida Water Management District, and the United States Environmental Protection Agency, the Alligator Creek Stormwater Treatment Facility was designed and completed in February 2013 (Alligator Creek Final Report, 2016). Phase 1, completed earlier in 2012, consisted of the redesign of an abandoned wastewater treatment facility to a Low Impact Development Stormwater Treatment Facility to combat high nutrient loads in Alligator Creek from the surrounding area. Also completed in Phase 1 was a baffle box, a component at the outfall point of the stormwater facility to Alligator Creek to capture any residual nutrients (Alligator Creek Final Report, 2016). Phase 2 of the project included reconnecting a nearby lake system and creating swales to reduce localized flooding, improve water quality and increase the size of a bioretention pond by 65% (Alligator Creek Final Report, 2016).

Table 1: Stormwater Facility Reach Land Use

Land Use Type	Acres	Percentage
Residential; Medium Density	157.25	23.52%
Residential; High Density	393.56	58.86%
Commercial and Services	38.52	5.76%
Open Land	11.73	1.75%
Water	67.56	10.10%
Total Acres:	668.62	

The table above shows the land use breakdown by acreage within the Alligator Creek Stormwater Treatment Facility reach. Medium- and high-density residential encompass over 80% of the total project, indicating that most excess nutrients entering Alligator Creek are likely sources such as fertilizers. Out of all the counties in Florida, Sarasota County has 11th highest population density in the state at 533 people per square mile

(Sarasota County). High population density surrounding a waterbody would not indicate high water quality and the LID Stormwater Treatment Facility was the county's first step to reducing nutrients and improving water quality in Alligator Creek draining into the Lemon Bay Aquatic Preserve.

Watermark Engineering, Inc. designed the Phase 1 LID Stormwater Treatment Facility and outfall baffle box (Alligator Creek Final Report, 2016). At the completion of Phase 1 in November 2012, a pollutant load reduction estimate was created to predict the total impact of the LID Facility on improving water quality in Alligator Creek. These values were estimated using a model from the Southwest Florida Water Management District and Camp, Dresser and McKee construction engineering company (Alligator Creek Final Report, 2016). The model predicted the reduction of total phosphorus and total nitrogen in pounds per year based on GIS aerial land use (Alligator Creek Final Report, 2016).

Table 2: Estimated nutrient reduction from Phase 1 projects

Site #1 Stormwater Treatment Train	**TP**	**TN**
	lbs./yr.	lbs./yr.
Pre-Project	644	2,467
Post-Project	180	789
Pounds Reduced	464	1,678
Percent Reduced	72%	68%
Site #2 Baffle Box	**TP**	**TN**
	lbs./yr.	lbs./yr.
Pre-Project	97	937
Post-Project	58	843
Pounds Reduced	39	94
Percent Reduced	40%	10%
Total Phase I	**TP**	**TN**
	lbs./yr.	lbs./yr.
Pre-Project	741	3,404
Post-Project	238	1,632
Pounds Reduced	503	1,772
Percent Reduced	**62%**	**59%**

The table above breaks down estimates for Total Phosphorus and Total Nitrogen reduction between the two separate projects in Phase 1. The bulk of nutrient reduction is estimated to come from the LID Stormwater Treatment Facility, with a predicted 72% reduction of Total Phosphorus and 68% reduction of Total Nitrogen. The baffle box nutrient reductions are estimated to be less than reductions from the LID Facility but may increase in effectiveness during major rain events should the LID Facility become saturated (Alligator Creek Final Report, 2016). If these estimates are accurate regarding nutrient load reductions to Alligator Creek, water quality entering the creek from the LID Facility outfall will be improved, which may lead to overall improved water quality throughout the entire creek.

In addition to predicting nutrient reduction loads from Phase 1 projects, Watermark Engineering completed water quality monitoring from September 2013 to March 2015 with the LID Stormwater Facility (Alligator Creek Final Report, 2016). The purpose of continued monitoring was to determine the impact of the LID Stormwater Treatment Facility and baffle box on pollutant reduction entering Alligator Creek from the surrounding high-density and medium-density residential area. Water quality monitoring occurred bi-monthly. After two years, Total Nitrogen reduction was 2,053 pounds and Total Phosphorus reduction was 91 pounds (Alligator Creek Final Report, 2016). Watermark Engineering noted that nutrient reduction was higher during the first year after construction (2013-2014) compared to the second year (2014-2015). Possible explanation for a drop-off in nutrient reduction is an overload of the LID Stormwater Treatment Facility system from the surrounding residential areas (Alligator Creek Final Report, 2016).

The goal of the Alligator Creek LID Stormwater Treatment Facility is to reduce nutrient pollutants entering the creek (Alligator Creek Final Report, 2016). Nutrient data from three water quality sampling sites spaced throughout Alligator Creek were downloaded from the University of South Florida's Water Atlas online program. The three sampling sites were selected based on availability of data over several years for a time-series analysis, even spacing throughout Alligator Creek to differentiate between upstream, middle and downstream, and minimizing data collection error by selecting sampling sites from the same source. Data was downloaded for Total Nitrogen.

The image below shows the Alligator Creek region in Sarasota County. Important features are the location of the three original water quality sampling sites, ALL-1, ALL-2, and ALL-3, as well as the location of the outfall site from the Alligator Creek LID Stormwater Treatment Facility, which had a separate water quality sampling site in the creek directly at that outfall. The image shows the reach of medium-density and high-density residential land use areas that surround Alligator Creek, potentially the cause of nutrient pollution overload and poor water quality entering the creek and Lemon Bay Aquatic Preserve.

Image 1: Labeled map of Alligator Creek area

As detailed in the methodology section, the water quality data for Total Nitrogen were divided into four temporal timeframes with reference to the completion of the LID Stormwater Treatment Facility in 2013- before, right before, right after, and after. Data of nutrient load data was further broken down into years within the temporal timeframes, months, and the three sampling sites. As nitrogen is the biggest nutrient issue in Florida, statistical analysis of Total Nitrogen in Alligator Creek was performed. The dataset for Total Nitrogen had result values for enough sites, months, and years to produce meaningful statistical analysis.

An Analysis of Variance (ANOVA) test was run to determine if differences in total nitrogen values between temporal timeframes, years, or months were significant or only due to chance. Resulting P-values less than 0.05 are considered significant, meaning that the differences in values are likely not the result of simple fluctuations.

Analysis of Variance for Total Nitrogen

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Temporal	**2**	**1072304**	**536152**	**4.11**	**0.027**
Year	1	307594	307594	2.36	0.135
Temporal*Year	2	290967	145483	1.11	0.341
Month (Year)	8	770170	96271	0.74	0.658
Temporal*Month (Year)	16	3110618	194414	1.49	0.169
Error	30	3917270	130576		
Total	59	9468922			

The ANOVA results above show that the only feature with significant difference in nitrogen values are between temporal timeframes as this parameter is the only one with a p-value less than 0.05. From this analysis, determination can be made that the Total Nitrogen values from before the LID Stormwater Treatment Facility construction are significantly different than the total nitrogen values after the LID Facility was completed. This analysis, however, does not determine the Total Nitrogen values are significantly more or less when comparing pre-LID values and post-LID values.

The Tukey Method of statistical analysis was used to calculate and compare means of temporal timeframes as a second method to determine if significant changes occurred across temporal timeframes. The Tukey Method was used with 95% confidence, meaning that any stated changes have a 95% probability of being significant and not happenstance.

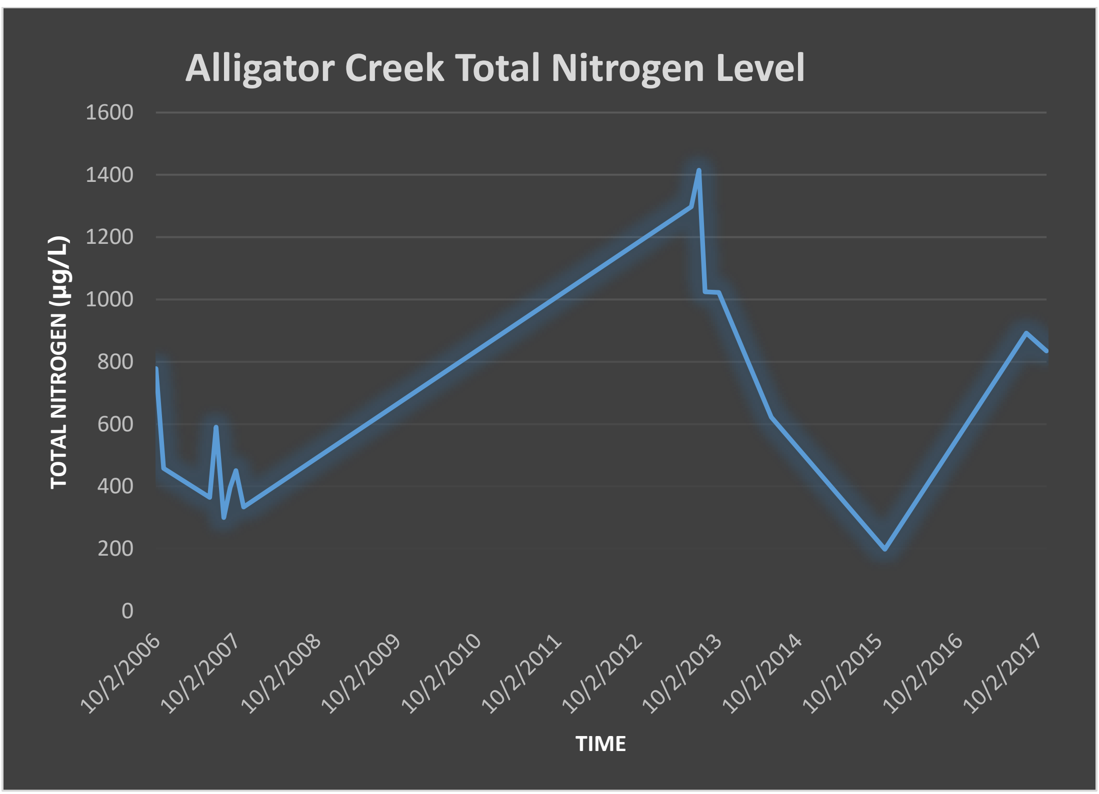
Grouping Information Using the Tukey Method and 95% Confidence for Total Nitrogen

Temporal	N	Mean	Grouping	
Right After	20	1307.10	**A**	
Right Before	20	1271.15	A	B
Before	20	1007.25		**B**

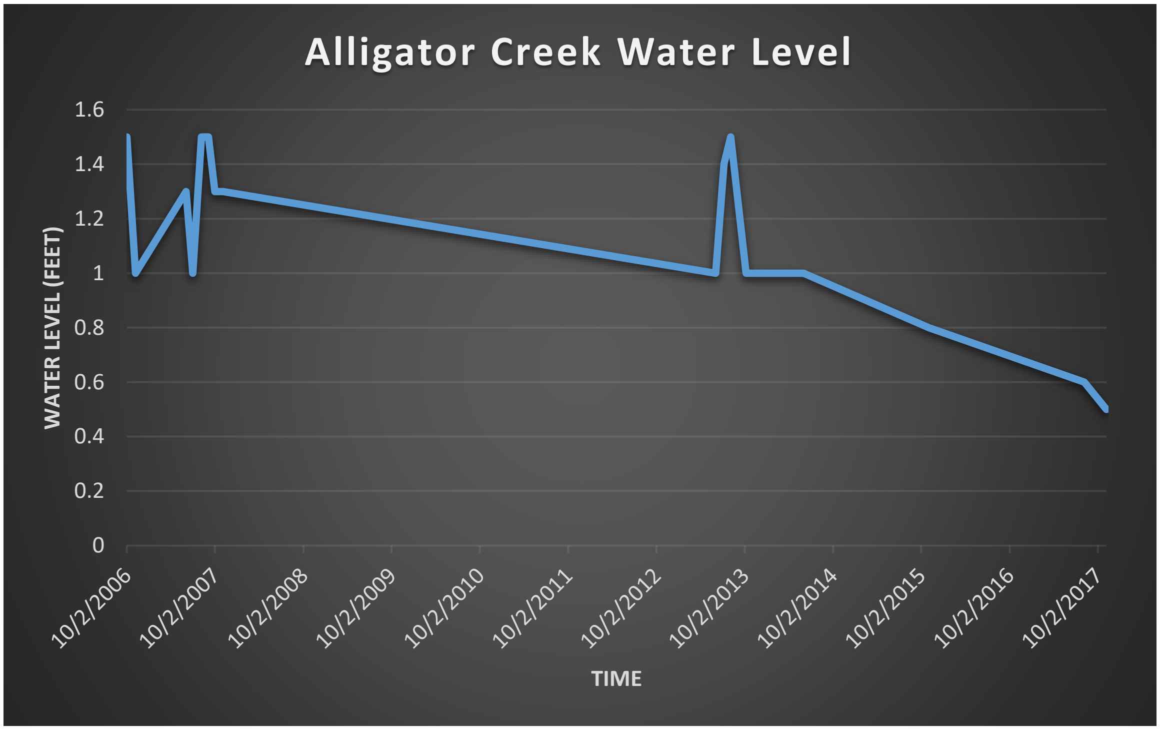
Means that do not share a letter are significantly different.

As shown in the analysis above, there were no significant differences between before and right before LID implementation. There were also no significant differences between right before and right after LID implementation, meaning that the LID Stormwater Treatment Facility did not seem to have a significant impact on nitrogen levels in the entirety of Alligator Creek. There was, however, a significant difference in the nitrogen load of Alligator Creek from before (2006-2008) and right after (2013-2015). The mean value of nitrogen before LID implementation was 1,007 μg/L and the mean value right after LID implementation was 1,307 μg/L. The surprising result from this statistical analysis is that the mean nitrogen value significantly increased from the 2006-2008 temporal timeframe to the 2013-2015 timeframe, despite the construction of the LID Stormwater Treatment Facility to combat heighted nitrogen in Alligator Creek. Additional inquiry into the workings of this creek were necessary to understand the story of this waterbody.

Graph 1: Downstream Nitrogen Load over Time



Graph 2: Mean Water level over Time



To understand the trend of total nitrogen load in Alligator Creek over several years before and several years after the construction of the LID Stormwater Treatment Facility, total nitrogen values from the most downstream water quality sampling site were graphed over time and compared to the mean water level as a proxy for rainfall. Graph 1 above shows a steady increase in total nitrogen in downstream Alligator Creek just before draining into the Lemon Bay Aquatic Preserve from 2007 to 2013. The mean water level for Alligator Creek over the same time span, however, is stagnant, gradually dropping from 1.3 feet to 1 foot between 2007 and 2013. For both total nitrogen and mean water level, the peak is in 2013, signifying that the time with the highest nitrogen load in the creek correlates with a heavy rainfall year, possibly draining higher levels of nutrient-rich runoff into Alligator Creek. Increases in total nitrogen load in Alligator Creek independent of high rainfall events from 2007 to 2013 could be due to increases in housing parcels with direct drainage into the creek.

From 2013 to 2015, there was a drop in total nitrogen which, although meaningful, is short-lived as total nitrogen increased again after 2015. It is possible that decrease in mean water level and, therefore, lack of heavy rain events during those years could contribute to lower total nitrogen load. That trend, however, did not correspond when total nitrogen was increasing from 2007 to 2013 and mean water level was dropping during that same time, so lack of rain impacting total nitrogen load seems unlikely.

A potential explanation for the drop in Total Nitrogen in Alligator Creek in 2014 and 2015 is the initial success of the LID Stormwater Treatment Facility. Watermark Engineering, Inc. estimated an almost 60% decrease in total nitrogen entering Alligator Creek from the LID Stormwater Treatment Facility outfall after Phase 1 project completion. Watermark also noted that the LID Facility dropped in nutrient reduction efficiency after the first year of pollutant removal (Alligator Creek Final Report, 2016). While the drop in total nitrogen does look like a significant decrease from Graph 1, the upstream and middle total nitrogen values may have increased between 2014 and 2015, causing the Tukey Method statistical analysis to show a significant increase in the mean total nitrogen values for the whole creek from 2006-2008 and 2013-2015. Further analysis is necessary to determine what caused the decrease in total nitrogen from 2014 to 2015 in the downstream Alligator Creek and what caused an upturn of total nitrogen load in 2016.

A water quality sampling site is located directly at the LID Stormwater Treatment Facility outfall to Alligator Creek. Image 1 above shows that the outfall is located between sites ALL-1 and ALL-2 in the middle reach of Alligator Creek. Total nitrogen data was downloaded for this site to compare to sites ALL-1 and ALL-2 and determine if the LID Facility had any impact on water quality.

Unfortunately, water quality data for the LID Stormwater Treatment Facility outfall was very limited. Data was only collected in 2011 and 2017 and during those years, not every month was sampled for total nitrogen. Months and years were compared between sites ALL-1, ALL-2, and the LID outfall and values were pulled out for instances where data was available for all three sites. The comparable sampling dates were August 2011 and June 2017.

Table 3: Total Nitrogen from 3 Alligator Creek Sampling Sites

Year	Month	Nutrient	Site ALL-1	LID Outfall	Site ALL-2
2011	August	TN (µg/L)	912	**1454**	796
2017	June	TN (µg/L)	1757	**902**	1619

The table above shows total nitrogen values from August 2011 and June 2017 at sampling sites mid-stream ALL-1, the LID Facility outfall in between, and upstream ALL-2. August and June are comparable months as they are both high rainfall summer months in Florida and fall during hurricane season. As the table clearly shows, total nitrogen values at sites ALL-1 and ALL-2 increase significantly between 2011 and 2017, possibly due to increased residential land use surrounding Alligator Creek. If the LID Outfall site followed the same trend as the rest of the creek, including the upstream total nitrogen values that flow in the direction of the LID outfall sampling site, then the total nitrogen values at the LID outfall should also increase from 2011 to 2017. However, total nitrogen load at the LID Outfall site clearly decreases significantly from 2011 to 2017, the opposite trend from the sampling site nitrogen loads upstream and downstream.

A potential explanation for this decrease in total nitrogen at the LID Outfall site is that the runoff entering Alligator Creek from that outfall has significantly lower nutrient loads than the runoff entering Alligator Creek at other upstream and downstream points. This significant drop in total nitrogen and opposite trend to the other sampling sites in Alligator Creek suggests that the LID Stormwater Treatment Facility is succeeding in reducing nutrient pollutants into Alligator Creek, even though the mean nitrogen values for the overall creek have significantly increased before and after LID Facility construction. If the LID Stormwater Treatment Facility is, in fact, meeting the goal of reducing nutrient pollution entering Alligator Creek, the overload of nutrient pollution from other sources entering Alligator Creek as runoff are masking the impacts of the LID Facility unless water quality samples are taken directly at the LID Facility outfall site. Additional water quality analysis of other LID projects in Florida will be necessary to specifically determine impacts of such sustainable stormwater infrastructure on nutrient pollution in Florida's waterways.

Cost-Benefit Results

The United States Environmental Protection Agency completed a report of 17 case studies in 2007 comparing the costs of projects using LID and conventional stormwater system techniques. Project sites were in Washington, Arkansas, Wisconsin, Illinois and Maryland states (US EPA, 2007). This evaluation was done to combat incorrect views that green infrastructure and LID techniques are more expensive than traditional techniques and show both environmental and economic benefits of green infrastructure. Notable environmental benefits mentioned in the EPA report are downstream resource protection, groundwater recharge, reduced cost on mitigating runoff pollution, and improved quality of coastal habitats (US EPA, 2007). Additionally, economic benefits have been identified, including increased value of property, reduced property damage from flooding during rain events, and increased value of aesthetically pleasing areas (US EPA, 2007).

Table 2: Case Study Project Costs

Site	Traditional Cost	LID Cost	Cost Difference	Percent Difference
2nd Avenue. Seattle, WA	$868,803	$651,548	$217,255	25.01%
Auburn Hills, WI	$2,360,385	$1,598,989	$761,396	32.26%
Bellingham City Hall, WA	$27,600	$5,600	$22,000	79.71%
Bellingham Park, WA	$52,800	$12,800	$40,000	75.76%
Gap Creek, AR	$4,620,600	$3,942,100	$678,500	14.68%
Garden Valley, WA	$324,400	$260,700	$63,700	19.64%
Kensington Estates, WA	$765,700	$1,502,900	**-$737,200**	**-96.28%**
Laurel Springs, WI	$1,654,021	$1,149,552	$504,469	30.50%
Mill Creek, IL	$12,510	$9,099	$3,411	27.27%
Prairie Glen, WI	$1,004,848	$599,536	$405,312	40.34%
Somerset, MD	$2,456,843	$1,671,461	$785,382	31.97%
Tellabs Campus, IL	$3,162,160	$2,700,650	$461,510	14.59%

The table above shows the traditional infrastructure costs or estimates, costs or estimates of LID infrastructure, cost difference and percent difference of 12 of the 17 projects considered in the study. 5 of the sites in the case study did not have traditional cost estimates. A project in Toronto had only one LID technique implementing green roofs, which would not have a traditional cost comparison. Other projects were small-scale pilot projects that also would not have an appropriate traditional cost comparison (US EPA, 2007).

In all except for one project, Kensington Estates in Washington State, the costs of LID techniques were lower than the costs of traditional infrastructure techniques. Percent reduction of the 11 sites with cost savings of LID techniques were 14% to almost 80%. The site with increased costs of LID methods compared to traditional methods had almost double the cost to implement LID. The project with the highest percentage of cost savings from LID was Bellingham City Hall in Washington state, which ended up being the site with the overall lowest LID price tag.

Understanding the price differences between traditional and LID costs requires a breakdown into the cost of several project components (US EPA, 2007). Project components include site preparation, stormwater management, paving, sidewalks, and other hard infrastructure, landscaping, and miscellaneous costs. Breakdown is critical to identify project components that may reduce overall costs and components that could increase costs. Fluctuations in specific component prices may occur over time due to resource availability or demand, which could either increase or decrease the total cost of LID projects. Important to note is that these price considerations do not include changes in maintenance costs from using LID over traditional stormwater infrastructure or reduction of regulatory municipal fees for LID methods (US EPA, 2007).

Table 3: 2nd Avenue, Seattle, Washington Costs.

Item	Traditional Cost Estimate	LID Actual Cost	Increase/ Savings	Percent Savings
Site Preparation	$65,084	$88,173	**-$23,089**	**-35.48%**
Stormwater Management	$372,988	$264,212	$108,776	29.16%
Paving and Sidewalks	$287,646	$147,368	$140,278	48.77%
Landscaping	$78,729	$113,034	**-$34,305**	**-43.57%**
Misc.	$64,356	$38,761	$25,595	39.77%
Total	$868,803	$651,548	$217,255	25.01%

The table above breaks down specific costs of project components for both traditional estimates and the actual LID price for a street redesign project in Seattle, WA (US EPA, 2007). This project, tackled by Seattle Public Utilities, redeveloped a 660-foot block with numerous LID techniques to reduce stormwater runoff pollutants and create a more aesthetic right-of-way corridor (US EPA, 2007). Infrastructure changes were agreed upon by the Public Utilities and residents, which included reducing street width, installing bioswales on both sides of the street, and removing the curbs and gutters previously used for stormwater management.

The Public Utilities, first and foremost, spent a good amount of time on community outreach (US EPA, 2007). Because this was a pilot project for LID in Seattle in a residential area, community acceptance of this project that was not the typical street stormwater system typical of the area was critical for project success and success of future LID projects.

The project components with the highest amount of cost savings were paving and sidewalks. Since the overall street width was decreased, costs of repaving the street were significantly decreased. The LID project components that were more expensive than a traditional street stormwater system were the site preparation and landscaping. For vegetated bioswales on both sides of the street to capture and filter stormwater runoff, 100 evergreen trees and 1,100 shrubs were planted throughout the project (US EPA, 2007). Such vegetation, typically not present in a conventional stormwater system, drove the landscaping cost of the project up significantly higher than if vegetated bioswales were not included in the retrofit. While some components cost more and some cost less, the overall cost of this LID project compared to a conventional system is estimated to save the City of Seattle over $200,000.

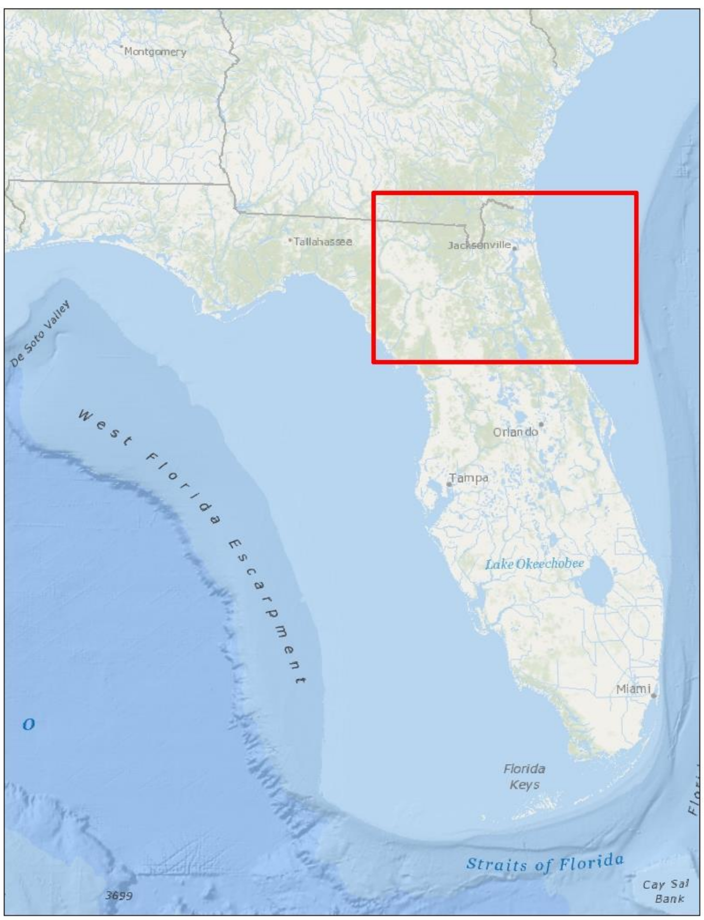
In addition to the cost savings of using LID methods instead of conventional stormwater management methods on the 2nd Avenue project in Seattle, WA, the environmental benefits of LID were equally, if not more, important for the area (US EPA, 2007). Monitoring of the street hydrology concludes that the stormwater runoff prevention of using LID methods was more than originally predicted. From 2002 to 2007 when the cost-benefit report from the EPA was published, no stormwater runoff was recorded from the 2nd Avenue site, even though that time period had a record rain event (US EPA, 2007).

The cost-benefit analysis done by the US EPA shows the potential economic and environmental benefits to municipalities when comparing LID methods to conventional stormwater systems. More case studies will need to be analyzed, especially more recently than 2007 and in Florida and the Southeast, to determine the economic benefits of LID techniques in Northeast Florida and Southeast Georgia.

GIS Spatial Results

Northeast Florida

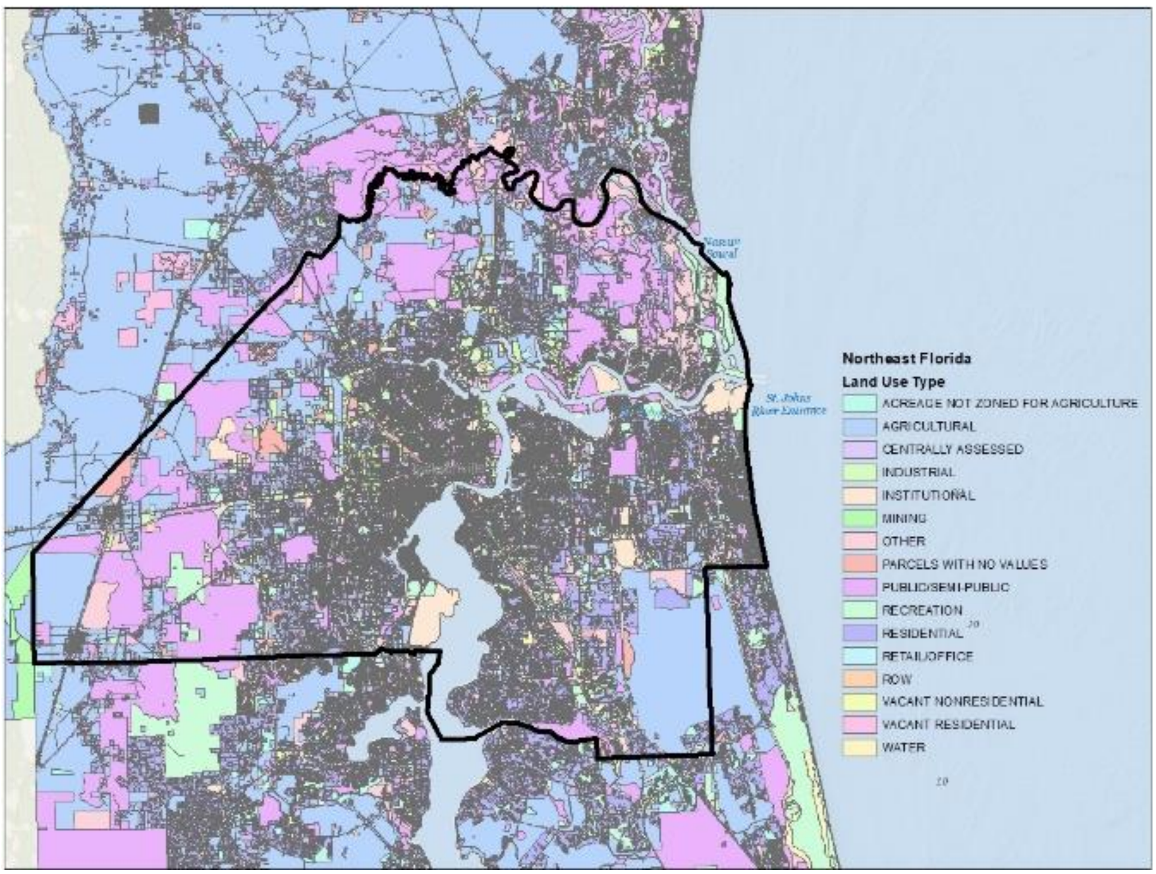
Map 1: Northeast Florida Region



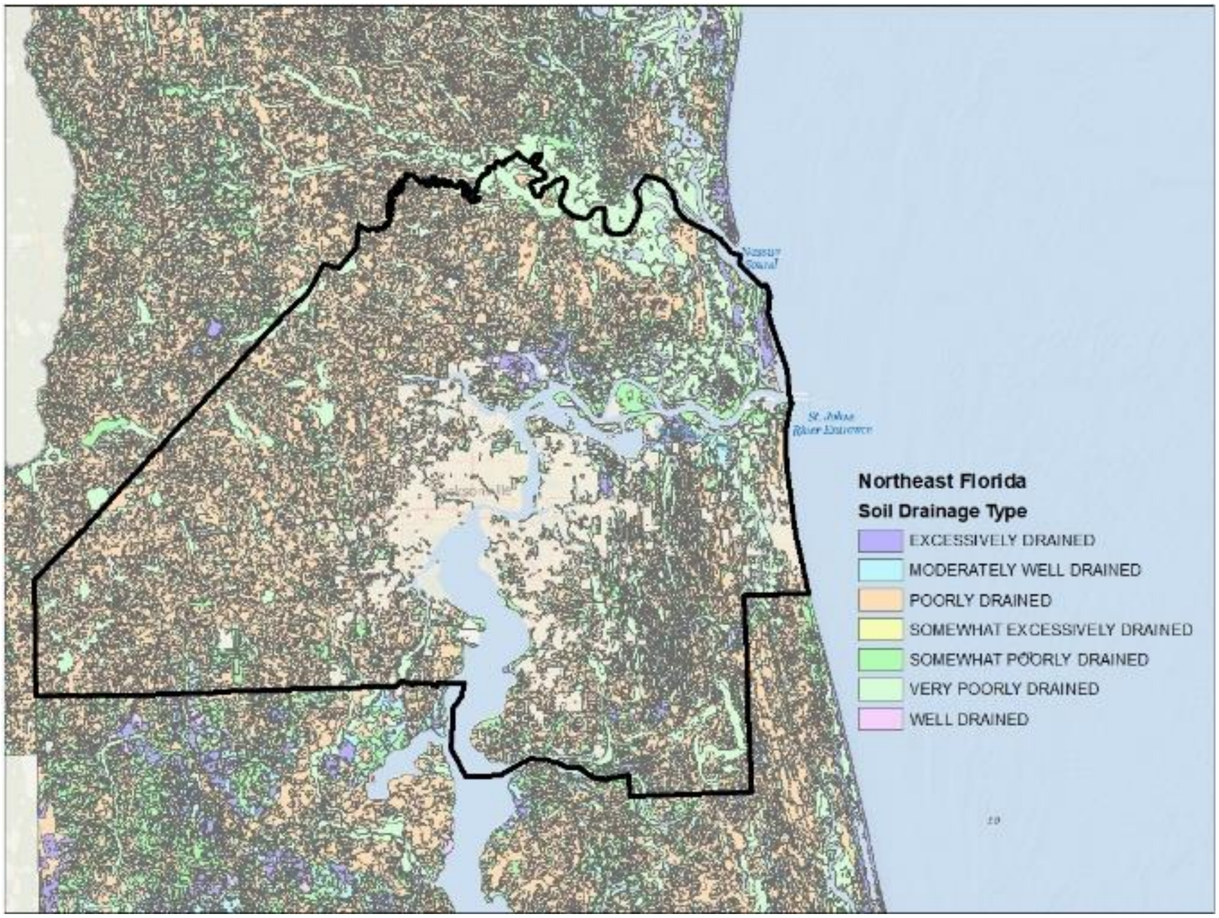
The seven counties of the Northeast Florida study area include Nassau, Baker, Duval, St. Johns, Clay, Flagler, and Putnam counties. Map 1 above outlines this study region in relation to the State of Florida. While not all municipalities in these seven counties drain stormwater pollution directly into the St. Marys River, nutrient overloads in one area can have impacts far beyond municipality borders. For this reason, all municipalities in the Northeast Florida region are included in GIS analysis for LID site suitability and, ultimately, to adopt and enforce the LID model ordinance.

In Northeast Florida, data was available in all seven counties for land use and soil hydrology. Maps 2 and 3 below depict land use and soil hydrology separately and zoomed in on Duval County to differentiate the different category extents before GIS analysis.

Map 2: Duval County Land Use Categories



Map 3: Duval County Soil Hydrology categories

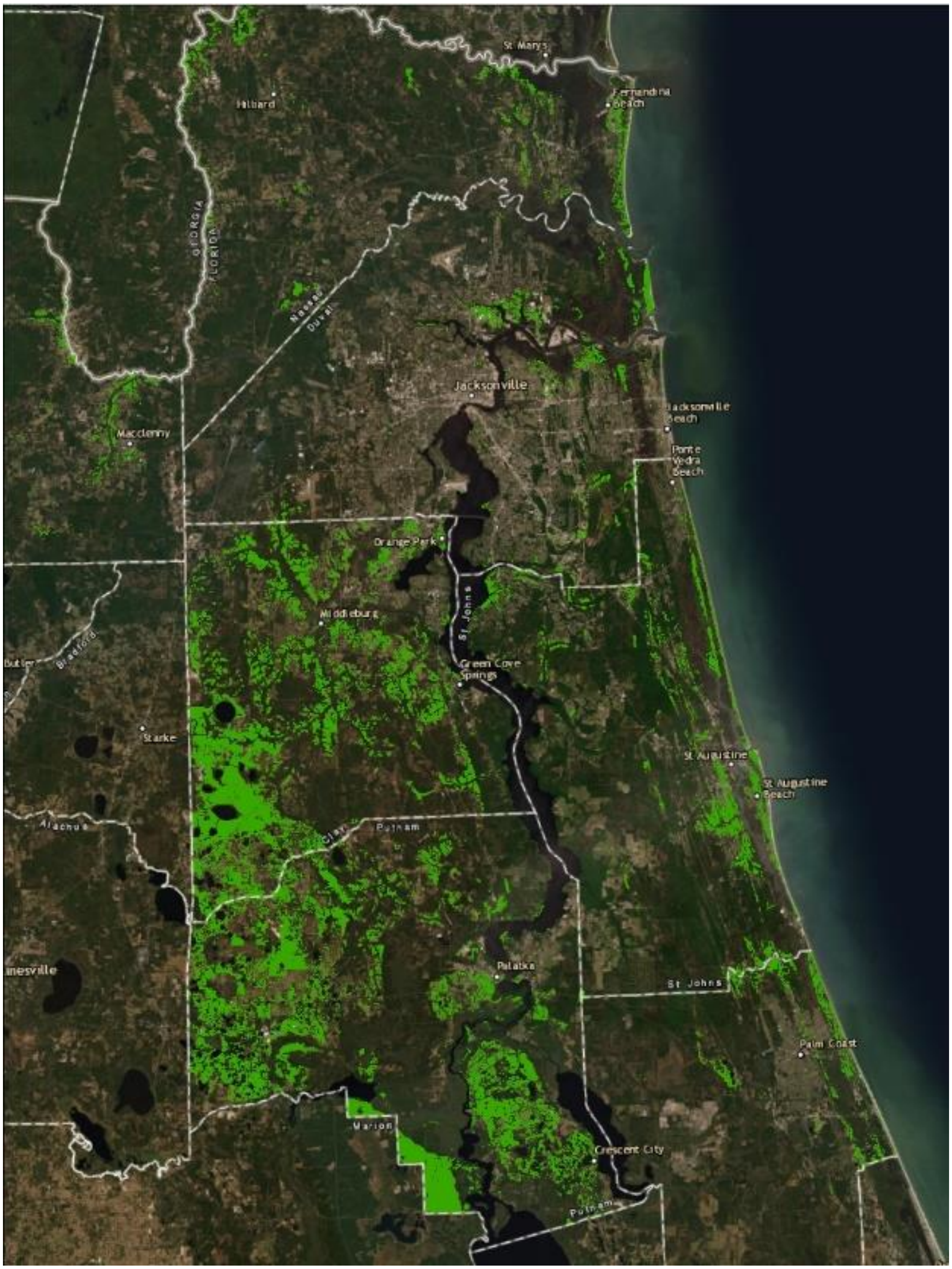


Land Use and Soil Hydrology were reclassified in two ways; first, only as 1s and 0s for suitable or not suitable binary overlay, and second on a scale from 1-5 for a range of suitability. The binary suitability output can be used for urban developers with flexibility to construct new neighborhoods and can designate construction within areas of high LID suitability. The weighted suitability output can be used in municipalities with limited options for new development and would want to incorporate LID methods in areas of redevelopment with the best chance for stormwater pollution reduction.

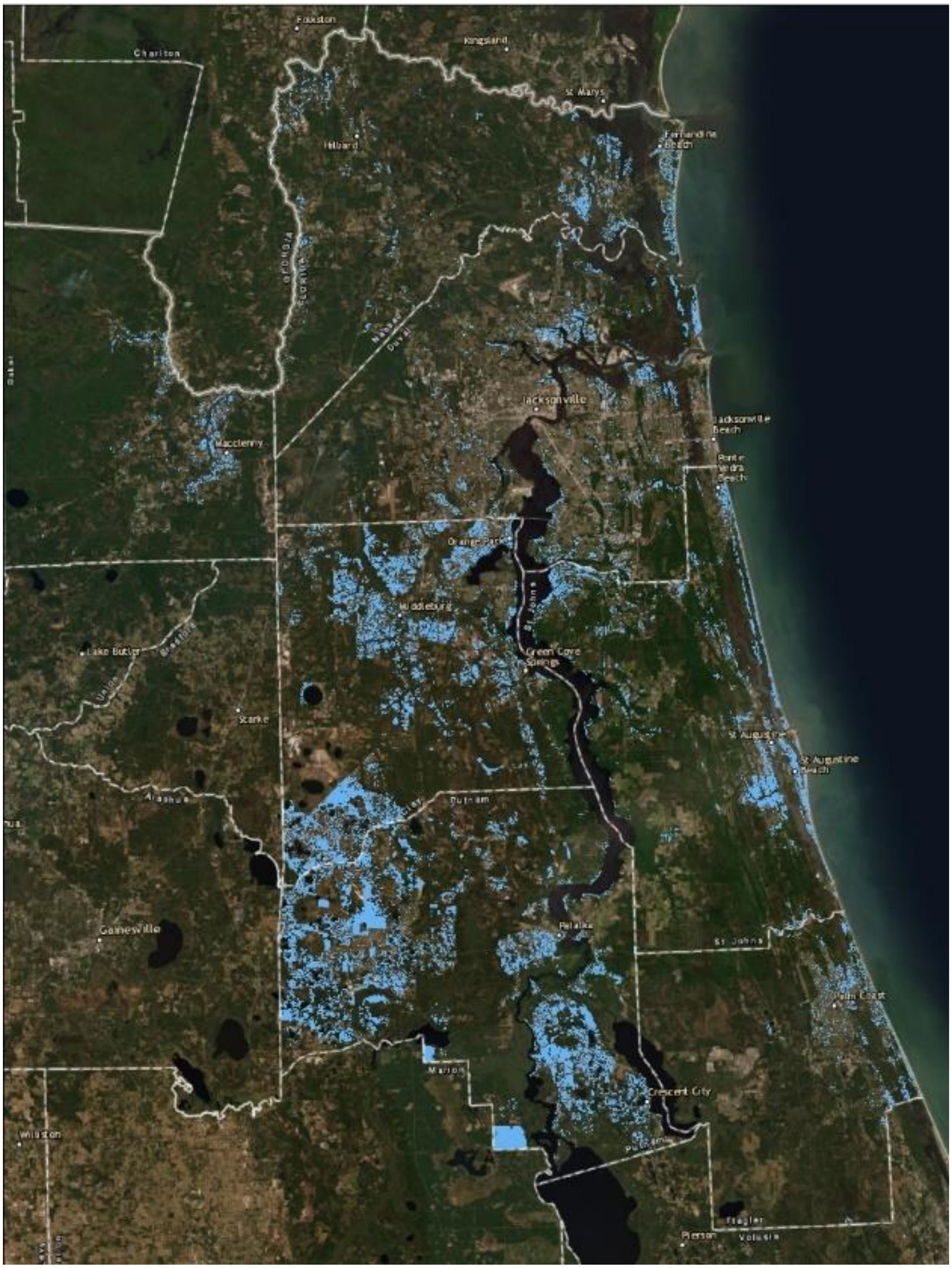
Map 4 and Map 5 below show the results from the binary suitability model and the weighted suitability model. The binary suitability depicts areas in green that were given a value of 1 for suitable. The weighted suitability depicts areas in blue that were somewhat suitable or suitable and grouped together to form one dataset. The outputs of both overlay methods show similar areas throughout Northeast Florida that are suitable for LID implementation.

For both maps, LID is shown to be suitable around major towns with high urban development, in agricultural areas to reduce nutrient overloads, and along high-density and medium-density residential beach communities.

Map 4: Northeast Florida Binary Suitability Output

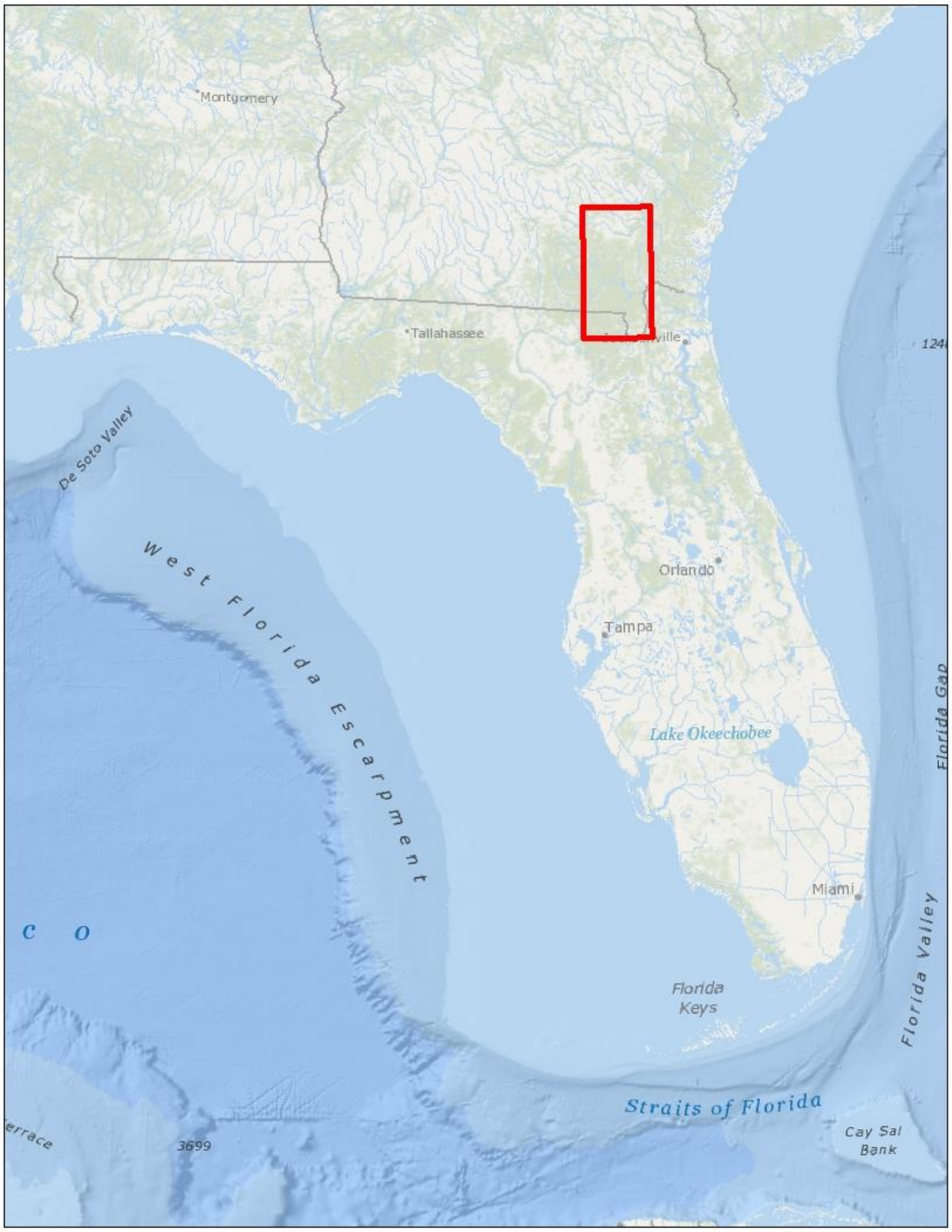


Map 5: Northeast Florida Weighted Suitability Output



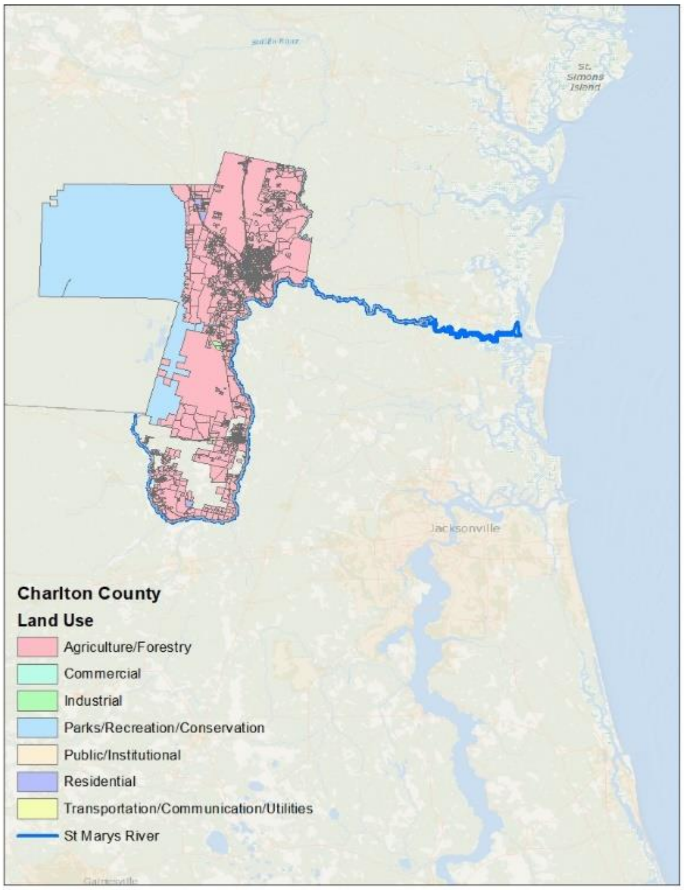
Southeast Georgia

Map 6: Southeast Georgia Region

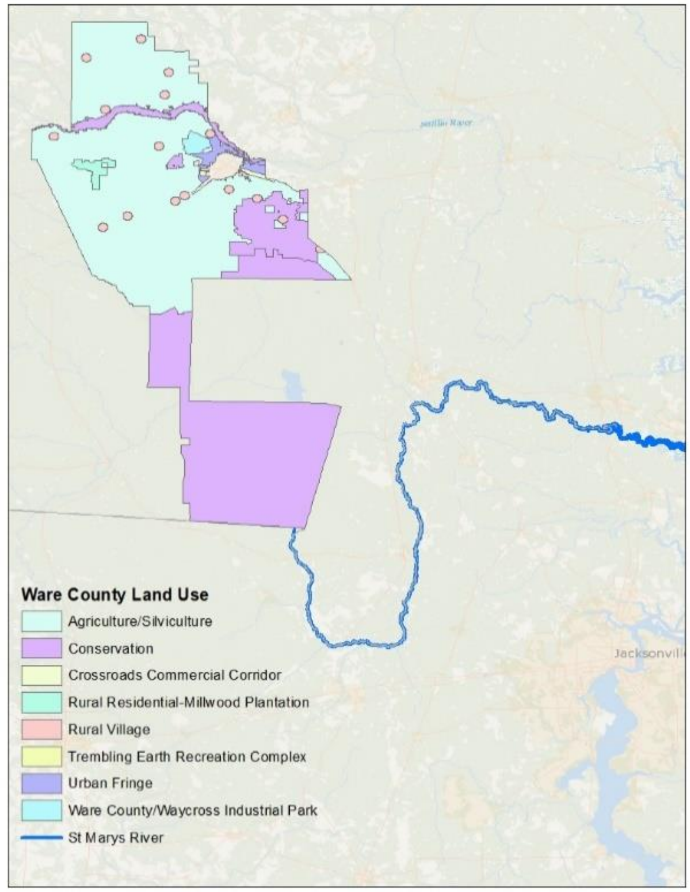


The three counties in Southeast Georgia part of the study area are Camden, Charlton, and Ware counties. GIS data provided by the Southern Georgia Regional Council only included Charlton and Ware counties and within those counties, only land use data was available. Map 6 shown below outlines the Southeast Georgia study region. This created an entirely different output compared to Northeast Florida, which had both land use and soil hydrology data to utilize.

Map 7: Ware County Land Use



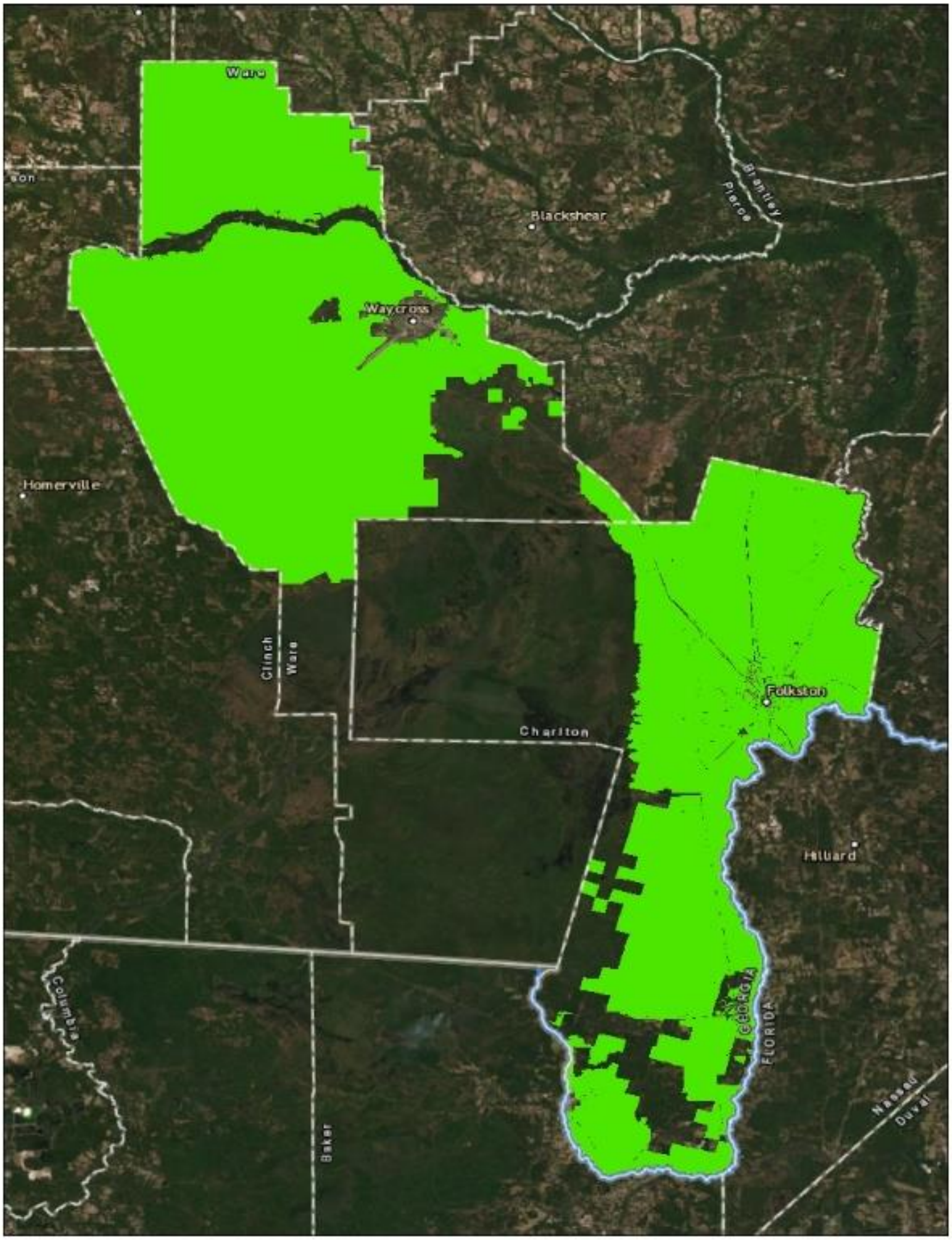
Map 8: Charlton County Land Use



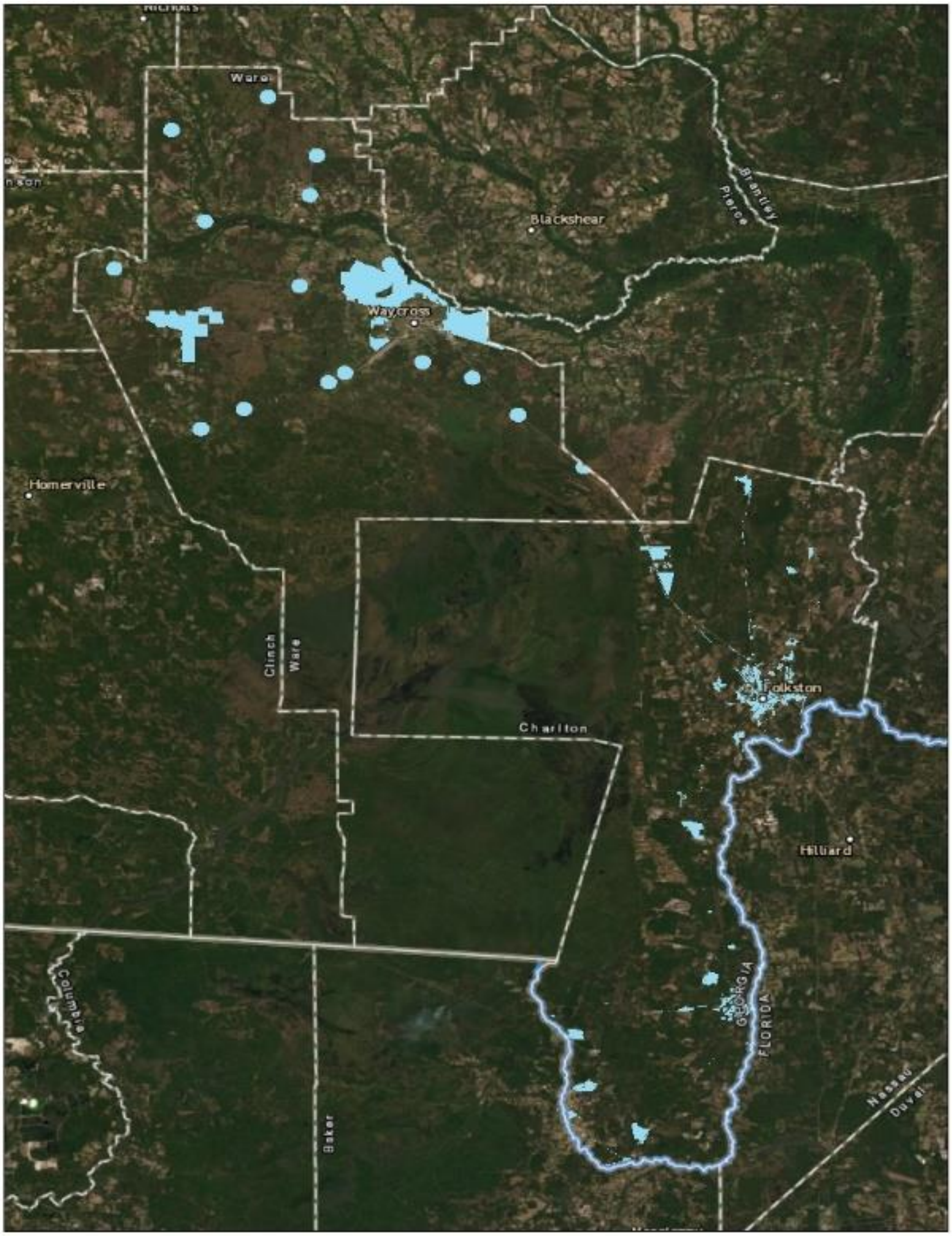
The only available data for Ware and Charlton counties was the land use and land use categories in each county were different. Map 7 and Map 8 above show the breakdown of land use in Ware and Charlton, respectively. Land use alone was used to create a binary and weighted suitability model for the two available Southeast Georgia counties.

Map 9 and Map 10 shown below are the binary suitability results and weighted suitability results from Southeast Georgia land use data. Unlike the binary and weighted suitability outputs in the Northeast Florida region, the two outputs for Southeast Georgia are very different. Binary suitability in green shows the values given a 1 for suitable. Weighted overlay shows the grouping of categories for somewhat suitable and suitable. The binary suitability map has significantly more land that is considered suitable for LID compared to the weighted overlay. The binary suitability map considered the category agriculture/silviculture as suitable for LID due to the amount of excess nutrients leaving agricultural lands. In the weighted overlay, agriculture was excluded from somewhat suitable or suitable categories, leaving only the developed areas around the major towns of Folkston and Waycross as suitable for LID.

Map 9: Southeast Georgia Binary Suitability output



Map 10: Southeast Georgia Weighted Suitability output



IV. Conclusions

The goal of this research project was to identify the potential impacts of a Low Impact Development model ordinance on water quality improvements in Northeast Florida and Southeast Georgia, specifically in the St. Marys River. The three-part analysis of LID, from both nation-wide and Florida, have shown green infrastructure stormwater techniques to have potentially positive environmental and economic benefits for Northeast Florida and Southeast Georgia.

The water quality analysis in Sarasota County, initially seemed to show no benefits from the LID Stormwater Treatment Facility, did show that LID methods can reduce input of Total Nitrogen and potentially other nutrients into Alligator Creek. The overall trend of total nitrogen in Alligator Creek is increasing significantly, showing that medium-density and high-density residential development could be contributing to the poor water quality of the creek. The decrease of total nitrogen directly at the LID Stormwater Treatment Facility indicates that those LID methods are succeeding in filtering nutrients, but these benefits are masked by the overload of nutrients entering the system outside of the LID Facility. If LID facilities and methods were more common around the Alligator Creek drainage basin, nutrient reduction throughout the entire creek would be possible if implemented correctly.

A significant barrier to wide-spread implementation of LID methods is the public perception that LID, and green infrastructure in general, is a much more expensive alternative to conventional stormwater management systems. While certain components of LID construction may cost more than conventional stormwater systems, such as increased landscaping costs for vegetated bioswales or bioretention ponds, the overall savings from LID can and typically do drive the total project costs lower than conventional system costs. The EPA case studies of LID conducted in 2007 show that LID projects around the nation are economically beneficial apart from one project where LID costs were higher than conventional method costs. Since LID methods can save municipalities money, efforts should be made to implement more LID projects over conventional stormwater systems in Northeast Florida and Southeast Georgia.

While LID methods have been shown to be environmentally and economically beneficial in other areas of the country and state, GIS analysis of the Northeast Florida and Southeast Georgia region showed that LID methods could potentially have the same positive impacts in this area. Both binary and weighted suitability models of Northeast Florida and Southeast Georgia showed that LID is suitable in many areas of the region, especially in areas such as residential beach-side communities and larger cities and towns with continued urban development. Implementing LID techniques in areas designated as LID suitable can ensure that water quality improvement efforts have the highest potential for success.

With this completed analyses, local community members and policymakers now have proper information to begin implementing new regulations for stormwater management systems in the Northeast Florida and Southeast Georgia region.

V. Policy Recommendations

St. Marys River Region LID Model Ordinance

The action item set out by the Water Beyond Borders initiative in 2017 was to create a model ordinance for Low Impact Development that each municipality in the St. Marys River region could adapt, implement, and enforce to improve water quality and reduce coastal flood risk by limiting impervious surfaces (Water Beyond Borders, 2017). The St. Marys River Region LID Ordinance is modeled after ideas and components in the Sarasota County LID Guidance Document and the Duval County LID Manual, both which only recommend use of LID as a stormwater infrastructure alternative. Wording for LID requirements was modeled after the City of Los Angeles Low Impact Development Ordinance and worked into an ordinance structure typical for Northeast Florida and Southeast Georgia.

The main component of the St. Marys River ordinance that differs from other Florida and Georgia LID Guidance Documents considered in this research is that LID will be a requirement for all new development and redevelopment projects. By including LID as a requirement allows this region to be the first community in Florida to change the mindsets away from traditional, centralized stormwater systems to a sustainable system. This region can then serve as a model to other communities in Florida and the Southeast to protect coastal ecosystems, reduce flood risks, and become more resilience to sea level rise and more intense hurricanes.

The ordinance is constructed as a framework that allows each municipality to tailor the regulations to individual community needs. This generalize framework is necessary because each municipality has its own set of stormwater infrastructure needs. An inflexible ordinance would not account for differences in regional municipalities such as rate of urban development and soil hydrology differences between coastal and inland communities. The ordinance also includes a section where each municipality can input the required water quality standards for the area, which may differ between states and counties.

The model ordinance has instructions for two different types of site suitability analysis to be used in different situations. The first suitability analysis is done for new construction in large, open areas that are flexible with stormwater infrastructure locations. An example where this large-scale LID suitability mapping would be appropriate is if a developer was looking for an area to build a new neighborhood and wanted to purchase a residential-zoned parcel with the highest potential for LID method success. A site suitability analysis in this case can determine which locations have the best land use, habitat, and soil hydrology for LID technique success that would infiltrate the maximum amount of water into the ground and reduce runoff.

The second type of site suitability analysis is done in redevelopment areas or highly urbanized areas where open, green space is not readily available. In this case, the available locations that could be fit with LID practices is analyzed to determine which method would best work in that specific area. These distinctions in site suitability modeling help bring LID practices into a multitude of projects.

The last two components of the model ordinance detail the goals of LID in this region. The stormwater runoff will be controlled at the point of rainfall, meaning that the centralized and divert traditional system that moves water over impervious surfaces will no longer be the status quo. Stormwater will be captured, retained, infiltrated, and used with minimal flow over impervious surfaces and with minimal nutrient and pollutant capture. In terms of specific LID stormwater end goals, the focus will be on infiltration of rainwater back into the ground instead of flowing into waterways. By focusing on infiltration, less runoff pollutants will reduce water quality in coastal ecosystems and more water will be available to recharge the aquifers.

The policy recommendation from this research is for each municipality in the Northeast Florida and Southeast Georgia region to take the St. Marys River Region LID Ordinance and tailor requirements to the needs of that specific area. Steps must be made ensure community support so that LID will become a requirement in all new development and redevelopment projects where possible. If, and only if, LID requirement for new development and redevelopment is impossible for a municipality to adopt and enforce, LID method guidelines can be introduced as a preferred option for new development projects with or without a green infrastructure incentive.

Changing the mindset of local policymakers and community members from a short-term way of thought to a long-term, sustainable way of thought takes time, energy, and the right leadership to push for new ideas and policies that can make a last impact on the community. In coastal communities of Northeast Florida and Southeast Georgia, the time is here to make changes to the status quo urban development and stormwater management systems so that future generations can enjoy pristine waterways and beaches and the economic and environmental benefits they bring to local municipalities.

MUNICIPALITIES OF NORTHEAST FLORIDA AND SOUTHEAST GEORGIA

ORDINANCE 2020 - xxx

AN ORDINANCE OF THE MUNICIPALITIES OF NASSAU COUNTY, BAKER COUNTY, DUVAL COUNTY, ST. JOHNS COUNTY, CLAY COUNTY, FLAGLER COUNTY, AND PUTNAM COUNTY, FLORIDA, AND THE MUNICIPALITIES OF CAMDEN COUNTY, WARE COUNTY, AND CHARLTON COUNTY, GEORGIA, CREATING A CHANGE IN ANY COMPREHENSIVE PLANS, STORMWATER MANAGEMENT PLANS, AND IMPERVIOUS SURFACES REGUALTIONS; PROVIDING FOR CONFLICTS; PROVIDING FOR RATIFICATION OF PRIOR ACTS; PROVIDING FOR CODIFICATION AND EXHIBITS; PROVIDING FOR SEVERABILITY, AND AN EFFECTIVE DATE

WHEREAS, the Town Commission of the Municipality of **NORTHEAST FLORIDA OR SOUTHEAST GEORGIA** enacted local ordinances and comprehensive plans to combat stormwater; and

WHEREAS, the local ordinances of the Municipality of **NORTHEAST FLORIDA OR SOUTHEAST GEORGIA** do not reduce stormwater runoff pollutants efficiently; and

WHEREAS, Low Impact Development is an environmentally and economically viable alternative to traditional stormwater management systems; and

WHEREAS, new development and redevelopment projects in the Municipality of **NORTHEAST FLORIDA OR SOUTHEAST GEORGIA** should consider the environmental and economic benefits of Low Impact Development; and

WHEREAS, the Municipality of **NORTHEAST FLORIDA OR SOUTHEAST GEORGIA** Town Commission hereby finds that this Ordinance is in the best interests of the health, safety, and welfare of the citizens of **NORTHEAST FLORIDA OR SOUTHEAST GEORGIA.**

NOW, THEREFORE, BE IT ORDAINED BY THE TOWN COMMISSION OF THE MUNICIPALITY OF NORTHEAST FLORIDA OR SOUTHEAST GEORGIA, THAT THE MUNICIPALITY'S COMPREHENSIVE PLAN IS AMENDED AND ADOPTED AS SHOWN IN THE ATTACHMENT WHICH IS HEREBY INCORPORATED IN ITS ENTIRETY:

SECTION I

LEGISLATIVE & ADMINISTRATIVE FINDINGS

Legislative and Administrative Findings.

(a) The above recitals (whereas clauses) are hereby adopted as the legislative and administrative findings of the Town Commission of the Municipality of **NORHTEAST FLORIDA OR SOUTHEAST GEORGIA**.

(b) The Town Commission of the Municipality of **NORTHEAST FLORIDA OR SOUTHEAST GEORGIA** hereby adopts and incorporates into this Ordinance the adopted LID additions to the Comprehensive Plan of the Municipality of **NORHTEAST FLORIDA OR SOUTHEAST GEORGIA**. The Exhibit to this Ordinance is incorporated herein as if fully set forth herein verbatim.

(c) The Municipality of **NORHTEAST FLORIDA OR SOUTHEAST GEORGIA** has complied with all requirements and procedures of Florida law in processing and advertising this Ordinance.

SECTION II

LOW IMPACT DEVELOPMENT (LID)

The ordinance shall be construed to assure consistency with the requirements of the Federal Clean Water Act and acts amendatory thereof or supplementary thereto, applicable implementing regulations, and any other regulations set forth in **NORTHEAST FLORIDA OR SOUTHEAST GEORGIA.**

1. Each municipality of **NORTHEAST FLORIDA OR SOUTHEAST GEORGIA** will create a Low Impact Development Best Practices (BMP) Manual containing requirements and needs for that Municipality.
2. Development of Redevelopment involving Nonresidential Use, or five or more units intended for Residential Use.
   a. Development or Redevelopment resulting in an alteration of at 50% or more of the impervious surfaces on an existing developed site, the entire site must comply with the standards and requirements of the Municipal LID BMP Manual.
   b. Development or Redevelopment resulting in an alteration of less than 50% of the impervious surfaces of an existing developed site, only such incremental

development shall comply with the standards and requirements of the Municipal LID BMP Manual.

3. A Development or Redevelopment of any size that would create 2,500 square feet or more of impervious surface area and is located partly or wholly in an impaired waterbody drainage basin shall comply with the standards and requirements of the Municipal LID BMP Manual.
4. A Development or Redevelopment of any size that would create more than 10,000 square feet or more of impervious surface area and total one acre or more of disturbed area shall comply with the standards and requirements of the Municipal LID BMP Manual.
5. Street and road construction of 10,000 square feet or more of impervious surfaces shall comply with the standards and requirements of the Municipal LID BMP Manual.
6. The Site for every Development or Redevelopment shall be designed to manage and capture stormwater runoff, to the maximum extent feasible, in priority order: infiltration, evapotranspiration, capture and use, treated through high removal efficiency biofiltration/biotreatment system of all of the runoff on site. High removal efficiency biofiltration/biotreatment systems shall comply with the standards and requirements of the Municipal LID BMP Manual.

SECTION III

CONFLICTS/RATIFICATION OF PRIOR ACTIONS

Conflicts/Ratification of Prior Actions.

All ordinances or parts of ordinances in conflict herewith are hereby repealed. The prior actions of the Town Commission and its agencies in enacting, amending, and implementing the Municipality of **NORTHEAST FLORIDA OR SOUTHEAST GEORGIA** Comprehensive Plan are hereby ratified and affirmed.

SECTION IV

CODIFICATION/INSTRUCTIONS TO CODE CODIFIER

Codification/Instructions to Code Codifier.

It is the intention of the Town Commission of the Municipality of **NORHTEAST FLORIDA OR SOUTHEAST GEORGIA**, that the provisions of this Ordinance shall become and be made a part of the codified version of the Municipality of **NORTHEAST FLORIDA OR SOUTHEAST GEORGIA** Comprehensive Plan and/or the Code of Ordinances of the Municipality of **NORTHEAST FLORIDA OR SOUTHEAST GEORGIA**. The actual text of the Sections to this Ordinance need not be codified. The Codifier of the Town is given broad and liberal authority to appropriately codify the Exhibit into the provisions of the Municipality of **NORHTEAST FLORIDA OR SOUTHEAST GEORGIA** Comprehensive Plan in a format that can be readily published and distributed in a usable and manageable format. The Town Mayor, in conjunction with the Town Clerk and the Town Attorney are hereby granted the authority to take any and all necessary and appropriate actions to accomplish the provisions of this Section.

SECTION V

SEVERABILITY

Severability.

If any section, subsection, sentence, clause, phrase or provision of this Ordinance is held to be unconstitutional or otherwise invalid by a court of competent jurisdiction, such unconstitutionality or invalidity shall not be construed as to render unconstitutional or invalid the remaining provision of the Ordinance.

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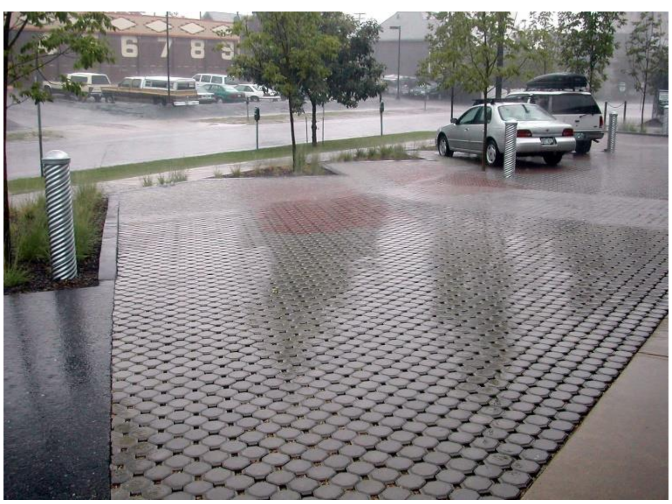
APPENDIX

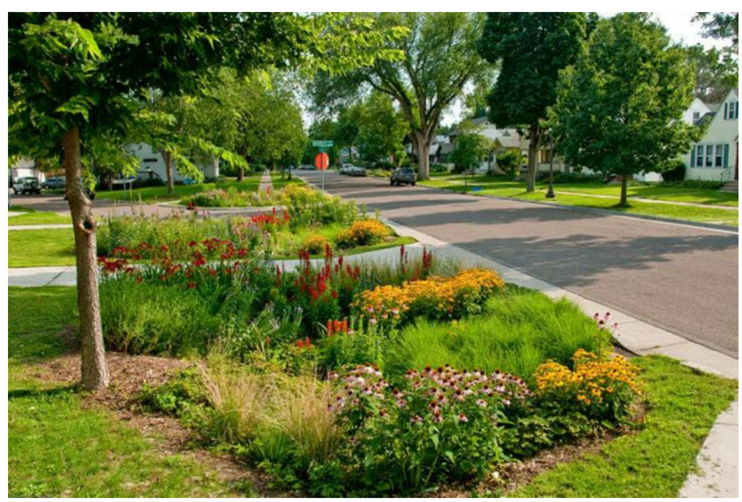
Appendix I: Low Impact Development Methods

Bioretention Pond

Green Roof



Permeable Pavement



Rain Garden