UTILIZING LUCIS MODEL TO ENHANCE CORRIDOR PRIORITIZATION AND DESIGN PLANS FOR THE WESTERN GREENWAY PROJECT IN MIAMI-DADE COUNTY, SOUTH FLORIDA

by

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(Under the Direction of Rosanna G. Rivero)

ABSTRACT

Miami is a city of rapid and constant change, some of which is at the expense of its neighboring wetland area, the Everglades. The Miami-Dade County Parks, Recreation and Open Spaces Department (MDC-PROS) has embarked on an ambitious planning effort in partnership with The Trust for Public Land (TPL) to develop a Western Greenway along the county's western edge. To assist with Greenway planning efforts, this project used NASA satellite imagery to derive a vegetation index and a land cover classification map which served not only as inputs for the Land-Use Conflict Identification Strategy (LUCIS) model, but also provided tree cover parameters which helped explore more specific design and greenway alignment. Conclusions drawn from the LUCIS model identified the most suitable land for recreation, conservation, and agritourism. This project contributed to decision support tools of MDC-PROS and The Trust for Public Land for planning green infrastructure corridors preserving the Everglades.

INDEX WORDS: Green Infrastructure, Miami-Dade County, Western Greenway, Land Use and Land Cover Change, Everglades, LUCIS model, Ecological Forecasting

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DEDICATION

For those who love nature.

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CHAPTER 1

RESEARCH INTRODUCTION

The Problematic and the Origin of Western Greenway Project

Miami-Dade County covers a total area of 4,916 km^2 and has an average elevation of 3.66 meter above sea level. In 2012, the United States Census Bureau reported Miami-Dade County's population at just over 2.5 million residents. Miami-Dade County is uniquely situated between natural boundaries. With the Everglades to the west and the Atlantic Ocean to the east, this County has little room to grow without disrupting biological diversity and natural resources. As the largest subtropical ecosystem in the United States, the Everglades are located along avian migratory routes and are home to many endemic plant and animal species. The restoration and protection of the Everglades is critical not only for ecological reasons, but also for the protection of water recharge services that could become vital for future urban water consumption (Pittman 2006).

Urban sprawl has historically played a central role in altering the environment by contributing to habitat fragmentation, the introduction of exotic species, and changes in land use and cover (Bryant 2006b). Today, urban development is threatening the attempts to maintain and restore this system. Even without the uncertainty associated with ecosystem systems self-regulation, the "restoration" of the Everglades is a very complex process. A restored and sustainable Everglades, as Davis and Ogden define, is one that mimics as closely as possible the appearance and behavior of the system as if drainage and development had not occurred. Fortunately, all the major components of the flora or fauna are still there, as William Robertson, Jr, the long-time senior scientist of Everglades National Park, has noted (Robertson and Kushlan 1974).

As for the Miami-Dade County urban area, certain problems arise as the city sprawling in such a fast speed. Like other big cities in the US, urban spatial expansion results mainly from three powerful forces: a growing population, rising incomes, and falling commuting costs. Urban growth occurring purely in response to these fundamental forces cannot be faulted as socially undesirable, but three market failures may distort their operation, upsetting the allocation of land between agricultural and urban uses and justifying criticism of urban sprawl (Brueckner 2004). There is no doubt that this rapidly growing area requires immediate responses and decisions about land use alternatives. To adjust context confusion and to ensure south Florida continually to be an environmental friendly place to live, some works are worth doing in both the scientific and public sectors utilizing the most recent technology (Lodge 2010).

Coping with this reality, the Parks, Recreation and Open Spaces Department (MDC-PROS) and Trust for Public Land had embarked on an ambitious project to develop the Western Greenway. The Western Greenway project is part of a long-term, complex solution to protect this delicate system. The project has been heard before numerous bodies of elected officials and was approved by the Board of County Commissioners at a public hearing on February 19, 2008. It is described as a green infrastructure that will help protect the Everglades from the invasion of fast sprawling urban areas. The Western Greenway planning effort is critical to the development of the project and must be completed before any action can be taken. It is not meant to be an absolute fix to all threats posed to the Everglades; however, it is meant to help with conservation efforts in several ways. These include through the acquisition of land by MDC-PROS for greenway and conservation purposes as opposed to urban development, the preservation and highlighting of environmentally endangered lands, and through bringing awareness of the importance of the surrounding ecosystem to the public. The greenway will provide a transition between developed areas and the Everglades to conserve ecosystem functions and provide associated ecosystem services. It is also planned as an important recreation and agritourism destination for the people of Miami-Dade County.

This project's study area (Figure 1) encompassed the southern tip of Florida for the entirety of the Western Greenway. The site spans from the urban-wetland fringe of Miami-Dade County's western edge, which borders Everglades National Park in the South, Water Conservation Areas in the West, the Northern Lake Belt Area in the North, and Biscayne National Park in the East.

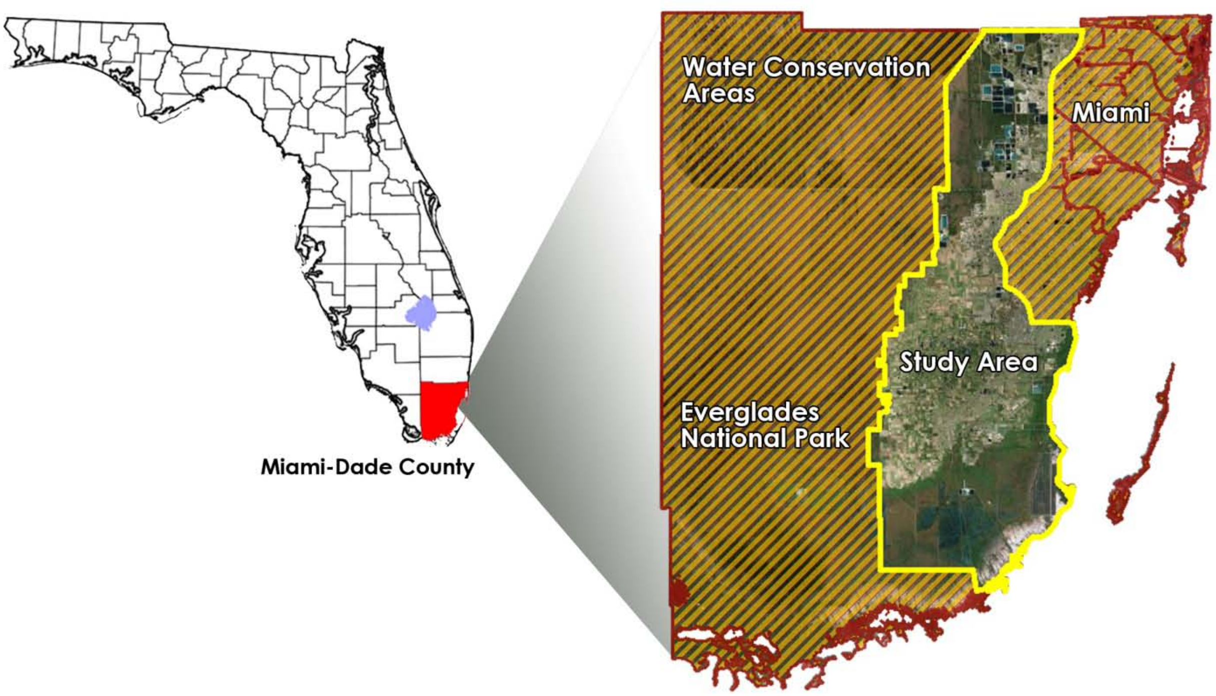


Figure 1: The location of Western Greenway study area

Purpose of Study

The purpose of this research is to examine several green infrastructure implementations being practiced to help promote sustainable developments of cities in the US, to evaluate the ecological benefits of these case studies; Based on the insights and evaluations, the design principles will be concluded and be applied to help guide the implementation of Western Greenway project in the Miami-Dade County in Southern Florida. The main purpose of this project is to design and illustrate the most effective areas to implement greenway system with a focus on biodiversity conservation within Miami. Successfully initiating a greenway requires the parties involved to have an understanding of both the natural ecology and the social obstacles presented by the city. To cope with this issue, this project utilized Land Use Conflict Identification Strategy (LUCIS) model (Carr and Zwick 2007) to assess the greenway's specific goals of conservation, agritourism, and recreation. By tweaking the LUCIS model inputs based on normalized vegetation index, land use classification results, fieldwork observations, and direct conversations with project partners, this model assessed conflicts of land use based upon user-specified weighted inputs and helps to visualize opportunity areas for the greenway alignment. Ultimately, recommendations were developed to enhance the decision making process by identifying potential opportunity areas for the Western Greenway and proposing design interventions for focal areas along the trail system.

Research Question and Methodologies

Is it possible to develop a green infrastructure system that can help achieve the ecological and aesthetical co-existence between the Everglades and the city of Miami?

Sub-questions:

1. What is the process to define appropriate locations that obtain high ecological and aesthetic value?
2. What are the design strategies for creating sense of place in these locations?

This paper conducted a literature review that synthesized the concepts related to green infrastructure and their applications, and described the history of human impacts towards the Everglades ecological system. Pre-published documents are provided by partners from Miami-Dade County and Everglades National Park. Three case studies about previous green infrastructure applications in the US were collected and synthesized from online publications. The environmental benefits and their evaluation methods were summarized. After conducting an extensive documentation of the site existing conditions through land cover classification analysis and field observations, a series of geospatial modeling efforts were taken to identify potential green infrastructure locations, with design strategies proposed based on specific site locations and characteristics. The whole process was performed within an innovative Geodesign framework. As Dr. Carl Steinitz defined: "Geodesign is changing geography by design." (Steinitz 2012) Steinitz's six models (Representation Model, Process Model, Evaluation Model, Change Model, Impact Model, Decision Model) is often advocated as a typical workflow of the Geodesign process (Steinitz 2012). This framework allowed various shaping forces join together to create design strategies based on the geographical simulations.

Ecological forecasting applies knowledge of physics, ecology and physiology as well as socio-economic consideration to better understand the complexity of ecosystems related to their affecting factors and to predict how ecosystems may change in the future in response to environmental factors or stressors such as climate change and rapid population. It is a way to project changes in living ecosystems by including possible uncertainties and errors to allow for alternative decisions to be made. In addition to that, the integration of programs, tools, and resources is necessary to restore biodiversity within developed communities (Bryant 2006). Among all of these elements, stakeholder participation plays an essential role in shaping the planning process.

This project collaborated with Miami-Dade County, Environmentally Endangered Lands Program and the Trust for Public Land, and performed ecological forecasting analysis using one of the Geodesign tools: LUCIS model, to assist the design of the Western Greenway in a rapidly changing environment of Miami-Dade County. The Western Greenway project aims at establishing a system of connected greenway trails and recreational areas along Miami-Dade County's western edge. The greenway's benefits for the public include scenic corridors, restored freshwater canals and a more completed public park system for recreational activities.

The GIS ancillary data were obtained from Miami-Dade County GIS Portal: 2013 Land Use Management Application (LUMA) data set; Florida Natural Areas Inventory: Cooperative Land Cover Map, United States Geological Survey Land Cover, functional wetlands, strategic habitat conservation areas, Rare Species Habitat Conservation Priorities; and Florida Geographic Data Library datasets: roads, FEMA flood zone, and soil drainage.

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) were chosen for satellite data acquisition. ASTER has 15m spatial resolution in its visible and near-infrared bands, which were the bands utilized in this study. Three adjacent Level 1B ASTER images of the study area were acquired from March 7, 2011, with 0 % cloud cover. These were the most recent ASTER images of the study area found with 0 % cloud cover (Figure 2). The three ASTER images were mosaicked together using the Mosaic tool in ENVI software in order to create one continuous image. At this point, only a spectral subset consisting of the first three 15m bands was kept from the images (Green, Red, and NIR). Next, QUick Atmospheric Correction (QUAC) was performed on the mosaicked image in order to correct for confounding effects of the atmosphere between the ground and the sensor. Finally, Normalized Difference Vegetation Index (NDVI) analysis and supervised land cover classification were conducted to evaluate the vegetation condition, these information were combined with more detailed Land-Use Management Application (LUMA) map and served as main inputs for the LUCIS model.

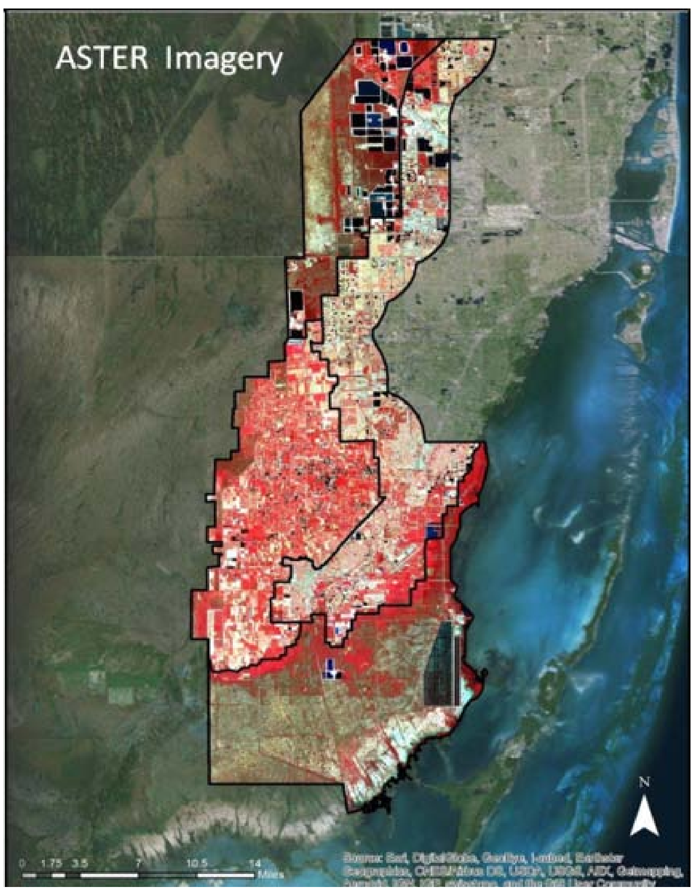


Figure 2: Study area in false color image

Fieldwork included a trip to the city of Miami and the Everglades, to discuss specific goals and criteria with the project partners, as well as to observe the study area firsthand. The information gathered from interviews and inventory analysis played a decisive role in the project. The greenway's proposed routes, destinations, and gateways from MDC-PROS were visited in order to assess and document specific opportunities for greenway development. Based on the adjustments to the other successful applications in the US, a series of context-specific design guidelines were developed (See Chapter 4).

CHAPTER 2

LITERATURE REVIEW AND SYNTHESIS

The history of human impacts on the Everglades

The Everglades was once a vast and unique 15,000km^2 wetland located in central and south Florida (Graf 2013). Its subtropical climate, pulsing with heavy summer rainfall, allowed a mix of temperate North American and tropical West Indian plants and animals to flourish. Wading birds were especially numerous, nesting by the hundreds of thousands in good years (Davis, Ogden, and Park 1994). The predominant vegetation of Everglades consists of freshwater wetlands dominated by vast graminoid marshes and coastal estuaries of mixed mangrove forests. Inland marshes are interspersed with plant communities that include hardwood forest, pineland savannas, long-hydroperiod marshes dominated by sawgrass (Cladium jamaicense) or spike rush (Eleocharis cellulosa), short-hydroperiod prairies dominated by muhly grass (Muhlenbergia filipes) and bayheads (with species such as sweet bay (Magnolia virginiana) and red bay (Persea borbonia)), and cypress (Taxodium ascendens and T. distichum) forest (Doren, Rutchey, and Welch 1999).

Preceding urban development within the area, rainfall within Central Florida would flow from Kissimmee River to Lake Okeechobee. When the lake reached its capacity, the excess water spilled over and moved south through fifty-mile wide and two-inch deep sawgrass, which served as a water filtration system. Water from Lake Okeechobee once made its way to the Gulf of Mexico unhindered (Pittman 2006). The watercourse consisted of a main central channel from the pond apple swamp at the southern edge of Lake Okeechobee, with peripheral wetlands of cypress or marl prairie along either side; the highest elevation is only 6m above sea level. The ever-changing local conditions assured suitable feeding and nesting habitat for the diverse wildlife (Davis, Ogden, and Park 1994).

However, in 1947, this natural flow was altered by a flood control project enacted by Congress after the city of Fort Lauderdale was flooded by two hurricanes. This project consisted of more than 1,600 kilometers of canals, 150 water control structures, and 16 major pumping stations, all completed by 1968. This cleared the way for human settlement, but unfortunately resulted in a 90% loss of the wading bird population. In a short period of time, this system over-compensated by draining more than one billion gallons of water a day on average back to the sea (Pittman 2006). At the same time, agriculture took over much of the newly dried land which was considered rich in peat soil; exotic plant species invaded and altered many of the remaining native plant communities. The southernmost portion of the original ecosystem which is currently located within the range of Everglades National Park remains more or less intact. However, the quantity and quality of water entering the park cannot be guaranteed (Davis, Ogden, and Park 1994).

More than half of the original Everglades have already been lost to human land use in the form of residence, farming, mining, and commercial development (Pittman 2006). As suburbs are developed around a city, natural habitats are fragmented and biodiversity is lost. Urban development in particular causes land disturbance, surface conversion, and removal of native vegetation, introduction of exotics, and isolation and fragmentation of the remaining natural areas (Bryant 2006b).

Among all the negative impacts brought by the urban developments, the largest threats that damage the functions of ecosystem service are the widely spread invasive plants in natural landscapes. There are total of 779 introduced plants that have notoriously invaded natural environments, which account for 45% of the total plant species in South Florida. Among them, 106 kinds have become so pervasive as to distinguish themselves as “Category I” exotic pest plants, on the list created by the Florida Exotic Plant Pest Council. Only 179 kinds of introduced plants are related to agriculture, and the remainders have unknown origins. The top three most threatening exotic species to South Florida ecosystem are melaleuca, Brazilian pepper, and Old World climbing fern (Lodge 2010).

Melaleuca (Figure 3), also called paper-bark, punk tree, cajuput, or white bottlebrush tree, was introduced in mid-1940’s with the purpose of controlling levee erosion. It can grow up to 100 feet in a straight stature with no natural predators present in South Florida. Because of its sensitivity to freezing weather, the melaleuca habitat has been restricted to the southern Florida peninsula. It grows into dense forest and widely spreads in uplands and wetlands, excludes native vegetation in partially drained sawgrass marshes, pine flatwoods, and cypress swamps, thus deteriorating the animal habitat and destroying the original ecosystem. At first it was planted as a good dewater tool for the purpose of land development, but gradually it destroyed the ecosystem regulating services because of its strong ability of transpiring more water than native marsh vegetation. To make things worse, later it was artificially seeded into the Everglades in order to aid windbreaks and honey production in horticulture and agricultural fields. Its extreme tolerance of fire is another reason for its uncontrollable spread (Lodge 2010).

Figure 3: Typical monoculture of Australian melaleuca trees in Florida prior to control efforts (USDA Invasive Plant Research Laboratory 2006).

The value of ecosystem services provided by the wetlands prior to the melaleuca infestation is estimated to be $14,785 per hectare per year, considering economic and ecological factors relating to provisioning, regulating and habitat services provided by inland wetlands. The damaged ecosystem services would lead to a total loss of approximately $30 million per year, even with the minimum assumption that only 1% of these services are lost. Effective control of this invasive plant is vital in assuring both the balance of the ecosystem and the successful economic development of the state in a long run(USDA Invasive Plant Research Laboratory 2006). Several methods such as introducing tested insects from Australia have been proved to be highly successful but are not considered as permanent solutions. More biological control efforts should focus on the established patches: making them grow lower with more branching stature and hierarchical plant communities, just like native forest. In 2001, the Area-wide Management and Evaluation of Melaleuca quinquenervia (TAME Melaleuca) was established by the USDA Agricultural Research Service’s Pest Management Initiative. This collaborative, multi-agency project applies the available control techniques, including hand applied herbicides, tested insects introduction, helicopter applications to all types of lands across infested ecological zones, rather than carrying out control on a site-by-site basis. This project has brought about definite improvement on the overall effects of melaleuca long-term control and management plan (USDA Invasive Plant Research Laboratory 2006).

Compared to melaleuca, Brazilian pepper's (Figure 4) invasion can occur in broader range of locations in upland communities. This large shrub was initially called Florida holly for marketing as an ornamental plant in South Florida. Due to its temperature limitation, the dispersed Brazilian pepper seeds can only reach the northern peninsula of Florida. After Hurricane Donna in 1960, Brazilian pepper grew rapidly and invaded aggressively many Everglades region plant communities, especially pinelands and various coastal lowland habitats such as shallow mangrove swamps. Its strong ability to form closed forests in deserted fallow land and shallow coastal marsh habitats excludes native vegetation from healthy growth. To complicate matters, its proliferation prevents the recovery of pinelands after hurricane damage. Currently large areas of the western region of Everglades National Park are occupied by Brazilian pepper forests and can no longer serve as effective feeding habitat for wading birds. Had it not been for the great efforts taken by the government and numerous volunteers, all pine rock lands damaged by Hurricane Andrew in South Florida would have been eliminated due to the invasion of Brazilian pepper. However, targeted biological controls are still in its early testing stage and have yet to be widely used in practice (Lodge 2010).


Figure 4: Brazilian pepper trees (University of Florida IFAS 2014).

The Old World climbing fern (Figure 5) is a relatively new intruder in South Florida compared to melaleuca and Brazilian pepper. Soon after it was established in the natural habitat in Martin County in 1965, it became a trouble in the Loxahatchee River system's headwater cypress wetlands. By 1989 it had spread into the northern Everglades and completely covered tree islands in extensive areas of the Loxahatchee National Wildlife Refuge. The fern elevates and escalates the surface fires that would otherwise not kill the trees, and also forms a physical obstacle for hiking. There is currently a lack of practical approach preventing its invasion to the Big Cypress Swamp and western Everglades National Park (Lodge 2010).

Figure 5: Old World climbing fern infestation (University of Florida 2007).

Aside from the various noteworthy invasive plants mentioned above, there are also innumerable non-indigenous animals that have become established in South Florida. The impact of non-indigenous animals is outside the scope of this study, and thus will not be detailed here. This project mainly concentrates on observing the impacts of invasive plants and proposing design strategies to guide the ecological restoration of this region. In addition, the human economic development is another contributory factor for the constantly increasing number of invasive plants. For the ornamental landscape and pet-trade industries, regulations lead to mainly to reduced profits, which is responsible for public reluctance to require demonstration of compatibility because of economic profits. Currently there are only a few regulations in place that deal with species that are known to have already caused serious problems. Implementation of a well-organized restriction system to direct the sustainable development is still a difficult goal to achieve (Lodge 2010).

The Previous Planning and Management Plan

In 1989, scientists with different specialties brought up the issue of "restoring" the ecosystem at the Everglades Symposium in Key Largo, Florida. A series of workshops were found instructive and productive, during which it became clear that the restoration of Everglades would require a whole interdisciplinary research process, including the application of computer modeling and the integration of data from diverse fields such as hydrology, ecology, and mathematics. It was concluded that a large scale restoration plan would be needed to reverse the declining ecosystem within the Everglades. The plan could help better manage endangered and control exotic species, guide the development of a water-delivery system that is beneficial to both humans and wildlife (Davis, Ogden, and Park 1994).

In 2000, the Comprehensive Everglades Restoration Plan (CERP) began an initiative to reverse the negative impacts caused by this complex system of levees and canals built to drain South Florida for settlement. CERP’s main objective was to hold water in reservoirs, release it at a slower, controlled pace, and redirect it towards the Everglades, to be consistent with its natural flow. The complex system developed by CERP is critical because it provides the drinking water for Florida’s growing population. The Clinton administration, the Department of Interior, and the public soon were well aware of the importance of CERP and provided significant support for the protection of this natural system. However, once these leaders left office, the push for restoration ceased (Graf 2013). The State and the Corps of Engineers’ restoration efforts continued, but often contradicted their work by approving development in the region that is detrimental to the natural system. Miami-Dade County is currently using aerial photography for their

Environmentally Endangered Lands (EEL) program to prioritize and monitor land acquisition (Pittman 2006).

Studies about Green Infrastructure and its Benefits to the Environment

Benedict and McMahon define green infrastructure as strategically planned and managed networks of natural lands, working landscapes, and other open spaces that conserve ecosystem functions and provide associated benefits to human populations. Green infrastructures provide a systematic and strategic approach to land conservation, encouraging land use planning and practices that are beneficial to nature and people (Benedict and McMahon 2006). The planning and management of a green infrastructure network can guide the creation of an open space system that supports multiple objectives and can be applied to situations where public infrastructure, such as roads and utility lines are being developed (Weber and Allen 2010).

Green infrastructure offers a contemporary approach to the conceptualization and management of landscape resources (Mell 2010). Tzoulas (2007) presented a conceptual framework of associations between urban green space, ecosystem and human health, based on a synthesis of the literature review of the possible contributions of urban and peri-urban green space systems, or Green Infrastructure, on both ecosystem and human health. The proposed conceptual framework highlighted many dynamic factors, and their complex interactions, that affect ecosystem health and human health in urban areas. The dynamic factors for green infrastructure were GR: green roofs; UP: urban parks; GC: green corridors; EC: encapsulated countryside; DL: derelict land; HG: housing green space and domestic gardens; CS: churchyards, cemeteries and school grounds; OW: open standing and running water. This framework forms the context into which existing and new research can be placed (Tzoulas et al. 2007).

Ignatieva (2011) defined the main role of green corridors as providing habitat rather than acting as connectors of nodal habitats (Ignatieva, Stewart, and Meurk 2011). Bryant (2006) conducted a biodiversity planning study of a highly urbanized area in Washington, DC that demonstrated the vital role of ecological greenways and parks in urban species conservation (Bryant 2006a). Stepping stones are utilized in most organisms to accommodate desired meta-populations and to deter pest movement. From the biological aspect, drainage swales and treatment ponds provide riparian services and serve as biodiversity corridors. From the visual aspect, studies were conducted to define people's perception towards corridors: they are viewed as green fingers that replace the previous urban grey areas. The health benefits of green corridors have been proven both psychological and biophysical (Maria Ignatieva 2010).

Paolo La Greca (2010) defined Non-Urbanized Areas (NUAs) as part of agricultural and green infrastructures that provide ecosystem services. They play a fundamental role in minimizing urban pollution and in adapting to climate change. NUAs are threatened by urban sprawl just like all natural ecosystems. Strategic regulation of urban sprawl is a key issue for contemporary land-use planning. Paolo La Greca (2010) proposed a land use suitability strategy model to guide Prospective Land Uses (PLUs) of NUAs, based on integration of Land Cover Analysis (LCA) and Fragmentation Analysis (FA). The percentage of surface evapotranspiration for each land use type was calculated using LCA; dimensions and densities of NUAs patches were quantified through FA. A Land Use Suitability Strategy Model (LUSSM) was represented by a matrix, in which evapotranspiration degree was divided into four classes and fragmentation was divided into three classes. Squared items inside the matrix represented new PLUs for each intersection (Paolo La Greca 2010).

A greenway's potential to serve as habitat for native plant and animal species will depend upon its size: the larger the greenway, the more species and individuals it will support (Labaree 1992). Edge effect leads to an increase of non-interior species, which feed on interior species or compete with them for food. Edge species also bring along set of diseases to which interior species may be vulnerable. Because of edge effect, many greenways are most suitable for species whose natural habitat is linear. One of the good examples is the river corridor system. As a general rule, wildlife ecologists recommend that there be a one-to-one ratio between edge and interior habitat in a conduit greenway. That is 400 feet wide to balance 200 feet of edge habitat (100 feet of edge on either side) with 200 feet of interior habitat (Labaree 1992).

In reality, greenways can increase the effective size of a series of fragmented landscapes. Greenways allow animals to move among them rather than utilizing just an individual patch (Figure 6). The sum of all the connected natural areas thus becomes the actual effective size of the whole protected area. In addition, connecting patches which contain different habitats with greenways can greatly increase species' opportunity to reach the diverse habitats they need to survive (Labaree 1992).

Figure 6: Two patches of forest connected by a corridor (Labaree 1992).

In a landscape with little natural land, a greenway, no matter how narrow it is, will be beneficial (Labaree 1992). Take agricultural landscape as example: hedgerows (Figure 7), shelterbelts, and fencerows only offer wooded or shrubby habitat, but this kind of shelter trees provide habitat for birds in Minnesota (Swihart and Yahner 1982). In Great Britain where agriculture dominates much of the landscape, roadsides are critical breeding habitat for many species of rodents, birds, and insects (Way 1977).

Figure 7: Hedgerows in an agricultural landscape (Labaree 1992).

Maintaining greenway with native plant species and avoiding exotic species to move along corridors are considered as important as width in the creation of a high effective greenway. In order to achieve this, minimizing the amount of edge habitat can help prevent exotic species from displacing the desirable ones. The surrounding land will also influence the effectiveness of the greenway. The continuous greenways must avoid disturbance from roads and other development as much as possible. The more urbanized developments nearby, the wider the greenway will need to be (Labaree 1992).

Evaluating the impacts of exotic species towards the surrounding ecosystem services is still an issue left to be further explored, according to Charles and Dukes (2007) research findings. Essentially all ecosystem services can be negatively influenced by exotic species, although positive impacts do exist. Increased research efforts will be important in forecasting the effects of invasive species in conjunction with global climate changes and land use transitions, which have been found to affect ecosystem service supply (Schröter et al. 2005). Cooperation between ecologists, economists, and policymakers is vital in promoting this research process. Specific examples of exotic species alteration to ecosystem services will also provide references to help decision makers prioritize eradication and control efforts (Charles and Dukes 2007).

In order to design greenways as effective corridors, three requirements must be addressed: 1. the preliminary planning will need to identify both the potential interior habitat and edge habitat based upon the information of the area's native mixture of species, special plants and animals. 2. Design should focus on matching the natural characteristics of the landscape -- both in terms of species composition and connecting patches of habitat which were left isolated due to human developments. However, according to Charles and Dukes (2007) findings, since current research has not provided a thorough quantitative evaluation of the positive impacts of invasive species towards ecosystem services, this requirement is not always appropriate. The management authorities must be sufficiently observant to identify specific situations first, and then propose strategies accordingly which aim at increasing ecosystem services value, by keeping certain invasive species that have positive impacts, and restoring negative ones back to the native status. 3. The greenway corridors should provide the possibilities of movement for certain species which are most sensitive to people, with disturbance from urban development as little as possible (Labaree 1992).

Lusk (2002) concluded twenty-three design guidelines for greenways in her dissertation. The research concentrated on inquiring what are the physical qualities that help create a sense of place along a greenway and, and particularly, how far should these various features be set apart, how to define their unique characteristics in order to meet human needs. The twenty-three design guidelines were evolved from three main thematic sections: A) number and characteristics of destinations, B) the corridor and distance between destinations, and C) human needs. In real-world planning practice it is not required that all the design guidelines must be applied to a certain physical environment. In fact, even adopt one or more of the guidelines might be beneficial for a well-designed greenway corridor (Lusk 2002).

Three green infrastructure applications are described below, each of them focused on solving various problems under different backgrounds and scales. The first example is Maryland Green Infrastructure Assessment, which addresses the issue of natural land conservation within the state level. The second one is Richmond Green Infrastructure Assessment, which focuses on reforestation efforts within urban context through making use of vacant parcels. The last one is J.R. Alford Greenway Planning in North Florida, which deals with greenway land acquisition process for local communities. Each case study follows a consistent format, which includes a general overview of the existing problems, the design objectives, the methodologies and the green infrastructure strategies.

Case Study I: Maryland Green Infrastructure Assessment, MD

Existing Problems

Maryland is extraordinarily diverse in natural features and has been called “America in miniature”. It is also a typical urbanized region with both big cities and small towns, and transitioning from forested to agricultural to urban. Although even backyards and street trees provide some benefits, the state’s most important natural lands are those that are large and intact enough to provide a full range of environmental functions. They serve as vital habitat for native and migratory species, maintain a diverse genetic library, and contribute in many ways to the health and quality of Maryland residents' daily lives (Maryland Department of Natural Resources 2006).

Design Objectives

Maryland's Green Infrastructure Assessment (GIA) is a tool developed in the Maryland Department of Natural Resources (DNR) to help detect and rank those areas of greatest statewide ecological importance, as well as those at greatest risk of loss to development. This tool initially performed a coarse-filter landscape analysis, striving to include a full range of ecosystem elements. It identifies large contiguous blocks of natural land (hubs), interconnected by natural corridors to allow animal and plant propagate dispersal and migration. Hubs and corridors were ranked within their physiographic region for a variety of ecological and development risk parameters, as well as combinations of these (Maryland Department of Natural Resources 2006). The hub and corridor framework identified through the Green Infrastructure Assessment is being used to guide Maryland's ongoing land conservation efforts at all kinds of scales from multi-states down to parcel scale (Weber, Sloan, and Wolf 2006).

Methodology

In the GIA model, features such as the followings were identified from Geographic Information Systems (GIS) spatial data that covered the entire state: large blocks of contiguous interior forest containing at least 250 acres, plus a transition zone of 300 feet; large wetland complexes, with at least 250 acres of unmodified wetlands; important animal and plant habitats of at least 100 acres, including rare, endangered species locations, unique ecological communities and migratory bird habitats; relatively pristine stream and river segments; existing protected natural resource lands which contain one or more of the above. Corridors were identified using many sets of data, including land cover, roads, streams, slope, flood plains, aquatic resource data, and fish blockages. These identification processes were done at two different scales: by individual hub or corridor (Figure 8) and by individual cell (about a third of an acre) (Figure 9) (Maryland Department of Natural Resources 2006).

Green Infrastructure Strategies

Maryland green infrastructure assessment used a series of well represented graphics to show the methods of solving the conflicts between the urban expansion and the existing natural environments. The GIA provided an approach for ranking or prioritizing land protection efforts. Hubs and corridors were assessed for a variety of ecological parameters, and then ranked within their physiographic region. Green infrastructure hubs and corridors were also examined for their level of protection, management status, and risk of development (Weber, Sloan, and Wolf 2006).

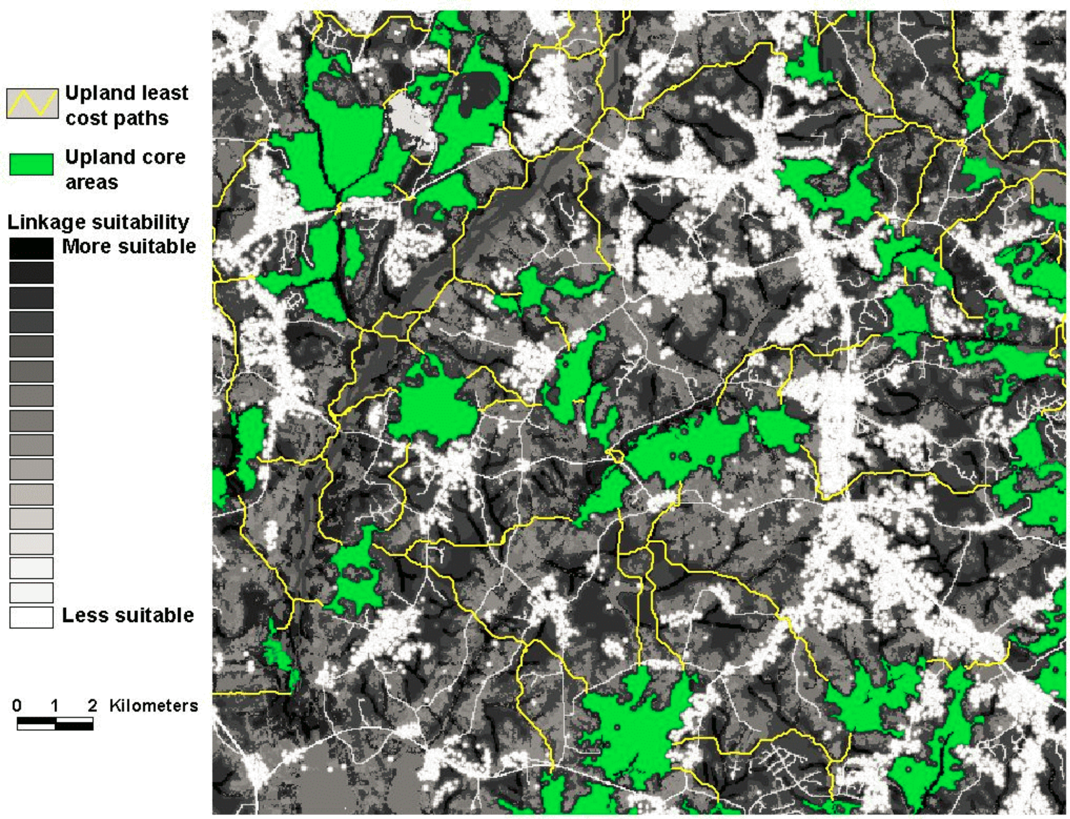


Figure 8: Upland corridor suitability surface and potential connections (least cost paths) for part of Maryland (Weber, Sloan, and Wolf 2006).

The vast majority (74%) of the Green infrastructure is unprotected. And only 13% of hubs, and less than 1% of corridors, were in areas managed primarily for natural values (Figure 10). Some of the factors used to estimate relative development risk included land ownership, regulatory restrictions, zoning, water and sewer service, population trends, commuting distances, land value, proximity to roads, presence of waterfronts, and proximity to preserved open space. A hub or corridor's risk of development can be combined with its ecological score to help prioritize conservation efforts (Weber, Sloan, and Wolf 2006).

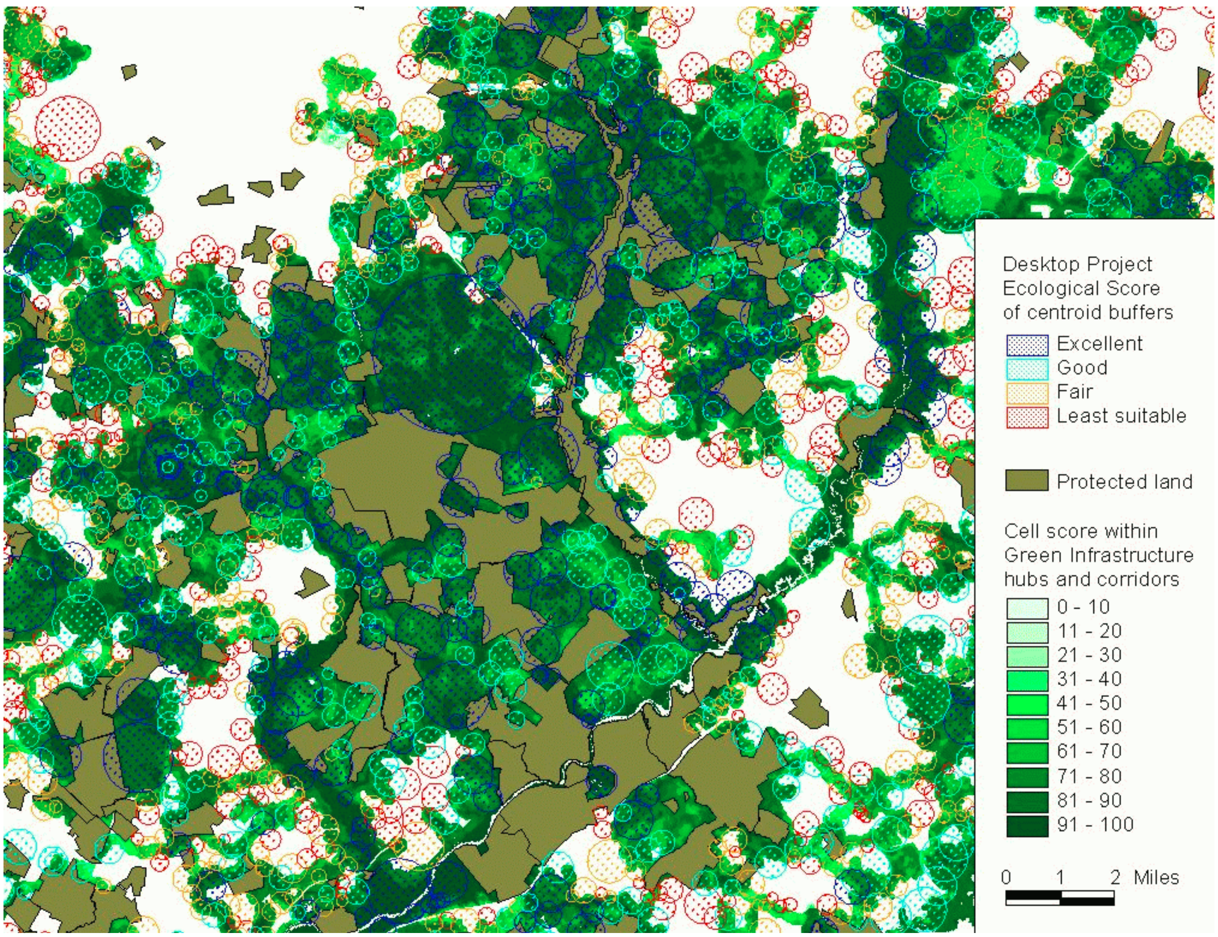


Figure 9: Desktop Project Ecological Score calculated for parcel centroid buffers, based on combination of acres of GI, % of GI, mean cell ecological score in GI, protected land within 1 mile, and % gain to hub or corridor (Weber, Sloan, and Wolf 2006).

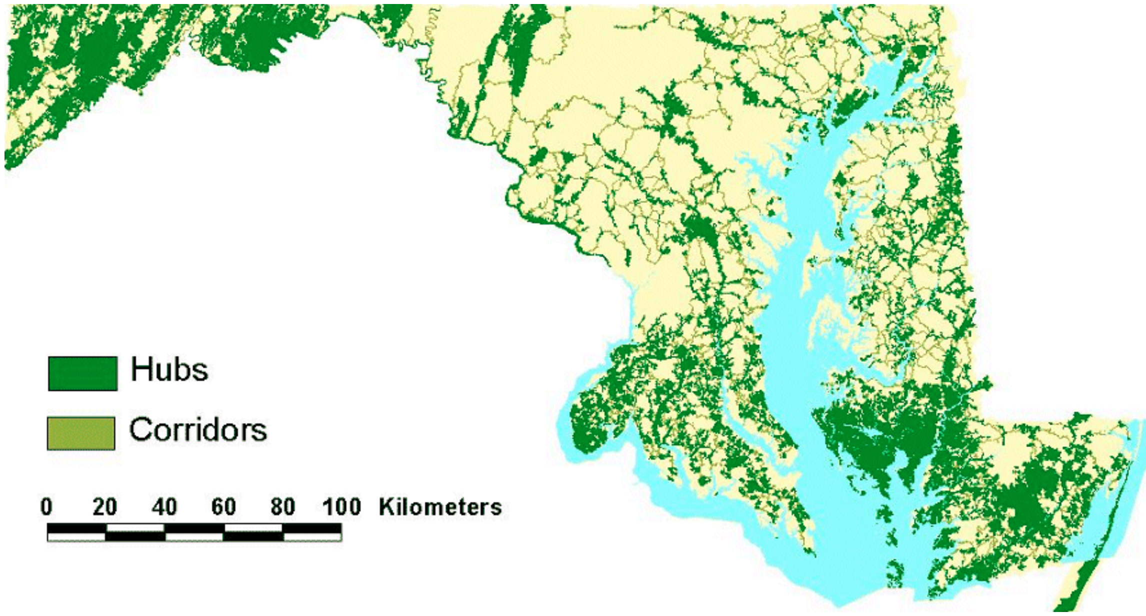


Figure 10: Maryland's green infrastructure network (Weber, Sloan, and Wolf 2006).

This kind of assessment has been widely applied in real world planning, in 2010 Maryland State Highway Administration initiated a project that identified and evaluated natural resource stewardship opportunities in four Maryland watersheds that could potentially be affected by a highway bypass construction. Firstly they modeled and validated a conservation network of high-quality wildlife and plant habitat (core areas), large contiguous natural areas (hubs), and linkages to facilitate wildlife movement and gene flow (corridors); Then, they ranked elements of this network at multiple scales, and identified high priority areas for conservation and restoration; Finally, they developed and proposed routes for the highway that optimized the cost-benefit assessment result (Weber and Allen 2010).

Case Study II: Richmond Green Infrastructure Assessment, Virginia

Existing Problems

As modern urbanization rapidly replacing traditional contexts of built environment, disinvestment caused vacant lots are cutting down the quality of community life in urban neighborhoods (Richmond Green Infrastructure Center 2010).

Design Objectives

Through identifying and making use of vacant parcels, this project aimed at adding significant value to the city's open space system by creating a more completed green infrastructure network. The Richmond green infrastructure assessment provided a tool that can be used to: inform future planning, leverage public and private development, prioritize and target sustainability pilots, secure implementation funding, enhance the tree canopy, increase pedestrian and bicycle connections, improve storm water management strategies, and promote Richmond as a sustainability model for other municipalities (Richmond Green Infrastructure Center 2010).

Methodology

Richmond Regional Planning District Commission (RRPDC) was the leader of project's phase I conduction. The main task of this phase was to identify the city's existing green assets. The results of the assessment were compiled into a report which contained maps that illustrate citywide green infrastructure asset. Phase II was the focal point of the whole project. It identified the vacant and underutilized properties in the city (Figure 11), then evaluated the potential of these vacant parcels that may evolve into parts of the Richmond's green infrastructure network (Figure 12) based on suitability analysis, and proposed green infrastructure concept plans that connect the green infrastructure network between various neighborhoods (Richmond Green Infrastructure Center 2010).

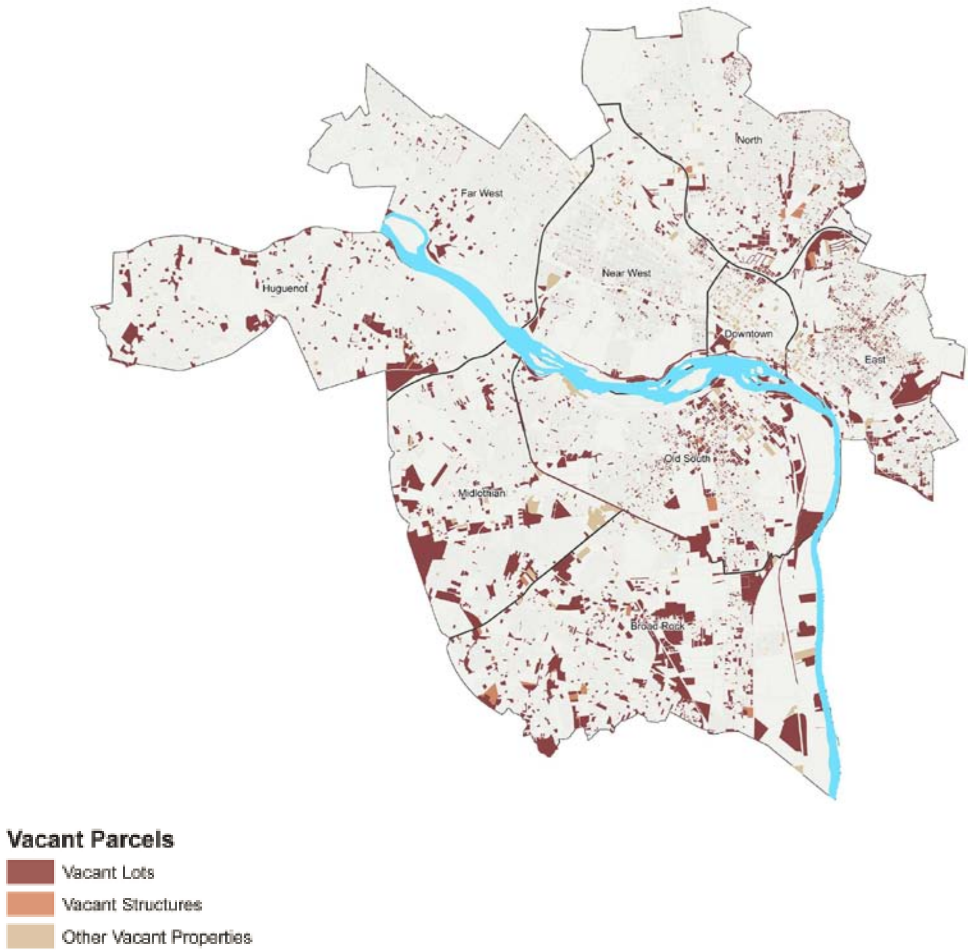


Figure 11: Citywide Vacant Parcel Inventory by Vacancy Type (Richmond Green Infrastructure Center 2010).

Vacant parcels that fell into one or more of the following criteria were selected as the potential locations that help expand the green infrastructure network: location within Priority Conservation Area, intersection with a stream corridor, location within a wetland, location within a floodplain, location within Natural Resource Heritage area (Richmond Green Infrastructure Center 2010).

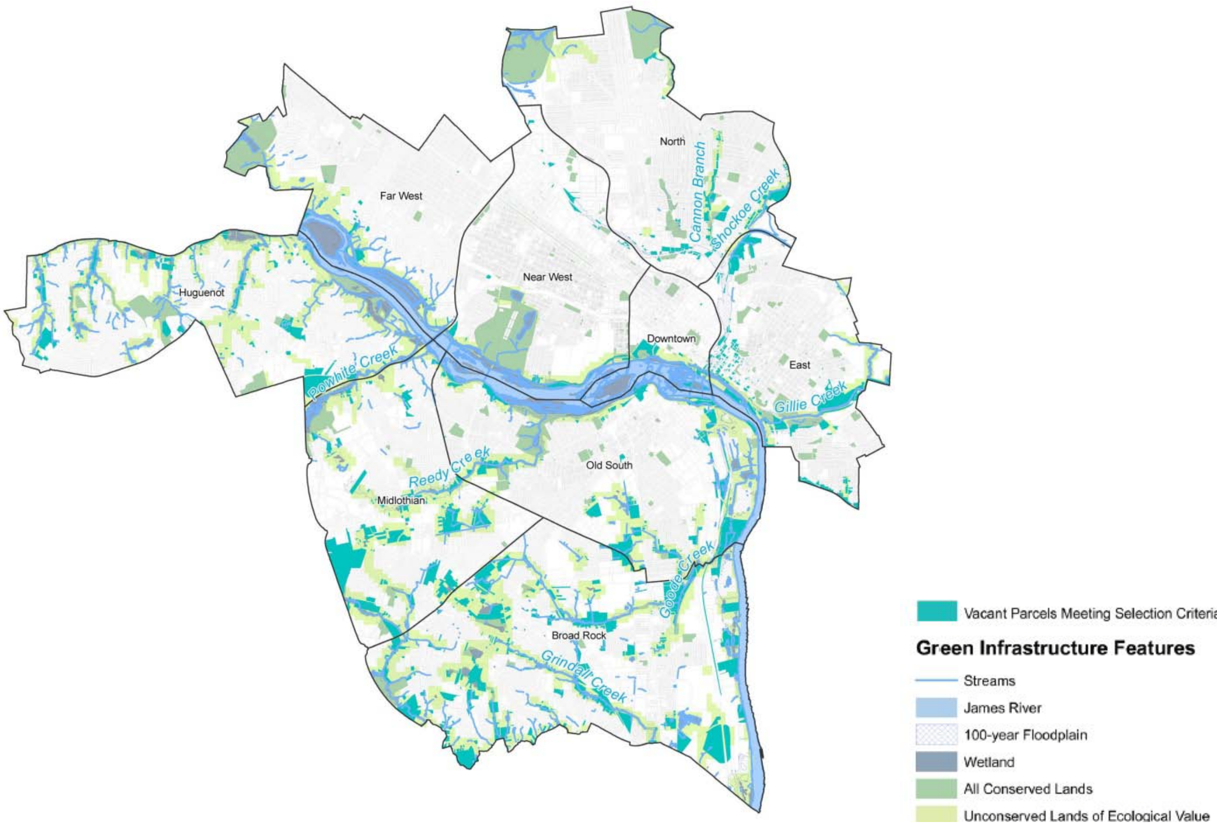


Figure 12: Citywide Vacant Parcels Intersecting the Existing Green Infrastructure Network (Richmond Green Infrastructure Center 2010).

Green Infrastructure Strategies

The final map highlighted a series of vacant parcels that helped to enhance the green infrastructure connection. In one of the focal areas (Figure 13), the prioritized vacant parcels with significant ecological value completed a loop trail in the Reedy and Goode Creek corridors that promoted the quality of green infrastructure service for the neighborhoods south of the James River (Richmond Green Infrastructure Center 2010).

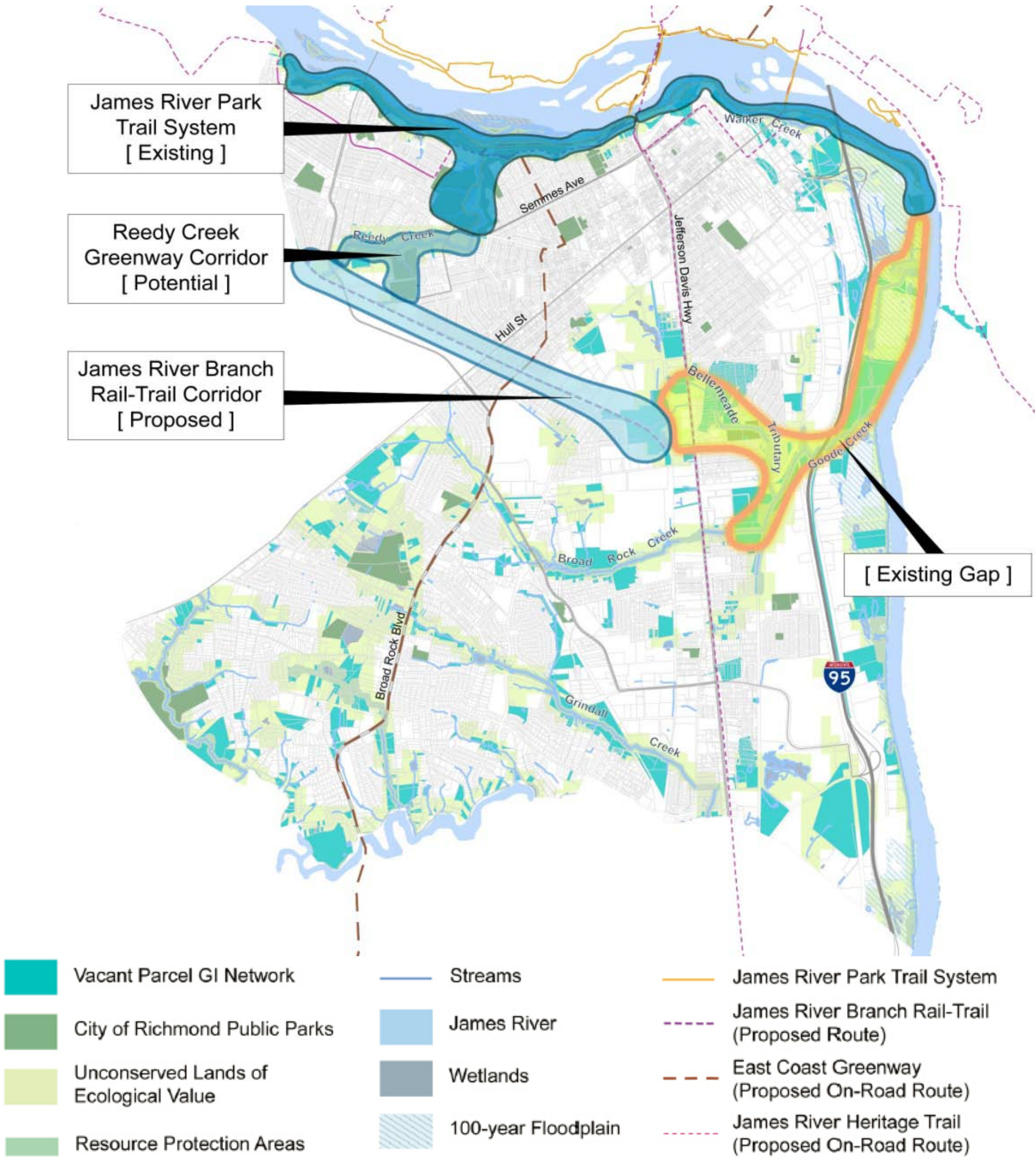


Figure 13: District-Scale Green Infrastructure Expansion Opportunities: A Vision for Comprehensive Connectivity (Richmond Green Infrastructure Center 2010).

Blackwell Green Links concept plan (Figure 14) was presented as neighborhood scale example of the Richmond City Green Infrastructure Assessment. This is a green infrastructure strategic plan for a dense urban community in transition. The concept plan highlighted how vacant parcels could be used as catalyst sites, along with green streets, to link neighborhoods to the citywide green infrastructure network (Richmond Green Infrastructure Center 2010).

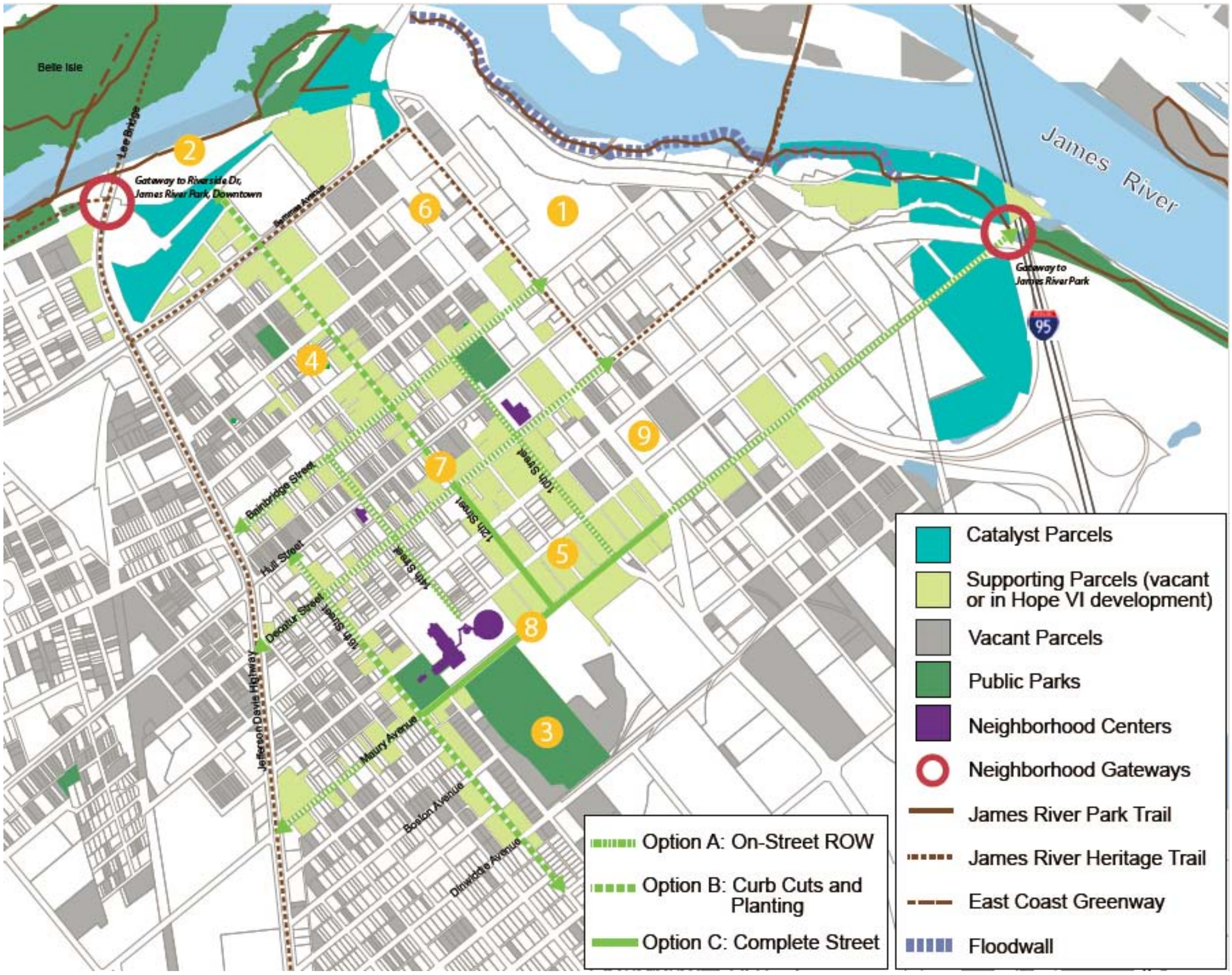


Figure 14: Blackwell Green Links concept plan opportunity sites (Richmond Green Infrastructure Center 2010).

The green street design (Figure 15 and 16) emphasized not only enhancing pedestrian and bicycle connections, improving storm flow and water quality, but also increasing tree canopy that beautified the neighborhood, thus connecting neighborhood to the wider range of green infrastructure network (Richmond Green Infrastructure Center 2010).

Figure 15: The green streets envision (Richmond Green Infrastructure Center 2010).

Figure 16: The greenway conceptual section (Richmond Green Infrastructure Center 2010).

Case Study III: J.R. Alford Greenway, Leon County, Florida

Existing Problems

The J.R. Alford Greenway (JRAG or Greenway) property belongs to the Florida Tallahassee – Leon County Greenways system, which is home to numerous native avian, mammalian, reptilian and other species. Until recently fourteen invasive exotic plant species and only one known invasive exotic animal species were found within the range of the Greenway. The Tallahassee - Leon County Greenways Master Plan serves as the guidance to the local government for environmental land acquisition activities, with the purpose of preserving the vast ecosystems, and providing passive recreational sites for residents and visitors (Leon County 2013).

Design Objectives

The JRAG was an indispensable component for not only expanding Lafayette and Buck Lake Greenway systems by doubling the existing trail length, but also helped to promote the connection between several established residential areas. The main purpose of parcel acquisition was to support the conservation efforts for the historical sceneries, rolling hills, and forested open areas of the Greenway, its wildlife habitat and cultural resources, and to supplement enough green space for an area with continuing growing population in the County (Leon County 2013).

Methodology

The JRAG Trails Plan (Figure 17), created by the Capital Region Transportation Planning Agency (CRTPA), was a vital element of the Regional Mobility Plan. This trail system aimed at providing a transportation alternative for those prefer non-motorized commuting options, with emphasis placed on effectively reducing motor vehicles transportation. The onsite natural community was an influential factor in designing the trail plan. Based on the site specific survey from Florida Natural Areas Inventory (FNAI), basin swamp, marsh lake, mesic hammock, and upland pine forest were classified as the dominating plant species that shaped the layout of the trail system (Leon County 2013).

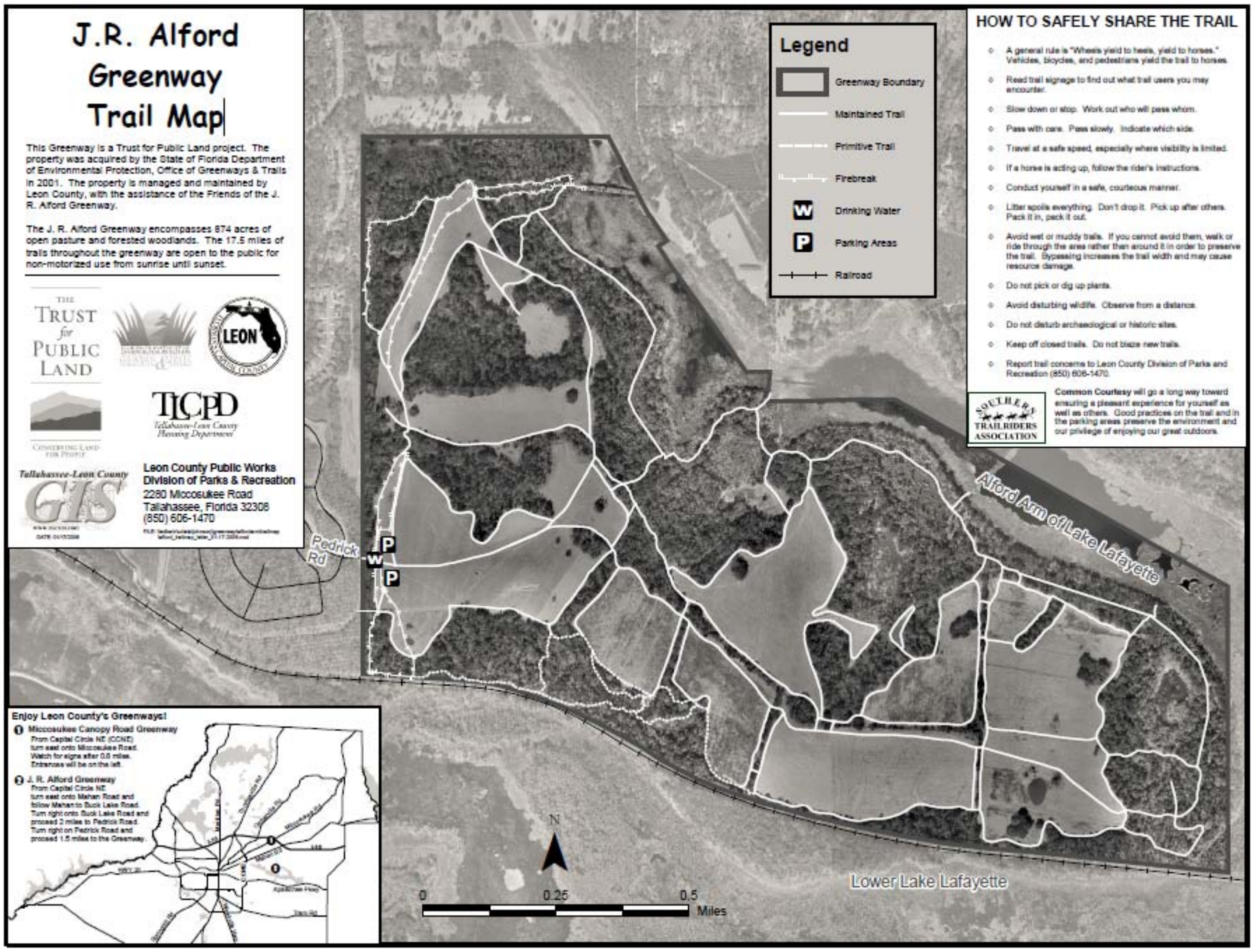


Figure 17: J. R. Alford Greenway Trail Map (Leon County 2013).

Green Infrastructure Strategies

This project successfully preserved potential future urbanized properties as neighborhood-level green hub through carrying out land acquisition regulations, then a series of long-term effective management efforts were taken to strike the balance between natural resources conservation and growing recreational trails accessibility. Flexibility was another important component to ensure the plan may adapt to constant changes. Public facilities such as signage features, benches, trail surface types, and shading were also considered as important design components. The greenway plan will continue making improvements to the Pedrick Road Trailhead and to the existing 16 miles trails. Efforts include stabilizing the trunk trail system through the application of finely crushed stone/shell rather than asphalt, and creating disabledaccessible trail with grass or natural surface to keep harmonious with the rural nature of the Greenway. In the future onsite trail assessment will be conducted prior to the final decision of improving, closing any existing trails, or creating any new trails. This trail assessment will help decide the location of a main loop trail consisting of existing trail segments where appropriate and practical (Leon County 2013).

Green infrastructure performance evaluation

To prepare a relative thorough knowledge for Chapter 5 design evaluation section's reference, this section conducted a literature review about green infrastructure performance evaluation methods. Among them, two were identified as most commonly applied methods. The first one evaluated green infrastructure performance using qualitative analysis: Youngquist (2009) conducted an assessment of ten green infrastructure practices in various locations across the United States. Fifty-one indicators were developed as evaluation criterion to capture the characteristics of green infrastructure planning. These indicators included plan foundations, stakeholder involvement, conservation vision, network design criteria, network suitability, priorities and relationship to plan goals, decision support tool, implementation, funding, conservation strategies, and development opportunities (Youngquist 2009). The plans were evaluated according to each indicator using four evaluation standards (Table 1):

Table 1: Evaluation standards for various indicators (Youngquist 2009).

The indicator was not mentioned in the plan	**-**	**0**
It was mentioned but not discussed	**(+)**	**3**
It was mentioned but briefly discussed	**+**	**8**
It was fully analyzed	**++**	**10**

Plans who totally failed to mention an indicator would receive a "-" mark with a numerical score of 0. Indicator scale that receives a "(+)" would be given a numerical score of 3. This mark refers to plans who merely mentioned the indicator criteria with a sentence or two, without going into further depth. The indicator criteria who receive a scale of "+", or a numerical score of 8 means the project briefly mentioned more detail than those receiving a "(+)" therefore should be assigned with a higher score due to more in depth analysis. "++" is the highest possible score within this evaluation criteria system. Therefore, in order to receive a "++" or a numerical score of 10 equivalently, projects are required to discuss the indicator fully in detail, and thoroughly analyze the issue. The plan framework evaluation emphasizes in four main stages of the plan: 1. Goal setting, 2. Analysis, 3. Synthesis, 4. Implementation (Youngquist 2009). Below (Table 2) is an example of the evaluation of the first stage:

Table 2: Indicators most fully analyzed under the goal setting criterion (Youngquist 2009).

GOAL SETTING	Prince George's County Maryland	Twin Cities, Minnesota	Chicago, Illinois	Pima County, Arizona	Portland, Oregon	Montgomery County, Maryland	Chester County, PA	Saratoga County, NY	Anne Arundel County, Maryland
Was the plan led by a vision, formal plan goals, and strategies for guiding plan development?	++	++	++	++	++	++	+	++	++
Did the planning process include an adequate public engagement process that provided stakeholders with ample opportunities to weigh in on plan development?	++	++	++	++	++	++	++	++	+
Was plan development led by goal(s) to protect ecological processes and functions?	++	++	++	++	++	++	+	++	++
Did the plan include goals for open space and its associated human benefits?	++	++	++	++	++	++	++	++	(+)
Did the plan include strategic connection of ecosystem components - parks preserves, riparian areas, wetlands, and other green spaces?	++	++	++	++	++	++	++	++	++

Similar processes with each different indicator are applied on the other three stages. The overall results of the evaluation are displayed below (Table 3). Chicago, Portland, and Saratoga constantly rated as high scores among all of the indicators; they conducted really good performances especially in the foundations of the plan and the goal setting section. On the other side, Chester, Anne Arundel, and the Twin Cities did not fully understand the overall mechanism of green infrastructure plan, their projects did not successfully accommodate real-world implementation strategies, which drastically cut down their overall scores (Youngquist 2009).

Table 3: Overall results from thesis research (Youngquist 2009).

Overall Results

	Prince George's County Maryland	Twin Cities, Minnesota	Chicago, Illinois	Pima County, Arizona	Portland, Oregon	Montgomery County, Maryland	Chester County, Pennslyvania	Saratoga County, New York	Anne Arundel County, Maryland
Goal Setting	131	145	152	150	147	147	128	151	103
Analysis	153	149	157	147	162	146	128	152	136
Synthesis	48	37	46	44	48	50	44	50	41
Implementation	112	99	120	120	126	115	88	120	91
Total Score	444	430	475	461	483	458	388	473	371
Percentage	87%	84%	93%	90%	95%	90%	76%	93%	73%

The second approach conducted green infrastructure performance evaluation through quantitative calculation. Table 4 below provided a list containing the ecosystem service value of 10 main biomes expressed in monetary units. The mean value of each ecosystem service within each biome category was calculated and then summed. This is an estimation of the total mean value for all the ecosystem services that can potentially be provided by a biome on a sustainable basis. Being aware of the uncertainties and contextual nature of any assessment, the analysis revealed that the total value of ecosystem services is significant and ranges between 490 int.$ per year for the whole ecosystem services that can potentially be provided by an ‘average’ hectare of open sea to nearly 350,000 int.$ per year for the potential services of an ‘average’ hectare of coral reefs. More importantly, these results showed that most of this value should be considered as non-tradable public benefits outside the market. The livelihood of the future generations have to pay for the debts caused by our generation's continued over-exploitation of ecosystems. (de Groot et al. 2012).

Table 4: Summary of monetary values for each service per biome (values in int.$/ha/year, 2007 price levels) (de Groot et al. 2012).

	Marine	**Coral reefs**	**Coastal systems**	**Coastal wetlands** [a]	**Inland wetlands**	**Fresh water (rivers/ lakes)**	**Tropical forest**	**Temperate forest**	**Woodlands**	**Grasslands**
Provisioning services	102	55,724	2396	2998	1659	1914	1828	671	253	1305
1 Food	93	677	2384	1111	614	106	200	299	52	1192
2 Water				1217	408	1808	27	191		60
3 Raw materials	8	21,528	12	358	425		84	181	170	53
4 Genetic resources		33,048		10			13			
5 Medicinal resources				301	99		1504			1
6 Ornamental resources		472			114				32	
Regulating services	65	171,478	25,847	171,515	17,364	187	2529	491	51	159
7 Air quality regulation							12			
8 Climate regulation	65	1188	479	65	488		2044	152	7	40
9 Disturbance moderation		16,991		5351	2986		66			
10 Regulation of water flows					5606		342			
11 Waste treatment		85		162,125	3015	187	6	7		75
12Erosion prevention		153,214	25,368	3929	2607		15	5	13	44
13 Nutrient cycling				45	1713		3	93		
14 Pollination							30		31	
15 Biological control					948		11	235		
Habitat services	5	16,210	375	17,138	2455	0	39	862	1277	1214
16 Nursery service		0	194	10,648	1287		16		1273	
17 Genetic diversity	5	16,210	180	6490	1168		23	862	3	1214
Cultural services	319	108,837	300	2193	4203	2166	867	990	7	193
18 Esthetic information		11,390			1292					167
19 Recreation	319	96,302	256	2193	2211	2166	867	989	7	26
20 Inspiration		0			700					
21 Spiritual experience			21							
22 Cognitive development		1145	22					1		
Total economic value	**491**	**352,249**	**28,917**	**193,845**	**25,682**	**4267**	**5264**	**3013**	**1588**	**2,871**

To improve decision making process for ecosystem restoration and sustainable management, the quantitative evaluation method was adopted in this project, to estimate the ecosystem services value that has been restored from land use transition. Compared to the quantitative method, the qualitative approach was too subjective to be carried out, due to the fact that this method is usually applied from the third person point of view.

CHAPTER 3

THE STUDY AREA INVESTIGATION

The successful planning and design of a greenway system cannot be achieved without a thorough understanding of its surrounding environment. This chapter focused on the NASA Terra ASTER satellite data acquisition and interpretation of the key study area (provided by the project partners), in order to extract the land cover information from satellite imagery. These results not only served as important source to analyze tree cover parameters that guided the greenway alignment and parcel-level designs in the later chapters, but were also used to quantify and evaluate the greenway performance.

The land cover characteristics of the study area

Land Cover Classification Analysis

Three NASA ASTER Satellite images were originally acquired from USGS Global Visualization Viewer, which covered the whole study area. Given the prevalence of vector data in this study, the mosaicked and atmospherically-corrected image was loaded into ESRI ArcGIS 10.1 for further image and vector analysis. Normalized Difference Vegetation Index (NDVI) calculation follows the formula that quantifies the density of plant growth on the Earth — near-infrared radiation minus visible radiation divided by near-infrared radiation plus visible radiation (NASA Earth Observatory 2000). The NDVI calculations were then classified following natural breaks, the results (Figure 18) revealed coarse vegetation density information in the study area.

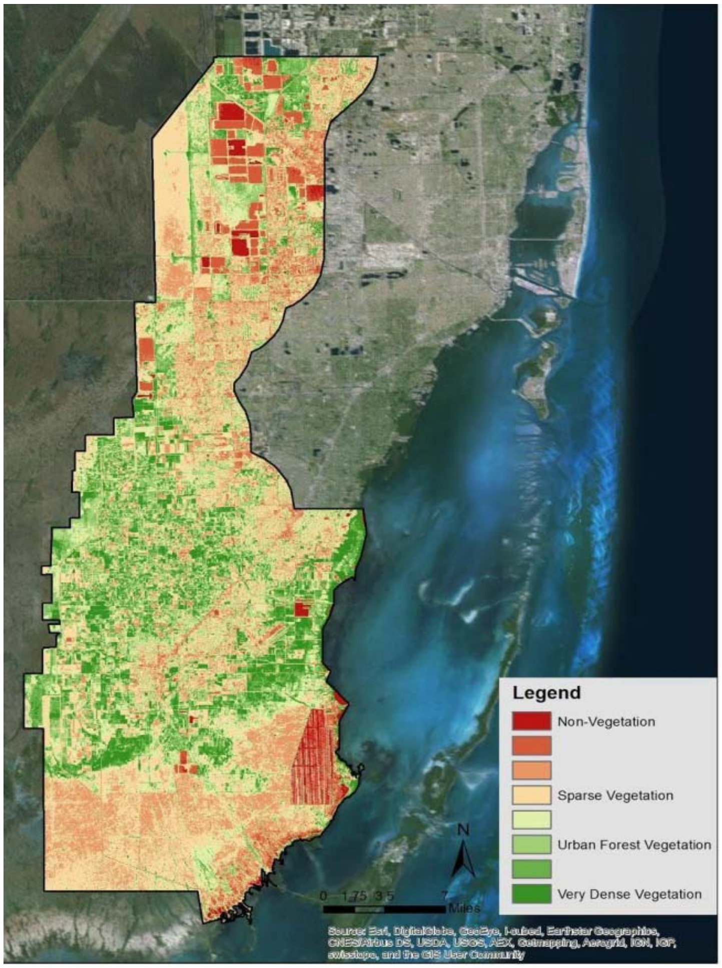


Figure 18: NDVI vegetation density map

Maximum likelihood supervised classification of the image was performed in ArcGIS. Given the variability in land-use profiles in different parts of the study region (i.e. eastern = mostly urban, western = mostly agricultural, southern = mostly wetlands) the image was divided into four areas to be classified separately (see Figure 2). This step helped to eliminate some confusion between classes and also allowed different team members to simultaneously work on the classification process. Even from these results, though, it was apparent that agriculture classes were still misclassified in several sections due to the highly variable nature of these pixels. To more accurately identify agricultural areas, a separate analysis was performed using Principal Components (PCs) and a maximum likelihood unsupervised classification. This was performed on the original image and displayed results that well-captured the majority of the agricultural areas. This image was then clipped according to the boundaries of the agriculture classes selected from the Miami-Dade County Land Use Management Application (LUMA) to extract only areas of agriculture from the original image. A maximum likelihood unsupervised classification of this clipped image was performed to classify the different densities of agriculture. This classified image was used to replace areas of the earlier classification, and improved the resulting maps (Figure 19).

Accuracy assessment was performed by generating 771 ground control points through stratified random sampling in ArcGIS, then comparing the classified image and ground truth image at these points. United States Department of Agriculture (USDA) 2010 1-meter resolution aerial photo imagery was used as the ground truth dataset. This was the closest available dataset to the ASTER imagery date. An error matrix was produced in Excel (Table 5) based upon the ground truth checking, from which overall accuracy (84%) and the Kappa coefficient (0.81) were calculated.

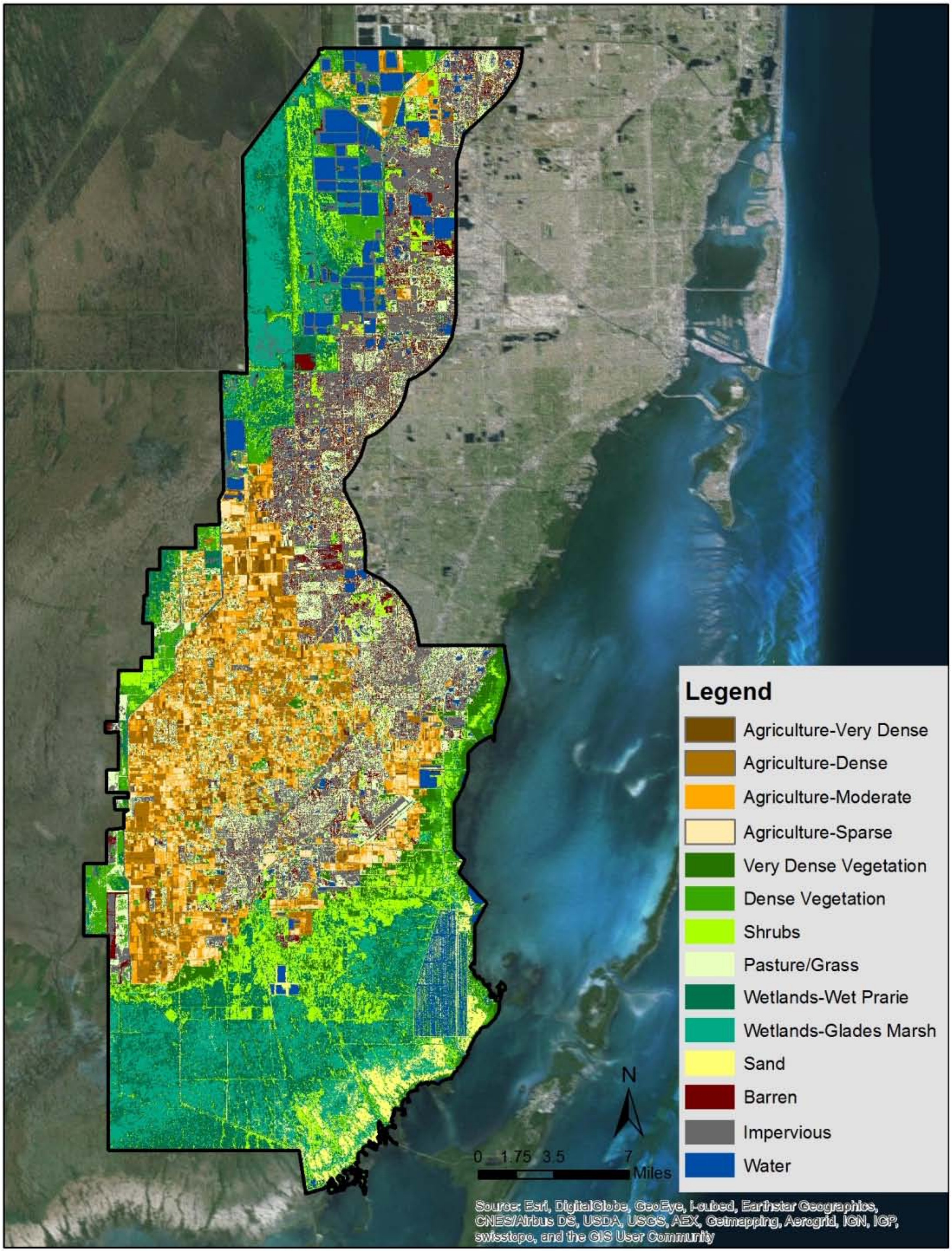


Figure 19: Land Cover Classification Map

Table 5: Land cover statistics and accuracy assessment error matrix

Land Cover Types	Percentage (%)
Agriculture	21.09%
Dense Vegetation	6.03%
Open Pasture/Grass	8.30%
Wetland	27.94%
Sparse Vegetation/Shrubs	10.73%
Barren Lands/Bare Earth	6.88%
Water	5.64%
Impervious Pavement/Buildings	13.39%

Overall Accuracy: 84.05%
Cohen's Kappa Coefficient: 0.81

				USDA Ground Truth							
	1 agri	2 dense	3 pasture	4 wetland	5 shrubs	6 barren	7 water	8 imperv	9 sand	Total	User's
1 agri	138	2	3	1	0	0	0	5	1	150	92%
2 dense veg	1	58	0	1	8	1	1	0	0	70	83%
3 pasture	5	15	56	1	3	1	1	8	0	90	62%
4 wetland	2	5	0	167	5	1	4	0	6	190	88%
5 shrubs	0	2	1	4	73	0	1	0	0	81	90%
6 barren	0	0	0	0	0	3	1	1	0	5	60%
7 water	0	0	0	0	0	0	49	0	0	49	100%
8 imperv	7	3	10	0	2	1	2	91	0	116	78%
9 sand	0	1	0	0	1	0	5	0	13	20	65%
Total	153	86	70	174	91	7	64	105	20	771	
Producer's	90%	67%	80%	96%	80%	43%	77%	87%	65%		

Invasive species and more detailed land use information

Based on the information from land cover classification results, further analysis was performed utilizing Trimble eCognition to extract land use information from the image. eCognition Developer 9.0 is featured by its collection of object-based image analysis tools and algorithms. Object-Based Image Analysis is an approach used to extract features from remotely sensed data in which the unit of analysis is the object rather than the pixel. These techniques were proved to be far superior to the pixel-based feature extraction approaches that had been used for decades. The image objects are created through the use of a segmentation algorithm in which pixels are grouped into polygons based on their spatial and spectral properties. Topology is inherent to the objects allowing not only the spectral information, but also the spatial information, such as shape, size, texture, and context to be used in the feature extraction process (O'Neil-Dunne 2014).

Bing maps with thirty centimeters resolution were used as the reference which provided more detailed land use information for classification category identification (Rischpater and Au 2013). By comparing previous land cover classification results (Figure 19) with the aerial image (Bing maps), several types of agricultural lands were identified to explain the complexity of human impacts to the surrounding environment, they were: General agriculture, orchard/groves with houses, agricultural crops and bare soil. As for natural vegetation community, three types of marsh were identified: glades marsh, coastal mangrove and saltwater marsh (Figure 20). In addition to these, the range of invasive species was delineated to be used as reference for greenway performance evaluation. The classification process took advantage of one of most important eCognition's key features: it allows the users to isolate certain classes by their unique features following a predefined sequence. The sequence of classification and the rule set for each land cover category is listed in the below: 1) water, 2) bare soil/sand, 3) residential, 4) orchard/ groves with houses, 5) general Agriculture, 6) invasive plants, 7) glades marsh, 8) coastal mangrove, 9) saltwater marsh, 10) agricultural crop, 11) manually assign class, 12) export vector layer into ArcGIS for statistical analysis.

A series of rule set (Table 6) was developed based on the ASTER thermal band characteristics of each land cover type:

Table 6: eCognition rule set for each land cover category

Land Cover Category	SD Mean Red	SD Mean NIR	SD Mean Green	Ratio (NIR/Red)	Brightness	Shape Index/ Pixel Number
General Agriculture	104-255	210-255	40-200			
Agricultural Crop	120-240	70-205	50-200			
Bare Soil/Sand	<=45	<=55	<=57	<=1.098	204-255	Number of Pixels <7000
Orchard/Groves with Houses	20-51	9-44	20-62	>=1.11		
Residential	30-39	10-25	34-46	1.018-1.45	162-204	
Glades Marsh	130-240	70-210	20-200			
Invasive Plants	80-140	120-250	20-90	>1.07		
Coastal Mangrove	0-45	0-55	0-57			
Saltwater Marsh	18-22	12-15				
Water	1.8-29	2-40	2-26	<=0.89	0-183	Number of Pixels>270 Shape Index: 0-2.5

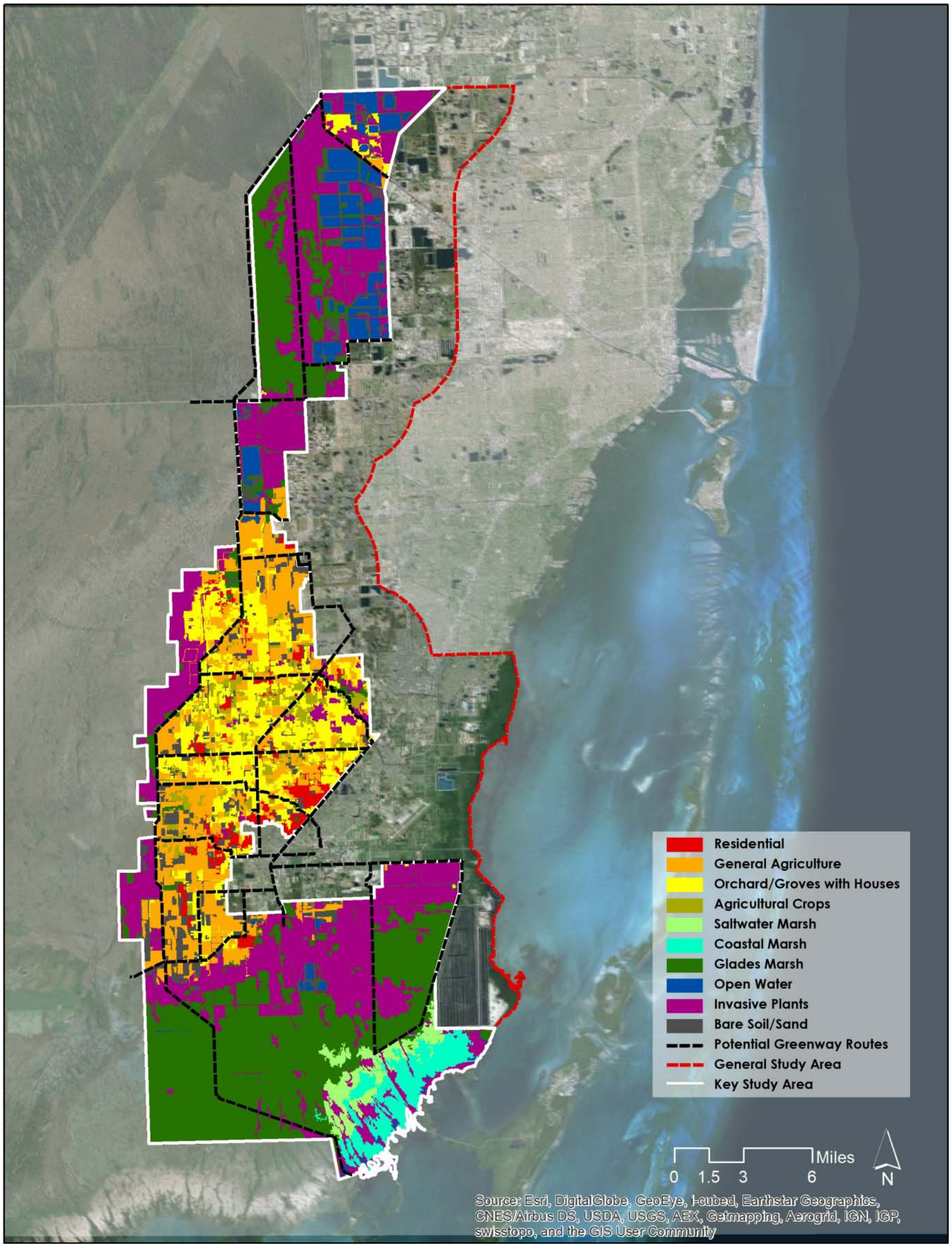
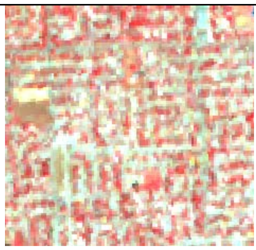
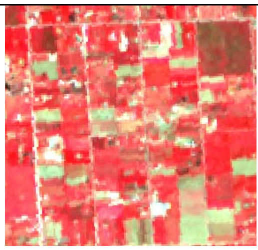
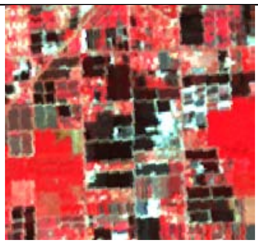
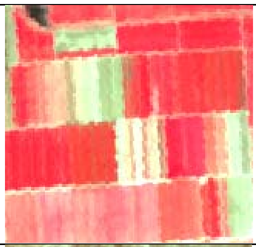
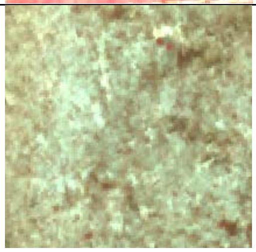
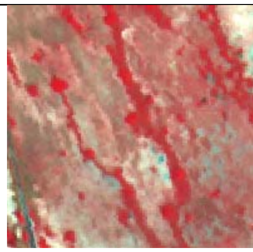
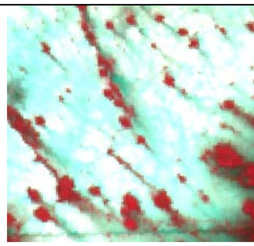
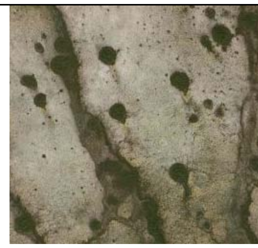
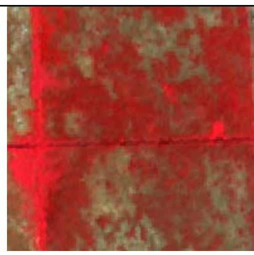
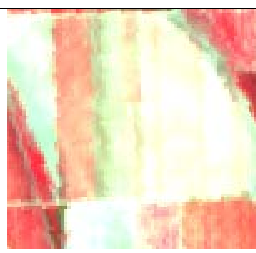
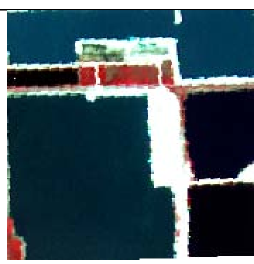


Figure 20: Invasive plants/ land use information map

The general description of key features for each category is listed below, the image samples were the screenshots taken from the ASTER satellite image and the Bing maps aerial photo (Table 7):

Table 7: Land cover type's key feature description (Florida Fish and Wildlife Conservation Commission 2014).

Land Cover categories	**Terra ASTER Satellite Image**	**Bing Maps Aerial Photo**	**Description**
Residential			Consists of areas of intensive use with much of the land occupied by man-made structures. Included in this category are cities, towns, villages, strip developments along highways. Such areas as those occupied by residential, industrial, commercial complexes and institutions.
Orchard/ groves with houses			Less than two dwelling units per acre. Areas of low intensity residential land use, such as farmsteads, will be incorporated into the rural structures category. This class is for active tree cropping operations that produce fruit, nuts, or other resources not including wood products.
Agricultural crop			Nurseries that grow corn, tomatoes, potatoes and beans for transfer to other destinations. There may be other products grown at the facility, such as flowers and ornamentals, but they are not the predominant use. Trees may be grown in-ground or in containers.
General Agriculture			Land that is cultivated to produce food crops and livestock. Wheat, oats, hay, sugarcane, and grasses are the primary types identified as field crops.
Glades marsh			Broad, shallow channel with peat/marl substrate directly overlying limestone; seasonally inundated; slow flowing water; frequent to occasional fire (3-10 years); dominated by sawgrass, spikerush, maidencane, beaksedges, and mixed emergents.

Saltwater marsh			Estuarine wetland on muck/sand/or limestone substrate; inundated with saltwater by daily tides; occasional or rare fire; treeless, dense herb layer with few shrubs; saltmarsh cordgrass, needle rush, saltgrass, saltwort, perennial glasswort, seaside oxeye.
Coastal mangrove			Estuarine wetland on muck/sand/or limestone substrate; inundated with saltwater by daily tides; central peninsula and Keys; no fire; dominated by mangrove and mangrove associate species; red mangrove, black mangrove, white mangrove, and buttonwood.
Invasive plants			Upland and wetland areas dominated by non-native trees that were planted or invaded native plant communities. These include melaleuca, Australian pine, and Brazilian pepper, etc. This class includes sites known to be vegetated by non-native but for which the actual species composition could not be determined.
Bare soil/sand			In urbanized areas, it is an area of bare soil or rock that has very little or no vegetation and limited potential to support vegetative communities. In this study, fallow lands were also classified as bare soil.
Water			Aquatic community of an excavated basin that is created as part of a rock quarrying operation. The sides of the basin are often very steep, thereby eliminating any shallow shoreline habitats. Water levels usually fluctuate.

The percentage of each land cover type is listed below (Table 8):

Table 8: Land cover statistics

Land use category	Area in acres	Percentage (%)
General Agriculture	27790.26	12.63
Agricultural Crop	5475.14	2.49
Bare Soil/Sand	14145.5	6.43
Orchard with Houses	23862.72	10.84
Residential	5328.09	2.43
Glades Marsh	60829.06	27.64
Invasive Plants	60709.98	27.59
Coastal Mangrove	7190.1	3.27
Saltwater Marsh	4299.69	1.95
Water	10416.47	4.73
SUM	**220047.01**	**100**

Based on the information from the chart, glades marsh and invasive plants are two dominating land cover types within the study area. The sum of these two accounts for more than half of the whole range; vast areas of invasive plants are still the primary issue. The main industry of the study area is agriculture; lands are cultivated to produce food crops, fruits and ornamentals (sometimes kept within certain facilities such as greenhouses).

The NDVI and land cover/use classification maps were extremely useful in providing a better understanding of the vegetation types within the greenway study area, as well as serving as vital inputs for the LUCIS model and design evaluation. Additionally, the LUMA dataset was able to supplement these maps with more detailed land use information for the suitability analysis of the three goals: conservation, recreation, and agritourism.

The value assessment of the study area

Based on the literature review and the site analysis, assessment of the value of the study area being investigated was narrowed down to the following aspects: historic, scientific, aesthetic, cultural and tourism. The value system was an indispensable step prior to proposing design strategies. This project carried out the value assessment under current specific circumstances concluded from several public meeting notes, which not only addressed the historical inheritance issue, but also tried to envision its future development pattern, in order to better adapt to the ever-changing natural environment. Therefore, the stakeholders played a vital role in shaping the assessment criteria that facilitated the Geodesign process.

Historic value

Everglades witnessed the changing landscape of southern coastal area of Florida in the past hundreds year, the imprints of human activity can be traced in many places of this region, especially clustered within the study area. More importantly, Everglades itself is one of the best representatives of much longer ecosystem evolution results in the North American continent. This delicate system has been evolved for thousands of years and has reached the perfect balanced point that established the biological foundation for southern Florida. Human intervention started with pre-colonial Native Americans, their living proofs are the numerous indigenous villages and archeological sites scattered around. Today, many places are still named after the Indian culture. The biggest change was brought by early colonial settlers and developers, who treated Everglades as potential agricultural and residential land (Grunwald 2007). A series of efforts was taken against Mother Nature by draining the wetland and making it fit for cultivation. After a serious disaster caused by a hurricane in the Everglades in 1928, the Army Corps of Engineers built levees and canals to solve the overflowing drainage issue, which converted half the Everglades into sprawling suburbs and sugar plantations. As the most distinct human-built structures in this area, levees and canals are the evidence of another failed human intervention towards the existing ecosystem and the species it sustained (Grunwald 2007).

Scientific value

View from the aspect of bigger ecosystem mechanism, the Everglades serve as a crucial barrier against the devastating tropical storms and hurricanes, and an essential habitat for marine species of great biodiversity value. Its information richness in the fresh-water wetland and various species habitats deserve attention from scholars all over the world to investigate. The Everglades are made up of a vast, intertwined collage of various unique ecosystems. These diverse habitats are in a state of continuous change, resulting from the various forces from a full set of natural processes. Issues such as wildlife management, hydrology, water quality and wetland restoration have attracted scholars from all over the world to explore; besides, this area is famous for various rapidly-growing invasive species as well. Other research involves scientific collaboration and partnerships between universities, non-governmental organizations, federal, state, local government agencies, and stakeholders (National Park Service 2015).

Aesthetic value

Everglades National Park was established to conserve a representative piece of the vast southern Florida wetland ecosystem, primarily as wildlife habitat, in addition to protect its majestic scenery. A vast array of subtropical flora and fauna live in the park where mild climatic from the northern latitude merging with tropical Caribbean conditions. Wildlife viewing has always been one of the most popular activities in this area, due to normally pleasant weather conditions during the winter, and wildlife congregation at central water locations with low standing water levels (McCormick et al. 2012). Shark Valley, the Anhinga Trail at Royal Palm, and Eco Pond in the Flamingo area are hot tourism spots for viewing alligators and other wildlife. In Florida Bay and Gulf Coast, extra access opportunities for wildlife viewing are available for boaters as well (National Park Service 2015).

Cultural value

The colonization of Florida by Paleoindians four thousand years ago marks the starting point of the history of Indians in Florida. The influential Glades culture reached as far as the south Florida, Atlantic coast and Florida Keys. Settled down in the Miami area, the Tequesta Indians led a typical Glades' life, having fishing, plant hunting and animal hunting as their chief means of living. In approximately mid-1500, Florida underwent a turbulent metamorphosis as European settlers arrived at this land. The population of north Florida Indians was drastically reduced due primarily to the disease, forced labor, and military encounters that were rampant in the seventeenth century, whereas the population of European settlers gradually became preponderant. The European settlers established their sense of belonging over years as making significant contributions to the landscaping and resource exploitation. Among the settlers, the research activity on Everglades conducted by the conservationists and scientists gave birth to the "Gladesmen Culture". This term is an acknowledgement of their contribution to reshaping the Everglades landscape. Their conservation efforts were featured by 218 projects, through which they re-imagined human-environment interactions in culturally specific way. This cultural recognition has created a unique sense of place and heritage (Milanich 1998).

Tourism value

The Everglades is the largest subtropical ecosystem in the United States, a national park, and a world heritage site, meaning that it has been specially designated as a place of natural importance. Since the study area is located in the transition zone between urbanized area and natural ecosystem, it serves not only as a vital barrier that prevents the city from expansion, but also as ecotourism destinations to the visitors of Everglades. Carrying out public education and entertainments for local communities and visitors, raising funds for conservation, directly benefiting from the economic development such as agritourism, fostering respect for native American cultures and for human rights, and providing service facilities for tourists are the main functional structures of this area. Beyond all of that, promoting conservation efforts by adopting a sustainable behavior is the principal task, just as a very common slogan goes: take only memories and leave only footprints. Low impact tourism activities such as airboat, fishing and wildlife viewing are highly encouraged in this area but need to be carried out under strict regulations (National Park Service 2015).

The design strategies based on the spatial pattern analysis and value assessment results

Based on the value assessment, this section proposed preliminary design strategies, to promote conservation planning from the following aspects: sustainable management of the ecosystem, built structure negative impacts mitigation, and economic development of mainstay industry. These preliminary ideas set the foundation for more detailed design proposals in the next chapter.

Strategies deal with the sustainable management of ecosystem

Biodiversity is a key characteristic of healthy ecosystem. However, this balanced composition has been severely disturbed ever since modern civilization set foot on this area. Human built environment not only obstructed the original water flows from inland to the sea, but also largely altered the native landscape that used to sustain various species. One of the biggest problems is the introduction of invasive species. Florida has a long history of managing invasive species and has established many organizations such as the Florida Exotic Pest Plant Council, Noxious Exotic Weed Task Team, Florida Invasive Animal Task Team and Invasive Species Working Group to deal with this difficult issue. A series of Everglades restoration efforts have put forward new challenges for invasive species management and urged for a well-defined commitment to cooperation among agencies and organizations at higher levels of policy and management (Center for Invasive Species and Ecosystem Health 2015). The Western Greenway project provided a chance to join all the related efforts to address the invasive species issue, through a more systematic designation of certain focal areas that may require prioritized treatments to mitigate current situation.

Strategies deal with built structures negative impact mitigation

Infrastructures such as levees and canals were intended to alleviate the negative impacts brought by fast expanding urban area, over the years they have been helping mitigate the flooding issue but still cannot fundamentally solve the problem. Establishing more natural flows in the south Florida is urgently demanded these days. Currently many projects are aiming at restoring ecosystem back to its original status; one of the best representatives is the C-111 Spreader Canal Western Project. By creating a nine-mile hydraulic ridge adjacent to Everglades National Park, this project will effectively retain more natural rainfall and water flows within Taylor Slough. The hydraulic ridge is actually a 590-acre above-ground detention area that is constructed in the Frog Pond area, with two 225 cubic feet per second pump stations installed, and other project features integrated. The project will also deal with Southern Glades and Model Lands restoration, using an operable structure located in the C-111 canal lower area (US Army Corps of Engineers 2009). This type of project should be encouraged in the Western Greenway planning and design, certain parcels that are ranked as high priority because of their important role in ecological restoration, or being a vital part of the greenway composition can be incorporated with functions that improve the effectiveness of nearby canals.

Strategies deal with the economic development of mainstay industry

Agriculture and tourism have been two dominating industries in the study area. The proposed greenway routes and destinations should recognize and promote the local industries through several ways: 1. the greenway routes should try to connect as many points of interest as they can, in order to provide visitors an easy access to the local attractions. 2. By identifying unique characteristics of the destinations along the routes, the greenway should aim at creating a sense of place for local communities as well as tourists. 3. A series of suitability analysis can help identify focal areas that are flexible enough to be equipped with functions such as passive recreation and agritourism, or to be maintained as conservation lands with limited uses. To sum up, the greenway design strategies should carefully incorporate with local condition, try to enhance the community development as well as dealing with environmental issues. It is necessary for the pre-design analysis to integrate with these strategies, which emphasis in providing spatial development opportunities for agritourism, recreation, and delineating natural barriers for biodiversity conservation; these three objectives are further defined as Western Greenway's main functionality.

CHAPTER 4

GREEN INFRASTRUCTURE IMPLEMENTATION ON THE STUDY AREA

This project proposed a series of design strategies based on three levels of analysis: city scale, district scale and neighborhood scale. Each level of analysis was performed based on the results from the previous larger scale. The main task in the city scale analysis was to identify a potential green infrastructure corridor system based on the LUCIS model output results. The district scale analysis aimed at developing a methodology that helped to prioritize parcels suitable for green infrastructure functions. Finally, in neighborhood level analysis, three categories of conceptual ideas were proposed specifically according to each unique context the sites located in.

City Level: LUCIS Model analysis and fieldwork observations

In order to determine future opportunities for the Greenway's goals of agritourism, recreation, and conservation, the Land Use Conflict Identification Strategy (LUCIS) model was utilized. LUCIS is a goal-driven GIS model that produces a spatial representation of probable patterns of future land use. The power of LUCIS model comes from the application of its results to develop alternative land-use futures (Carr and Zwick 2007). For this particular project, the LUCIS model was adapted from the original model that incorporated urban growth, agriculture, and conservation factors, as described by Carr and Zwick (2007). Based on the complexity characteristics of the study area, three types of lands must be identified according to what lands are appropriate to allow public access, what lands should be set aside for conservation, and what lands should be assigned with agritourism use. The model allowed these three specific goals to be assessed individually through suitability analysis with user-specific weighted inputs. The stakeholders' values and opinions were translated into weighting factors by project partners during public input meetings (Appendix B), and then the weights were further tweaked by project members according to specific goals and existing data. The results of the suitability analysis were coded into a suitability matrix map with 3-digits number representing each pixel value, these numbers helped to visualize the conflict and opportunity areas for the greenway alignment. Finally the results were interpreted from the aspect of conservation goal, and the optimal areas for future development were highlighted through selecting several pixel values that fit into this category.

The shapefiles used as raw inputs for the conservation suitability map included land cover classification map, strategic conservation lands, vegetation habitats, natural hydrology, artificial hydrology (channels), etc. Certain shapefiles were converted directly into raster for further reclassification; while some others were converted into raster utilizing Euclidean distance tool; these raster files were then reclassified into pixel value ranging from 1 to 9, following the priority criteria collected from our partners, or online sources. Finally all the raster files were assigned with different weights according to how important certain elements are in determining lands for conservation use. In this project, the classification map received the highest weight in all three suitability analysis, since it contained the most detailed and complete tree canopy information. Similar process was carried out in the agritourism and recreation suitability analysis. Raster files contained soil, unprotected conservation lands, and farm lands information were assigned with relative high weights in agritourism suitability analysis; As for the recreation suitability analysis, elements such as gateway locations, impervious pavement, parks, soil, existing trails, schools, invasive plants and cultural features received equal weight, which is lower than the highest weight assigned for land cover classification map. The results of each suitability map had pixel values ranging from 1-9, with 9 representing the highest suitability and 1 representing the least. The values were reclassified into the range of 1-3 to represent three normalized preference degrees within each suitability map [1=1-3, 2=4-6, 3=7-9].

This project adopted a three digit approach which helped easily allocate a preference number to each category. To achieve this, the value of each pixel in the agritourism map was multiplied by 1, by 10 in the recreation map, and by 100 in the conservation map. Then the three maps were coded together by raster calculator tool producing a new set of pixel values, this intermediate result (Figure 21) showed the preferential degrees of different land cover types and compared them with one another. The comparison placed an emphasis on conservation as the leading criteria to consider for future development for this particular project. When the same preferential degrees occurred in one pixel, a decision was made as to which one was referred based on the project objectives (Figure 22).

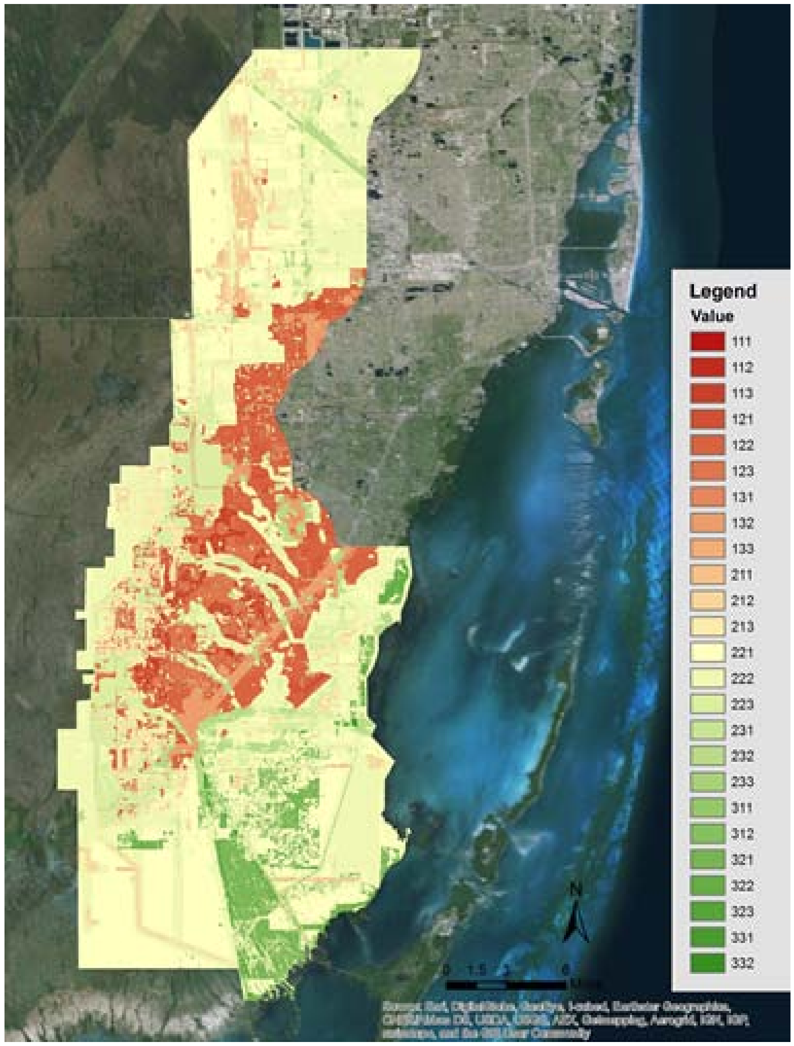


Figure 11: LUCIS Model Suitability Matrix Map

Twenty five new pixel values were calculated and were interpreted into four groups indicating the different levels of land use for conservation in future development. They are categorized as follows:

Group 1: Strict Conservation Areas. This group contained the set of pixels with conservation pixel value 3, representing areas needing strict conservation regardless of how suitable they are for recreation and agritourism. The pixel values are: 311, 312, 321, 322, 323, 331, 332.

Group 2: Moderate Conservation Areas combined with recreation / agritourism. This group contained all the pixels with conservation pixel value 2 except for three (explained in Group 4 below). This group represented areas needing moderate conservation and can be considered for passive recreation / agritourism at the same time. These areas were defined as potential locations for the Western Greenway development. The pixel values are: 213, 222, 223, 231, 232, 233.

Group 3: Least Conservation Areas with recreation /agritourism. This group contained the set of pixels with conservation pixel value 1. These pixel values represented areas needing the least conservation. The next two following digits showed relatively strong biases towards recreation / agritourism. The pixel values are: 111, 112, 113, 121,122, 123, 131, 132, 133.

Group 4: Moderate Conservation Areas with few recreation / agritourism uses. This group contained the excluded set of pixels from Group 2 but also contained conservation pixel values of 2. This represented areas that need moderate conservation. However, the next two following digits did not show strong biases for other land uses. Thus few recreation / agritourism uses could be carried out here. The pixel values were: 211, 212, 221.

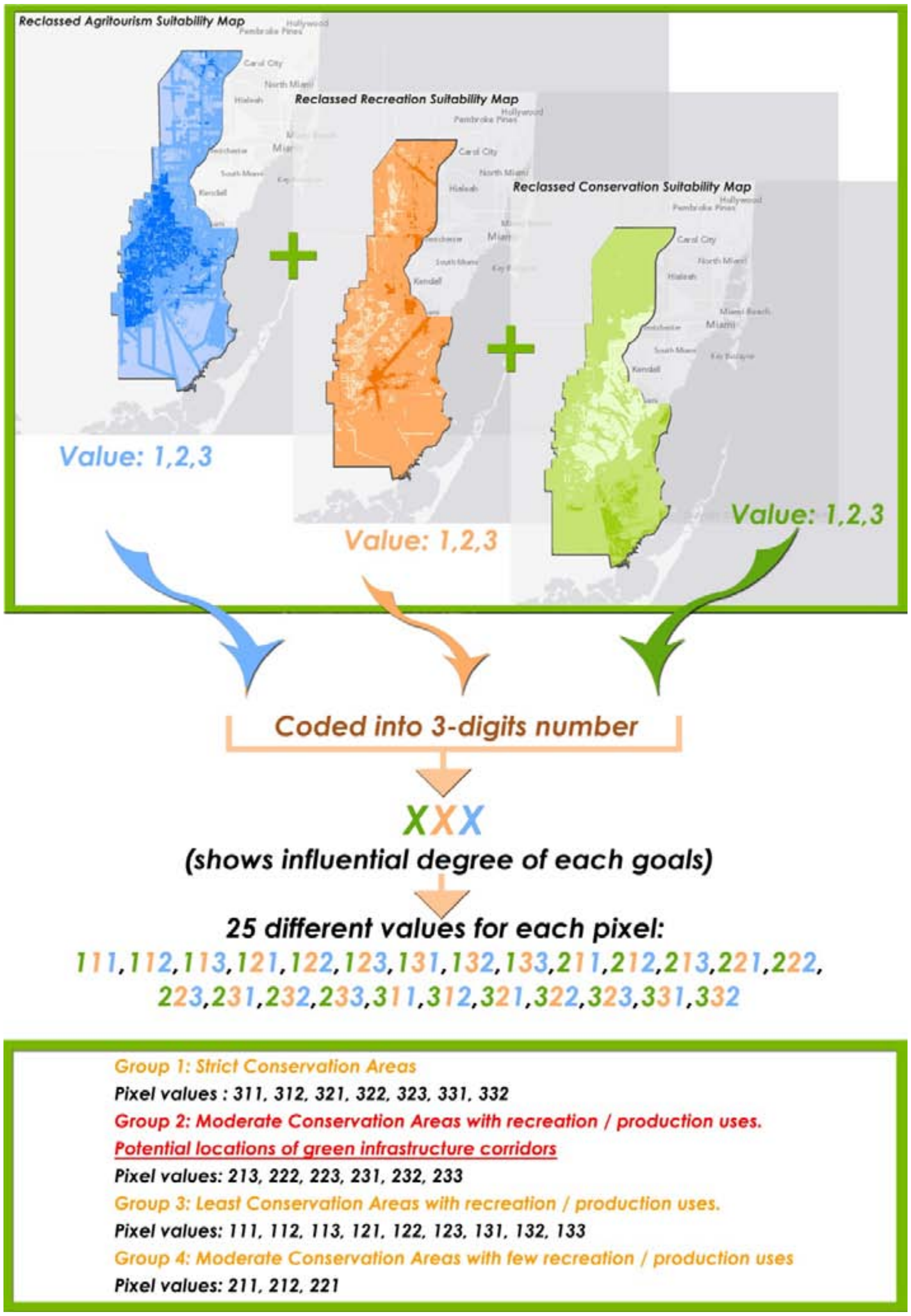


Figure 22: LUCIS model flow chart

The interpreted pixel values were manifested into the LUCIS Model Interpretation Matrix Map (Figure 23) with an overlay of the proposed Western Greenway route. The proposed route was issued by the Trust for Public Land and served as a preliminary model for this project. The LUCIS model analysis results further justified the rationality of the route alignment, due to the fact that all the proposed routes were located within the range of potential green infrastructure corridors.

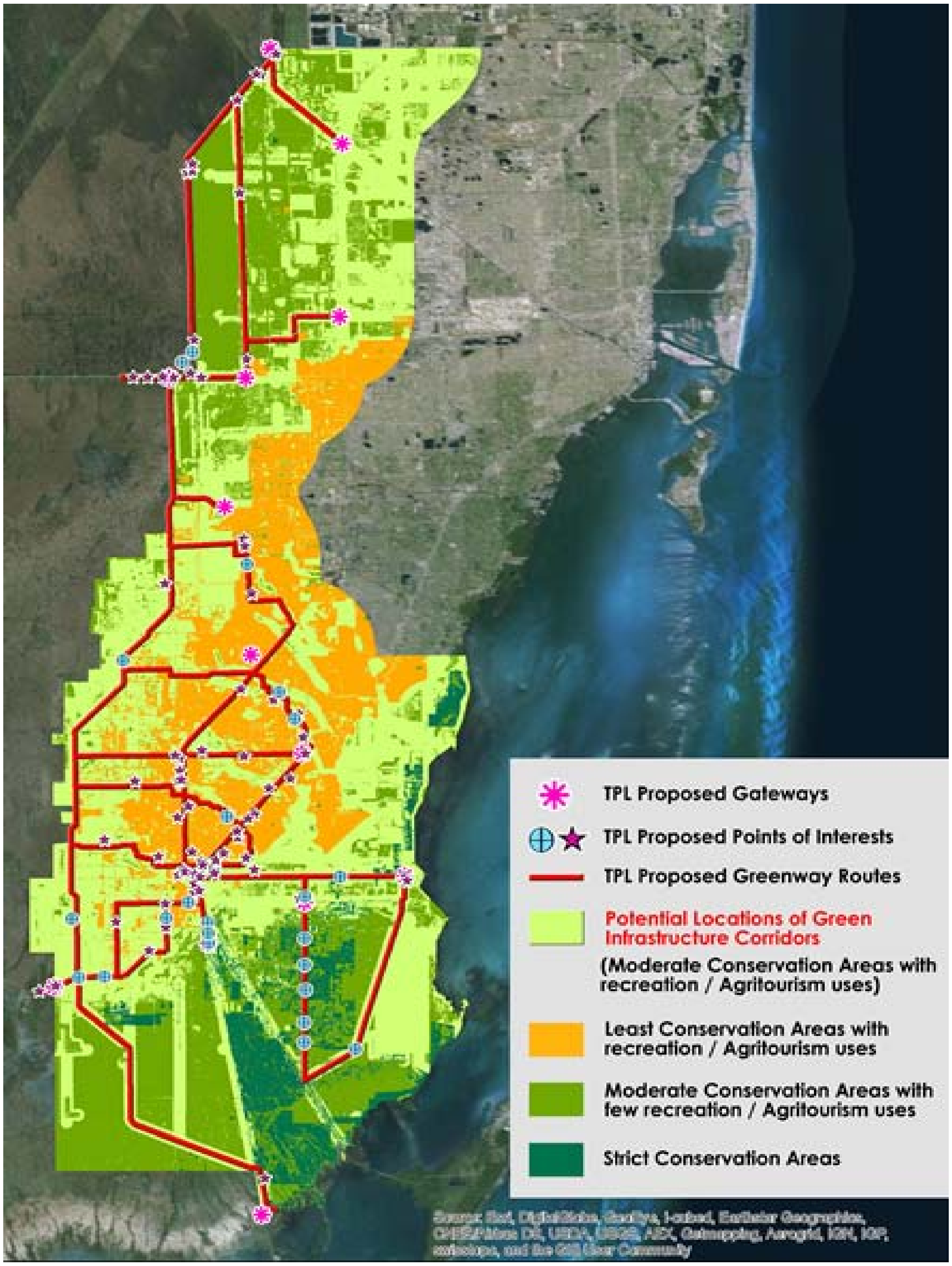


Figure 23: LUCIS model interpretation map

The results from LUCIS model greatly improved the identification process for future development within this study. This was made possible by using inputs from the land cover classification map as well as criteria system that was provided by project partners. From the model, 6.28% of the area was identified for strict conservation purposes that do not allow future development. These areas are mainly located in the southern part of the study area and represent the importance of biological diversity. A calculated 47.78% of the area was identified as potentially suitable land for the greenway development, also allowing for recreation and agritourism activities without disturbing the environment. However, 27.40% of the area was identified as moderate conservation with only limited recreation and agritourism purposes. The rest, or 18.54%, was identified as being most conducive to agritourism and recreational development.

The LUCIS model was able to identify the optimal areas to promote the goals of conservation, agritourism, and recreation along the proposed greenway route, with a particular focus on the southern segment, where the majority of agricultural land is located. The model's effectiveness was assessed through the direct field observations. Photographs and notes were taken on the locations for potential gateways and public access points into Environmentally Endangered Lands (EEL). The EEL was previously acquired by Miami-Dade County's Environmentally Endangered Lands (EEL) Program for the purpose of protecting pinelands and other natural areas (Miami-Dade County 2015). The observations made were collected and later summarized into a trail analysis map (Figure 24). This information helped the project partner create the natural landscape category of online StoryMap utilizing ESRI's Story Maps technology (Figure 25), an interactive tool using geography as a means of organizing information, and combining maps with other rich content (ESRI 2015).The online StoryMap provided the public an essential virtual tour of the proposed greenway routes and gateways.

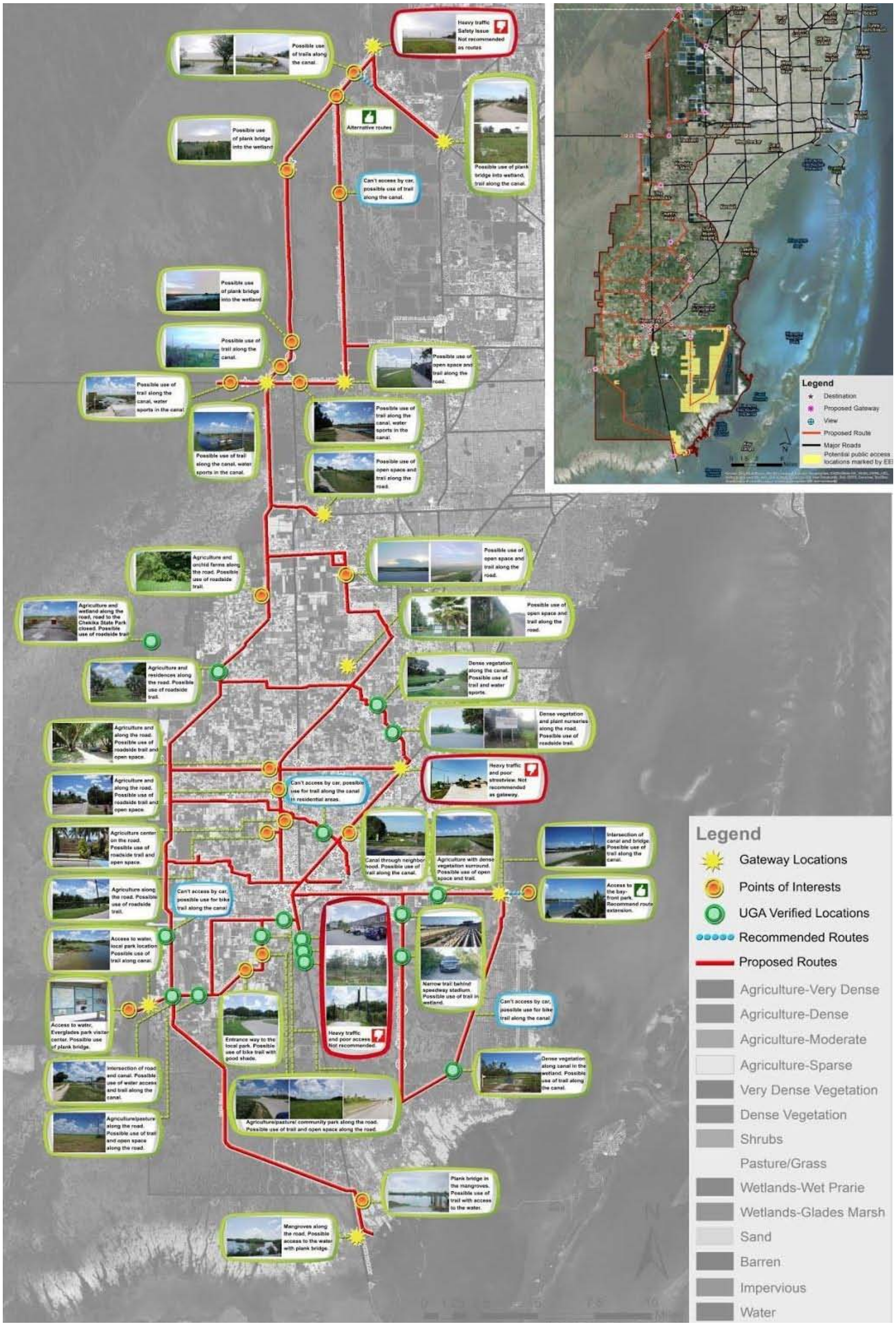


Figure 24: Greenway trail analysis map

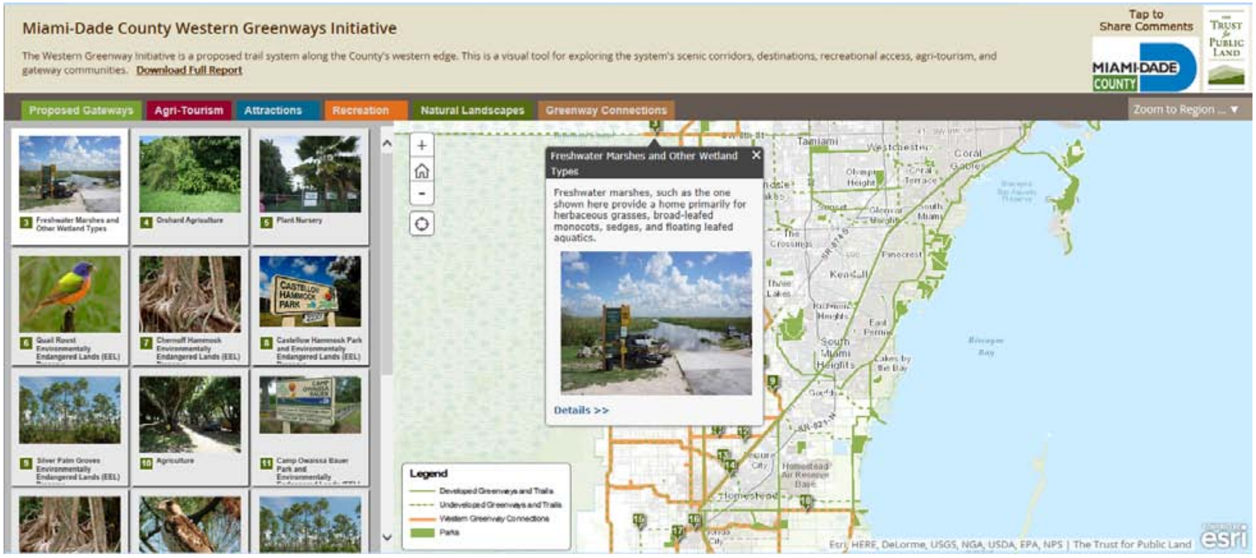


Figure 25: Online Story Map Natural Landscape Category (The Trust for Public Land 2014).

<u>District Level: seven design guideline for the creation of Western Greenway</u>

The implementation of the Western Greenway needs a guiding mechanism that is suitable for its short-term and long-term developments. Such a mechanism concerns various factors from the physical construction to public policies and regulations, even includes the quality touring services for both local residents and visitors. Combining the information provided by the partner and the city level analysis results, this section looked into more specific district level and investigated spatial distribution of certain key areas within the potential greenway locations. The review of literature suggested that there are physical qualities that can be addressed and there are specific criteria that are necessary in creating a sense of place (Lusk 2002). To give a comprehensive and thorough explanation, this project concluded seven design guidelines. These were evolved from Lusk (2002) research findings, by adopting some of the necessary elements as well as the indicator criteria:

1) Organizing certain numbers of destinations that provide wide range of recreational opportunities along the greenway. Taking advantage of the existing points of interest in the study area (Figure 26 to the left), partners from MDC-PROS proposed three types of recreational features along the greenway routes (Figure 26 to the right): destinations, gateways and viewpoints. Based on the preliminary proposal, this project conducted more detailed design strategies about the recreational features. A designated gateway with open space could be considered as potential social-stop/group gathering area, with paved paths and well-organized native plants that help to bring a sense of belonging to the place. The view point could be considered as stop-by place that has a good vision to certain scenery nearby. These places should be equipped with various public facilities corresponding to different scenery types such as bird viewing, featured landscape, community gardens, etc. As for the destinations along the trails, most of which are located within the city of Homestead. The design should take advantage of the existing community gardens, plant nurseries, canals and various cultural features, connect and strengthen these feature to create an authentic context for the multi-use trail system.

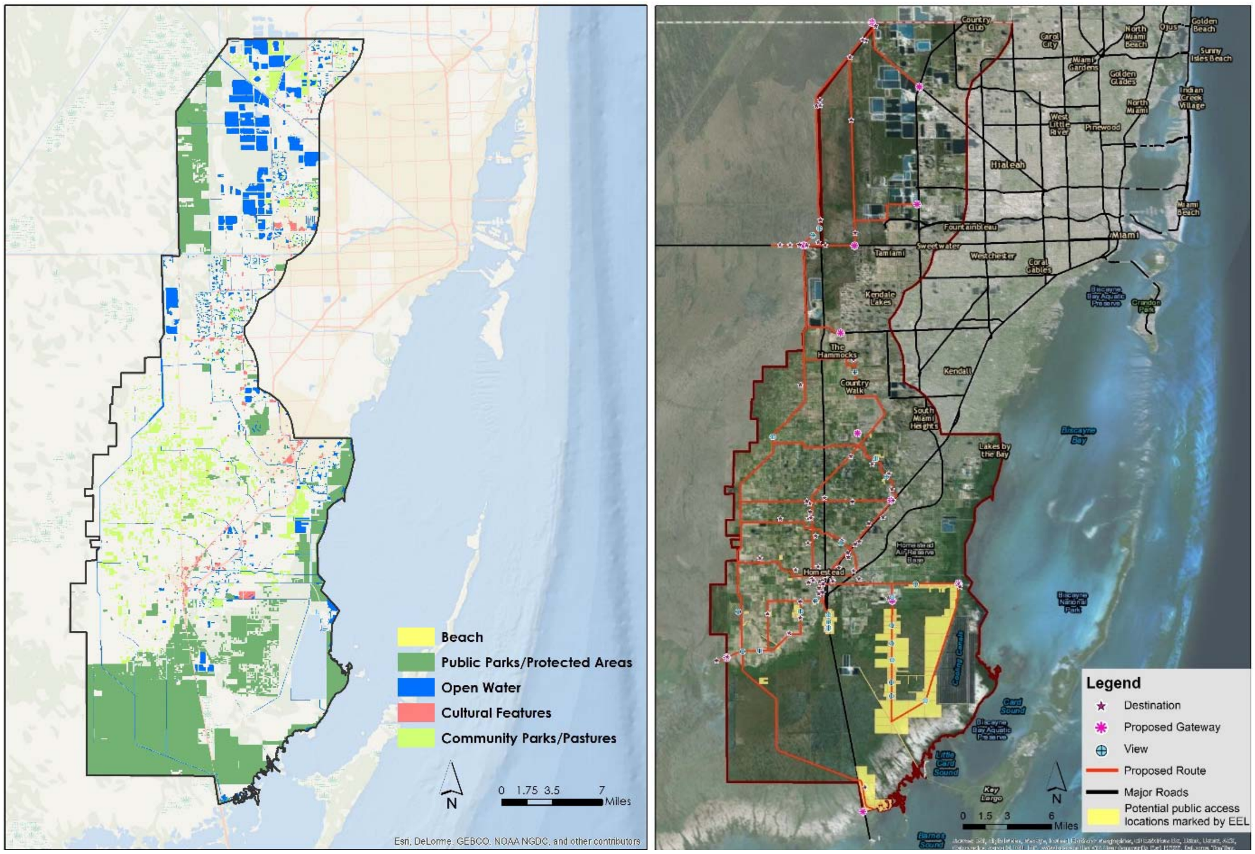


Figure 26: Left: existing points of interest map (derived from 2013 LUMA dataset). Right: recreational features proposed by the partners (Miami-Dade County Parks Recreation and Open Spaces 2014).

2) Take advantage of the location and integrate it with public education uses regarding environmental preservation and healthy life style. Studies have shown that the designation of greenway can bring positive psychological effects to the neighborhood nearby (Sanderson, Sebastian, and Shaw 2012). A 0.25 miles buffer (Figure 27) was made around existing residential/school areas (0.25 miles is considered as 5 min walking distance). Properties intersected with this buffer were considered as easy access by walk; if also located along the greenway, they could have the potential of further developed into outdoor classrooms, based on their ownerships and existing land use type.

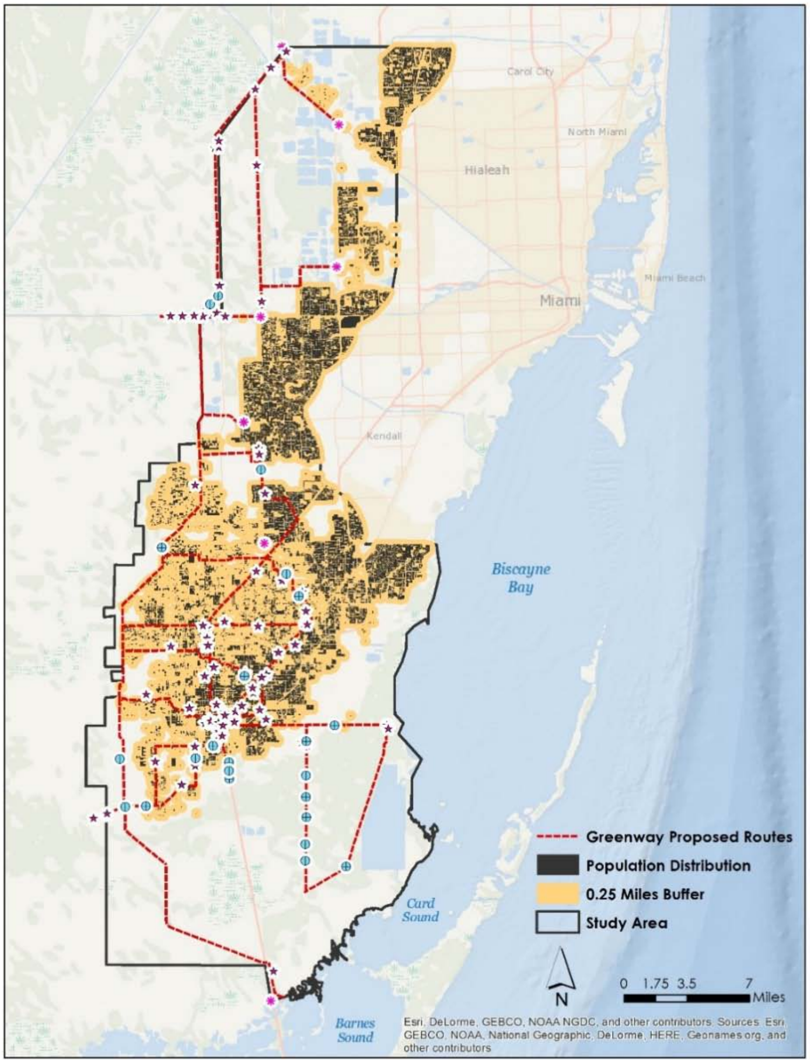


Figure 27: Residential / schools 0.25 miles buffer map

3) Creating different types of trails and destinations to meet all ages needs. Generally there are three types: 1. trails that run through the conservation lands that are featured by their rich collection of native flora and fauna, as well as invasive species; 2. trails located within urban areas provide visitors opportunities to experience the local cultures; 3. to enhance the diversity of the agricultural lands, several trails are designated to give visitors a comprehensive view of this unique feature. The experience of trails should be designed like a story line, with various attractions along the way (Figure 28).

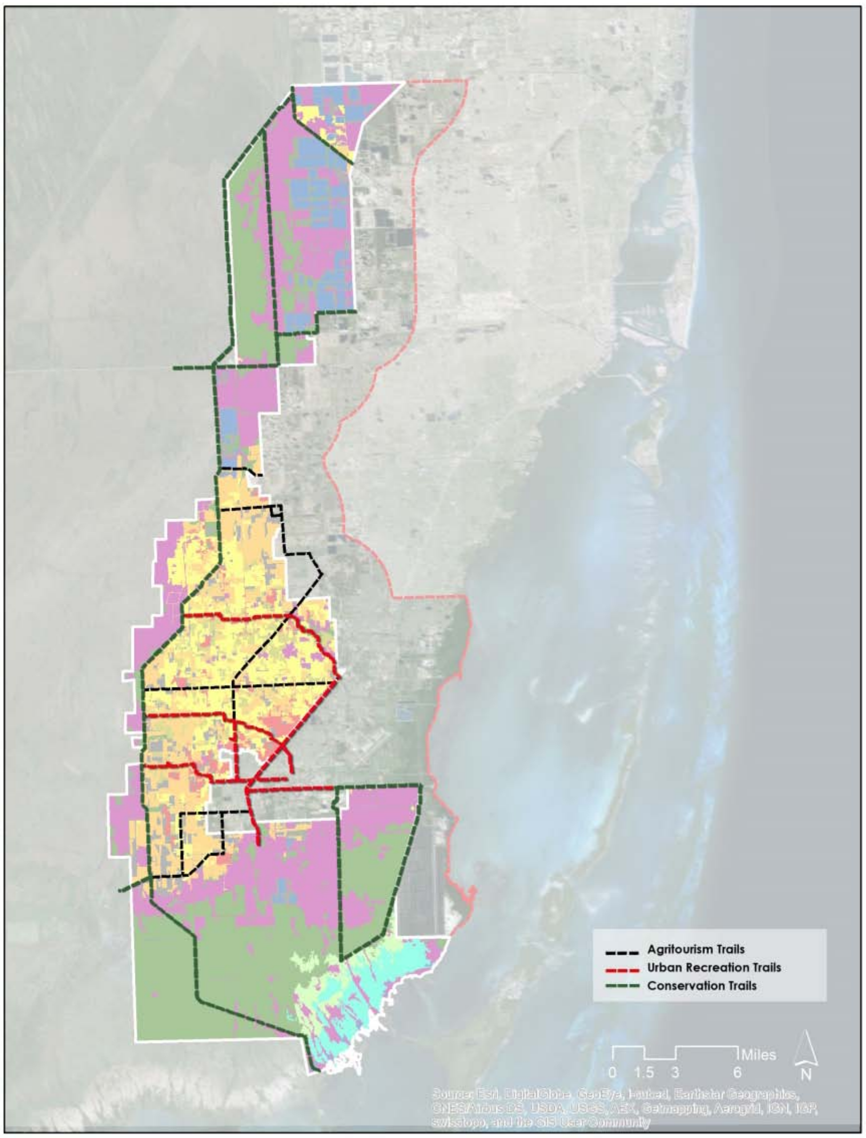


Figure 28: Trail characteristic map

4) Taking advantage of the greenway locations to foster the preservation efforts of native plants, and to prevent the expansion of invasive species towards Everglades. The design of the parcels located along the greenway should emphasize in reversing the decline of certain native species, especially for those adjacent to both trails and canals (Figure 29); if possible, some of the parcels should be transformed into detention pond with native vegetation, in this way the parcels are expected to imitate the original function of the wetland area, and retain as much natural water flow as possible.

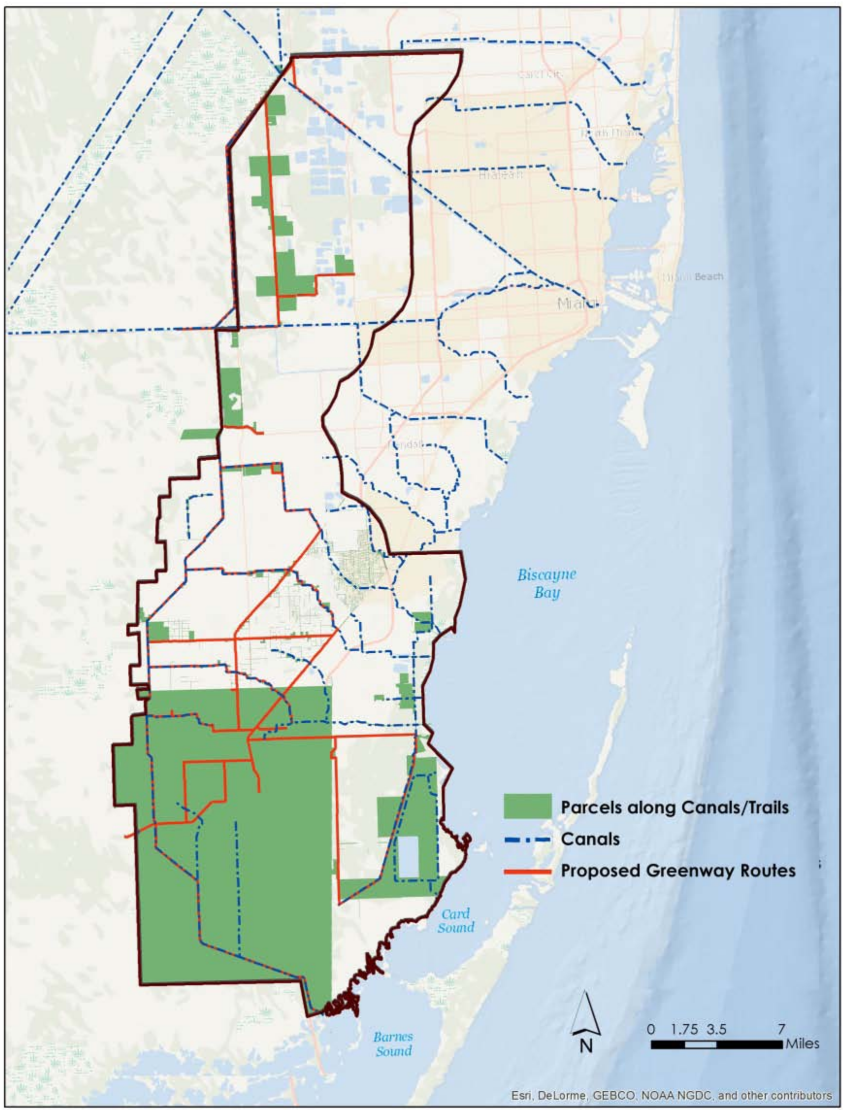


Figure 29: Map showing parcels located adjacent to both the greenway trails and canals

5) Increasing access to the public parks. A 0.25 miles buffer (Figure 30) was made around existing parks and community gardens (0.25 miles is considered as 5 min walking distance). Properties intersected with this buffer were considered as easy access to parks by walk; if also located along the greenway, these properties have the potential of further developed into parks to help connect the existing green spaces into a wider range of parklands system within the urbanized areas.

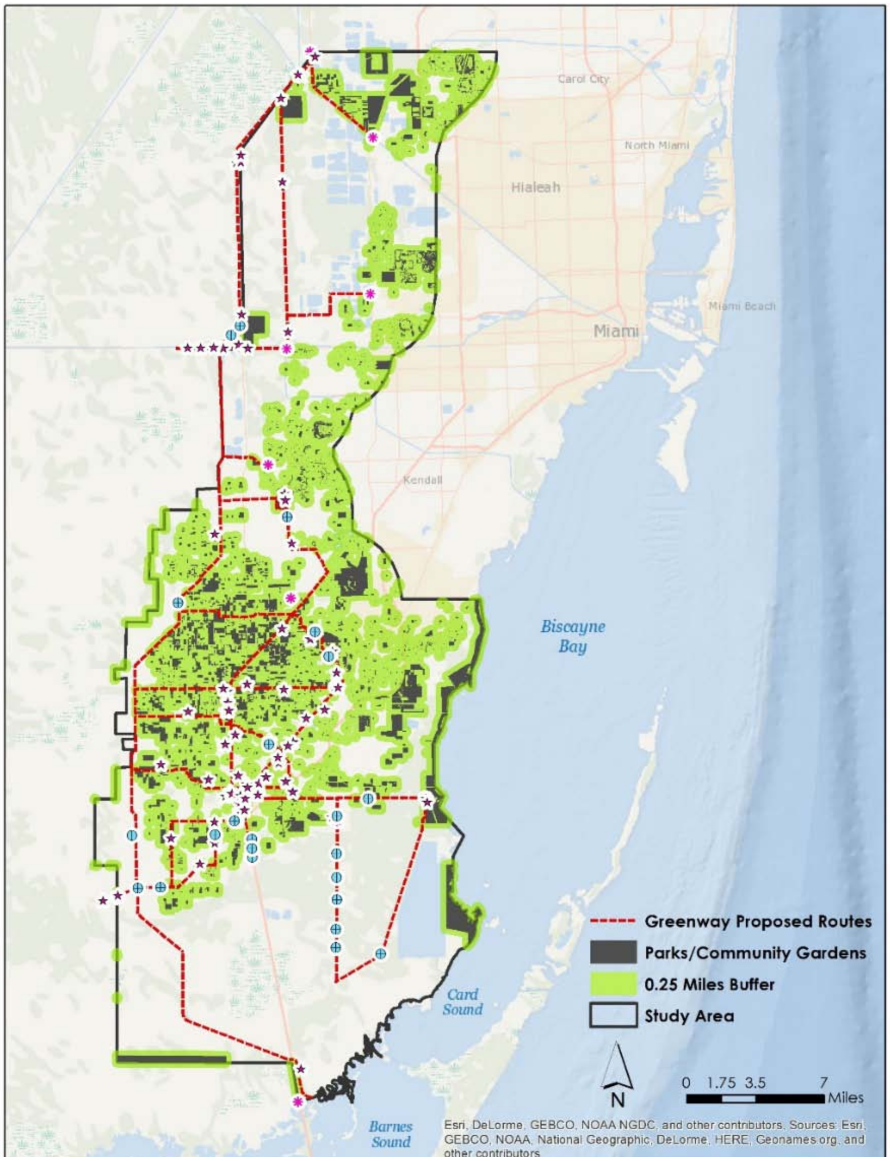


Figure 30: Parks 0.25 miles buffer map

6) Connecting the conserved landscape. A 100' buffer (Figure 31) was made around areas that were previously identified as conservation lands. Any parcel falls within the 100' buffer range should be considered as areas that contain ecological values, and have the potential to connect the existing conserved lands (conservation lands, water bodies and rivers, canal) into a wider range of corridor system.

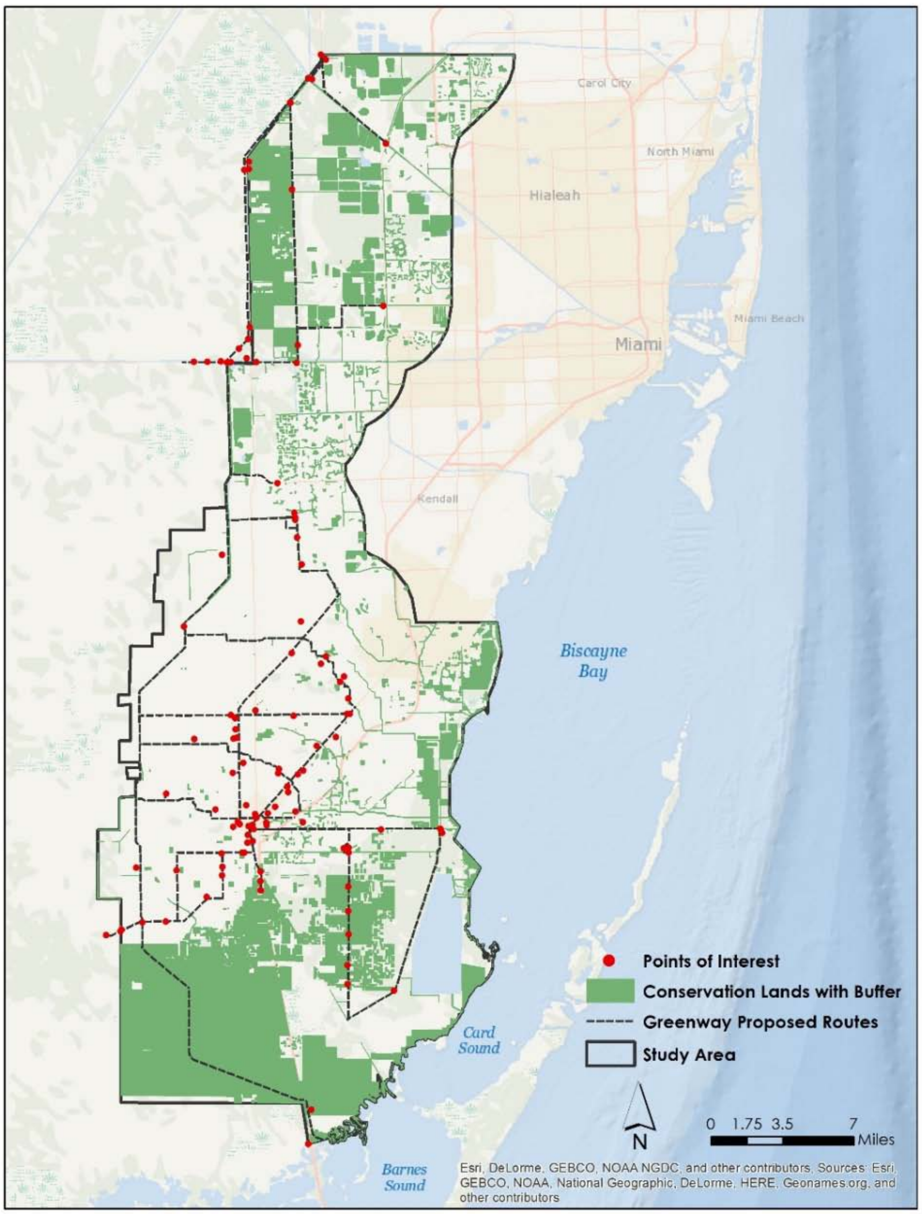


Figure 31: Conservation lands 100' buffer map

7) Expanding Trail Access. Vacant or undefined parcels with proximity to points of interest may be well-positioned to support the functionality of greenways. A 100’ buffer was made around previously proposed trails, any vacant parcel that falls within the 100’ buffer range (Figure 32) should be considered as areas that have the potential of expanding the trail access. Well-designed green spaces within these parcels could also expand the tree canopy or enhance the scenic view along the trails.

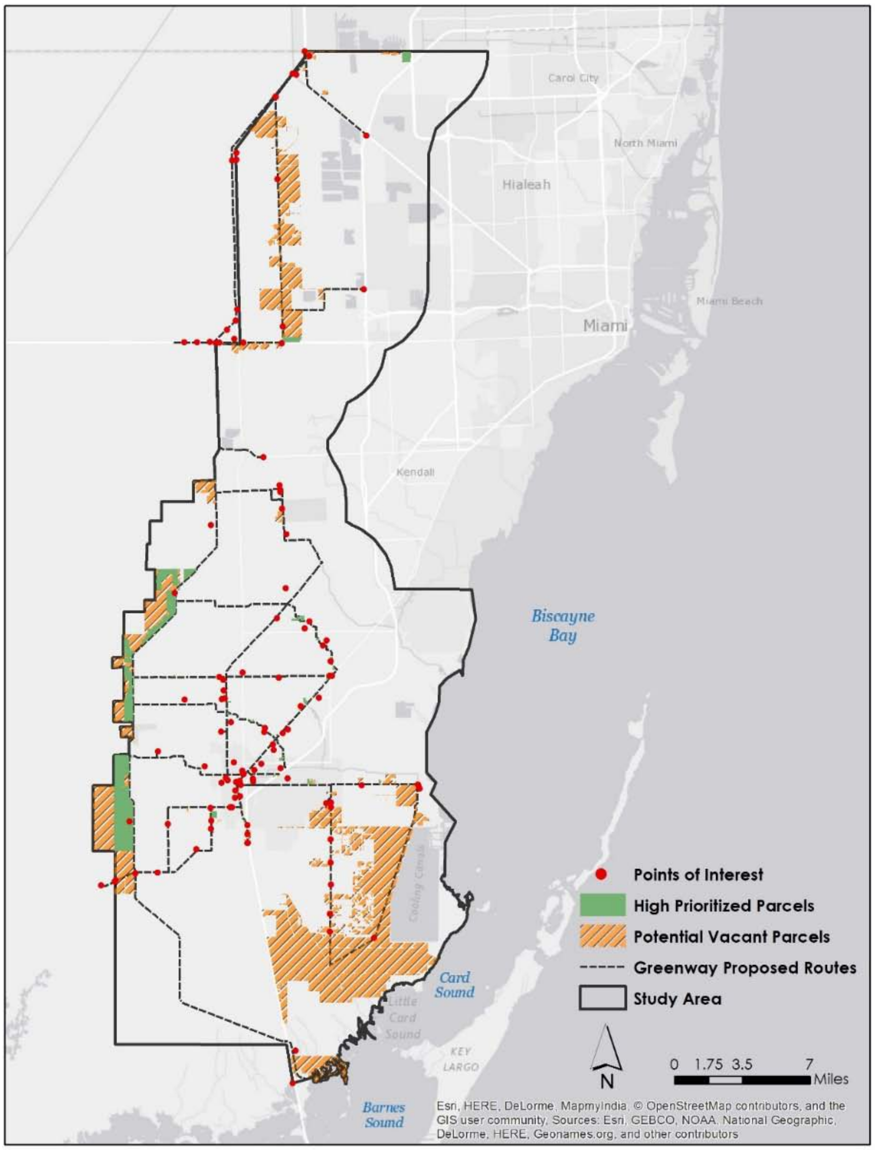


Figure 32: Map showing vacant parcels that fall within 100’ buffer of trail routes

After overlaying all the influential factors described above, the results below (Figure 33) showed the hierarchy of suitable parcels for greenway implementation:

1. Highly recommended parcels: parcels in dark green that were shared by four layers. They were identified as the most appropriate ones to be restored to promote greenways' development. Among them, there are some big parcels located along the western side of greenway, featured as the transition zone between the vast wetland and the agricultural lands. Some relative small parcels are distributed within the Homestead city range; these parcels should be ameliorated into community activity areas that help enhance the diverse functionality of the trail. Lastly, in the north region of the greenway, there are several other parcels scattered at the entrance areas of trails, some of these parcels were designated as important gateway locations in the overall planning of the greenway by project partners; the design strategy of the rest should focus on enhancing the gateway functionality.

2. Recommended parcels: parcels in light green that were shared by three layers. They were identified as recommended locations, the restorations of which could enhance the overall greenway connection.

3. Supporting parcels: parcels in beige that were shared by two layers. They were identified as supporting locations that form the context the trail system lays within.

The specific design strategy of these three types of parcels will be illustrated in the next section.

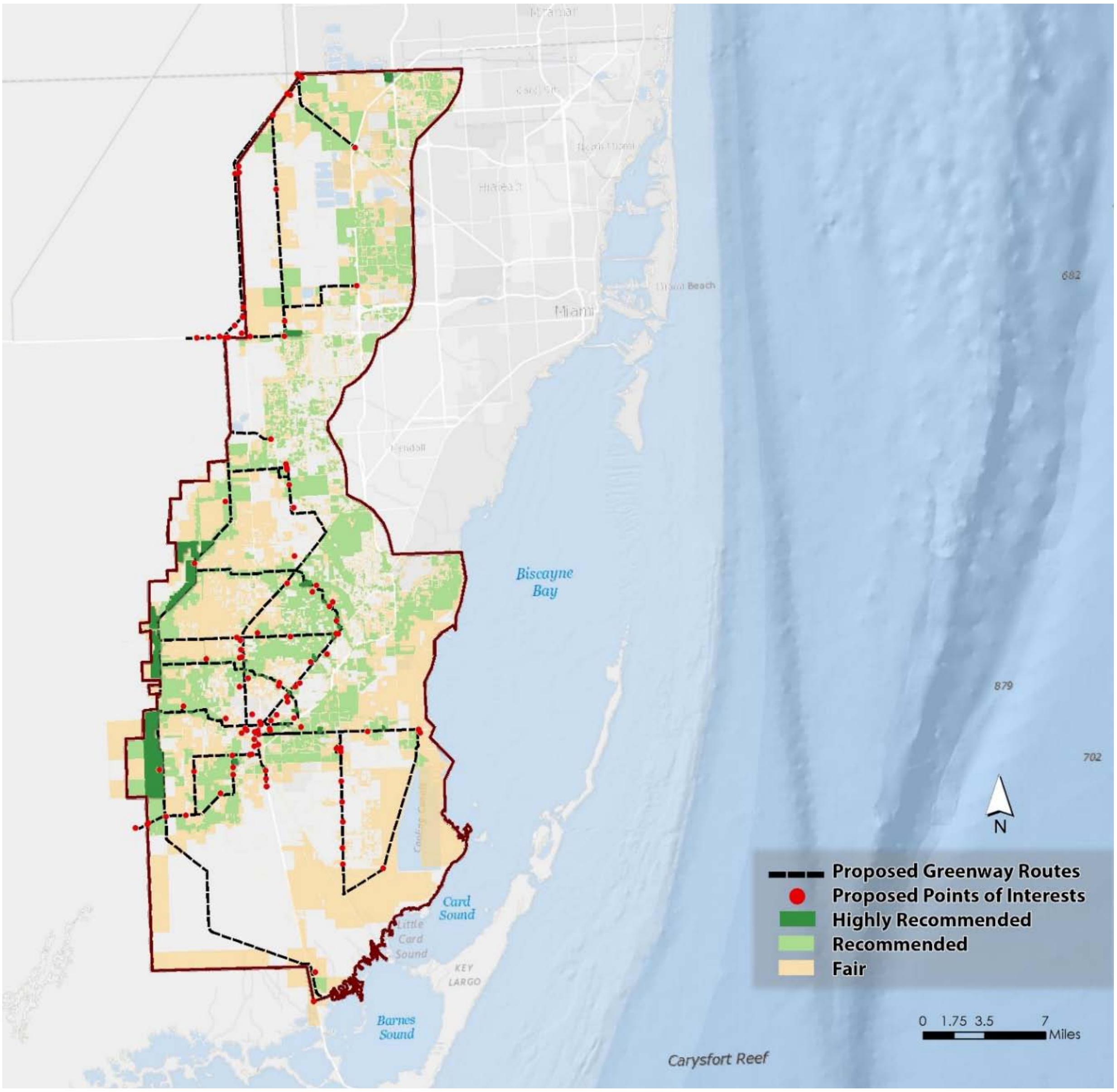


Figure 33: Hierarchy of suitable parcels for greenway implementation

Neighborhood Level: multi-use trail and parcel design conceptual plan

After assessing the regions of interests, three representative areas were selected (Figure 34) with conceptual ideas proposed on the future outlook of the Western Greenway. The first conceptual plan, called Wetland Corridor, was featured by a green infrastructure strategy for a transition area between built environment and wetlands. Parcels that fall into this category are currently located along the canals on the western side of the greenway, the design of which emphasized in the accessibility to the wetlands. The second conceptual plan, called Homestead Green Link, outlined a green infrastructure strategy in a formal neighborhood context merged with the canal system. Parcels that fall into this category are currently located within the Homestead City range, the design of which emphasized in the restoration of existing green space and the functionality improvements of certain parcels along the trails. The third conceptual plan, called Northern Gateway, was featured by a green infrastructure strategy for open space beautification, which indicated the entrance of the greenway. Parcels that fall into this category are currently covering all the proposed gateway locations and their surrounding regions, the design of which emphasized in the overall aesthetic feature of the area.

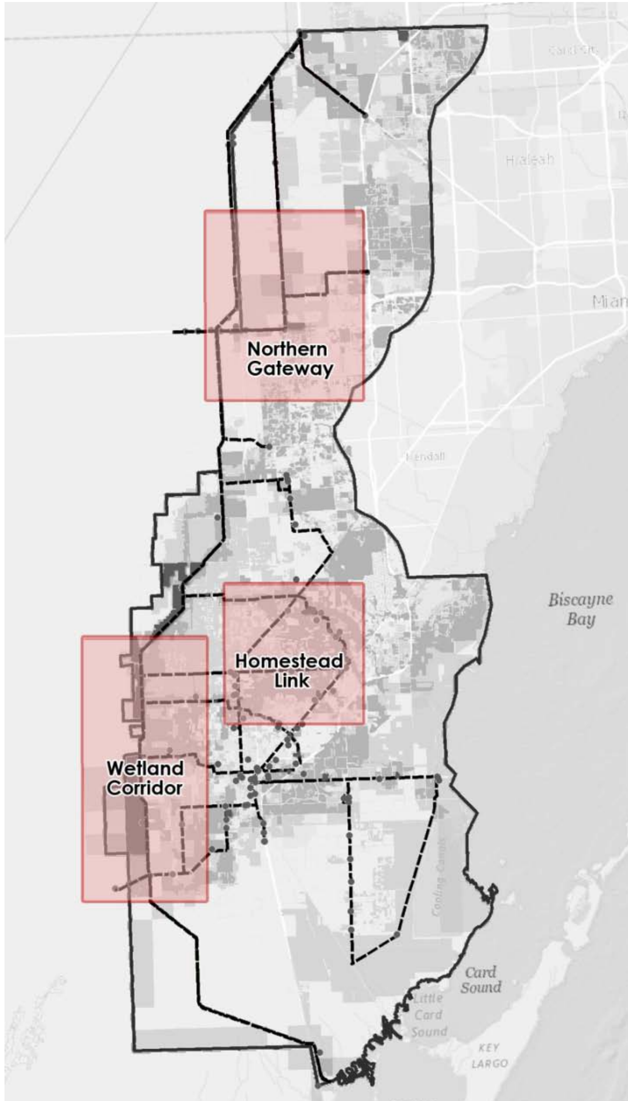


Figure 34: Map highlighted by three representative areas

In the Wetland Corridor plan (Figure 35), currently parcels located along the western side of greenway are largely influenced by the developments nearby, due to the fact that large amount of invasive species such as melaleuca and Brazilian pepper can be traced in these parcels. The surrounding land cover information provided clues about how these parcels should be treated; the green infrastructure strategy should focus on two aspects: 1. the restoration of native species and public education on invasive species. Besides those that have been previously identified as gateway locations by the partners, some other parcels that have been ranked as highly recommended could also be endowed with gateway functionality that indicating the entrance of protected wetlands. For some of the easy access parcels, project partners pre-defined them to be transportation hubs to support public access to the Western Greenway, as well as enabling local touring shuttles throughout the greenway corridor. As for the other gateway locations, they function like barriers that prevent further development into the wetlands. By creating trails with educational panels that can access the wetlands, these parcels could become outdoor classrooms that provide opportunities for visitors to get to know various species (Figure 36). 2. Census track undefined parcels could be designated as parklands; they can potentially become roadside habitat for some species, and are embedded with view point/destination functions pre-defined by project partners. Parcels that are located along the canals can be restored back into wetland detention ponds that help retain natural water flows within this area, with the objective of offsetting the ecological damage brought by the canals to the maximum degree. These include Frog Pond area which is already included in the C-111 Spreader Canal Western project.

Recommended parcels are those who have the potential of integrating green infrastructure components into future development; by coordinating with local redevelopment and housing authority, community renovation program can be carried out on existing residential and public/semi-public parcels in the near-term, this program should promote the implementation of environmental friendly plants in local community gardens, restore native species within certain public spaces (Figure 37), install public facilities to enhance storm water management, etc. Parcels that are ranked as fair covered almost 90 percent of the rest of project area, which means the whole study region needs design guidelines that effectively regulate the future development: the land use types should be restricted to agriculture, plant nursery and single family residential only, in order to prevent high-intensity development in the future. According to

Southwest Florida Regional Planning Council's 2010 statewide future land use plan: the development density of agricultural land should be restricted to equal or less than 1 unit per 5 acres; as for single family residential area, the development intensity should falls into the range of 1 unit per 1 acre to 5.9 units per 1 acre (Southwest Florida Regional Planning Council 2010).

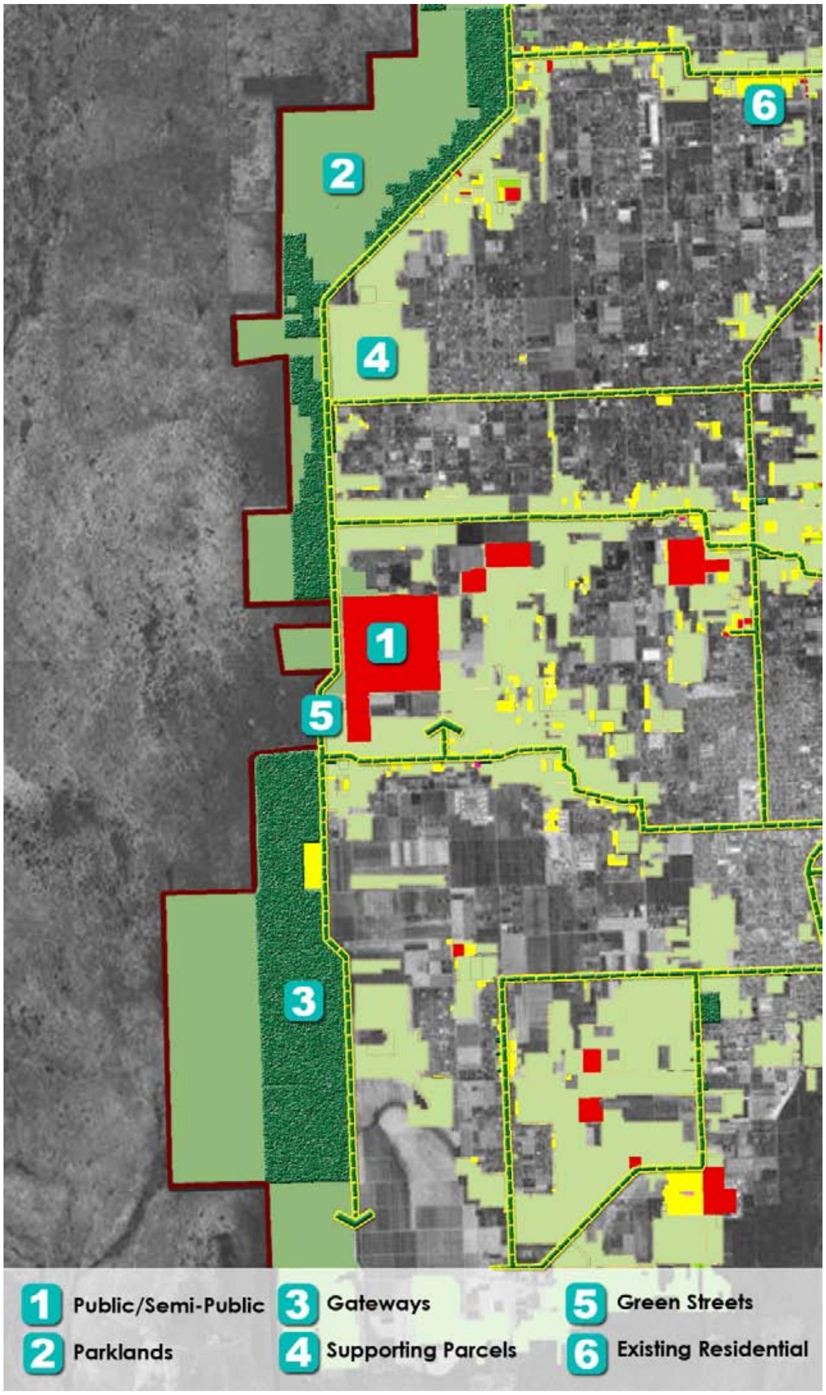


Figure 35: The Wetland Corridor plan in parcel level

Figure 36: Accessibility into the wetland through multi-use trails

Figure 37: Native species restoration in public space

Green Street is another important feature of this design. It is multi-use trail which is located alongside canals, and equipped with green infrastructure facilities such as a bioretention area located along the road side to infiltrate water and divert it to the detention pond nearby. The bioretention area could also provide adequate space to plant trees, shrubs and ground covers, which helps to create a pleasant walking experience for visitors, and functions as roadside rain garden as well. Generally the pavement of the Green Street can be divided into two parts: the bike lane in the center is paved with asphalt, while the pedestrian walkways on both sides are made from porous concrete, which maximize the infiltration of above ground storm water flow (Figure 38).

Figure 38: Green Street section view

In the Homestead Green Links plan (Figure 39), highly recommended parcels could be developed into urban parklands which diversify community recreation activities, these parcels can potentially become roadside habitat for some species as well. Currently undefined parcels could be designated as urban catalysts; taking advantage of their functional flexibility, parcels that are located adjacent to public spaces could be designated as urban landscape areas, and are planted with native plants that obtain high aesthetic value; parcels that are located near residential areas can be further developed into plant nurseries or community gardens to support local business; parcels that are located near parklands should be managed under environmental regulations, which set up a series of ecological restoration efforts to enhance the functionality of parklands, and eventually convert these parcels into parklands.

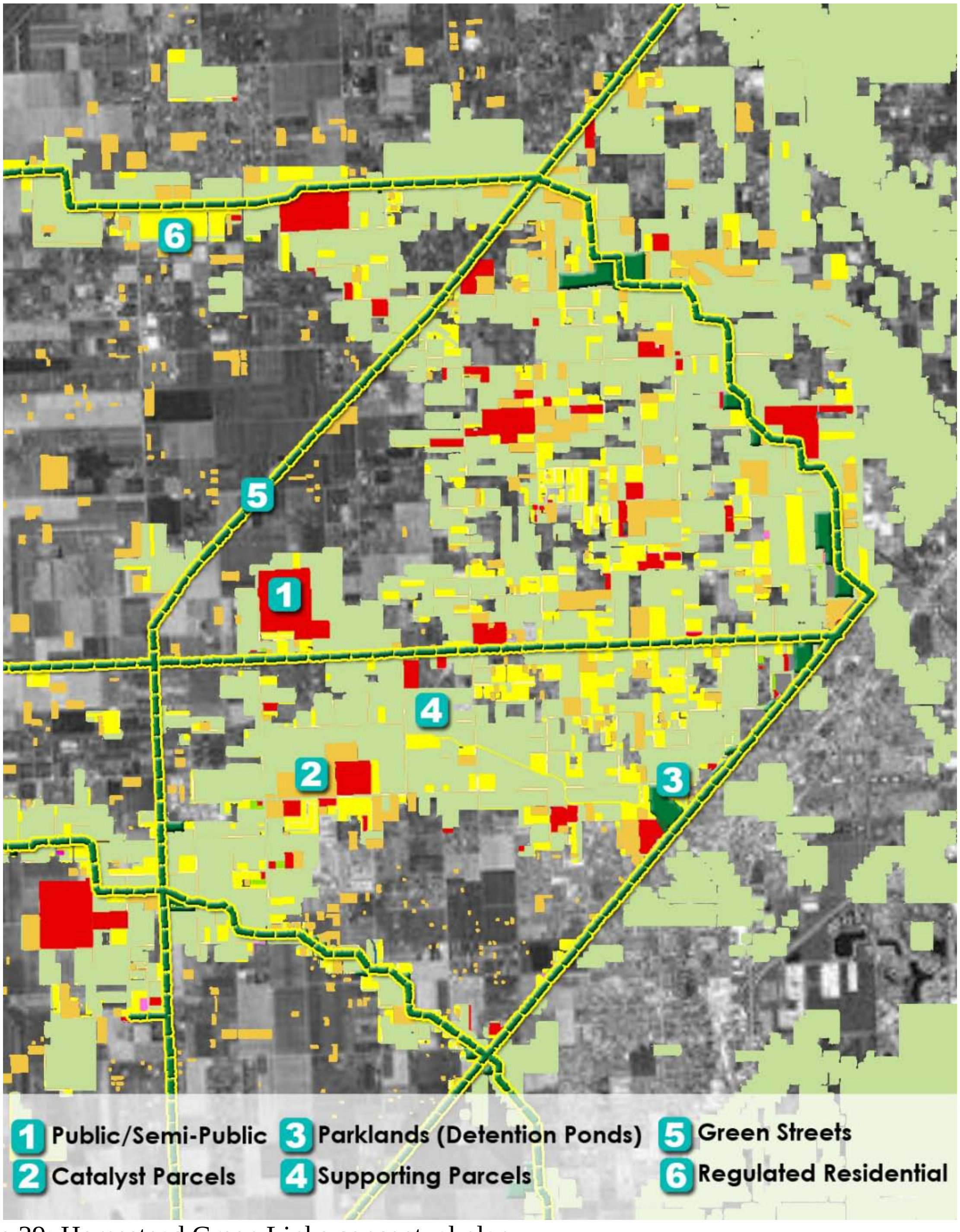


Figure 39: Homestead Green Links conceptual plan

A large amount of the recommended parcels cover many existing commercial and residential buildings, thus the green infrastructure strategy should emphasize promoting the application of environmental friendly plants in local community gardens (Figure 40), restoring native species within public spaces, and installing storm water management system in commercial areas. Local government and housing authority should take charge of the implementation. Parcels that are ranked as fair covered almost 75 percent of the rest of Homestead Link project area, which means the whole study region needs certain regulations that establish standards for the future development, urban design guidelines must be carried out to restrict land development intensity in these area: the development density of existing built environment should be kept the same as now; as for the agricultural land and single family residential area, the regulation should be the same as in the Wetland Corridor plan. Since the Green Streets (Figure 41) in this project are located in a more compact urbanized context, the design should make use of the space between the streets and the canals, perform public space beautification project which increases the overall aesthetic value of this area, the diverse vegetation hierarchy with designated gathering spots and trails could make this area become another main attraction to the visitors, as well as improving the quality of ecosystem services from surrounding natural environment.

Figure 40: Promote environmental friendly species and install storm water management system in community gardens

Figure 41: Green Street along the canals

In the Northern Gateway plan (Figure 42), highly recommended parcels could be designated as gateways indicating the entrance to the Everglades, there are two major gateways, one of them located at the entrance point of northern boundary, and the other one is located at a vital point: the cross road of the greenway and the famous Tamiami trail. In addition to these, there are three other gateways proposed by project partners. The design of these gateway locations should focus on upgrading the overall aesthetic feature by delicately arranging all levels of vegetation, which brings about a welcoming atmosphere indicating the entrance to the greenway (Figure 43). Furthermore, the successful creation of civic space cannot be done without the installation of public facilities such as signage system, visitor center, amenities, parking areas, etc. The installation of public facilities should vary from site to site depending on specific conditions. Currently undefined parcels especially those that are located along the canal could be developed into parklands, these parcels function as above ground detention pond that can keep more natural water flow within this area, and prevent the further expansion of invasive species into the wetlands. The green infrastructure strategies for recommended parcels are similar to the previous projects; the restoration efforts should focus on existing residential and public/semi-public parcels, by promoting the plantation of environmental friendly species, restoring native landscapes, and installing public facilities to enhance storm water management, etc. Since the study area is located much closer to the highly urbanized area, the role of the supporting parcels becomes more important comparing to the previous projects, these parcels were ranked as fair in the district level analysis, and should be treated as base context that helps promote conservation efforts and protect the focal parcels from further disturbance; the development density of the existing agricultural land and single family residential area should be the same as in the previous two projects.

The design of Green Streets in this project should pay more attention to the heavier vehicle traffic, in order to guarantee the safety of pedestrian transportation. Green Streets that are located along SW 177th Ave, SW 8th St, NW 25th St and North Okeechobee Rd should be delineated with more roadside space for pedestrian and cyclists' use, with desired colorful landscapes provide shading and create a pleasant walking experience for visitors. The planting design should also consider selecting species that are not attractive to wildlife, in order to avoid wildlife conflicts with surrounding busy traffic (Figure 44).

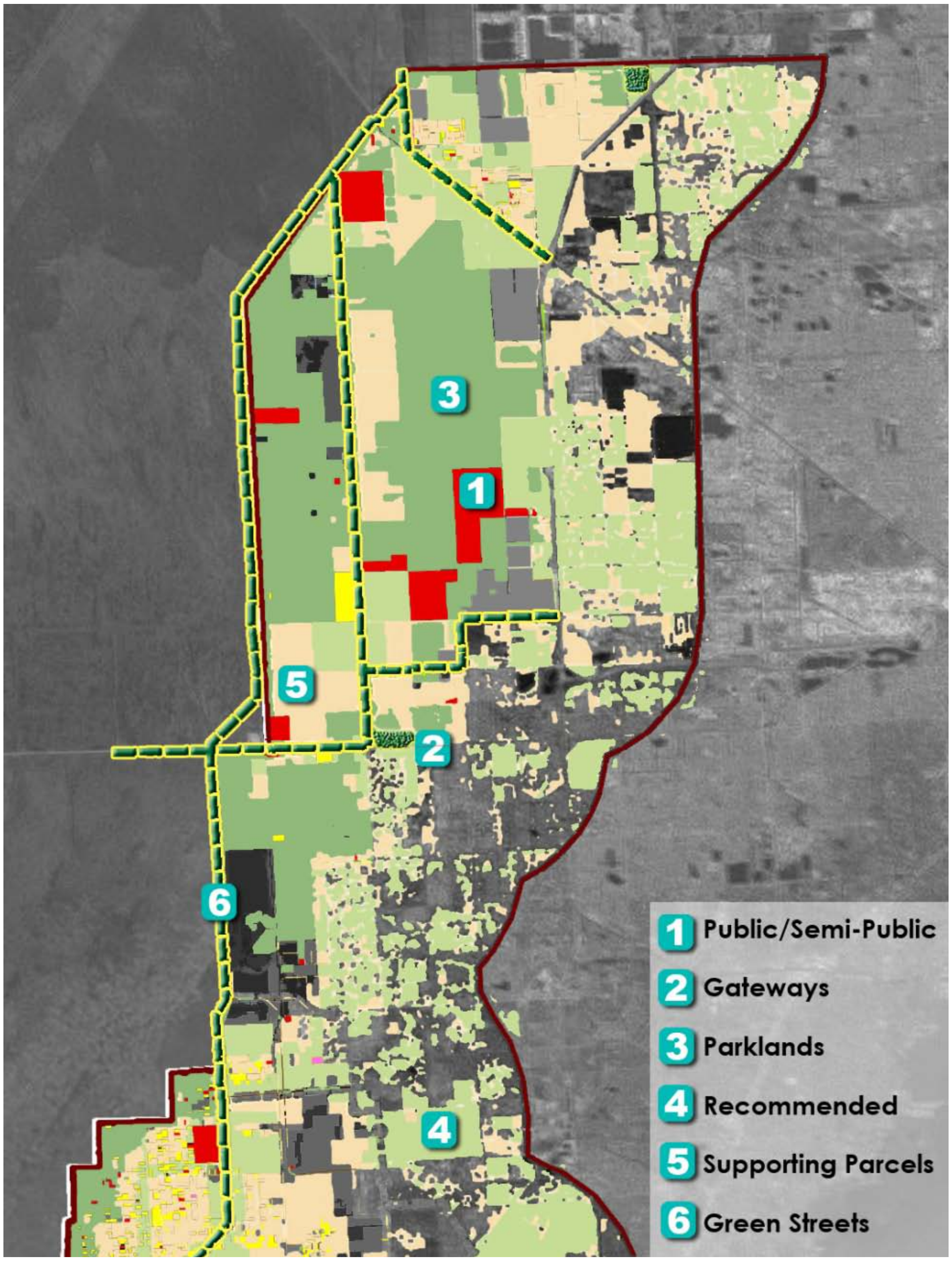


Figure 42: Northern Gateway conceptual plan

BEFORE

Figure 43: Greenway trails into the gateway location

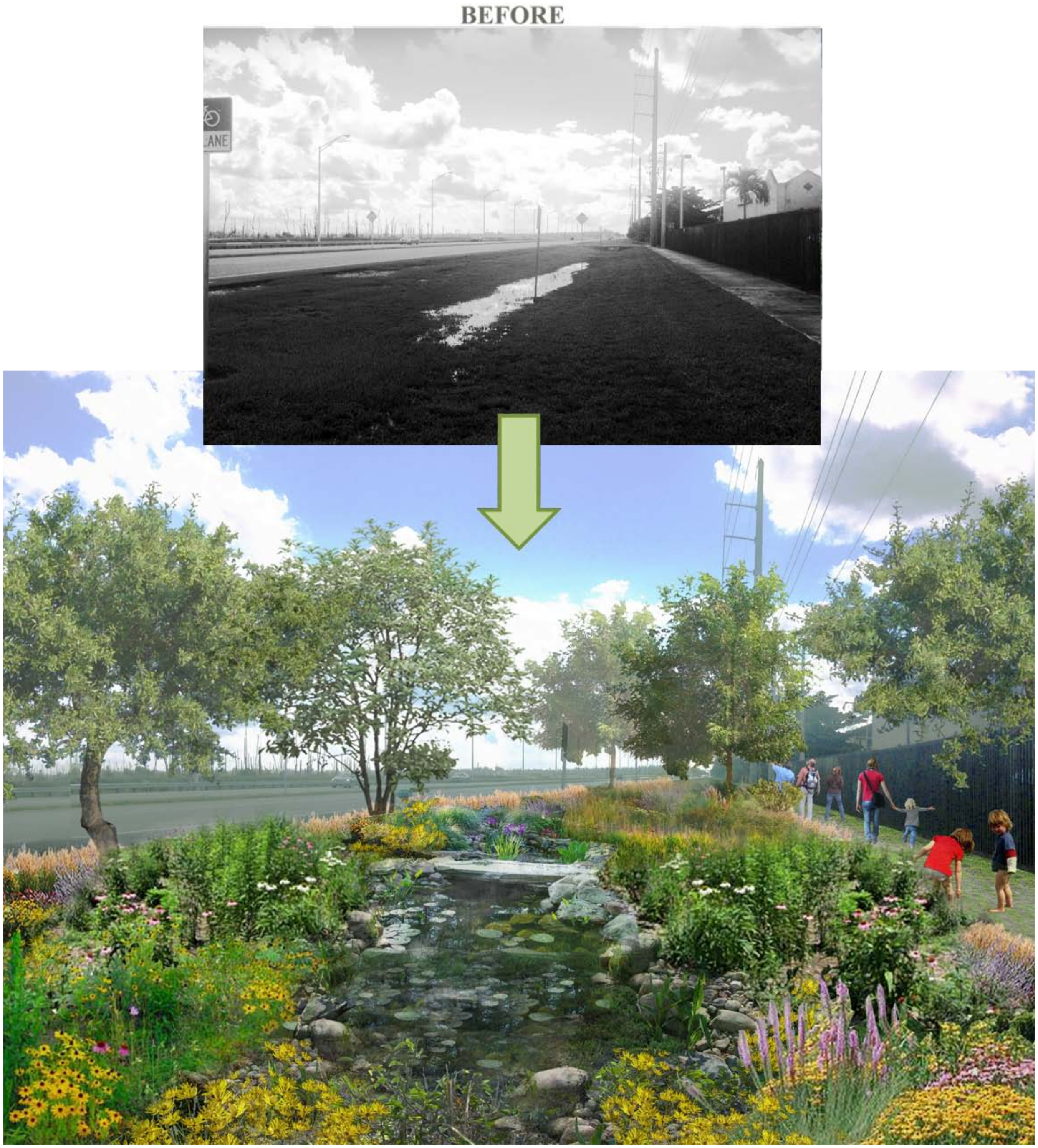


Figure 44: Green Street roadside space planting design

CHAPTER 5

A PATH FORWARD

Design Evaluation

This section tried to quantitatively assess the ecological improvements brought by the greenway, based on the assumption that the design proposal is fully implemented. The evaluation method and ecosystem services value were adopted from de Groot (2012) research findings (presented in chapter two). The design evaluation was performed based on an ideal scenario, to assess the trade-offs in order to optimize the benefits from the sustainable development. Although ecosystem services issues are too complex to answer by simply adopting values in monetary units, this method, to some extent, at least provide a way to quantitatively evaluate the performance, especially in representing the improvements of certain design proposals by comparing the before and after conditions. Since currently there is no fixed conclusion about the impact of exotic species towards the surrounding ecosystem services and how much the impact would be (Charles and Dukes 2007), this project assumed the ecosystem services value of the areas disturbed by the invasive plants to be zero. Through calculating area of native vegetation restored from invasive plants and certain manageable regions, the design was evaluated in different phases:

Phase I deals with highly recommended parcels, most of these parcels are currently located within the existing invasive plant regions. Ideally assuming all the invasive species affected regions are restored back to native vegetation, which means a saving of 835.24 hectares of inland wetlands to the existing ecosystem, that equals an average ecosystem service value of

21,450,712 dollars every year if using the total mean economic value as the calculation criteria. In practice, areas that are hard to be treated could be designated as public education spots. Parcels that are located within the urbanized area could be treated differently, aiming at properly mitigating the existing invasive plants and storm water management issues.

Phase II deals with the recommended parcels, the ideal scenario would be to remove all the invasive species out of the recommended parcels, which means 504.64 hectares of inland wetlands saved back to the existing ecosystem, that equals an average ecosystem service value of 12,960,212 dollars every year. As for the recommended parcels that encompass built environment, functionally they could be kept the same as they are, but should incorporate planning policies that help prevent the spread of invasive species; parcels that contain agricultural lands/plant nurseries should be restricted to environmental friendly species only.

Phase III deals with parcels that were categorized as fair, in the ideal scenario the restored inland wetlands from invasive species treatment would be 1150.44 hectares, that equals an average ecosystem service value of 29,545,708 dollars every year. Since these parcels function as a buffer zone that prevent the urbanized areas from further expansion, a series of urban design guidelines are needed to regulate the development intensity of this area, as described in the previous chapter.

Significance and Reflection

Using the Geospatial technology and LUCIS model as the platform, the NDVI and land cover classification maps derived from NASA satellite imagery provided important parameters for the analysis. However, some improvements are worth noting. First, the use of NDVI from a single time point may not be adequate to capture temporal variation of vegetative cover. Improvements can be made by including temporal NDVI features at least on a seasonal basis.

Second, although the suitability analysis process in this project was able to determine relative importance of certain variables based on the discussion with partners, it is still necessary to continue communicating with partners and adapt to the ever-changing needs of the stakeholders as well as the ecosystem.

The value of LUCIS model needs to be further explored in the future decision making process, since LUCIS was developed to go beyond traditional suitability models, and incorporates the user's values and preferences, in a very flexible framework that allows these users to tweak the weights of these preferences, and streamline the decision-making process, by comparing alternative land use scenarios. However, the sensitivity of the weighting factors was not fully tested in this project, but there is no doubt that modifying the weighting factors could have the potential to produce significant differences in model outcomes, which could be further explored in future practice.

This project analysis was an example of conservation scenario, in which conservation pixel value was the dominating factor that set the direction of the dilemma brought by the three land use categories. If the same set of LUCIS model matrix was interpreted using recreation (Figure 45) or agritourism (Figure 46) value as dominating factor, the scenario would be directed towards another pattern with specific planning objectives that fit into certain context (Table 9 and 10).

Table 9: LUCIS Model matrix interpreted from the aspect of recreation development

Land use types	**LUCIS Model matrix values**
Active recreation area	131, 132, 121
Passive recreation area with conservation and agritousim	221, 331, 332, 223, 321, 322, 323
Non-recreation area	111, 112, 113, 211, 212, 213, 311, 312
Multi-use recreation area with conservation or agritousim	123, 122, 133, 231, 232, 233, 222

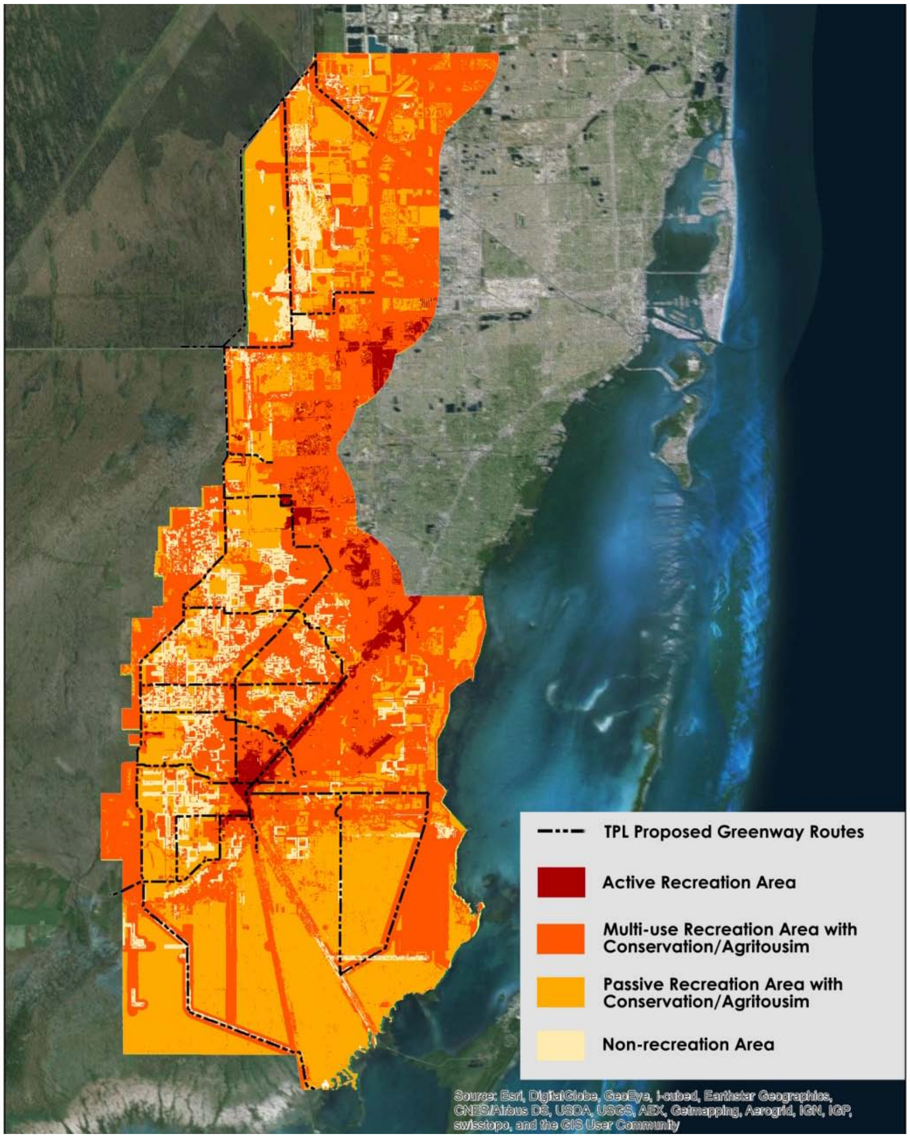


Figure 45: LUCIS Model matrix interpreted from the aspect of recreation development

Table 10: LUCIS Model matrix interpreted from the aspect of agritourism development

Land use types	**LUCIS Model matrix values**
Conservative agritourism area	213, 222, 223, 232, 312, 322, 323, 332, 212
Intensive agritourism area	113, 123, 133
Non-agritourism area	111, 121, 131, 211, 221, 231, 311, 321, 331
Moderate agritourism with recreation	122, 112, 132, 233

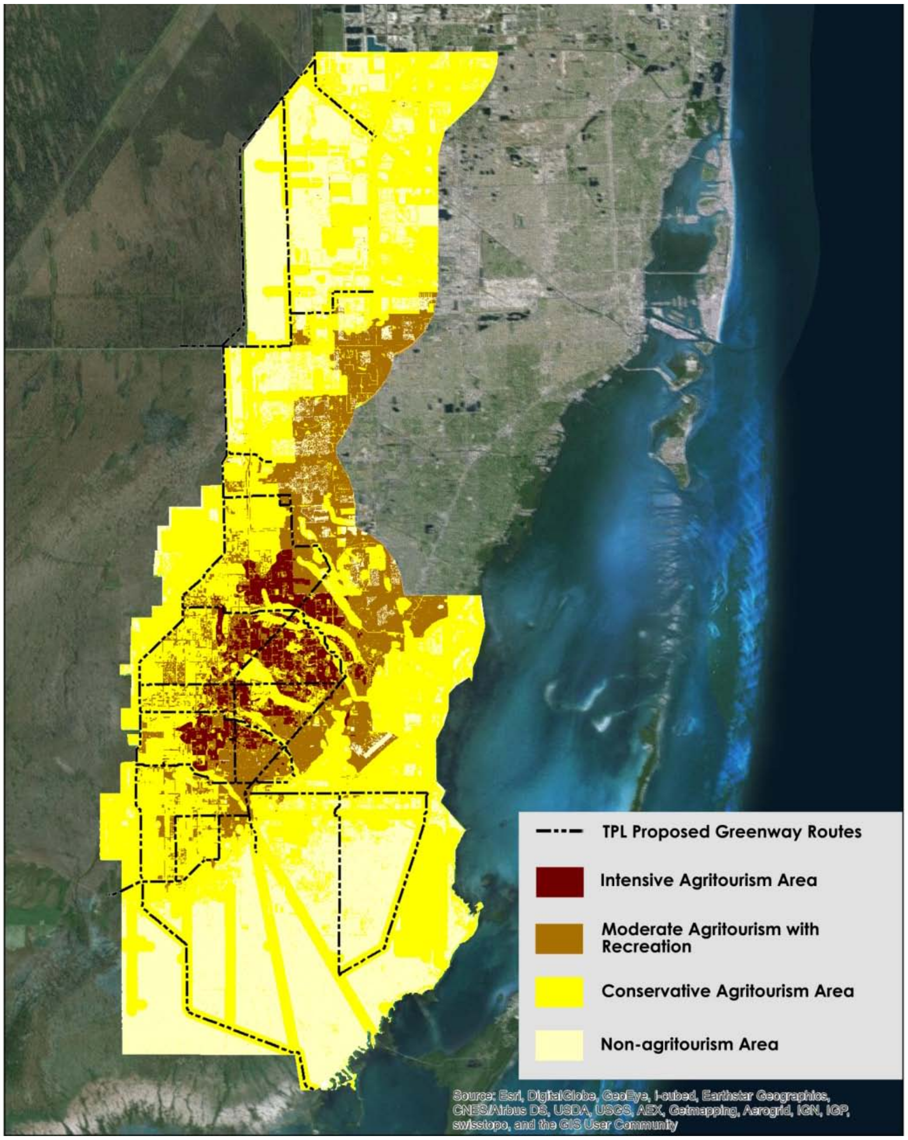


Figure 46: LUCIS Model matrix interpreted from the aspect of agritourism development

In the future, more recent remote sensing datasets such as Landsat 8 and updated Normalized Differenced Vegetation Index (NDVI) calculations are needed for monitoring the land cover changes. In addition to that, an improved version of LUCIS (LUCIS Plus) is to be published in August 2015, which can be applied in future projects. Eventually, results drawn from these tools could be synthesized into the Online Story Map, which helps bring awareness to the greenway and the importance of its surrounding ecosystem to the public. This outreach component is expected to provide visitors with valuable information about specific attractions along the trail, as well as raising avenue for potential supplemental funding for the greenway's construction. Education and engagement of the public is a vital part of the Western greenway project, where both users of the greenway and the surrounding ecosystem will reap its benefits.

Conclusion

This project fit into the timeline of the Western Greenway planning effort, and assisted the planning effort from its preparation phase to the design strategy finalization. The project was built upon a solid preliminary analysis conducted by the NASA Develop Miami-Dade Ecological Forecasting team, who was part of the Western Greenway project technical advisory team, and provided cutting edge analysis utilizing NASA Terra ASTER satellite imagery. The satellite data acquisition and interpretation completed by the NASA Develop team was considered of great use by the partners, in guiding the corridor routing priorities analysis and exploring more specific design and greenway alignment. The land cover information along with ancillary datasets were used in the LUCIS model to evaluate optimal areas for promoting the greenway's three goals of conservation, agritourism, and recreation. Later, this project proposed more specific neighborhood level design strategies. Environmental planning and Geodesign tools such as these served as effective methods for evaluating multiple factors incorporating users' inputs-- a process that could not otherwise be readily achieved. The end products played a vital role in guiding the policy making process, and were able to provide recommendations for future conservation, agritourism, and recreation developments in the study region.

The Land-Use Conflict Identification Strategy (LUCIS) model developed by Carr and Zwick from the University of Florida was applied in this project. The model framework was designed so that future users could explore alternative scenarios, varying the model's weights for specific objectives from future stakeholders' input. Applicability of the specific type of suitability analysis to other scenarios was considered to be a valuable tool for future researchers.

The importance of environmental planning and design was highlighted in this project particularly through the goal of promoting conservation in the study area. To further enhance the applicability of results for this project, observations made in the field were taken into consideration alongside on-paper analyses. The combination of all end products have aided project partners in making decisions regarding the Western Greenway's alignment, design, signage, and conceptualization.

Once fully implemented, the Western Greenway could serve local residents and visitors by providing recreational access to the western edge of the County. However, the increased public accessibility may also attract more development projects that contradict the conservation efforts, thus further regulations and laws should be carried out to strike a balance between those two, and to keep this transition zone acting like a catalyst that connects neighborhoods to the wider range of green infrastructure network.

REFERENCE

Benedict, Mark A., and Edward McMahon. 2006. *Green infrastructure : linking landscapes and communities / Mark A. Benedict, Edward T. McMahon*: Washington, DC : Island Press, c2006.

Brueckner, J. K. 2004. "'Urban Sprawl: Diagnosis and Remedies', International Regional Science Review, 23 (2), April, 160-71." *INTERNATIONAL LIBRARY OF CRITICAL WRITINGS IN ECONOMICS* no. 182:161-174.

Bryant, M. Margaret. 2006a. "Urban landscape conservation and the role of ecological greenways at local and metropolitan scales." *Landscape and Urban Planning*:23-44.

Bryant, M. Margaret. 2006b. "Urban landscape conservation and the role of ecological greenways at local and metropolitan scales." *Landscape & Urban Planning* no. 76 (1-4):23-44. doi: 10.1016/j.landurbplan.2004.09.029.

Carr, Margaret H., and Paul Dean Zwick. 2007. *Smart land-use analysis : the LUCIS model land-use conflict identification strategy*: Redlands, Calif. : ESRI Press, 2007. 1st ed.

Center for Invasive Species and Ecosystem Health. 2015. *Everglades Cooperative Invasive Species Management Area* 2015 [cited 9 February 2015]. Available from http://www.evergladescisma.org/.

Charles, Heather, and Jeffrey S. Dukes. 2007. "Impacts of Invasive Species on Ecosystem Services." In *Biological Invasions*, edited by Wolfgang Nentwig, 217-237. Ecological Studies, no. 193. Berlin and New York: Springer.

Davis, Steven M. , John C. Ogden, and Winifred A. Park. 1994. *Everglades : the ecosystem and its restoration*. Edited by Steven M. Davis, John C. Ogden and Winifred A. Park. St. Lucie Press: Delray Beach, FL.

de Groot, Rudolf, Luke Brander, Sander van der Ploeg, Robert Costanza, Florence Bernard, Leon Braat, Mike Christie, Neville Crossman, Andrea Ghermandi, Lars Hein, Salman Hussain, Pushpam Kumar, Alistair McVittie, Rosimeiry Portela, Luis C. Rodriguez, Patrick ten Brink, and Pieter van Beukering. 2012. "Global estimates of the value of ecosystems and their services in monetary units." *Ecosystem Services* no. 1:50-61. doi: 10.1016/j.ecoser.2012.07.005.

Doren, R. K., K. Rutchey, and R. Welch. 1999. "The Everglades: a perspective on the requirements and applications for vegetation map and database products." *PE&RS, Photogrammetric Engineering & Remote Sensing* no. 65 (2):155-161.

ESRI, Story Maps. 2015. *What is a Story Map?* 2015 [cited 25 March 2015]. Available from http://storymaps.arcgis.com/en/articles/what-is-a-story-map/.

Florida Fish and Wildlife Conservation Commission. 2015. *Florida Land Cover Classification System Final Report* 2014 [cited 24 March 2015]. Available from http://myfwc.com/media/2815396/LandCoverClassification-2014.pdf.

Graf, William L. 2013. "Water Resources Science, Policy, and Politics for the Florida Everglades." *Annals of the Association of American Geographers* no. 103 (2):353-362. doi: 10.1080/00045608.2013.754684.

Grunwald, Michael. 2007. *The swamp : the Everglades, Florida, and the politics of paradise*: New York : Simon & Schuster Paperbacks, 2007, c2006. 1st. Simon & Schuster pbk. ed.

Ignatieva, Maria, Glenn Stewart, and Colin Meurk. 2011. "Planning and design of ecological networks in urban areas." *Landscape & Ecological Engineering* no. 7 (1):17-25. doi: 10.1007/s11355-010-0143-y.

Labaree, Jonathan M. 1992. *How greenways work [microform] : a handbook on ecology / Jonathan M. Labaree*: [Ipswich, MA] : Rivers, Trails, and Conservation Assistance Program, National Park Service ; Quebec-Labrador Foundation's Atlantic Center for the Environment, [1992] 2nd ed.

Leon County, Office of Greenways and Trails. 2015. *J.R. Alford Greenway* 2013 [cited 19 April 2015]. Available from http://cms.leoncountyfl.gov/Portals/0/publicworks/parksandrecreation/docs/JR_Alford_Greenway.pdf.

Lodge, Thomas E. 2010. *The Everglades handbook : understanding the ecosystem*: Boca Raton, FL : CRC Press, c2010. 3rd ed.

Lusk, Anne. 2002. Guidelines for Greenways: Determining the Distance To, Features Of & Human Needs Met by Destinations on Multi-use Corridors.

Maria Ignatieva, Glenn H. Stewart, Colin Meurk. 2010. "Planning and design of ecological networks in urban areas." *Special Feature: Review*.

Maryland Department of Natural Resources. 2015. *Maryland's Green Infrastructure* 2006 [cited 19 April 2015]. Available from http://www.dnr.state.md.us/greenways/gi/gi.html.

McCormick, Bobby, Robert Clement, Daniel Fischer, Matt Lindsay, and Reed Watson. 2012. "Measuring the Economic Benefits of America's Everglades Restoration-An Economic Evaluation of Ecosystem Services Affiliated with the World's Largest Ecosystem Restoration Project."

Mell, Ian C. 2010. "Green infrastructure: concepts, perceptions and its use in spatial planning."

Miami-Dade County. 2015. *Environmentally Endangered Lands Program* 2015 [cited 25 March 2015]. Available from http://www.miamidade.gov/environment/endangered-lands.asp.

Miami-Dade County Parks Recreation and Open Spaces, The Trust for Public Land. 2015. *Miami-Dade County Western Greenway Recommendations Report* 2014 [cited 22 April 2015]. Available from http://206.169.56.66/StoryMaps/WesternGreenway/Report/FULL_REPORT_Miami-Dade_Western_Greenway_Recommendations_Report_121714.pdf.

Milanich, Jerald T. 1998. *Florida's Indians From Ancient Times to the Present, Native Peoples, Cultures, and Places of the Southeastern United States*. Gainesville: University Press of Florida.

NASA Earth Observatory. 2015. *Measuring Vegetation (NDVI & EVI)* 2000 [cited 24 April 2015]. Available from http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php.

National Park Service. 2015. *Florida National Park Everglades* 2015 [cited 1 February 2015]. Available from http://www.nps.gov/ever/naturescience/index.htm.

O'Neil-Dunne, Jarlath. 2014. A Review of eCognition.

Paolo La Greca, Daniele La Rosa, Francesco Martinico*, Riccardo Privitera. 2010. "Agricultural and green infrastructures: The role of non-urbanised areas for eco-sustainable planning in a metropolitan region." *Environmental Pollution*:2193-2202.

Pittman, Craig. 2006. "Bogged down in the Everglades: politics ensnares Florida's big restoration project." *Planning* no. 72 (8):12-17.

Richmond Green Infrastructure Center. 2014. *Richmond Green Infrastructure Assessment Report* 2010 [cited 27 Octobor 2014]. Available from http://www.gicinc.org/PDFs/RichmondGIA_Report_FINAL.pdf.

Rischpater, Ray, and Carmen Au. 2013. *Microsoft mapping : geospatial development with Bing Maps and C#*: [Berkeley, California] : Apress, 2013.

Robertson, William B., Jr., and James A. Kushlan. 1974. "The southern Florida avifauna." *Memoir - Miami Geological Society* (2):414-452.

Sanderson, Peter, Jordan Sebastian, and Ariel Shaw. 2012. Visioning the Allen Creek Greenway: Designing a Path, Creating a Place. 2012-04-20T17:53:33Z.

Schröter, Dagmar, Wolfgang Cramer, Rik Leemans, I. Colin Prentice, Miguel B. Araújo, Nigel W. Arnell, Alberte Bondeau, Harald Bugmann, Timothy R. Carter, Carlos A. Gracia, Anne C. de la Vega-Leinert, Markus Erhard, Frank Ewert, Margaret Glendining, Joanna I. House, Susanna Kankaanpää, J. T. Klein Richard, Sandra Lavorel, Marcus Lindner, Marc J. Metzger, Jeannette Meyer, Timothy D. Mitchell, Isabelle Reginster, Mark Rounsevell, Santi Sabaté, Stephen Sitch, Ben Smith, Jo Smith, Pete Smith, Martin T. Sykes, Kirsten Thonicke, Wilfried Thuiller, Gill Tuck, Sönke Zaehle, and Bärbel Zierl. 2005. Ecosystem Service Supply and Vulnerability to Global Change in Europe. 1333.

Southwest Florida Regional Planning Council. 2015. *2010 Future Land Use, South section* 2010 [cited 26 March 2015]. Available from http://www.swfrpc.org/maps.html.

Steinitz, Carl. 2012. *A framework for geodesign : changing geography by design*: Redlands, Calf. : Esri, 2012. 1st ed.

Swihart, R. K., and R. H. Yahner. 1982. "Browse use by eastern cottontails in a S.E. Minnesota farmstead shelterbelt." *Journal of the Minnesota Academy of Science* (2):13-15.

The Trust for Public Land. 2015. *Miami-Dade County Western Greenways Initiative* 2014 [cited 25 March 2015]. Available from http://206.169.56.66/StoryMaps/WesternGreenway/index.html.

Tzoulas, Konstantinos, Kalevi Korpela, Stephen Venn, Vesa Yli-Pelkonen, Aleksandra Kaźmierczak, Jari Niemela, and Philip James. 2007. "Review: Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review." *Landscape and Urban Planning* no. 81:167-178. doi: 10.1016/j.landurbplan.2007.02.001.

University of Florida IFAS, Center for Aquatic and Invasive Plants. 2015. *Brazilian pepper-tree* 2014 [cited 22 April 2015]. Available from http://plants.ifas.ufl.edu/node/405.

University of Florida, TAME Lygodium. 2015. *Lygodium Photo Gallery* 2007 [cited 22 April 2015]. Available from http://pesticide.ifas.ufl.edu/Lygodium/images/photo_gallery/blue-cypress.jpg.

US Army Corps of Engineers. 2015. *C-111 Spreader Canal Western Project* 2009 [cited 8 February 2015]. Available from http://www.usace.army.mil/Portals/2/docs/civilworks/CWRB/c_111/c_111_Briefing_slides.pdf.

USDA Invasive Plant Research Laboratory. 2015. *Melaleuca: TAME Melaleuca Project* 2006 [cited 22 April 2015]. Available from http://www.ars.usda.gov/Research/docs.htm?docid=3764.

Way, J. M. 1977. Roadside verges and conservation in Britain: a review.

Weber, Ted, Anne Sloan, and John Wolf. 2006. "Maryland's Green Infrastructure Assessment: Development of a comprehensive approach to land conservation." *Landscape and Urban Planning* no. 77:94-110. doi: 10.1016/j.landurbplan.2005.02.002.

Weber, Theodore C., and William L. Allen. 2010. "Beyond on-site mitigation: An integrated, multi-scale approach to environmental mitigation and stewardship for transportation projects." *Landscape and Urban Planning* no. 96:240-256. doi: 10.1016/j.landurbplan.2010.04.003.

Youngquist, Timothy Dennis. 2009. What is green infrastructure? An evaluation of green infrastructure plans from across the United States. Digital Repository @ Iowa State University, 2009-01-01.

APPENDIX A

LUCIS MODEL SUITABILITY MATRIX AND CRITERIA

For conservation goals: Identifying opportunities of lands important to water quality protection and habitat/climate resilience

Objective	Criteria/ Type of analysis	Influencing factors	High Priority	Medium Priority	Low Priority	References	Data Sources
		water features	Water body	50 ft buffer	All the other areas	LEED site selection credit 1	Water manegement Project: 2012 CERP Boundaries, Miami-Dade GIS portal: 2010 Waterbodies 2010 Streams 2012 Canals 2009 Lakes
Maximize protection of natural areas	Classification Map. Weights are given to each category based on land cover type.	Land cover type	Dense Vegetation, Wetland, Water and Sand	Agriculture and Shrubs	Pasture, Barren and Impervious Surface	http://earthobservatory.nasa.gov/Features/MeasuringVegetation/	Landsat 5 NASA satellite imagery
		Native Biodiversity	Strategic Habitat Conservation Areas criteria	Strategic Habitat Conservation Areas criteria	Strategic Habitat Conservation Areas criteria	Pine Rockland, Rockland Hammock, Scrubby Flatwoods, Coastal Uplands, Wetlands , Historic Transverse Glades, Ecotones.	Cooperative Land Cover (2012) 2013 Strategic Habitat Conservation Areas (ver 4) Florida Natural Areas Inventory (FNAI)
		Natural Floodplains	A, AE, AH, AO,AR, A99, V, VE	B, X (shaded) C, X (unshaded)	D	FEMA requirements: https://msc.fema.gov/webapp/wcs/stores/servlet/info?storeId=10001&catalogId=10001&langId=-1&content=floodZones&title=FEMA%2520Flood%2520Zone%2520Designations	2013 Natural Floodplains (ver 4) FNAI GIS Portal

Maximize protection of existing wetland areas	Buffer	Functional Wetlands	Functional wetlands criteria	Functional wetlands criteria	Functional wetlands criteria	Wetlands and Upland Buffer Requirements - 4.01.06 http://www.sjcfl.us/Environmental/Wetlands.aspx LEED site selection credit 1	2013 Functional Wetlands (ver 4) FNAI GIS Portal
Maximize connectivity to EEL lands	Buffer or distance function to these lands	Environmentally Endangered Lands (EEL)	EEL Lands		All the other areas	Western Greenway Technical Advisory Team	2013 Miami-Dade EEL Lands Miami-Dade Regulatory and Economic Resources (RER) Department
		Rare Species Habitat	Rare Species Habitat Conservation lands criteria	Rare Species Habitat Conservation lands criteria	Rare Species Habitat Conservation lands criteria	Western Greenway Technical Advisory Team	2013 Rare Species Habitat Conservation Priorities (ver 4) FNAI GIS Portal
Avoid Invasive Plants	Invasive Plants		All other Area		Invasive Species Area	Western Greenway Technical Advisory Team	South Florida Water Manage (SFWMM)
		Critical Restoration Projects	Critical Restoration Projects properties		All the other areas	Western Greenway Technical Advisory Team	2011 Critical Restoration Projects SFWMD GIS Portal

For recreation goals: Providing new opportunities for recreation access

Objective	Criteria/ Type of analysis	Influencing factors	High Priority	Medium Priority	Low Priority	References	Data Sources
Maximize use of water bodies for recreational fishing		fishing	Water body	50 ft buffer	All the other areas	Western Greenway Technical Advisory, Team LEED site selection credit 1	
Identify Land Cover Type	Classification Map. Weights are given to each category based on land cover type.	Land cover type	Dense Vegetation, Pasture, shrubs, barren, water and impervious surface	Agriculture, wetland and sand.		http://earthobservatory.nasa.gov/Features/MeasuringVegetation/	NASA Terra's ASTER satellite Image acquired on Mar. 2011
Avoid Invasive Plants	Invasive Plants		All other Area		Invasive Species Area	Western Greenway Technical Advisory Team	South Florida Water Manage (SFWMM)

Identify areas in proximity to project gateways and destination	Distance/proximity	Proposed gateways	1. Broward – Dade County Line 2. US Highway 27, 3. NW 25th Street, 4. 8th Street, 5. 88th Street 6. 184th Street 7. 248th Street or Silver Palm 8. Biscayne – Everglades Greenway 9. Black Point Park & Marina 10. River of Grass Greenway (5 min walking distance)	10 min walking distance	All the other areas	Western Greenway Technical Advisory Team	2014 Proposed Gateways to Western Greenway Miami-Dade GIS Portal
Maximize connectivity to existing parks and other recreational sites	Buffer or proximity to existing parks, for connectivity of expansion Absence/ presence of marks (higher priority where there is already a park or rec area)	Existing parks	The existing parks	5 min walking distance	All the other areas	http://islamorada.fl.us/comprehensive_plan/vp/Chapter%207%20DIA%20.htm 5 min walking distance 400 meters	LUMA map Miami-Dade GIS Portal
Maximize connectivity to existing trails.	Buffer to existing trails	Existing Trails	5 min walking distance		All the other areas	LEED site selection credit 5.1	Miami-Dade GIS Portal
Maximize accessibility to certain services but at the same time keep noise and less quiet	Extract Recreation/ cultural related features	Proximity to Schools, Libraries, supermarkets, theaters, community centers, restaurants, museums, place of worship, hospitals, etc	Within 0.5 mile of at least 10 basic services Buffer 0-0.25 mile	0.25-0.75 mile	All the other areas	LEED site selection credit 2	2013 Public Schools 2013 Private Schools 2012 Colleges and Universities 2013 Adult Living Facilities 2013 County Public Libraries 2012 Municipal Public Libraries Libraries,, Miami-Dade GIS Portal
Maximize accessibility	Define a max from public transit stations	Public Transit, Major roads, Railroads, Airports	Railroad stations, metro rail stations: 0.5 mile radius Bus stops: 0.25 mile radius	Highway/ Major roads: buffer 0.5 mile		LEED site selection credit 4.1 LEED site selection credit 5.1	2006 Major Streets, Highways, railroads 2013 Bus Stops 2013 MetroRail Stations 2013 MetroMover Stations Miami-Dade GIS Portal
keep noise and less quiet	Define a min from local road	Local Roads.			Local roads 0.1 mile		
Accessibility to coastal area		Marina (waterfront/ coastal line recreation)	5 min walking distance	10 min walking distance	All the other areas		Miami-Dade GIS Portal
Maximize accessibility but at the same time keep noise and less quiet		Proximity to residential areas	Existing Residential zone(high/medium density)	0.5 mile buffer	All the other areas	LEED site selection credit 2	Residential areas extracted from 2013 Existing Landuse (LUMA) Miami-Dade GIS Portal

	Proximity to Existing Recreation Destinations.	Proximity to recreation area	Within 0.5 mile distance	0.5 – 1 mile	All others	Western Greenway Technical Advisory Team	Miami-Dade GIS Portal
	Proximity to birding and wildlife viewing	Proximity to bird viewing area	Within 0.5 mile distance	0.5 – 1 mile	All others	Western Greenway Technical Advisory Team	Miami Western Greenway Locations Matrix
	Proximity to Historical and Cultural Areas.	Proximity to Historic and cultural area	Within 0.5 mile distance	0.5 – 1 mile	All others	Western Greenway Technical Advisory Team	Miami-Dade GIS Portal Florida Division of Natural Resources

For production goals: Promoting agri-tourism in the region

Objective	Criteria/ Type of analysis	Influencing factors	High Priority	Medium Priority	Low Priority	References	Data Sources
		Land cover type	Agriculture	Dense Vegetation, Pasture, Barren	Wetland, Shrubs, Water, Impervious Surface and Sand	http://earthobservatory.nasa.gov/Features/MeasuringVegetation/	Land sat 5 NASA satellite imagery
		Soils floodplain	Suitable soils for drainage	Medium drainage degree	Low drainage degree		
Avoid mining		Mining	All the other areas		Existing Mining sites		2013 Rock Mining Sites: LUMA Landuse Miami-Dade GIS Portal
		Canal	Existing canals + 5 min walking distance		All the other areas	LEED site selection credit 1	Miami-Dade GIS Portal
		Agriculture	Existing agriculture areas		All the other areas		
		Major roads	5 min walking distance		All the other areas		

APPENDIX B

LUCIS MODEL WORKFLOW CHART