Cities in the Everglades: The Implications of Compact Urban Development For Regional Water Storage in Palm Beach County

by
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Abstract

Alternative forms of urban development such as high-density or in-fill development are often promoted for their significant environmental benefits. South Florida presents an excellent testing ground for this assumption, as the region grapples with issues of rapid urbanization and degradation of the Everglades, a unique ecosystem containing the largest freshwater wetlands in the United States. Resolving the competition for water between growing urban populations, the agriculture sector, and the plants and animals of the Everglades is one of the fundamental challenges of Everglades restoration. Hydrologists claim that sufficient water is available for all three if the water is managed properly and sufficient water storage can be found. In recent years, South Florida has adopted compact development as a means of managing its urban growth and curbing the historical patterns of low-density urban sprawl, so that future urban growth is compatible with ecosystem restoration. However the hydrologic benefits of compact development have yet to be quantified and proven.

By using Palm Beach County as an example, this study evaluates the impact of compact development on aquifer recharge, which is an important means of storing water for the region. This analysis models the spatial distribution of future urban development under sprawl and compact development scenarios and evaluates potential aquifer recharge under the two development patterns. The results of this analysis indicate that while compact development confers some benefits to water storage, these benefits will pale in light of the growing water needs of the region's burgeoning population. Therefore, while the county should adopt compact development for its benefits, however small, policy makers should not count on this policy alone to ameliorate the negative environmental impacts of future population growth in the region.

Cities in the Everglades

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by Ambika Anand Prokop

Dedication

To Mom & Baba,

You gave me the gift of education and
instilled in me the commitment
to do my small part
to help make the world a better place.
This work is the fruit of your gifts to me.

I dedicate this to you.

Acknowledgements

To Kath Phelan, who so generously gave her time, energy, feedback, and moral support; this undertaking would have been immeasurably more difficult without her. To Professor Ana Barros, who patiently worked with me for hours at the end of her very long days, when I most needed help. To Professor Anne Spirn and Professor Dennis Frenchman, for their support and guidance. To Beth Miller, who provided invaluable feedback and resources. To Tom Grayson, for helping me wade through the mire of GIS. To all the friends—Basak Demires, Cagatay Ozkul, Fang Ke, Zhang Yan, Madhu Raghunath, Sanjay Grover, Asha Ghosh, Narasimha Rao, Pablo Rivera, and Kishore Varanasi, —who rallied with me at the end to bring this into being; their many contributions helped me more than they can know. And to Paul, for being my side every step of the way.

Thank you all.

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Chapter 1: Introduction

Urbanization and the Everglades

South Florida's Challenge

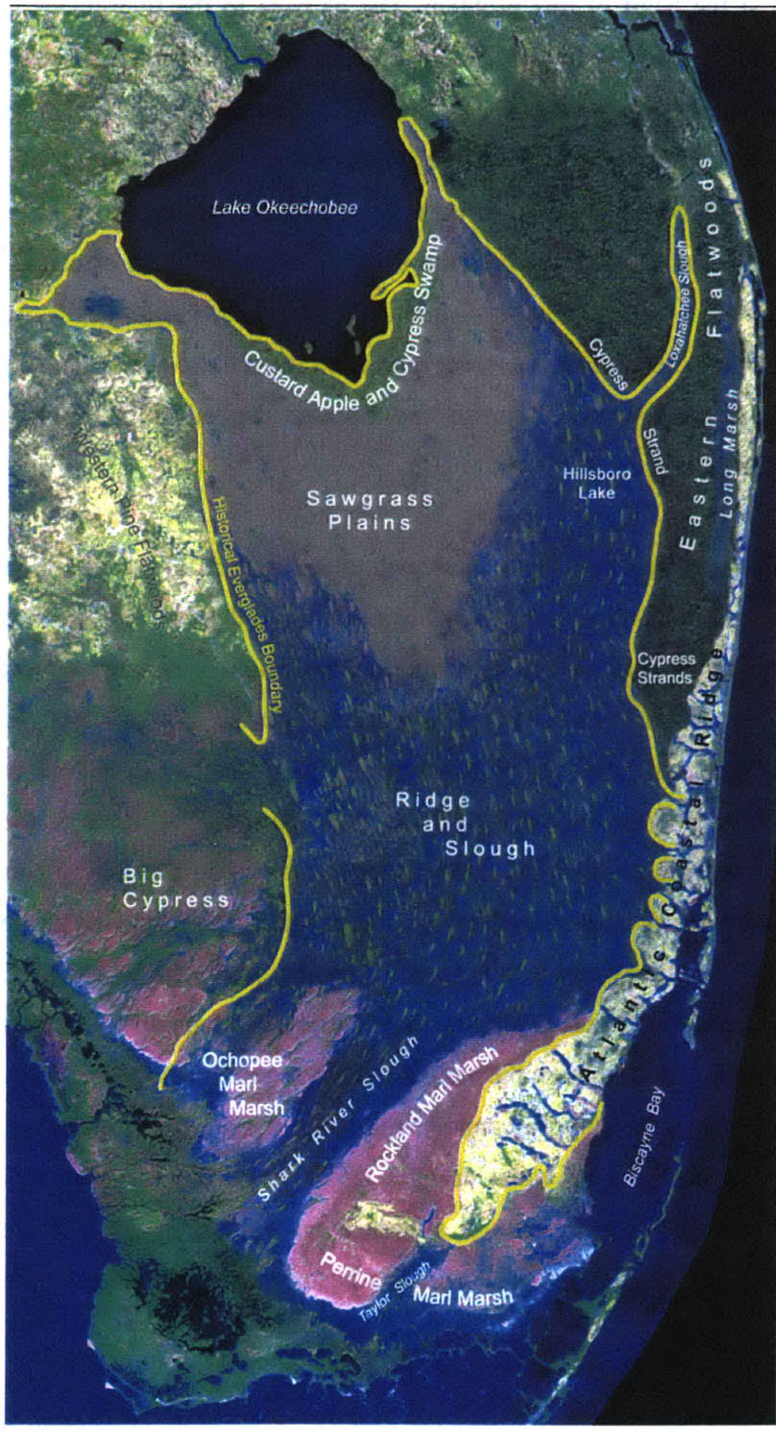
In recent years, new planning initiatives variously known as "smart growth", "sustainable development", and "green development" have increasingly been adopted as a means of addressing the environmental degradation that has resulted from rapid urbanization in the country. As part of such efforts, alternative forms of urban development such as compact development have been promoted under the assumption that they confer significant environmental benefits. The case of South Florida presents an excellent testing ground for these assumptions, which have yet to be quantified and proven. Few examples illustrate the complexities of human impact on the natural landscape as well as the development of South Florida over the last century. Carved out of the Everglades, a unique ecosystem containing the largest freshwater wetlands in the United States, the region now faces the daunting challenge of balancing ecosystem rehabilitation, rapid urban growth, and protection of the agricultural sector.

The Competition for Water

Before development, the Everglades contained vast expanses of sawgrass prairie, cypress stands, and mangrove swamps. The health of the ecosystem depended on a finely tuned hydrologic regime, since the plants and animals of the Everglades were uniquely adapted to the timing and duration of wet and dry periods in the region. In the last century, however, humans have disrupted this regime and badly damaged the wetlands that once occupied 3 million acres south of Lake Okeechobee. Large-scale drainage and flood control projects, initially for agricultural and later for urban development, dramatically altered the hydrologic regime and devastated the ecology of the region. (*see Figures 1.1 and 1.2*).

A shortage of water lies at the heart of this problem. The damage to the Everglades is largely the result of human manipulation of a finely tuned hydrologic regime. Before human settlement, heavy rains flooded the region during the rainy season, and vast amounts of water flowed south to give life to the Everglades. In the late 19th century, the first large influx of settlers brought large-scale economic development to the region. During the 20th century, humans drained much of the land and built a system of canals, levees, and flood control structures to support agriculture and urban settlement. As extensive canal systems diverted the water that once inundated the area to the ocean, the Everglades were cut off from their water source and became dependent on human-controlled releases of water to their wetlands.

The issue of water management has dominated the development agenda of the region in the last century: how to drain the water and protect agriculture and urban populations from flooding during the rainy season, and how to secure enough water to support agriculture, urban populations and needs of the Everglades during the dry season. Attempts to resolve these two interests put human needs first, and have resulted in inappropriate releases of water (both too much and too little) to the Everglades at the wrong times. During the wet season, the Everglades often receive too much water as floodwaters are diverted to the park to protect crops and cities. During the dry season, the Everglades compete with agriculture and urban populations for scarce water supplies. During years with normal rainfall levels, regional water supply is adequate to support agriculture and public water demand, though the natural system requirements are not met. But during drought years, the water supply cannot even support human requirements. Currently, the region is experiencing its worst drought in 50 years, taxing an already stretched water supply, and stressing the natural system even further. In such severe droughts, the need to reconcile human and natural needs becomes even more painfully apparent.

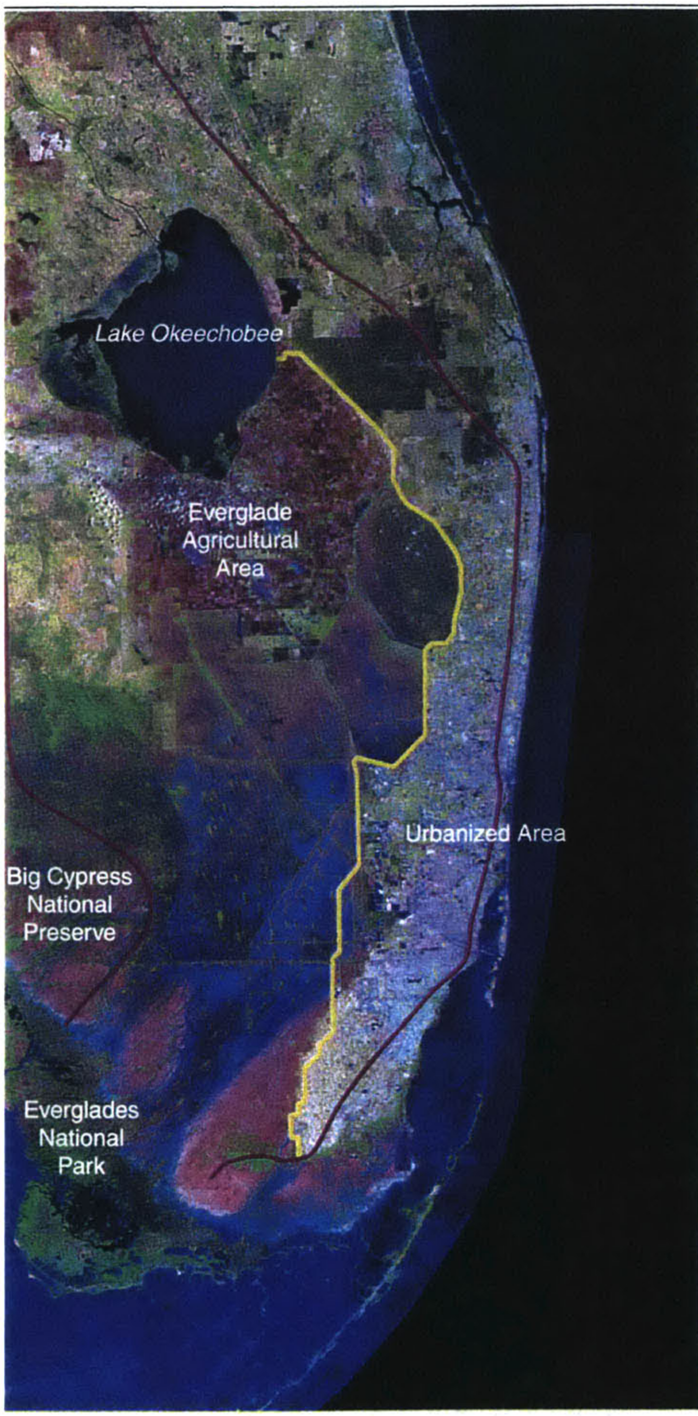


Note:

This graphic is conceptual and should not be used for analytical purposes. 1994 Landsat TM images were altered to reconstruct historic landscapes based on information prepared by South Florida Water Management District

Figure 1.1: Estimated South Florida Landscape Prior to Drainage (ca. 1850)

Source: South Florida Water Management District



LEGEND

- Approximate boundary of the original everglades drainage basin
- The east coast protective level

Figure 1.2: Present Day South Florida Landscape (1995)

Source: South Florida Water Management District

The Growth of Cities

The competition for water in South Florida will only grow more acute. While agricultural production in the region has steadily declined, urban development is expected to increase significantly in the coming decades (*see Figure 1.3*). From 1940-1990, the population of South Florida grew more than tenfold from 500,000 to 5.1 million, and is expected to increase another 60%, or 3 million by 2020 (Turner & Murray 2001, and Burchell 1999). The rapid growth has already strained the infrastructure, resulting in water and housing shortages, increased congestion and school overcrowding (Turner & Murray 2001). Accommodating this population increase will not only tax the current infrastructure system further, but it will also require the consumption of additional land and water, which will adversely impact the already precarious health of the Everglades. Indeed, westward urban expansion is already pushing up against conservation areas and the Everglades National Park (*see Figures 1.4 and 1.5*).

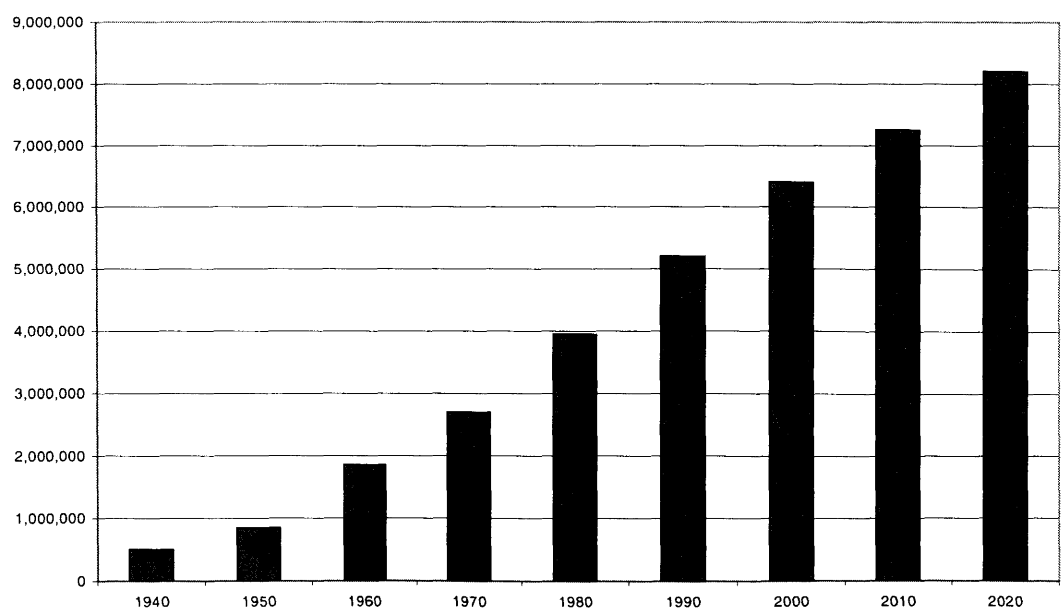
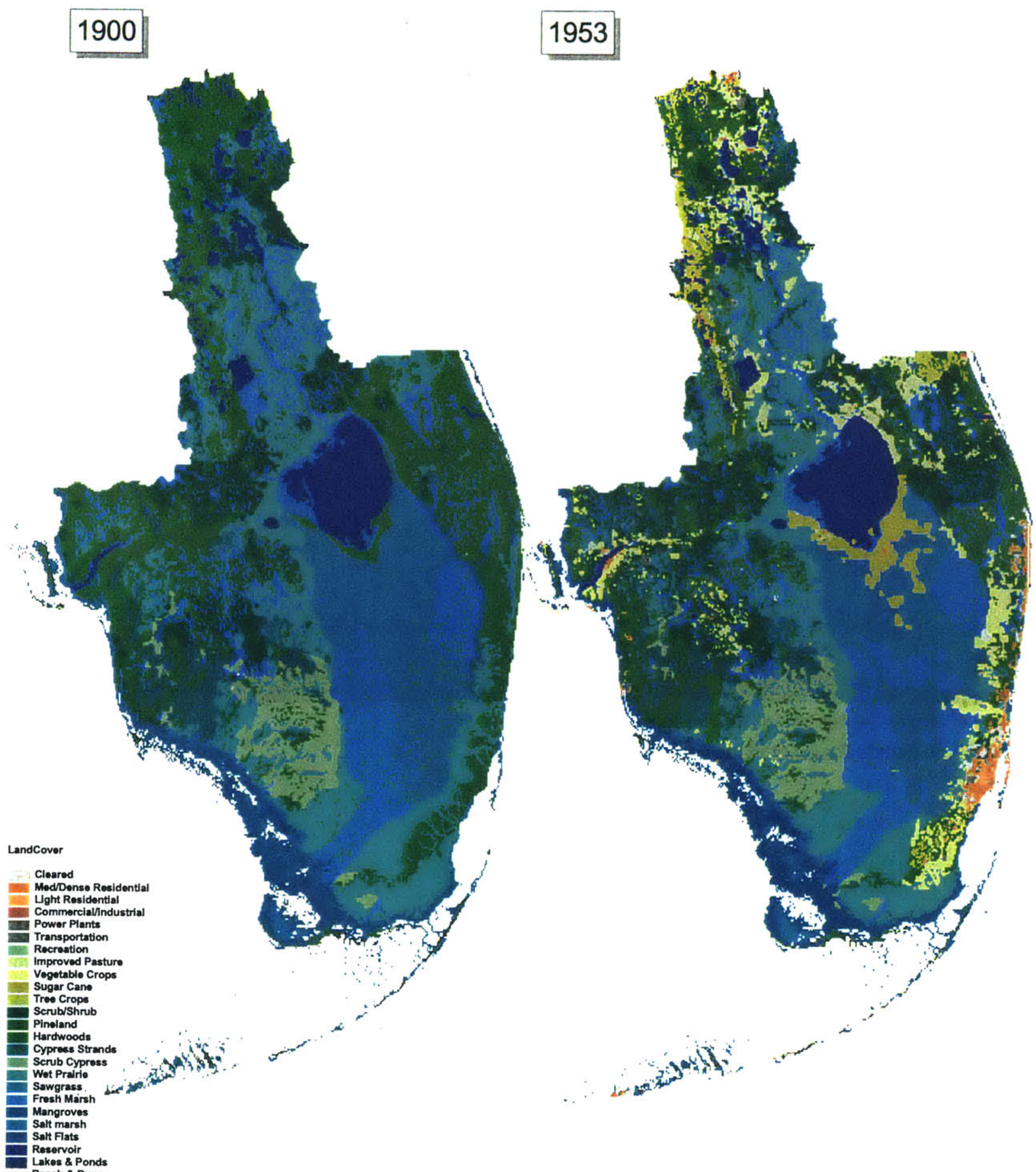


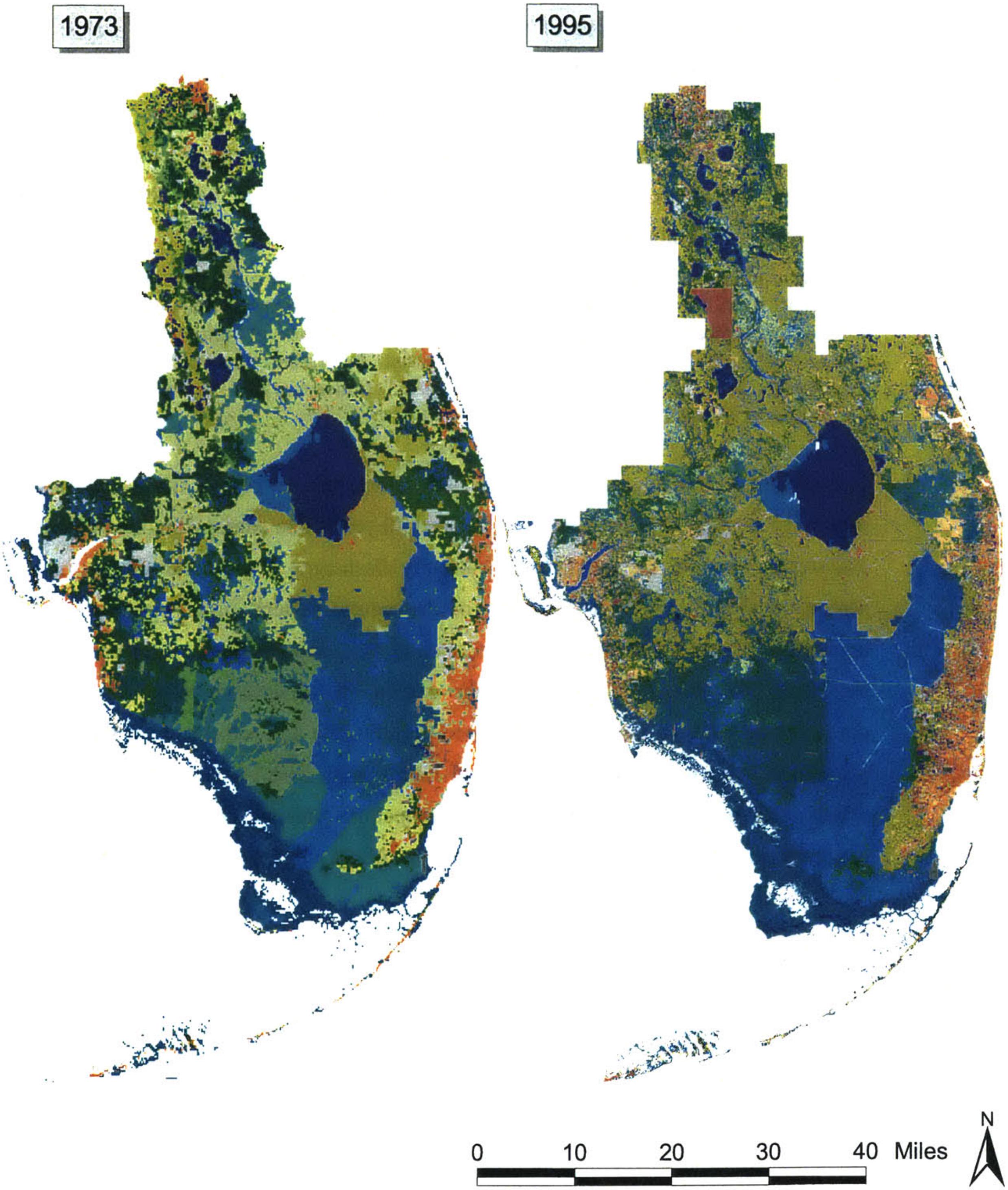
Figure 1.3: Historical and Projected Population Growth in South Florida
Source: South Florida Regional Planning Council

Figure 1.4: Urban Development in South Florida
Source: South Florida Regional Planning Council

Figure 1.5: Land Cover Change In South Florida (1900-95)



Source: Constanza Data (1900-1973 Maps); South Florida Water Management District (1995 Map)
Ambika Anand Prokop. Dept. of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.



1973
1995
0
10
20
30
40
Miles
N

Ecosystem Restoration

Today the region is the site of the largest-scale ecosystem restoration project ever attempted in the world (U.S. Department of the Interior 1999 and Boston Globe 2001). Hydrologists and planners claim that there is enough water to meet the needs of the natural system, urban populations, and agriculture if the 1.7 billion gallons of water that is currently lost to tide each day can be stored (Harwell 1996). In their 1995 final report, the Governor's Commission concluded:

> "Assuming adequate storage and timing of water delivery, the environment of South Florida has sufficient water to support all anticipated urban, agricultural, and ecological needs. The ultimate issue, therefore is not strictly competition among agriculture, urban, and natural areas, but rather the storage and wise management of this renewable resource." (Governor's Commission for a Sustainable South Florida, 1995)

In 2000, the U.S. Congress approved a $7.8 billion plan to restore the Everglades by improving the hydrologic regime over the next 40 years. The strategy involves capturing and storing much of the water that is currently discharged to the ocean during the wet season, so that it can meet the needs of the natural system, urban populations, and agriculture during the dry season. The crux of the restoration efforts centers around increasing the storage capacity in the region. However, since increased urban consumption of both land and water will significantly impact storage capacity, any restoration attempt must take into account future urban development patterns. Will the urbanization patterns of South Florida be compatible with the planned restoration and reengineering of the hydrologic regime? This thesis will attempt to answer this question.

Proposed Solution: Compact Development

Definitions and Rationale

Some planners and designers have argued that environmental degradation is largely the result of the form that urban expansion has taken (that of low-density development) and that alternative forms, such as in-fill and higher density development, could reduce some of the negative environmental impacts of urbanization.

Since the 1950s, when the population boom in South Florida began, urbanization in the region was characterized primarily by the low-density development pattern now commonly known as "urban sprawl". This pattern is characterized by scattered, unplanned low-density development outside existing urban centers. It usually consists of residential suburban subdivisions of .25-.5 acre lots and non-residential strip development including large shopping malls with floor to area density ratios of .2 or less (Burchell 1999) (*see Figure 1.6*). This urban form usually occurs at the periphery of existing

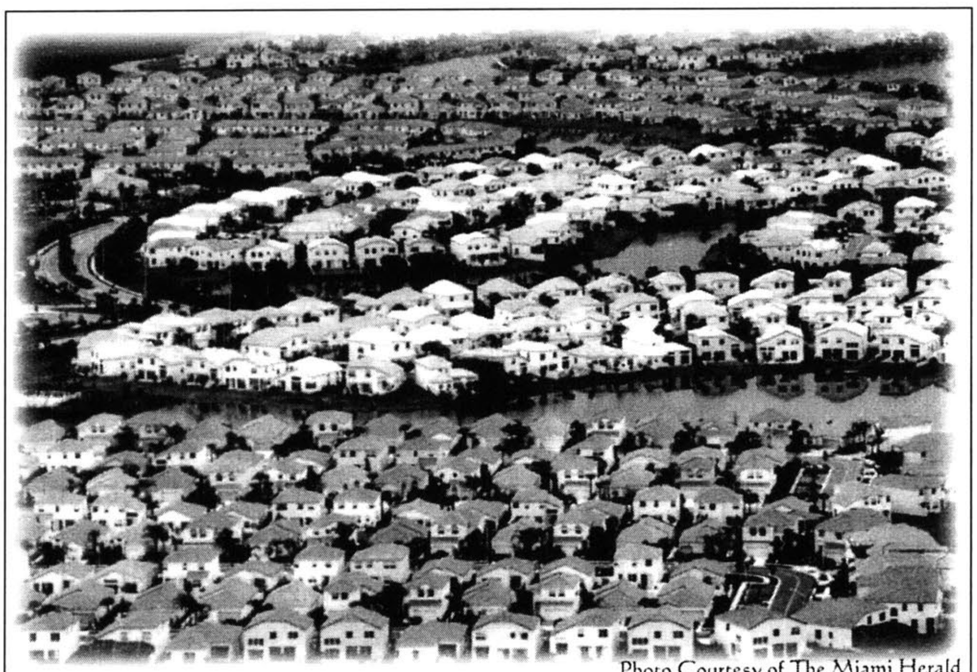


Figure 1.6: Typical Sprawl Development in South Florida

development where land is inexpensive. The location and separation of land uses associated with urban sprawl results in heavy dependence on the car, as people commute long distances from their homes in the periphery to jobs and other activities in central areas. Negative environmental aspects of urban sprawl include increased traffic congestion, air pollution, high per capita land consumption, and natural habitat fragmentation.

Compact growth is an alternative urban development pattern characterized by higher density development contained within existing centers, and limited development in rural and environmentally sensitive areas (Burchell 1999) (*see Figure 1.7*). This pattern of growth is usually achieved through more flexible zoning, which encourages redevelopment of sites in older areas, mixed-use development, and higher-density cluster development. Compact growth protects natural habitats and prime agricultural lands, reduces the need for new road construction and water/sewer infrastructure, reduces traffic congestion and associated air pollution, and increases the share and density of development close to existing population centers. Proponents of compact development also claim it yields significant economic savings to the public through reduced infrastructure costs, and that these savings can then be spent on further revitalizing urban areas, which have declined as people abandoned cities for the suburbs. On the other hand, critics argue that compact development increases the burden on existing infrastructure in cities and that by filling in undeveloped spaces in urban areas, it reduces open space available to people and animals.

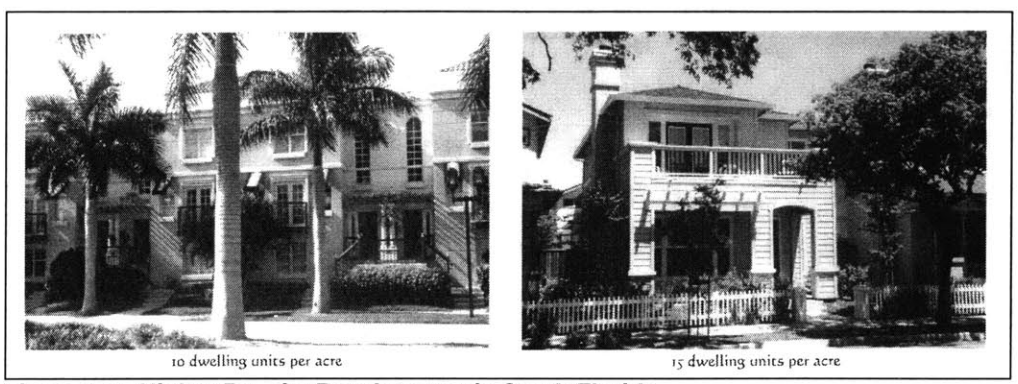


Figure 1.7: Higher Density Development in South Florida
Source: South Florida Regional Planning Council, 1996

Compact Development in Florida

Since the 1980s, lawmakers and planners in South Florida have adopted compact development as the preferred form of development due to concerns about environmental degradation, stress on public infrastructure (roads, utilities, etc) and the decline of urban areas (Burchell 1999). Nevertheless, the low-density sprawl development pattern prevails in the region (Turner & Murray 2001). Addressing this issue, the Governor's Commission for a Sustainable South Florida concluded in its initial report in 1995 that "Florida cannot achieve a sustainable Everglades ecosystem without also creating a more sustainable urban system in South Florida", and that "[There is] an inextricable link between the human community and the natural system...and continued suburbanization must be stopped because it is a serious threat to the sustainability of the region." (South Florida Regional Planning Council 1999 and Turner & Murray 2001). The Commission subsequently endorsed compact development in the form of the *Eastward Ho!* Initiative as the centerpiece of its urban restoration program. This initiative seeks to redirect urban growth away from western rural areas and back to existing developed areas along the eastern coast. The initiative specifically recommends establishing urban growth boundaries, in-fill development and redevelopment in urban areas, mass transit and other alternatives to single-occupancy auto travel, open space acquisition and adoption of gray water technologies (Turner & Murray 2001). *Eastward Ho!* has been dubbed the "urban side of Everglades restoration" (South Florida Regional Planning Council 1999).

The *Eastward Ho! Development Futures* Study

In 1999, the Environmental Protection Agency and the State of Florida Department of Community Affairs commissioned a study to evaluate alternate urban development scenarios in the five rapidly growing counties of Southeast Florida. The study was conducted by Dr. Robert Burchell of the Center for Urban Policy Research at Rutgers University, who has conducted similar studies for other states including New Jersey, Michigan, Maryland, South Carolina, and Delaware. The report, *Eastward Ho!*

Development Futures: Paths to More Efficient Growth in Southeast Florida, assessed two development scenarios:

- Existing (sprawl) development that consists of unlimited outward expansion, low-density and leapfrog development.
- Alternative (compact) development in which urban growth is redirected away from western rural areas. In-fill and redevelopment occurs at higher densities in existing urban areas to the east.

The report analyzed four costs related to each development scenario: land consumption, public infrastructure (road, sewer, water lines), housing, and fiscal impacts. The study concluded that in contrast to the typical low-density suburban development, compact development would provide substantial fiscal savings from lower land consumption and infrastructure needs. The report supported compact development as the preferred form of growth for the region, arguing that it would steer jobs and households to urban areas and increase tax base (Burchell 1999). The results of this report endorsed regional efforts to encourage compact development and curb urban sprawl in South Florida.

The Hydrologic Impacts of Compact Development

While the economic and land consumption benefits of compact development are compelling, the *Eastward Ho! Development Futures* report does not evaluate the hydrologic impacts of compact development. Quantifying these effects is crucial to determining whether South Florida can meet the water demands of its growing urban population while restoring the Everglades. Since water storage is key to ensuring adequate water supply for the region, the impact of urban development on the system's storage capacity must be addressed. Potential impacts of urbanization on water storage in South Florida include:

- Reduced aquifer recharge due the paving of surfaces, which diminishes their capacity to absorb rainfall and replenish water storage in the aquifer.
- Reduced availability of surface storage areas due to the consumption of land for urban development.
- Increased public water demand, which is met primarily by groundwater withdrawal from the aquifer and is supplemented by water from surface reservoirs that also supply the Everglades.

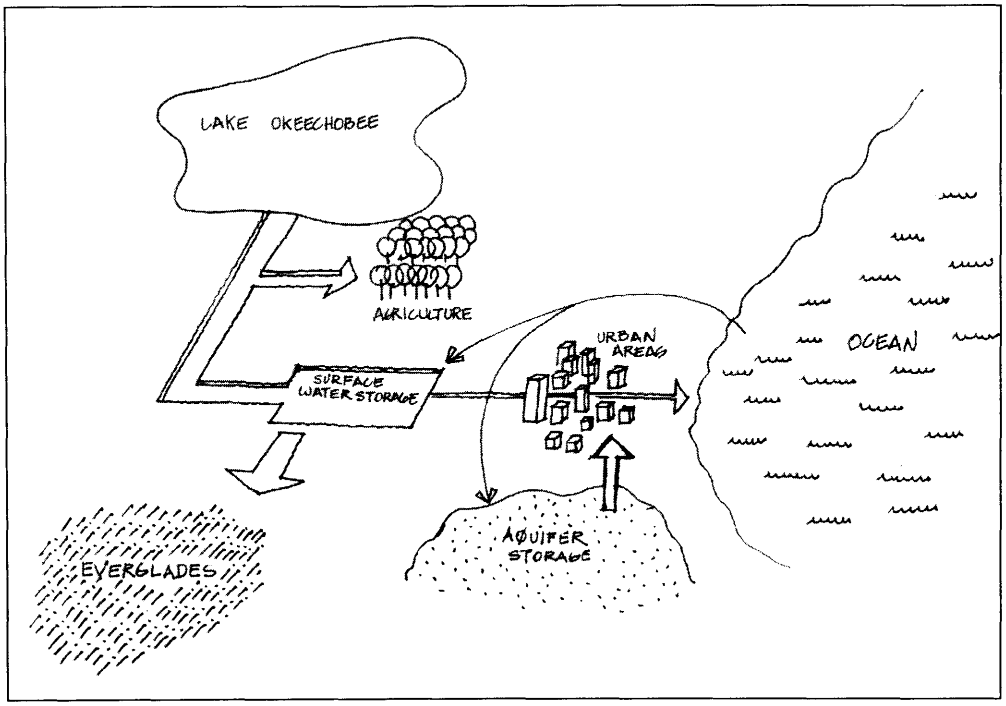


Figure 1.8: Water Flows in South Florida
(Illustration by Pablo Rivera)

This thesis compares the impact of compact urban development and sprawl development on aquifer recharge, which serves as the main source of drinking water for the urban populations of Southeast Florida. When this supply is inadequate, it is supplemented by stored waters intended for the Everglades (*see Figure 1.8*). Thus, this study evaluates whether compact development increases regional water storage capacity, and whether it can reconcile the competing demands of a rapidly growing population with ecosystem restoration.

This analysis focuses on Palm Beach County, which was one of the counties evaluated in the *Eastward Ho! Development Futures* report (*see Figure 1.9*). The sprawl in this county typifies the sprawl development pattern occurring throughout the country. Palm Beach County is also one of the fastest growing counties in Southeast Florida, with large tracts of its agricultural lands facing urbanization. In a 1999 report, the Sierra Club identified West Palm Beach as the fourth most "sprawl-threatened" medium-sized city in the country (Turner & Murray 2001). Palm Beach County also has several important conservation areas within its boundaries, including the Arthur R. Marshall Loxahatchee National Wildlife Refuge, a key Water Conservation Area that stores water for the region. In addition, several sites within the county have been identified as potential water storage areas for the Everglades restoration plan. Many of these lands have also been

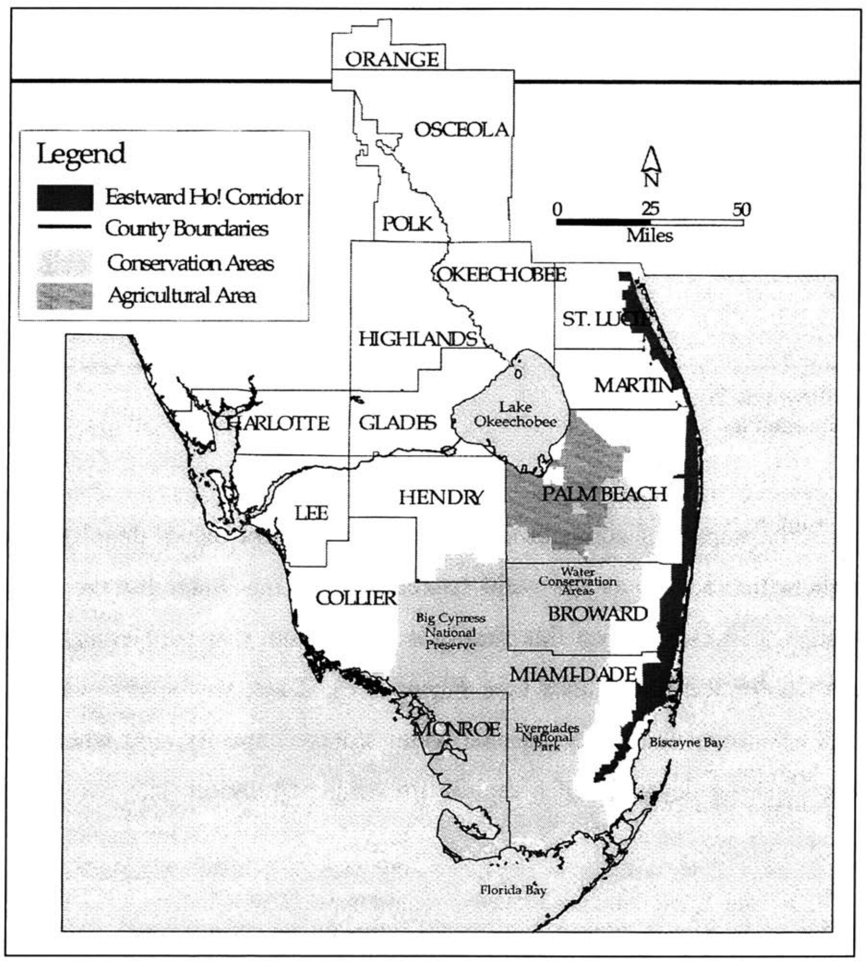


Figure 1.9: Map of South Florida with Eastward Ho! Study Area
Source: South Florida Regional Planning Council, 1998

targeted by developers for new suburban subdivisions. In an attempt to address the challenges of rapid urban growth, Palm Beach County adopted a new growth management plan in 1999, which endorsed compact development and sought to redirect urban growth away from western agricultural lands to existing urban areas along the eastern coast. In its land use patterns and current planning efforts, the county offers an interesting case study of how compact development may impact regional water storage capacity.

This analysis estimates the spatial distribution of future urban growth under sprawl and compact development scenarios, based on projections of the *Eastward Ho! Development Futures* report. The spatial projections were integrated with historical climate and soil data to estimate aquifer recharge under the two urban development scenarios using Geographic Information Systems (GIS) analysis. The results of this analysis indicate that while compact development confers some benefits for aquifer recharge, the magnitude of the benefits is small because compact development is likely to cover the permeable soils in urban areas that most contribute to aquifer recharge. Furthermore, with the implementation of stormwater regulations to guide new development, the difference between the impact of sprawl and compact development patterns on recharge becomes insignificant. Compact development in Palm Beach County will, however, allow for the allocation and buffering of water storage areas, which are important to the Everglades restoration plan.

These results suggest that planners must consider the specific local conditions before applying growth management strategies such as compact development to their locality: strategies that may yield significant benefits in one region may yield no benefits or even be harmful elsewhere. Furthermore, compact development does not address the challenge of urban demand for water, which will increase significantly as South Florida's population grows in the coming decades. This study concludes that increases in water demand will far outstrip the benefits to aquifer recharge that compact urban development would confer. Therefore, compact development cannot be viewed as a panacea for the negative environmental impacts of future population growth in the region.

Chapter 2: Water

The Hydrologic History of the Everglades

The Water Flows of South Florida: Pre-drainage

The Hydrologic Cycle

Understanding the flow of water is critical to understanding the Everglades and the development of the cities surrounding it. These flows vary from place to place and over time, as water cycles between the land, the ocean, and the atmosphere (*see Figure 2.1*).

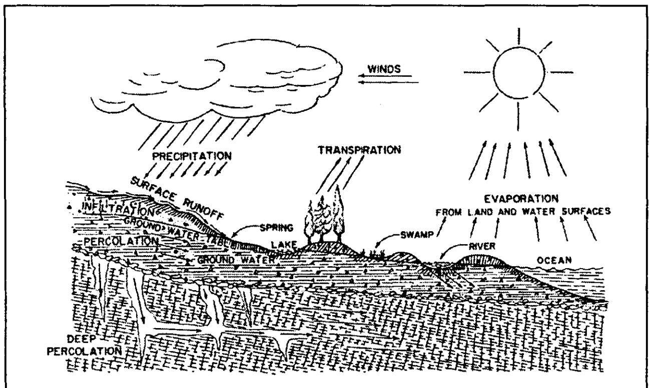


Figure 2.1: Hydrologic Cycle
Source: Hoffmeister 1974

In this cycle, precipitation occurs when warm moist air condenses and releases water onto the watershed. [1] From there, the water can take the following paths:

- Evaporation: direct return of the water to the atmosphere if the air is unsaturated temperatures are high.
- Transpiration: the physical removal of water from the soil by vegetation which ultimately releases a portion back to the atmosphere. This process constitutes a significant component of the hydrologic cycle in South Florida.
- Interception: the removal of water when it is blocked above ground by barriers such as buildings or vegetation. This water subsequently evaporates to the atmosphere.
- Overland Flow (Surface Runoff): the flow of water on the ground surface to lowland water bodies, including lakes, streams, canals and wetlands. Overland flow frequently occurs when the ground is saturated or covered with impervious surfaces characteristic of urbanized areas.
- Depression Storage: the storage of water in surface depressions. This water can evaporate or infiltrate the ground, or if it overflows the depression, it can flow overland until it reaches natural drainways. The amount of water held in depression storage depends on land use; for example, a paved surface does not hold as much water as a plowed field.

[1] A watershed is the drainage basin which captures water from higher elevations and drains it to water bodies at lower elevations.

- Infiltration: the flow of water into the ground by percolation through the earth's surface. Urban areas depend on this flow for drinking water, since it replenishes the deep aquifer. Because evapotranspiration is so high in South Florida, only a small percentage of precipitation infiltrates deeply enough into the soil to recharge the aquifer. The extent of infiltration depends on factors such as soil type, vegetative cover, time elapsed since the last precipitation, rainfall intensity and temperature.

Water from overland flow or infiltration eventually reaches streams and rivers where it can be retained in storage reservoirs and lakes. Ultimately, it reaches the ocean, from which it evaporates back to the atmosphere, beginning the cycle anew.

The hydrologic cycle is expressed by a formula known as the water budget. The water budget represents the overall inflows and outflows into the system as follows:

Inflows = Outflows
Precipitation = Evapotranspiration + Infiltration + Storage + Runoff

In South Florida, inflows are driven primarily by abundant precipitation, and the outflows by high rates of evapotranspiration. Average annual rainfall is 40-65 inches (Mcpherson & Halley 1997), and more than half of the precipitation falls during the wet season from May through October. The rainfall varies significantly from place to place and from year to year (*see Figures 2.2 & 2.3*). Hurricanes and tropical storms can produce severe weather conditions with high tides, and inland and coastal flooding, while other periods are characterized by severe drought. Indeed, the region is currently suffering its worst drought in 50 years, with water levels 24" below normal as of March 2001 (Swift 2001).

With the subtropical climate and abundance of wet vegetated surface areas, evapotranspiration in South Florida can account for up to 87% of annual precipitation (Fairbank & Hohner 1995) *(see Figure 2.4)*. Evapotranspiration is greatest in the wet summer season, when abundant water is available for surface evaporation and vegetative transpiration.

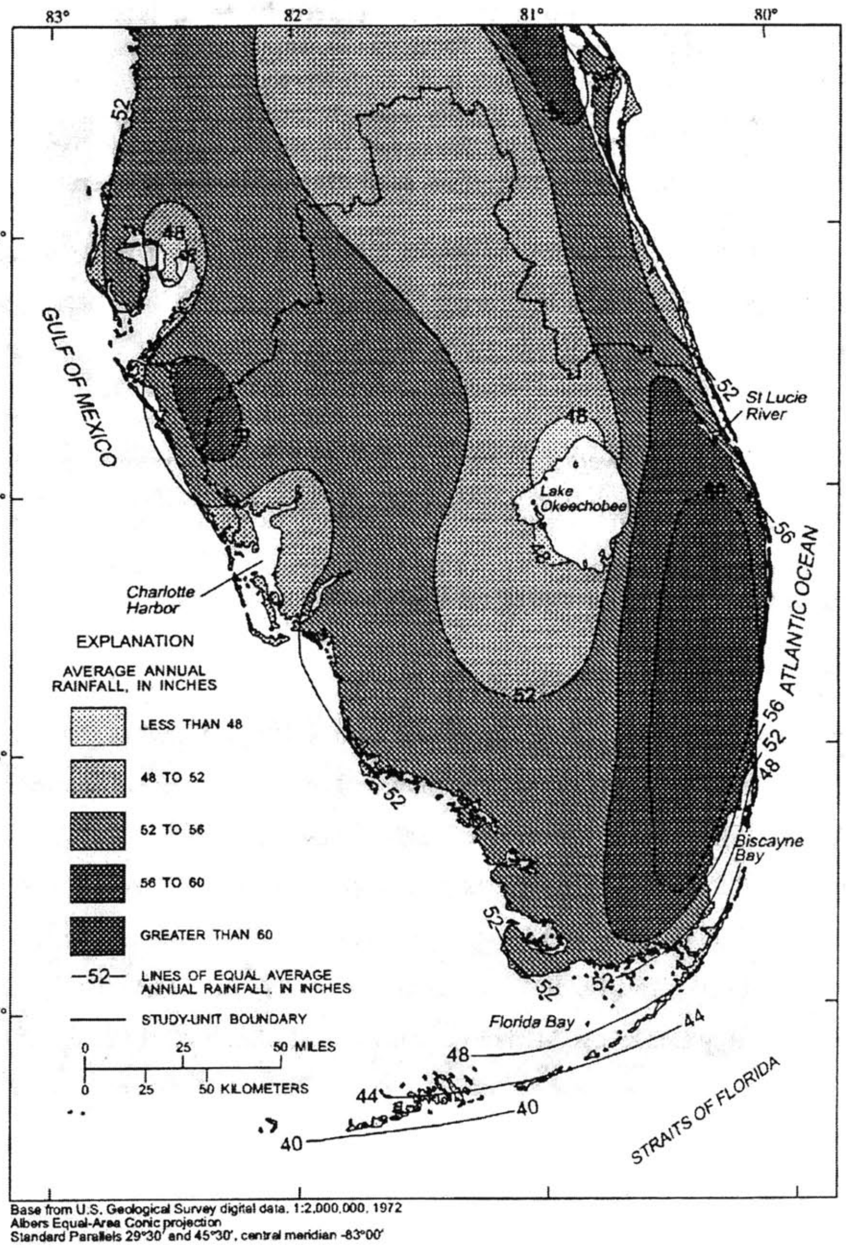


Figure 2.2: Spatial Variation of Rainfall in South Florida
Source: McPherson and Halley 1996

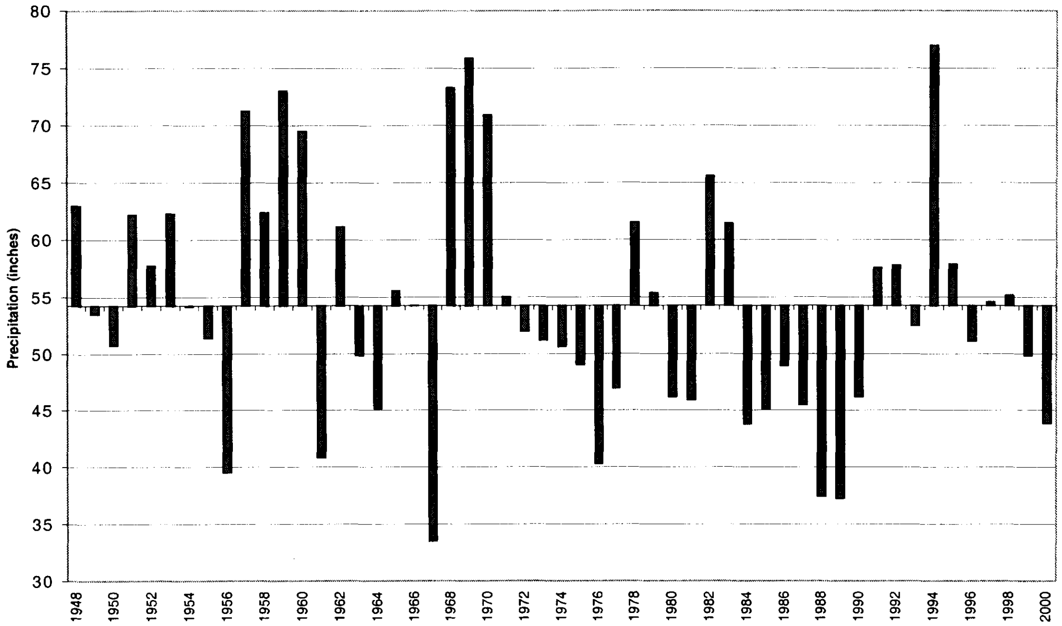


Figure 2.3: Deviation from Average Annual Precipitation at Belle Glade Experimental Station, Lake Okeechobee (1948-2000)
Source: National Climatic Data Center 2001

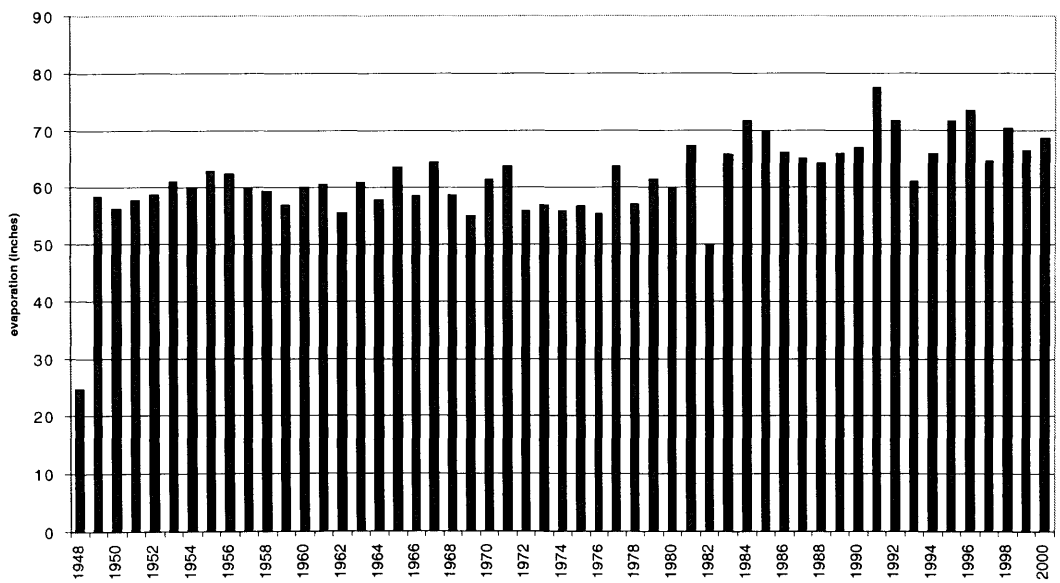


Figure 2.4: Average Annual Open Pan Evaporation at Belle Glade Experimental Station, Lake Okeechobee, FL (1948-2000)
Source: National Climatic Data Center 2001

Surface Flows and Water Storage

The Everglades were originally part of the Kissimmee-Okeechobee-Everglades watershed that extended through more than half the length of the Florida peninsula (*see Figure 2.5*). The hydrologic system is bounded by the Immokalee Ridge to west and the Atlantic Coastal Ridge to the east. Freshwater supply to South Florida came primarily from precipitation over the Kissimmee River basin during the rainy season, and was stored in Lake Okeechobee(*see Figure 2.6*). As water levels rose during the rainy season, water spilled over the banks of the lake and moved slowly south as sheet flow, nurturing the marshlands, pond apple forests, mangrove swamps and estuaries of the Everglades (*see Figure 2.7*). For this reason, Lake Okeechobee, which covers 730 square miles at an average depth of depth of 12 feet, is known as the "liquid heart" of South Florida's surface water hydrologic system. The Everglades itself is actually a 50-mile wide, 6-inch deep river spilling over the banks of Lake Okeechobee.

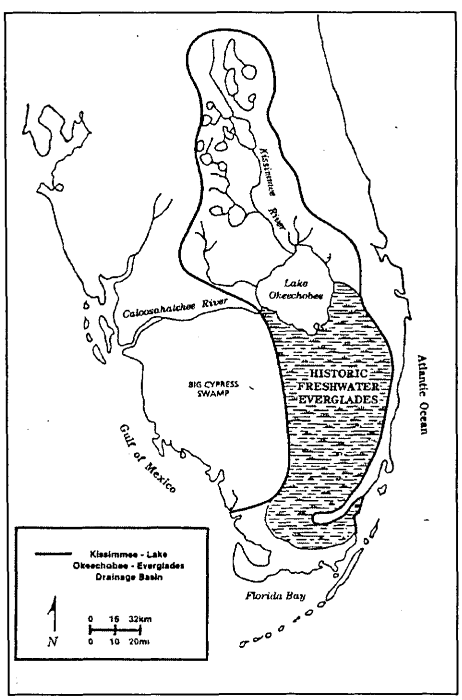


Figure 2.5: Original Drainage Basin in South Florida
Source: Light and Dineen 1994

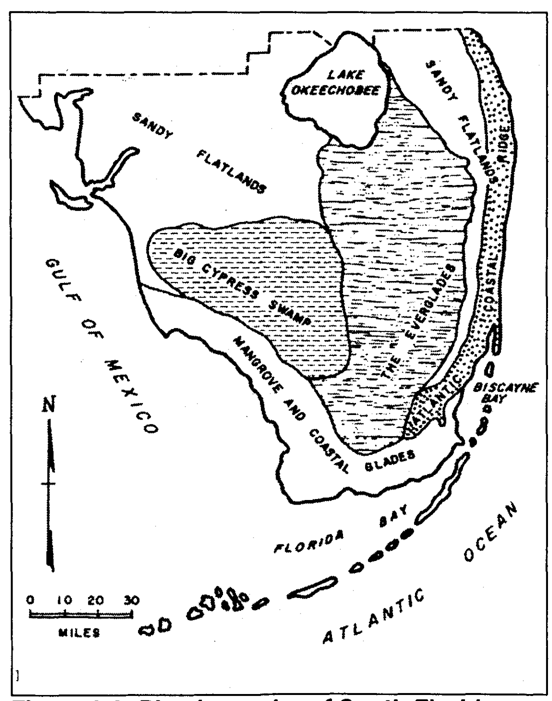


Figure 2.6: Physiography of South Florida
Source : Light and Dineen 1994

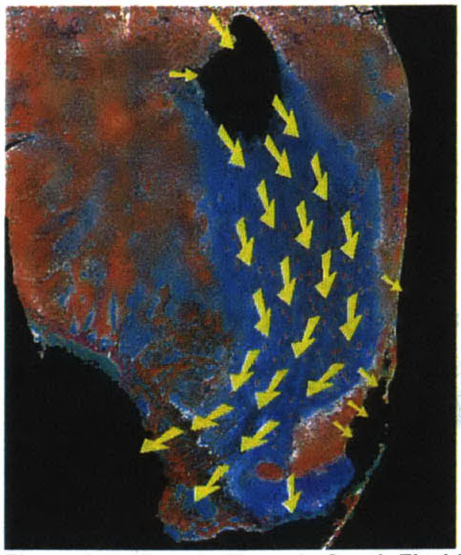


Figure 2.7: Historic Flows in South Florida
Source: South Florida Water Management District

In this regime, the Atlantic Coastal Ridge served as a bank to the Everglades, retaining freshwater in the Everglades Basin, and also serving as a bulwark against hurricane storm surges. The basin contained the majority of the overland flow, and the hydroperiod (median days of inundation) as the water flowed southward was 333 days/year (South Florida Water Management District 1999). During heavy rains, all but the highest tree islands flooded. Indeed, before human manipulation of this regime, 70% of South Florida would be flooded each year (Phelan 2000). The inundation during the wet season recharged surface and ground water supplies. As the water moved slowly southward, it seeped through the porous limestone bedrock and into the underlying aquifer. During the winter dry season, the marshes dried up, and water was concentrated in the deep indentations such as lakes.

Habitats

It is this hydrologic regime that produced the Everglades and its habitats. Wetlands emerged as the dominant landscape because of abundant rainfall and low, flat terrain. Slight differences in elevation, water salinity, and soil type produce varied communities of plants and animals, such as the elevated, teardrop islands of the hardwood hammocks,

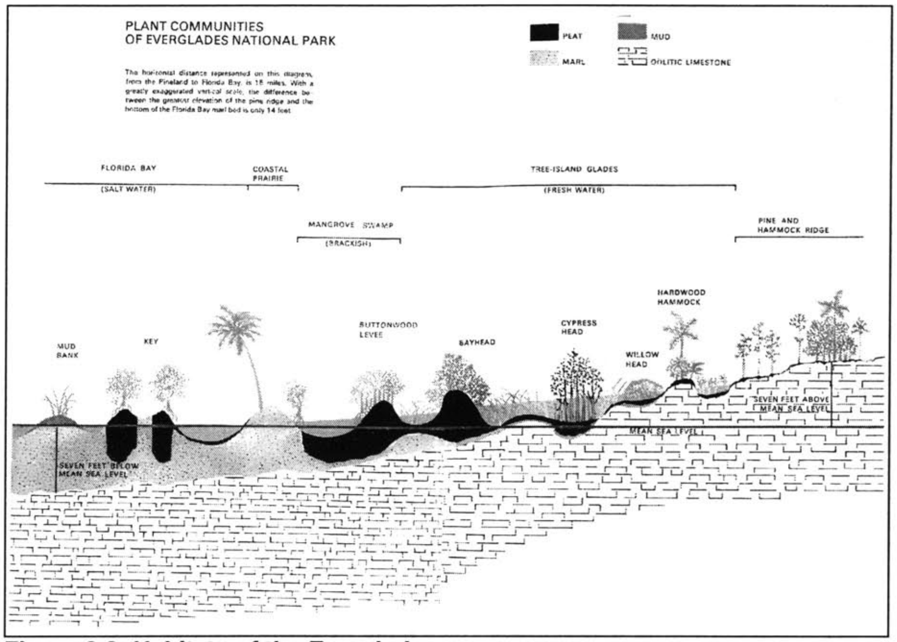


Figure 2.8: Habitats of the Everglades
Source: George 1988

the high elevations of pinelands, the predominant freshwater marsh, cypress swamps, and the brackish mangroves (*see Figure 2.8*).

The animal and plant populations adapted to and became dependent on the wide fluctuations of water levels throughout the year. For example, as water levels declined, fish and other aquatic animals concentrated in deeper parts of the marsh, where they became prey for predators, especially wading birds whose nesting season coincides with availability of food (*see Figure 2.9*).

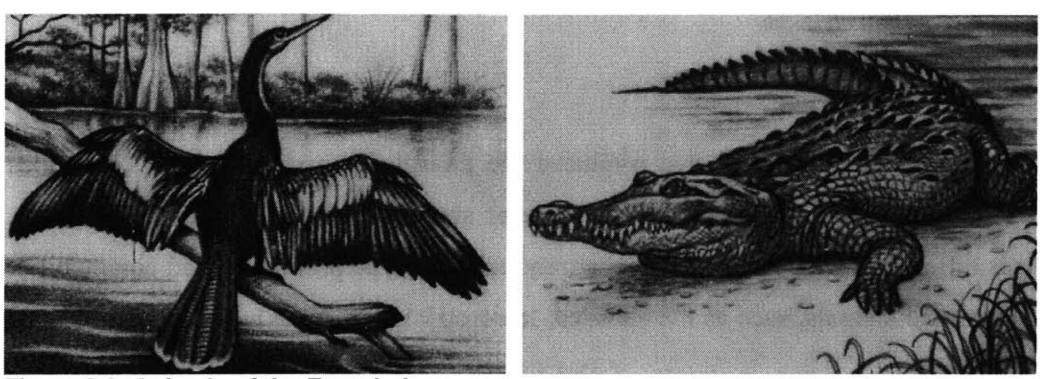


Figure 2.9: Animals of the Everglades
Source: South Florida Water Management District

The Water flows of South Florida: Post-drainage & Flood Control

Until the early 1900s, the frequent periods of flooding hindered development in areas of the Everglades Basin beyond the highlands of the Atlantic Coastal Ridge. However efforts to drain the area began in the early 1900s when the Everglades Drainage District was created to encourage drainage of the Everglades for agricultural and urban purposes. In 1903, canals were cut through the Atlantic Coastal Ridge, and by the late 1920s, five canals had been dug between Lake Okeechobee and the Atlantic Ocean. In subsequent years, the government authorized the enlargement of the canals and the construction of the 30-foot tall Hoover Dike around Lake Okeechobee (*see Figure 2.10*).

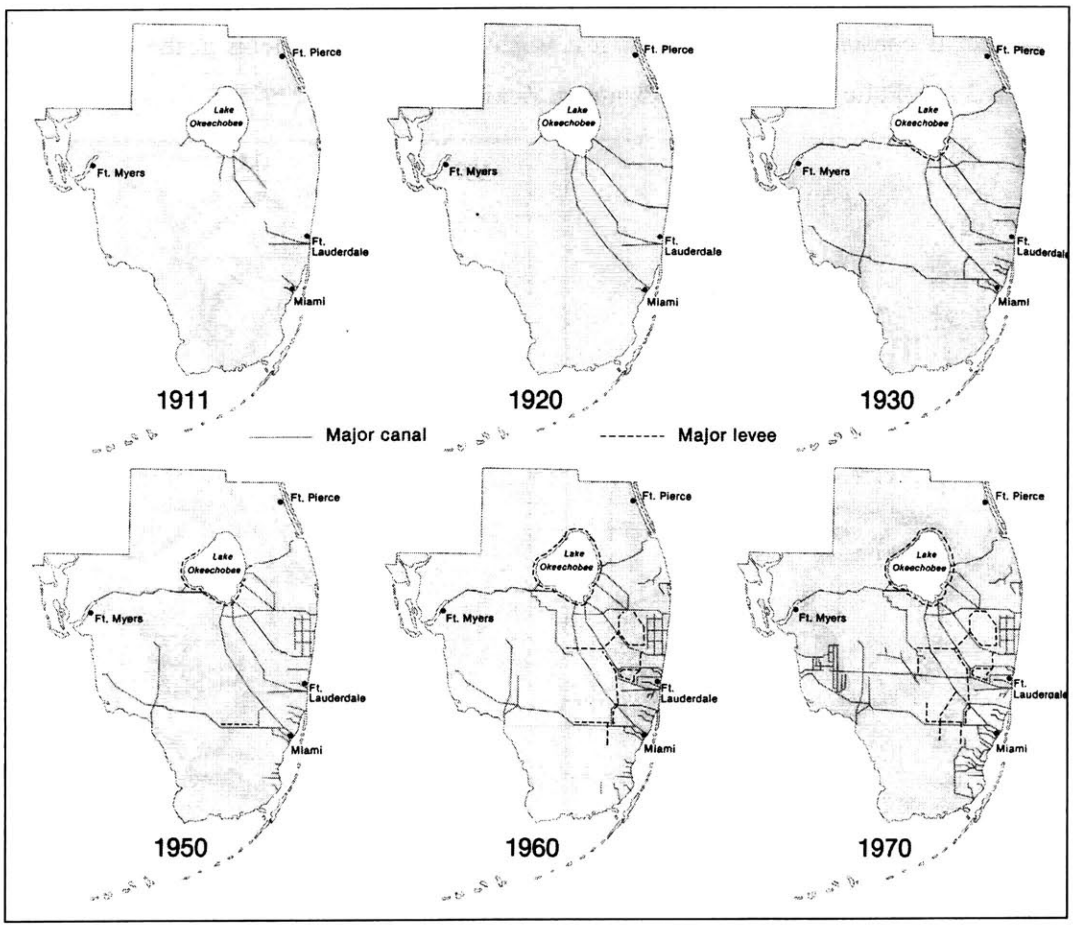


Figure 2.10: Expansion of Canal and Levee System in South Florida
Source: Fernald and Purdum 1992

Reengineering of the hydrologic regime began on an even greater scale in 1948 after devastating hurricanes flooded more than 3 million acres of land for months (*see Figure 2.11*). In response to this disaster, the U.S. Congress authorized the Central & South Florida (C&SF) Project. Under this effort, the U.S. Army Corps of Engineers built a federal water control system to prevent future catastrophic flooding and accommodate the post-war population boom by making more land available for agriculture and land development. The congressional act created what is known today as the South Florida Water Management District (SFWMD) to provide flood protection for urban and agricultural areas, and to supply the region's population and the Everglades with water. Flood control was the main goal of the project, and to this end, SFWMD was charged with reducing 80% of the damage incurred by extreme events such as the 1948 hurricane (Phelan 2000). The resulting system of canals, levees, pumps, and water control structures is considered one of the largest water management systems in the world (*see Figure 2.12)* (Palm Beach County Planning, Zoning & Building 1997).

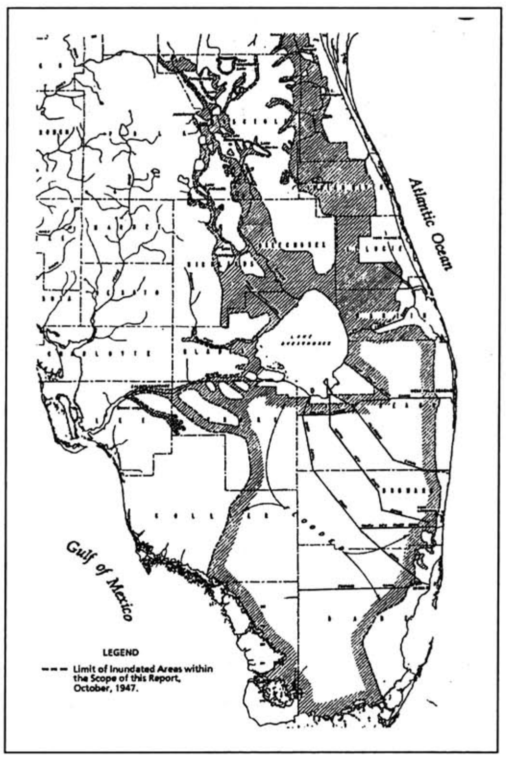


Figure 2.11: Extent of Flooding in 1947
Source: Light and Dineen 1994

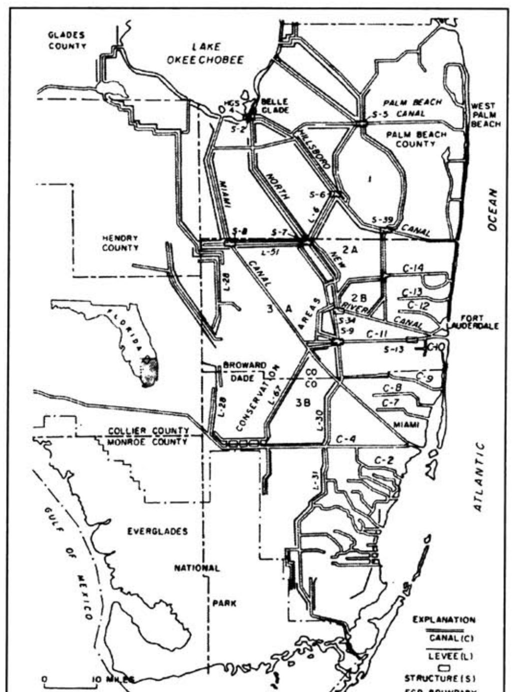


Fig. 73. *Map of southeastern Florida showing canal and levee system of the Central and Southern Florida Flood Control District.*

Figure 2.12: C&SF Structures
Source: Light and Dineen 1994

By the 1970s, South Florida had a complex system of 1,400 miles of primary canals, 150 water control structures and 16 major pump stations. This reengineering altered the natural flow of water through the region, diverting the natural flow south through canals to the Atlantic Ocean and the Gulf of Mexico (*see Figure 2.13*). The reengineering also changed the water budget of the region, although inflows and outflows were still dominated by rainfall and evapotranspiration, respectively (see *Figure 2.14)*. Discharges were also redirected so that the majority of overland flow traveled to the ocean rather than to the Everglades (*see Figure 2.15*).

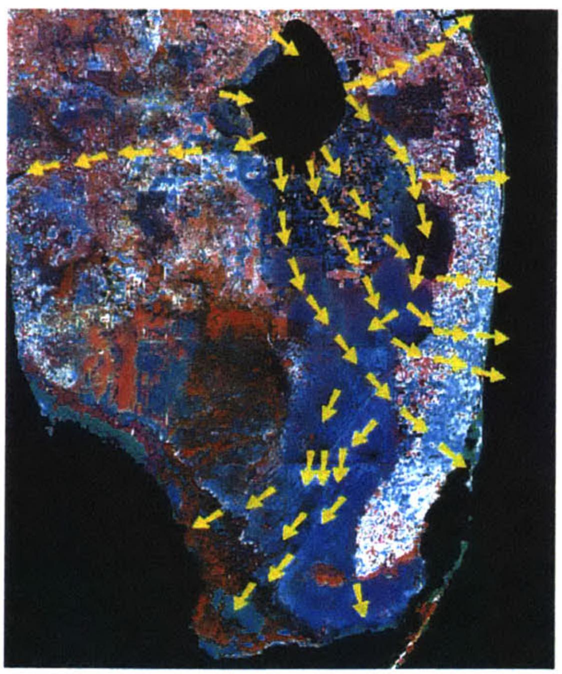


Figure 2.13: Present Day Water Flows in South Florida
Source: South Florida Water Management District

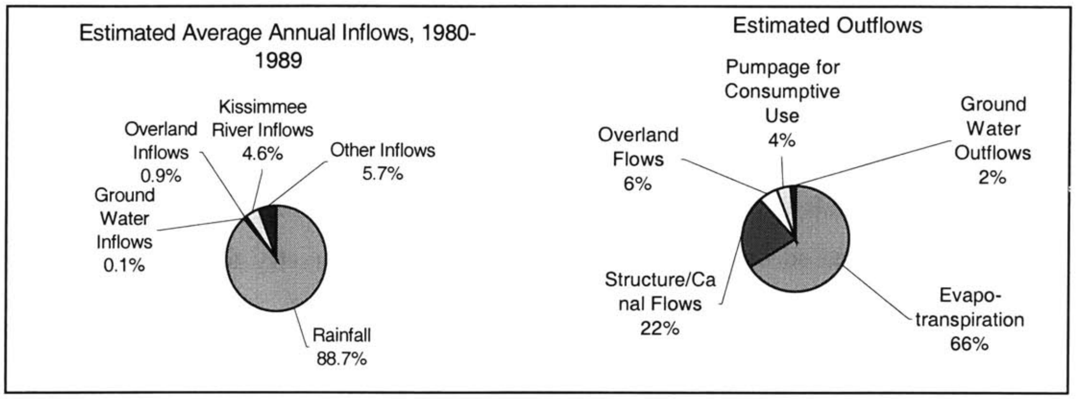


Figure 2.14: Water Budget in South Florida (post C&SF project)
Source: South Florida Water Management District

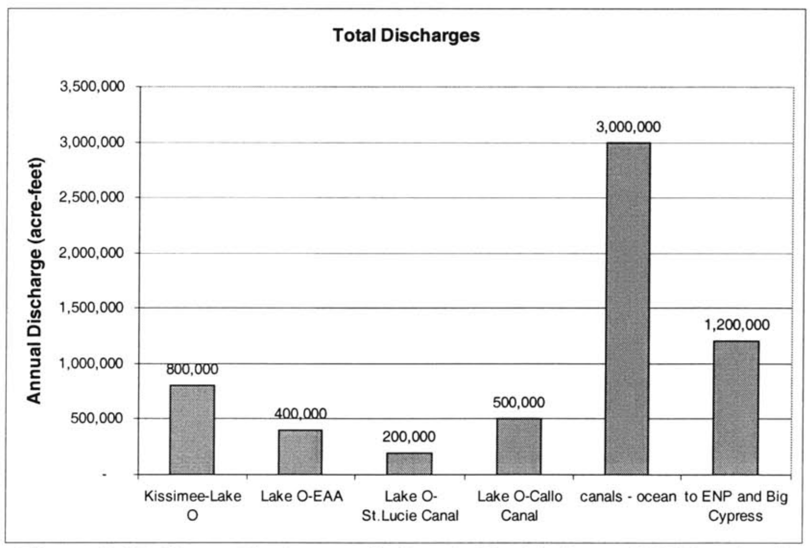


Figure 2.15: Water Discharges in South Florida (post C&SF project)
Source: South Florida Water Management District

The major components of the C&SF Flood Control Project include:

- Channelizing of the 90-mile Kissimmee River into a 54-mile canal that is cut off from its floodplain. Flow to Lake Okeechobbee is controlled by locks and dams.
- The damming of Lake Okeechobee for flood control and water storage.
- The construction of a complex system of canals, dikes, levees, and pumps to control the surface water flows in the region. The canals divert the waters which originally flowed from the Kissimmee River and Lake Okeechobee into the Everglades, and discharge them quickly into the Atlantic Ocean and the Gulf of Mexico; control structures at outlet of drainage canal release water in rainy season for flood prevention, and close in dry season to prevent overdrainage.
- Designation of Water Conservation Areas (WCAs) for flood control and water reservoirs. The WCAs enclose 900,000 acres of public lands, and provide flood protection by storing and discharging excess water to the ocean during the wet season. These areas supply water in the dry season for irrigation and municipal uses, and supply recharge for the coastal areas and Everglades National Park. The WCAs also provide a source of water to prevent saltwater intrusion into the aquifer along the coasts.
- Designation of 800,000 acres of the Northern Everglades as the Everglades Agricultural Area (EAA) to be drained and farmed. Water structures were designed to pump water from the EAA into the WCAs, a portion of which could be subsequently released to the Everglades National Park, according to a schedule determined by the Army Corps of Engineers and SFWMD.
- Designation of the Everglades National Park, as an area which could serve as flood control receiving excess waters during heavy rains.
  (See figure 2.16)

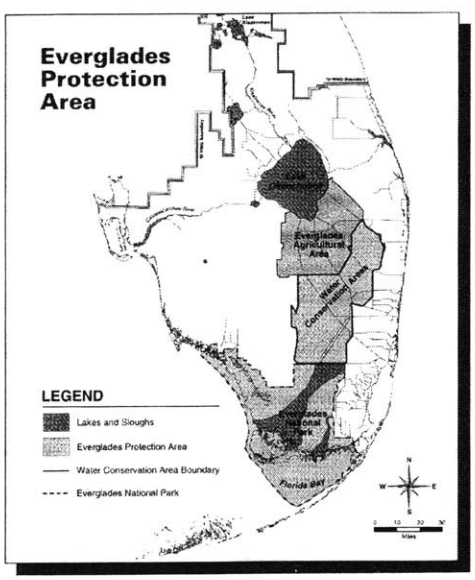


Figure 2.16: Key Areas of C&SF Project
Source: South Florida Water Management District

Impacts of the Central and Southern Florida Project

Ecosystem Impacts

The impacts of this reengineering have been dramatic for both humans and nature. The sheet flow so critical to the health of the Everglades no longer occurs; instead, these surface waters are held within the canal system, and are either used for irrigation or discharged to the ocean. Flood control measures to protect urban and agricultural areas have resulted in higher flows in the rivers and estuaries, and higher peak stages in Lake Okeechobee and the WCAs. Most importantly, since the water is discharged to the ocean during the wet season rather than stored, it is lost from the system and not available for the dry season. This loss of storage has been particularly damaging to the natural system, which relies on this supply to dampen the natural fluctuations in water flows.

> Because of the dynamic storage and slow rate of water flow throughout the natural system, wet season rainfall kept the wetlands flooded and maintained freshwater flow to the estuaries into the dry season. The carry-over effect of the enormous storage capacity of the natural system was so great that a year of high rainfall maintained surface water into subsequent drought years. (Harwell 1996)

By discharging the water that would otherwise have been stored, the system lost its buffering capacity during severe drought conditions. The combination of flood control, drainage and groundwater withdrawal for agriculture and public water supply has resulted in lower water tables throughout the system.

The ecological consequences to the Everglades have been dramatic, as the natural system requires a specific quantity, quality, timing, and distribution of water. The C&SF Project altered all these variables. The third of the Everglades that remained after lands were taken for agriculture and urban settlement became dependent on regular releases of water from Lake Okeechobee and the WCAs under an operating schedule managed by South Florida Water Management District and the US Army Corps of Engineers. While the releases mimic the natural seasonal flow, they do not recreate its duration and timing.

Furthermore, as a growing population increased its water demand, it left less water available to flow into the park. In 1968, federal legislation was passed to ensure that minimum monthly water delivery be made to the Everglades; however this allocation is insufficient during dry periods such as this year, and much of the supply is contaminated by surface runoff laden with fertilizers from the Everglades Agricultural Area. As a result, water levels in the Everglades are now shallower and have a shorter hydroperiod, and plant and animal life have suffered. In addition, the legislation did not protect the park from receiving too much water in extremely wet years. If too much floodwater is released into the park during the rainy season, alligator nests are flooded and eggs destroyed. Appendix A lists specific impacts to the ecosystem which have resulted from the C&SF project.

Human Impacts

While the C&SF Project allowed more people to settle in the region, the manipulation of the hydrologic regime has adversely impacted human populations primarily through reduced water storage in the system. "This drainage system has been so successful that a region that receives an annual average rainfall of over 50 inches a year is now facing a projected water supply crisis in dry years" (South Florida Water Management District 1999).

The urban populations of South Florida rely almost entirely on groundwater to support their freshwater needs. The region has three major aquifer systems: the Floridan, intermediate and surficial aquifers (*see Figure 2.17*). However only the surficial aquifer contains potable water which serves as the primary drinking water supply for the region. This system includes the highly permeable Biscayne aquifer *(see Figure 2.18*). However, increased water demand has reduced groundwater levels in both systems.

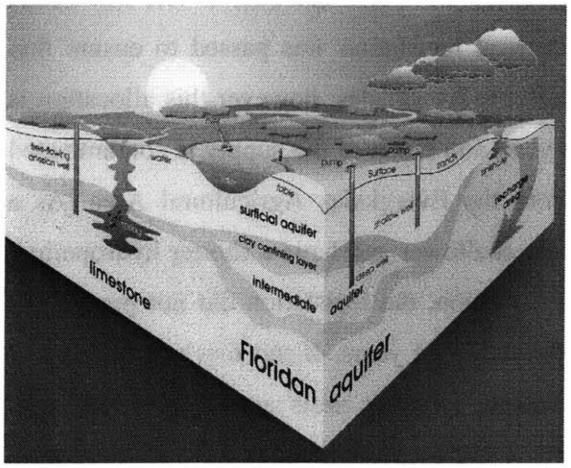


Figure 2.17: Aquifer of South Florida
Source: South Florida Water Management District

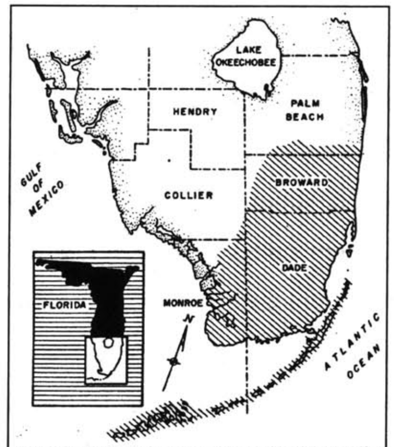


Fig. 70. Parallel lines show the geographic extent of the Biscayne aquifer.

Figure 2.18: Biscayne Aquifer
Source: Miller 1988

Groundwater recharge is essential to replenishing the water withdrawn from the aquifer. This recharge occurs when water infiltrates the soil and accumulates at the water table surface within a given aquifer. The amount of water available for recharge is whatever remains after interception, overland flow, surface water evaporation, and evapotranspiration. In general, direct and indirect sources of recharge include precipitation, river, canal, lake seepage, interaquifer flows or leakage, percolation of irrigation water, and urban recharge from leaky utility/sewer lines, drainage wells and drainfields.

Under ideal conditions, the system is in equilibrium when the aquifer recharge balances the discharge. Before drainage and flood control, seepage from the Everglades recharged the Biscayne and surficial Aquifer through the Atlantic Coastal Ridge. However human manipulation of the landscape in South Florida has greatly altered groundwater recharge, sometimes diminishing and sometimes augmenting it. The system of canals, levees, and floodgates diverts nearly 2 million acre-feet of water annually to the oceans instead of to the Everglades and the Biscayne Aquifer (Sharma 2001). Vegetation was removed and replaced with impervious pavement and buildings which prevent infiltration. In addition, groundwater withdrawal to support urban consumption and seepage to canals further reduce the amount of water in the aquifer (*see Figure 2.19*).

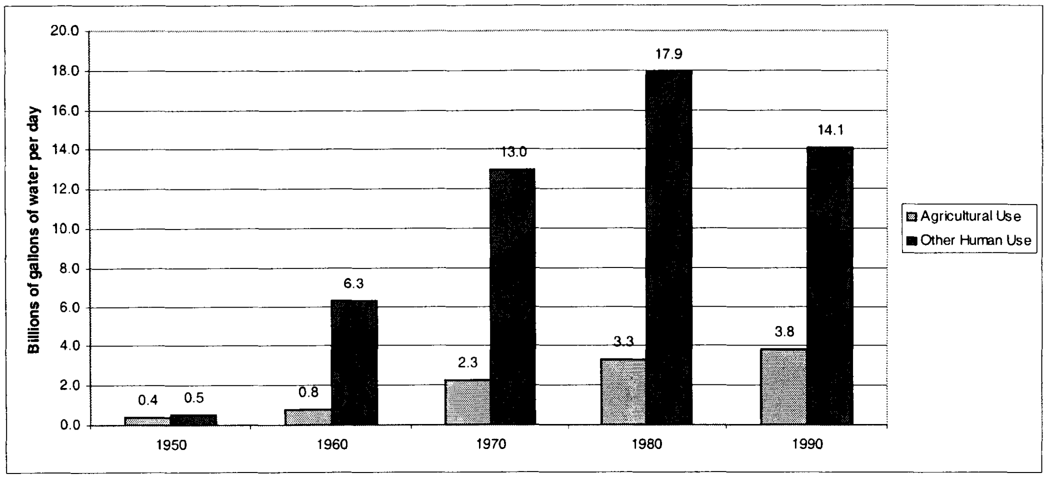


Figure 2.19: Historical Water Consumption in South Florida
Source: South Florida Water Management District 2000

On the other hand, aquifer recharge is augmented by leakage from water and sewage utilities, canals and surface water impoundments. Often more than 50% of the water flow in canals seeps to the groundwater table to replenish recharge (Fairbank & Hohner 1995). And in Miami, water losses from leaky water and sewer mains may be as high as 14% (Fairbank & Hohner 1995). Agriculture can also augment recharge depending on the type of irrigation system employed (flood, drip, overhead), time of year, and duration of application.

Overall, however, water storage in the system has been reduced, and that combined with regular droughts and an ever-increasing water demand, has led to more frequent and acute regional water shortages. These shortages usually occur in the dry winter season, coinciding with the influx of tourists who impose more demands on the system. The last major drought occurred in the late 1980s, and the region is currently experiencing its worst drought in 50 years.

The existing system is currently operating well beyond capacity. The C&SF Project was originally designed to provide drainage, flood protection, and water supply to meet the needs of approximately 2 million people by 2000. Today, however, the system provides for nearly 5.5 million people and 950,000 acres of agriculture. By 2010, it will have to support 8 million, and by 2050, 12 million people (Sharma 2001). The massive damage to the Everglades and frequent water shortages will only grow more acute with population growth. Consequently, planners and engineers have realized that the system must be modified to support the viability of both the natural system and regional growth in South Florida.

Ecosystem Restoration

History

Overall, the efforts to improve water supply and quality in South Florida depend on expanding availability of water for human and natural populations and on decreasing human demand. In 1994, the Florida Legislature passed the Everglades Forever Act to settle a federal government lawsuit against the South Florida Water Management District and the State of Florida for not enforcing water quality laws in the two federal areas of the remaining Everglades (the Loxahatchee National Wildlife Refuge and Everglades National Park). The Act resulted in the Comprehensive Everglades Restoration Plan (CERP) to restore a significant portion of the remaining Everglades through land acquisition, construction, regulation, and research. The plan will seek to retain as much water as possible in the system, and to modify the system to accommodate a population of 12 million people expected by 2050. The CERP plan specifically seeks to achieve the following (*see Figure 2.20*):

- modify surface structures to more closely mimic historic sheet flow from north to south.
- increase water storage capacity.
- provide flood protection and water supply for south Florida communities.

Strategy

The basic strategy of CERP involves increasing the storage capacity in the system. Planners and hydrologists believe there is enough water to support the needs of the entire system, but "the most critical constraint in restoring the Everglades is a shortage of areas for water storage" (South Florida Water Management District 1999). Therefore, the CERP plan seeks to:

- capture the 1.7 billion gallons of water per day that is currently lost to tide;
- store this water in underground and surface storage areas (the plan calls for 240,000 acres of undeveloped open space to be acquired for water storage and filtration, and 300 underground storage wells to be utilized)
- modify the timing and distribution of water to more closely mimic pre-drainage patterns;

- improve water quality with wetland and stormwater treatment areas (STAs) and require best management practices for agriculture;

The urban component of the restoration plan is somewhat limited in CERP. It involves establishing an East Coast Buffer to protect the Everglades from the urban areas, since current trends of westward urban expansion could impinge on the hydrologic function of the Water Preserve Areas. The plan refers to the South Florida Water Management District Water Conservation Plan as the means to address urban water consumption issues, but CERP itself does not include a detailed analysis of urban spatial patterns.

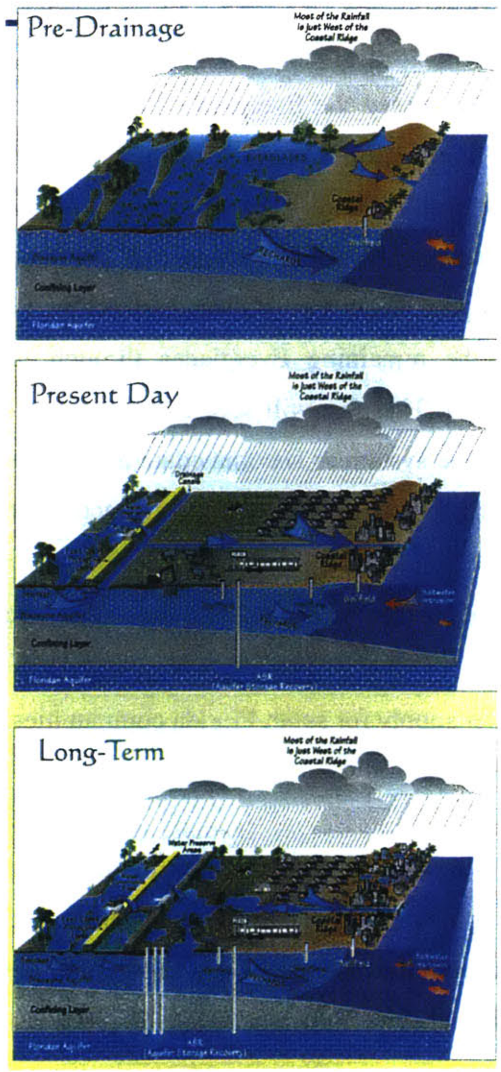


Figure 2.20: Alterations to Water Flows with Restoration Plan

Source: South Florida Water Management District 1999

Planners and engineers hope that these reconfigurations should reconnect severed links between the natural systems, improve water quality and direct more water to the Water Conservation Areas and Everglades National Park. Under current goals, 80% of the recaptured water will be allocated to the ecosystem and 20% will go to agricultural and urban uses. However, the distribution of water is still controversial, and the actual allocations have not been finalized. "Much less discussed in the Everglades Project are the growing cities and how their appetites will be served…Conservationists fear that dwindling bird populations and fragile vegetation will have a harder time making a comeback if water is siphoned off to communities first" (Boston Globe 2001). Federal officials say, however, that overseeing agencies cannot deviate from the program's primary mandate, ecosystem restoration, regardless of urban water needs. Water consumption patterns during the current drought suggest that Floridians find reducing water consumption difficult. As of April 2001, the South Florida Water Management District had barely reached 10% of a 30% water reduction goal, despite strict water restrictions (Boston Globe 2001). But even if the 80%-20% allocation is achieved, models predict that an additional 245,000 acre feet per year beyond the planned allocation are needed to achieve 90% of pre-drainage flows for the Everglades and Biscayne National Park. This highlights the need to reduce the reliance of urban and agriculture sectors on water that originally flowed to the Everglades.

Summary

Improving the hydrologic regime of South Florida is critical to the health of natural and human systems in the region. While manipulation of this regime has benefited humans, the systemic consequences have been very damaging and are growing worse. Improving the storage capacity of the system may allow the region to provide adequate water supply for the ecosystem, and to urban and agricultural areas. However, land consumption for urban development may hinder much-needed aquifer recharge and detract from efforts to purchase lands for surface water storage. Furthermore, increased urban water consumption, which exceeds the capacity of the underlying Biscayne and surficial aquifer systems, may compromise Everglades restoration efforts by requiring water diversion from the Water Conservation Areas. Therefore, providing for adequate recharge of these aquifers is an important means of ensuring that the needs of the urban population can be met without relying on supplements from other water sources. Thus, the influence of urban form and urban water consumption are key variables that must be studied in planning the restoration of the Everglades.

Chapter 3: Land Use

Development Patterns in Palm Beach County

Development Patterns in Palm Beach County

Palm Beach County presents an ideal opportunity to evaluate the hydrologic impacts of alternative urbanization patterns. The county has the third highest growth rate in South Florida, and West Palm Beach was designated as the "fourth most sprawl-threatened city among medium-sized cities in the country (Palm Beach County Planning Division 1999, Turner & Murray 2001). The population of the 2,000 square mile county is expected to increase 53% from 962,803 in 1995 to 1,477,204 in 2020 (Burchell 1999). The majority of new urban development is expected to occur in existing agricultural areas close to the Arthur R. Marshall Loxahatchee Wildlife Refuge, an important Water Conservation Area that releases water to the Everglades. In response to the pressures of a rapidly growing population, the county recently adopted the Managed Growth Tier System, a new growth management plan which encourages compact development as the preferred form of future urban development. This shift from the historical pattern of low-density sprawl development could significantly impact regional water storage capacity. This chapter provides an overview of historical urban development patterns in Palm Beach County and recent attempts to manage the adverse impacts of urbanization.

Early Settlement, Drainage, and Flood Control (1850s-1940s)

The difficulty of growing crops and building human settlements in the midst of the swamps and marshes that extend south of Lake Okeechobee prevented the development of the region for three centuries. However, this changed in the 1850s when the state of Florida sold the land cheaply to anyone who would drain and connect it to the railroad extension from the north. In 1894, the railroad magnate Henry Flagler extended his tracks through West Palm Beach to Miami along the dry highlands of the Atlantic Coastal Ridge. This led to large-scale settlement beginning in the early 1900s, and as people moved south, they drained the land for agricultural and urban development. It was during this period that Palm Beach County was settled, primarily as a vacation resort which later became home to a large number of retirees.

Initially, the population settled primarily along the coast, east of the Atlantic Coastal Ridge which was the natural boundary of the Everglades. However, even this area was subject to flooding during the rainy season as waters spilled through the cuts in the ridge and drained to the Atlantic Ocean. As flooding posed a significant impediment to further agriculture and urban development, the settlers built canals, dikes, and levees for flood control. These efforts only increased after the major hurricanes of 1926 and 1928. Continued urban and economic expansion drew more people to the region. With no income tax and favorable inheritance tax policies, the state attracted many new residents. Continued growth was viewed as a means to keep tax rates low and fuel economic expansion, which could produce more public revenue. The region's subtropical climate, and the fertile, year-round growing conditions were added incentives to settle there. Land speculation was rampant, and many small developers sought their fortune in building subdivisions for the winter tourists and the rising number of year-round residents. Along with urban development, agriculture dominated much of the economic activity in the early 1900s, with large areas of sugar cane and citrus coming into production. By 1935, agriculture was the highest source of income for the region after tourism, although less than 10% of the county's population lived in rural areas (Phelan 2000).

By the early 1940s, vast drainage primarily for agricultural purposes, had drastically reduced the size of the Everglades and severely damaged the remaining areas. Recognizing the need to protect the ecosystem, Congress designated the remaining undrained areas as a national park and conservation area in 1947. Despite these efforts to protect them, the Everglades were subjected to more drastic alteration by humans less than a year later. After two major back-to-back hurricanes ravaged the region in 1948, Congress authorized the Central & South Florida (C&SF) Project under the jurisdiction of the U.S. Army Corps of Engineers and the South Florida Water Management District (SFWMD) to implement large-scale flood control to protect urban and agricultural areas and to provide for water supply in the region (*see Chapter 2 for details*). This program facilitated further development of the agricultural sector and the urban areas in the region.

Population Boom and Sprawl Development (1950s-70s)

The end of World War II marked the beginning of the population boom in Palm Beach County, and an economic expansion driven by the tourism and service industries which continues to this day (*see Figure 3.1*). Settlement in Palm Beach County occurred primarily around Palm Beach and Boca Raton. Large numbers of retirees and tourists flocked to the region and continued to settle along the coast in the urban areas, fueling rapid urban expansion to accommodate the growing population. By 1970, most of the population was settled in the coastal cities or in small cities on Lake Okeechobee; however as demand for housing increased, the urban areas began to expand westward into the interior *(see Figure 3.2)*. By 1990, only 1/3 of the population lived in older coastal areas and lake settlements, and half a million people were added to the unincorporated areas of the county to the west, so that these areas comprised 50% of the regional population (Palm Beach County Planning Division 1999). According to the 2000 Census, this trend continued between 1990-2000 (Palm Beach Post 2001). As a consequence of this shift, agriculture declined or was pushed west, and the older cities went into a period of decline, following a broader nationwide trend at that time.

These development patterns have been characterized as "hasty, amenity-driven along shores, low density, and decentralized" (Audirac in Burchell 1999). Most of the residential development consisted of low-density single-family units, laid out on a grid, a pattern that continues today. According to the US Census, by 1990, most families lived in single-family detached units. In Palm Beach County for example, 62% of housing units are single-family (Burchell 1999). Densities are generally low, with 8-10 units per acre in urban areas, 4 units per acre in suburban areas, and less than 1 unit per acre in rural areas.

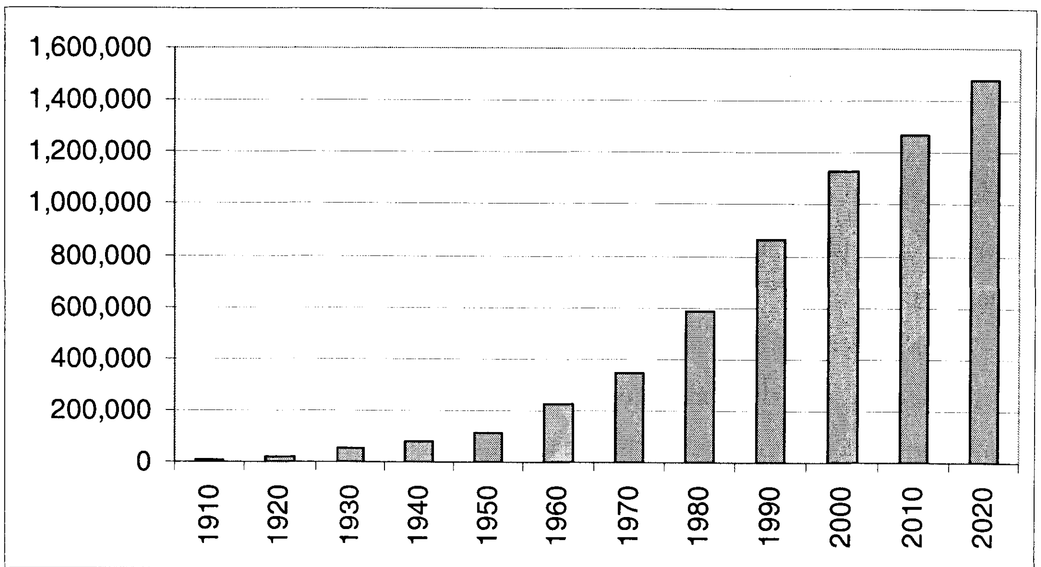
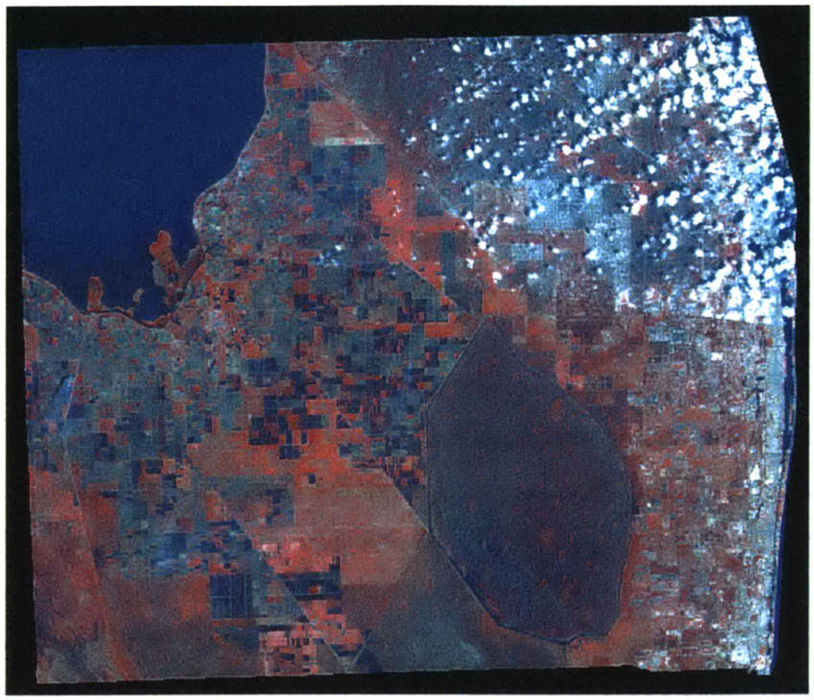


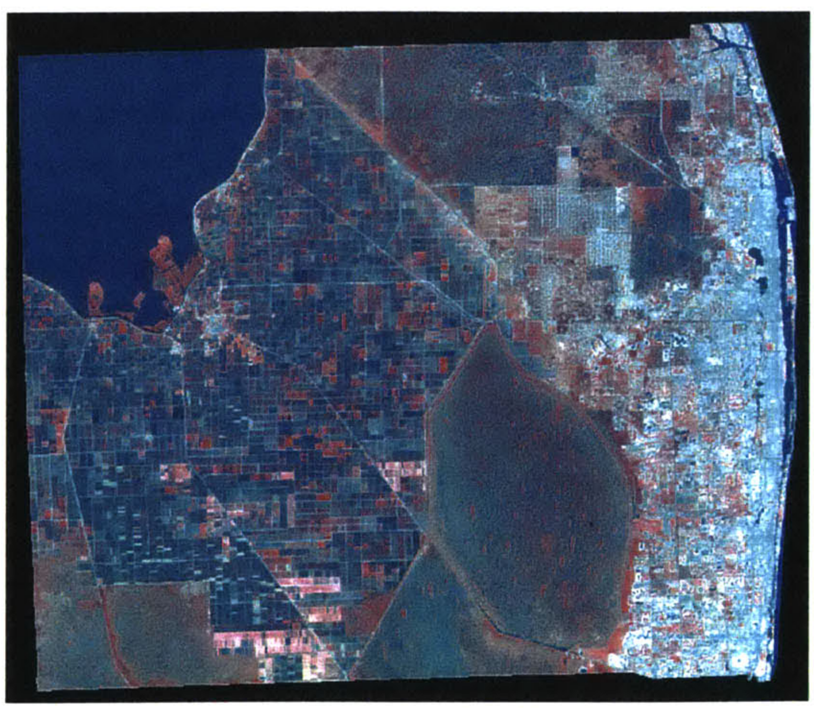
Figure 3.1: Historical and Projected Population Growth in Palm Beach County
Source: U.S. Census Bureau 2001

Figure 3.3: Urbanization in Palm Beach County

1973



1986



Source: Florida Geographic Data Library, University of Florida.
Ambika Anand Prokop. Dept. of Urban Studies & Planning. MIT. May 2001.

Development Impacts

Supporting this decentralized, low-density urban development pattern required expanding road and utility services, paving aquifer recharge areas, and redirecting rainwater to the ocean through drainage canals. These landscape changes have had significant impacts on the natural environment, including the loss of natural habitat, lowering of the water table, soil subsidence, and degradation of water quality which affected not only humans, but also the plants and animals of the Everglades. In addition, farmland was also converted to urban development in recent years because it was flat, dry, and inexpensive. Land clearing, dredging, and filling have also occurred on or adjacent to natural habitats, and since 1989, 3,721 acres (or 8% of these lands) have been lost to development (Palm Beach County 1999).

Growth in Palm Beach County has also strained basic infrastructure. Currently, the county faces heavy traffic congestion, overcrowded schools, and lack of affordable housing. Water resources have also been stretched. The regional water management system was implemented as part of the C&SF Project to accommodate approximately 1 million people in southeast Florida. However, by 2000, approximately 4 million people resided in the area, and studies project a population of 6 million people by 2020 (Palm Beach County 1999). Meanwhile, the system has not been upgraded to support this growth.

Comprehensive Planning and Growth Management (1970-80s)

Planners and politicians alike realize the stresses placed on both the natural environment and public infrastructure by the pace of urban development. In 1975, the Local Government Comprehensive Planning Act mandated that municipalities develop a master plan addressing land use, infrastructure, housing, and intergovernmental coordination. It also required that local governments tie zoning ordinances and capital facilities programs to these plans by 1979. In 1985, the Florida Growth Management Act was passed to address conflicts between economic development policies and environmental protection. The act required master plans to provide the following:

- **consistency**: requiring that local plans be consistent with state and regional planning goals.
- **concurrency**: requiring that public infrastructure be in place or under development before new housing or office development projects are approved. Development can occur only if the capacity is available, and the site has legal positive outfall (drainage).
- **compactness**: requiring that local planning policies encourage compact development.

Palm Beach County adopted its current Comprehensive Plan in 1989. The plan designates land for low, medium, and high-density development in urban areas, and for low-density development in rural areas. To facilitate these goals, the county designated urban and rural levels of utility service that accommodate growth consistent with county goals and the Concurrency Laws required by the Florida Growth Management Act.

The concurrency requirement of the Growth Management Act has proved very controversial. Some argue that it has promoted sprawl since adequate road infrastructure that meets the act's requirements is only available on the urban fringe. Others say that while it may have slowed overall development, the act also unintentionally encouraged "leapfrog" development and the building of sprawling subdivisions at low densities in rural areas, since only these areas offered sufficient septic systems and unused road capacity (Innes in Burchell 1999). Other critics claim the act may have actually slowed urban economic development, since the sewer and water systems in metropolitan regions are already at capacity.

Despite these disagreements, public support for efforts to manage urban growth and curb environmental degradation appears to have grown. There is a "more tolerant attitude toward growth management concepts in the economic and political spheres" (Kolo and Watson in Burchell 1999), and "special interest groups from all sectors of Florida's society reflect strong citizen support for managing growth effectively..." (DeGrove in Burchell 1999).

Nevertheless, for Palm Beach County, and South Florida as a whole, the challenges of rapid growth, urban sprawl, declining urban areas, encroachment on agricultural and conservation lands, road congestion, and strains on water supply, have only grown.

> The state's efforts to manage growth over the years seems to have been lost on South Florida. While the region's developers moved west over the years, they leapfrogged across pockets of agricultural areas, open space, and environmental havens to open new, planned communities such as Miami Lakes in Miami-Dade County, Weston in Broward County, and Wellington in Palm Beach County. (Turner & Murray 2001).

Present Situation and Future Projections (1990s-future)

Population and Demographics

According to the U.S. Census, Palm Beach County continued to grow rapidly between 1990 and 2000, and the county maintains its place as the third largest county in the state behind Miami-Dade and Broward. Since 1989, the county growth rate has been 2.3%, which exceeds the state average, and the county absorbs approximately 20,000 new residents each year (Palm Beach County Planning Division 1999). Further, population has continued to expand into the westward areas as illustrated by the municipality of Wellington, just west of the urban/suburban region, which grew 85% from 20,670 in 1990 to 38,216 in 2000 (Palm Beach Post 2001). Furthermore, the aftermath of Hurricane Andrew in 1992 sparked an exodus of residents from Miami-Dade and Broward Counties, which took the brunt of the storm, to Palm Beach County (Turner & Murray 2001).

According to planners, the county's most important demographic issue is its considerable in-migration: since 1985, in-migration has accounted for approximately 91% of the annual population increase (Palm Beach County Planning Division 1999). Palm Beach County also has a high seasonal population, with many nonresidents arriving in the winter. These nonresidents often stay 6 months on average and place high demands on water, sewer, transportation infrastructure and housing. The average seasonal population in Palm Beach County is 51,000 people with a peak of 103,000 people in January to a low of 13,000 people in August.

Land Use

According to planners, the last 20 years have brought a dramatic change in land use patterns, as large numbers of people sought a "vacation-like" environment (Palm Beach County Planning Division 1999). These development patterns are a response to the availability of large-lot antiquated subdivisions in the rural areas of Palm Beach County, whose designated low-densities predate the 1989 Comprehensive Plan.

The late 1980s saw significant building permit activity, with a peak of 14,655 permits issued in 1986. Building declined during the recession of the early 1990s, but recovered after 1991, and has risen steadily since. In 1995, 10,465 residential permits were issued. Historically, 50-60% of building permits issued were for single family homes (Palm Beach County Planning Division 1999).

Today, while the most heavily populated region in the county is the urbanized coastal area from Riviera Beach to Boca Raton, the unincorporated areas to the west have a larger population than any one of the 37 municipalities in the county. Between 1980 and 1990, the share of total population in the county that lived in unincorporated regions rose from 37% to 47%, (Palm Beach County Planning Division 1999) (*see Figure 3.3*). New development is occurring in the unincorporated areas and new jurisdictions of

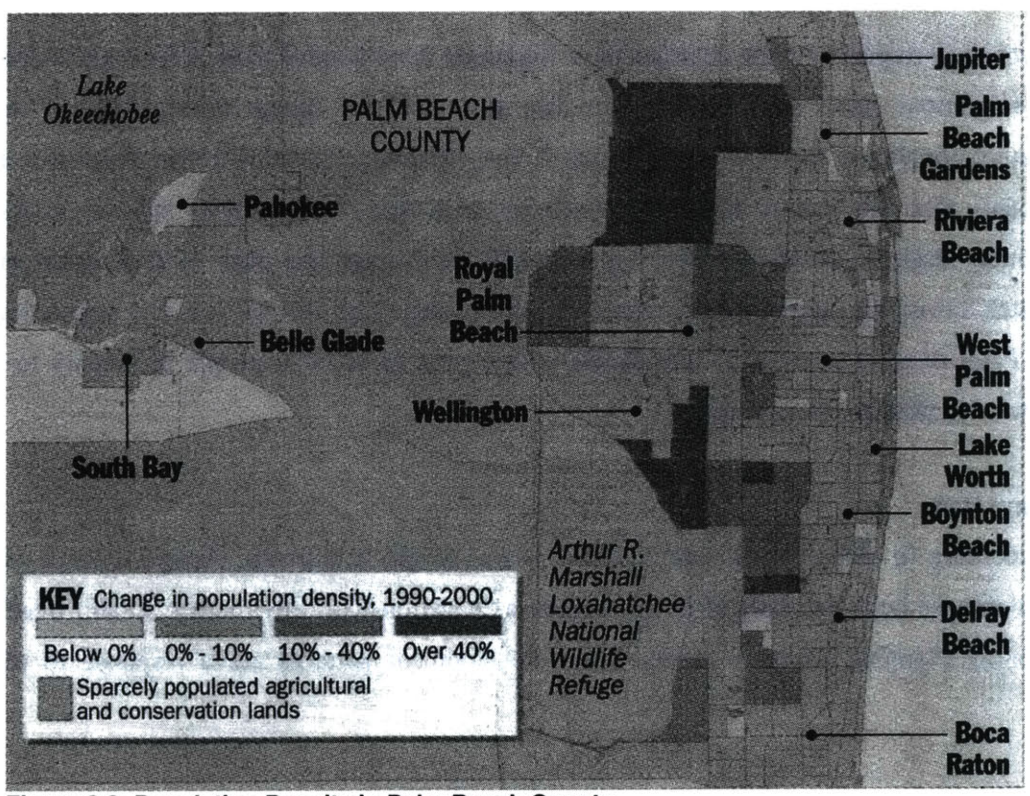


Figure 3.3: Population Density in Palm Beach County
Source: Palm Beach Post, 2001

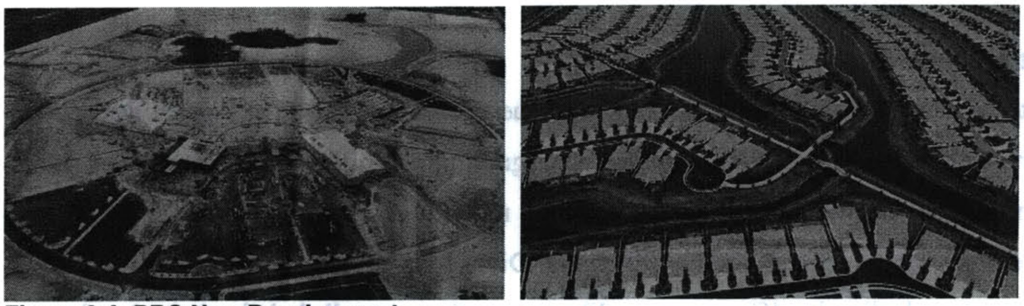


Figure 3.4: PBC New Development
Source: Palm Beach Post

Greenacres, Royal Palm Beach, Palm Beach Gardens, and Jupiter (*see Figure 3.4*). If these land use patterns continue, future development in Palm Beach County will be characterized by low-density single-family residential development in prime farmland.

Water Demand

Water consumption will also be a growing issue in coming years. The biggest water users in the county are public supply utilities and agriculture (Miller 1988). Total water use in Palm Beach County during 1990 was 347 million gallons, of which 72% went to agriculture (Palm Beach County Planning Division 1997). Agricultural water use is expected to decline by 4% over next 20 years as farmers sell their lands to developers. However urban water use will increase 94%, with the growth in urban population and tourism. Public water supply comprised 18% of 1990 demand and is projected to grow to 30% of the 2010 demand (Palm Beach County Planning Division 1997). "Water-use trends imply that public supply groundwater (withdrawals) are more likely to affect the aquifer system than those of agricultural irrigation (Miller 1988).

Palm Beach County has only one principal aquifer system: the surficial aquifer system including the unconfined Biscayne Aquifer in southern Palm Beach County. The Floridan Aquifer System located under the entire county is unsuitable for drinking purposes. Groundwater supplies are more abundant and readily accessible in the eastern part of the county. However, even if new development occurs closer to these regions, water demand models for 2010 indicate that shortages will arise unless supply increases or demand drops (South Florida Water Management District 2000).

Current County Growth Management Plans

Managed Growth Tier System

According to county planners, "the protection of the quality of life for present and future citizens, as well as the protection of natural resources of the county, is undermined by unplanned piecemeal development" (Palm Beach County Planning Division 1999). In an attempt to address the issues of urban sprawl, congestion and the burden on natural resources and public infrastructure, the Palm Beach County Planning Division adopted the Managed Growth Tier System in August 1999. The plan seeks to prevent further sprawl by encouraging compact, mixed-use, and in-fill development, and to protect natural resources and farmland. This amendment to the Comprehensive Plan specifically seeks to redirect growth to the eastern areas of the county. To accomplish this, the county established a tiered system that designates five development levels to be managed, with higher density development encouraged in existing urban and suburban areas, and limited lower density development allowed in the rural areas (*see Table 3.1 & Figure 3.5*). These approaches are consistent with the alternate (compact) development scenario projected by the *Eastward Ho! Development Futures* report.

Under the new system, the county will continue to abide by the Concurrency Laws to:

- ensure suitable levels of service
- ensure compatibility with adjacent land uses
- protect areas subject to seasonal/periodic flooding
- regulate stormwater management and drainage
- protect potable water wellfields, recharge areas, open spaces and natural resources

Under the new plan, the county will also restructure its utility service areas designations to three categories: urban, limited urban, and rural service areas, using the following determining factors:

- density and intensity of land use
- cost and feasibility of extending services
- need to protect natural resources
- degree of reinvestment desired

Urban/Suburban Tier: includes all lands in the urban service area both along the Atlantic coastline and along the eastern and southern edges of Lake Okeechobee (including the cities of South Bay, Belle Glade and Pahokee). This area will be managed to accommodate ~90% of the county population and to support urban and suburban densities, intensities and services. Under the new system, future residential developments must be built at densities of *at least* 2 units per acre. Residential density caps would be increased from 8 to 12 units per acre in some areas and from 6 to 8 units per acre in others. Floor to Area Ratios in commercial density caps would be raised from .20 to .25 in certain areas.
Exurban Tier: considered rural due to sparse development and agricultural operations. This area consists of vested residential subdivisions created prior to 1970 with lots sizes less than 2.5 acres without utility service. In recent years, these areas are being developed for small residential estate lots. Critical issues in the area include impact of population growth on infrastructure, concentration of septic tanks on small acre lots, and drainage and flood control. Under the new tier system, the area will be developed with a mix of urban and rural services. Permitted land uses include residential, commercial, agricultural, recreational, institutional, transportation and utility, and conservation uses. All new development must have a minimum 2.5 acre lot size. This area is a focus for growth management in the county.
Rural Tier: includes agricultural land with densities from 1 dwelling unit per 5 to 20 acres. Population growth in the area has been steady and total population has increased 38% from 1990 to 1998 due to encroachment of adjacent urban areas. Consequently, the region's many citrus farmers have come under pressure to sell their lands. Under the new system, future land use permitted includes rural residential, commercial, agricultural, recreational, institutional, transportation and utility, and conservation. All new development will have a minimum 5 acre lot size.
Agricultural Reserve Tier: includes unique farmland consisting mostly of sugar cane fields and wetlands where development has typically occurred at 1 unit per 5 acres. This area is also a potential 1,600 acre Water Preserve Area for the Everglades Restoration plan, which could serve as a surface reservoir with an adjacent aquifer storage and recovery well. These areas could supplement the central and southern county water supply and reduce reliance on Loxahatchee and Lake Okeechobee. Under the new plan, this area will generally be preserved for agricultural use; however, if necessary it may be urbanized at low residential densities.
Glades Tier: designated primarily for agriculture (mostly sugar cane). Future permitted land uses include agriculture, conservation, recreation, and transportation and utilities. While development pressure is considerable here, the low-lying muck soils prevent heavy urbanization.

Table 3.1: Palm Beach County Managed Growth Tiers
Source: Palm Beach County Planning Division 2000

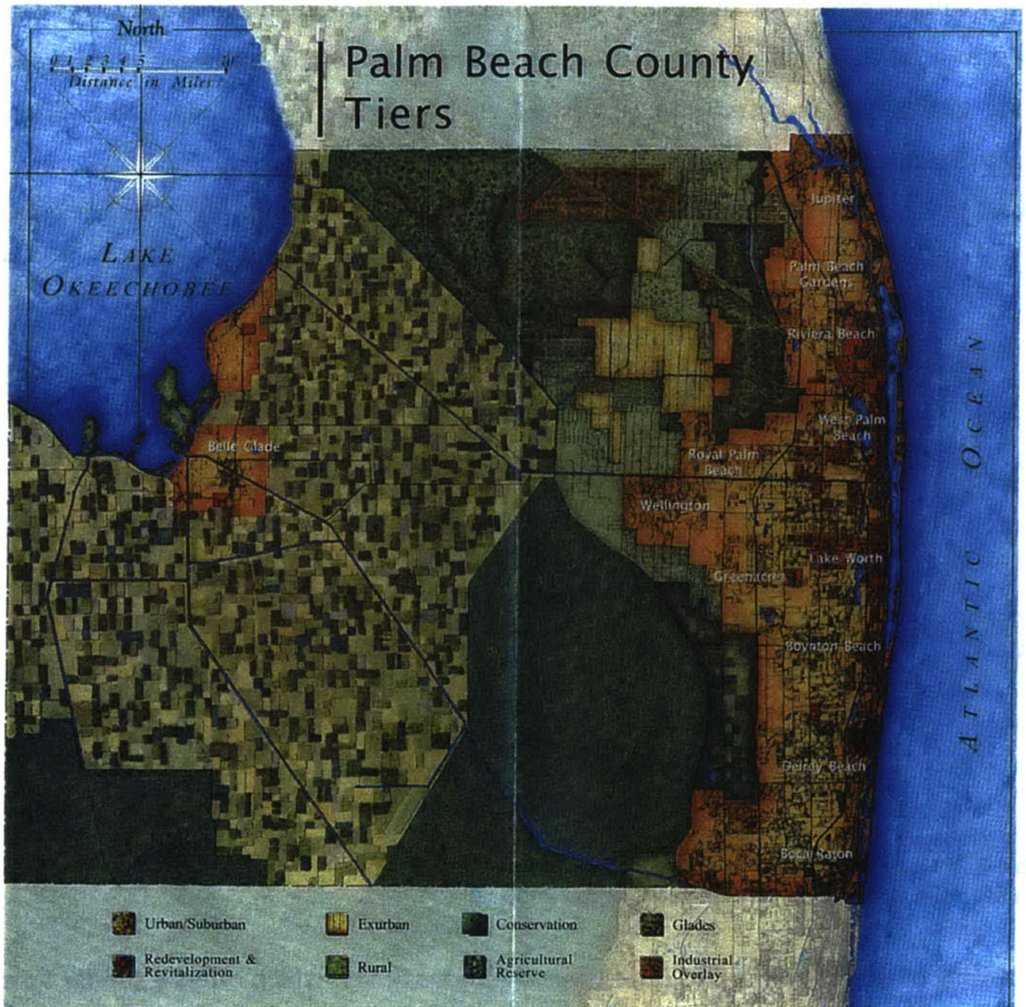


Figure 3.5: Tier System Map
Source: Palm Beach County Planning Division

Table 3.2 summarizes municipal water services under the growth management plan. The county will not provide or subsidize the provision of centralized potable water or sanitary sewer in rural areas unless such services are required to correct or prevent a projected public health hazard or prevent significant environmental degradation (Palm Beach County Planning Division 2000).

Service	Rural Service Area	Limited Urban Service Area	Urban Service Area
Stormwater	Standards will vary depending on development type and capacity of individual drainage basin	Standards will vary depending on development type and capacity of individual drainage basin	Standards will vary depending on development type and capacity of individual drainage basin
Potable Water	Well	• Well (minimum level of service) • Centralized Potable Water Supply System (allowable level of service)	Centralized Potable Water Supply System
Sanitary Sewer	Septic Tank	• On-site Sewage Disposal system (minimal level of service) • Centralized Sanitary Sewer System (allowable level of service)	Centralized Sanitary Sewer System

Table 3.2: Municipal Water Services in Palm Beach County
Source: Palm Beach County Planning Division 2000

According to the *Eastward Ho! Development Futures* Study, which offers a similar form of "alternative development" to the Managed Growth Tier System, a shift to compact development by 2020 would reduce the share of population living in nonurbanized areas from 67% to 55%, a reduction of 169,000 people.

One should note that while the county has embraced compact development, it has little jurisdiction over municipalities to implement it. And while the county has developed a transfer of development rights (TDR) program under which land owners can transfer development rights from rural areas to urban areas, few cities have participated in the program so far (Sharma 2001).

Open Space and Conservation Lands

Palm Beach County has three natural physiographic areas: the Atlantic coastal region (with terrestrial ecosystems), the Eastern Flatwoods (with swamp, marsh and terrestrial systems), and the Everglades (with freshwater marshes and swamps) (*see Figure 3.6*). The largest designated conservation areas in Palm Beach County are the Arthur R. Marshall Loxahatchee National Wildlife Refuge, which is part of the Water Conservation Area for the C&SF Project, and the J.W. Corbett Wildlife Management Area (*see Figure 3.7*). However, many of the adjacent areas are also important for ecosystem restoration. These areas are currently unprotected and threatened by development pressures. For that reason, in 1991, a $100 million bond issue was passed to fund the acquisition of approximately 25,000 acres of environmentally sensitive lands (*see Figure 3.8*) (Palm Beach County Planning Division 1997). Compact development is viewed as an urban form that facilitates the acquisition and protection of these lands. Furthermore, every new development would be monitored for impacts on natural systems, including high quality coastal and inland wetlands and future potable water supply wellfield areas.

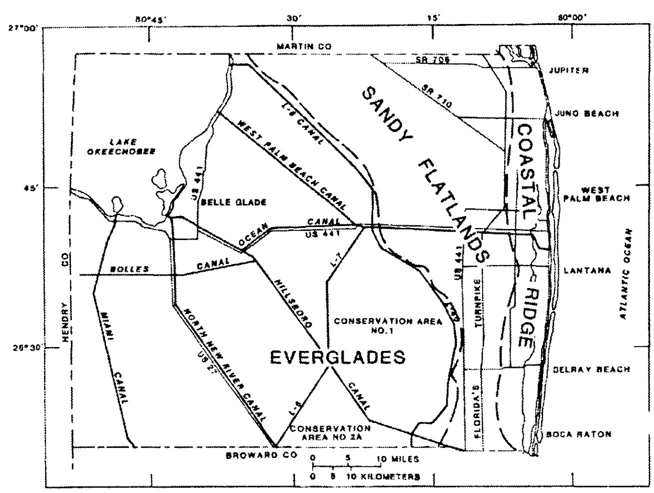
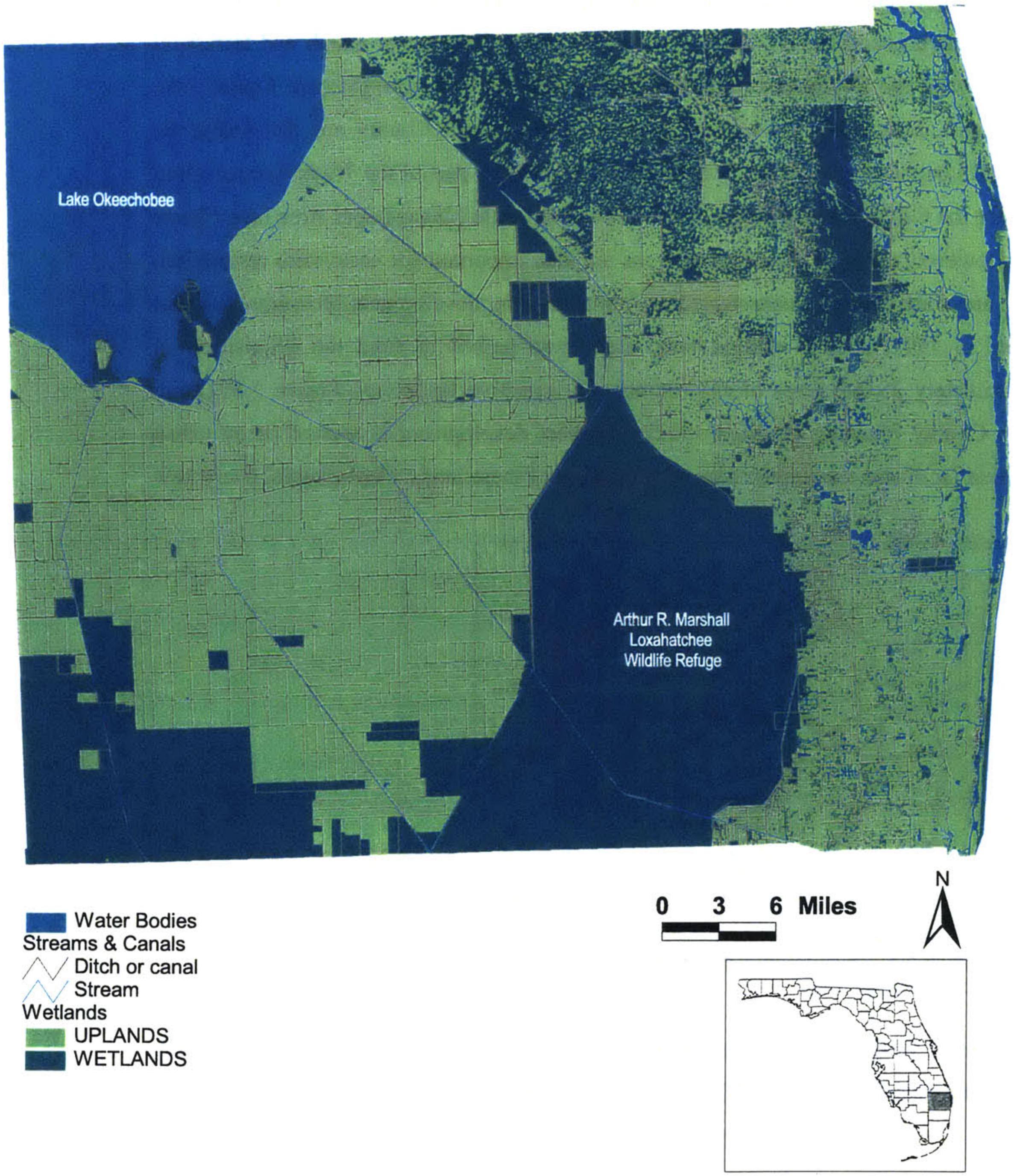


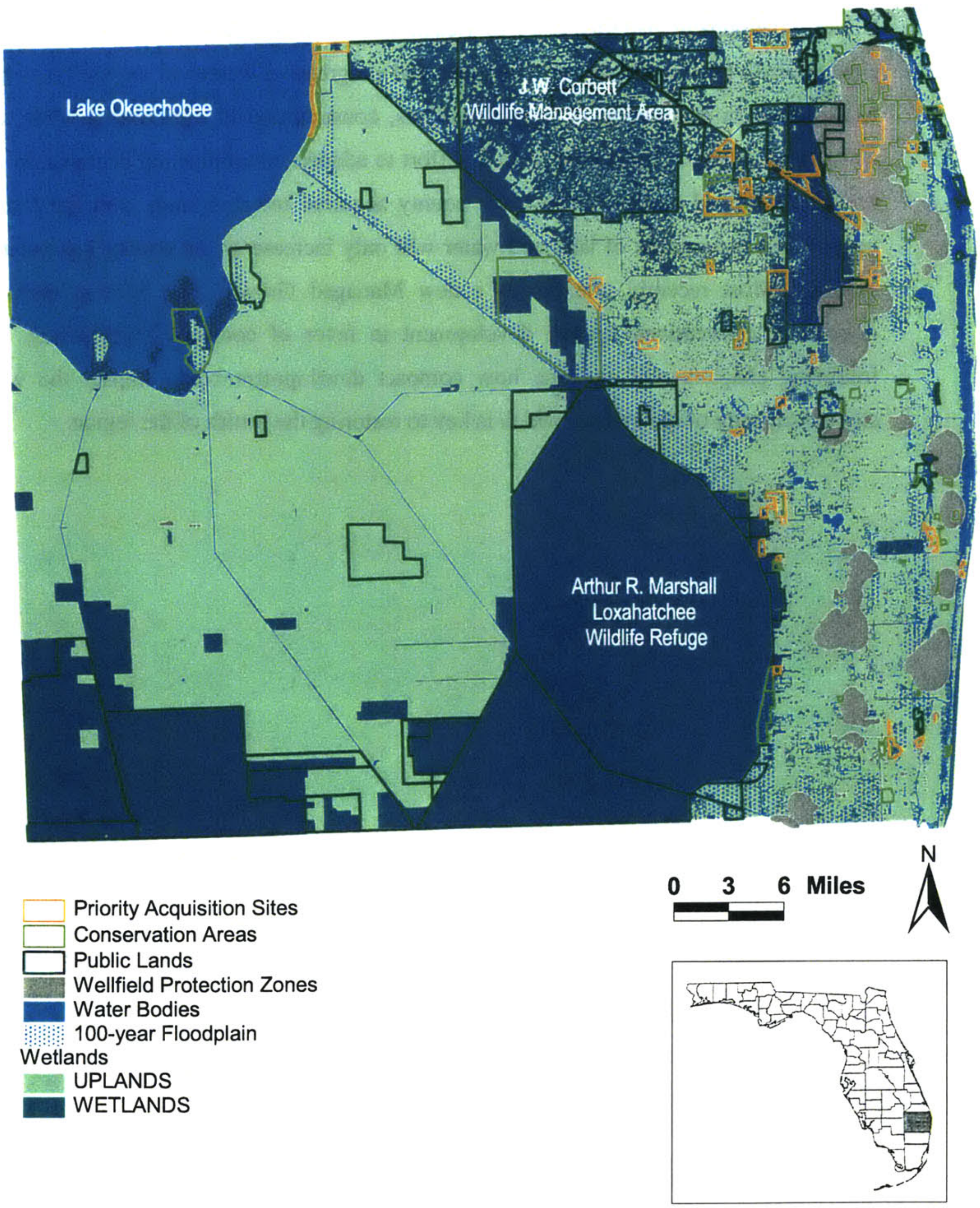
Figure 3.6: Physiography of Palm Beach County
Source: Miller, 1988

Figure 3.7: Hydrography of Palm Beach County



Source: Florida Geographic Data Library. University of Florida.
Ambika Anand Prokop. Dept. of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.

Figure 3.8: Environmentally Sensitive Lands in Palm Beach County



Source: Florida Geographic Data Library. University of Florida.
Ambika Anand Prokop. Dept. of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.

Summary

Urban development patterns in Palm Beach County in the last 100 years have been characterized by low-density development and progressive westward expansion, which has resulted in destruction of natural habitats, consumption of agricultural lands, and stress to the regional water supply. In an effort to address environmental degradation and protect threatened natural habitats, the county acquired selected lands over the last 20 years. But consumption of land and water will only increase as the county's population expands. Most recently, the county's new Managed Growth Tier System seeks to discourage conventional sprawl development in favor of compact development. The following chapters will examine how compact development could impact the water storage capacity of the system, which is key to restoring the health of the region.

Chapter 4: Methodology

Calculating Aquifer Recharge

Evaluating the impact of compact development on water storage in Palm Beach County requires projecting the intensity, type, and spatial distribution of future urban development in the region. This analysis expands on the land use projections of the *Eastward Ho! Development Futures: Paths to More Efficient Growth in South Florida* report. The report evaluated the different land consumption and infrastructure impacts of two scenarios of development – compact and sprawl – in South Florida. This study supplements the *Eastward Ho!* analysis by examining the implications of these two urban development scenarios for aquifer recharge in Palm Beach County. Further, it estimates the impact of these two development scenarios on the regional water budget in 2020.

***Eastward Ho! Development Futures* study: Summary of Methodology**

The *Eastward Ho! Development Futures* report projected two scenarios for future urban development, based on the premise that an alternative to current patterns is needed to protect natural resources and to minimize the stress on public infrastructure. The report examined the following scenarios:

- "**Sprawl Development**" – the historical pattern and current trend in urban development in the region characterized by low density and leapfrog development.

- **"Compact Development"** –alternative form of development characterized by:
  - In-fill development, redevelopment of established centers, and selected growth in new centers,
  - 20% higher densities in urban areas,
  - Clustering (development at conventional gross densities but with greater open space allocation through reduction of lot size), and
  - Buffering of wetlands and protection of agricultural and environmentally sensitive lands.

The report estimated the acreage consumed under the two development scenarios by converting projected increases in households and jobs into demand for residential and nonresidential lands. The details of the methodology used in the *Eastward Ho!* report are outlined in Appendix B. For purposes of analysis, each county was divided into urban and non-urban regions (*see Figure 4.1*).

In the compact development scenario, a percentage of the expected growth was redirected to the urban Eastward Ho! area from the other non-urban regions as follows:

Region	% Population and Households redirected to urban (Eastward Ho!) area	% Jobs redirected to urban (Eastward Ho!) area
Middle Area	20%	33%
Hurricane Hazard Area	50%	40%
Agricultural Areas	90%	33%
Conservation Areas	100%	100%

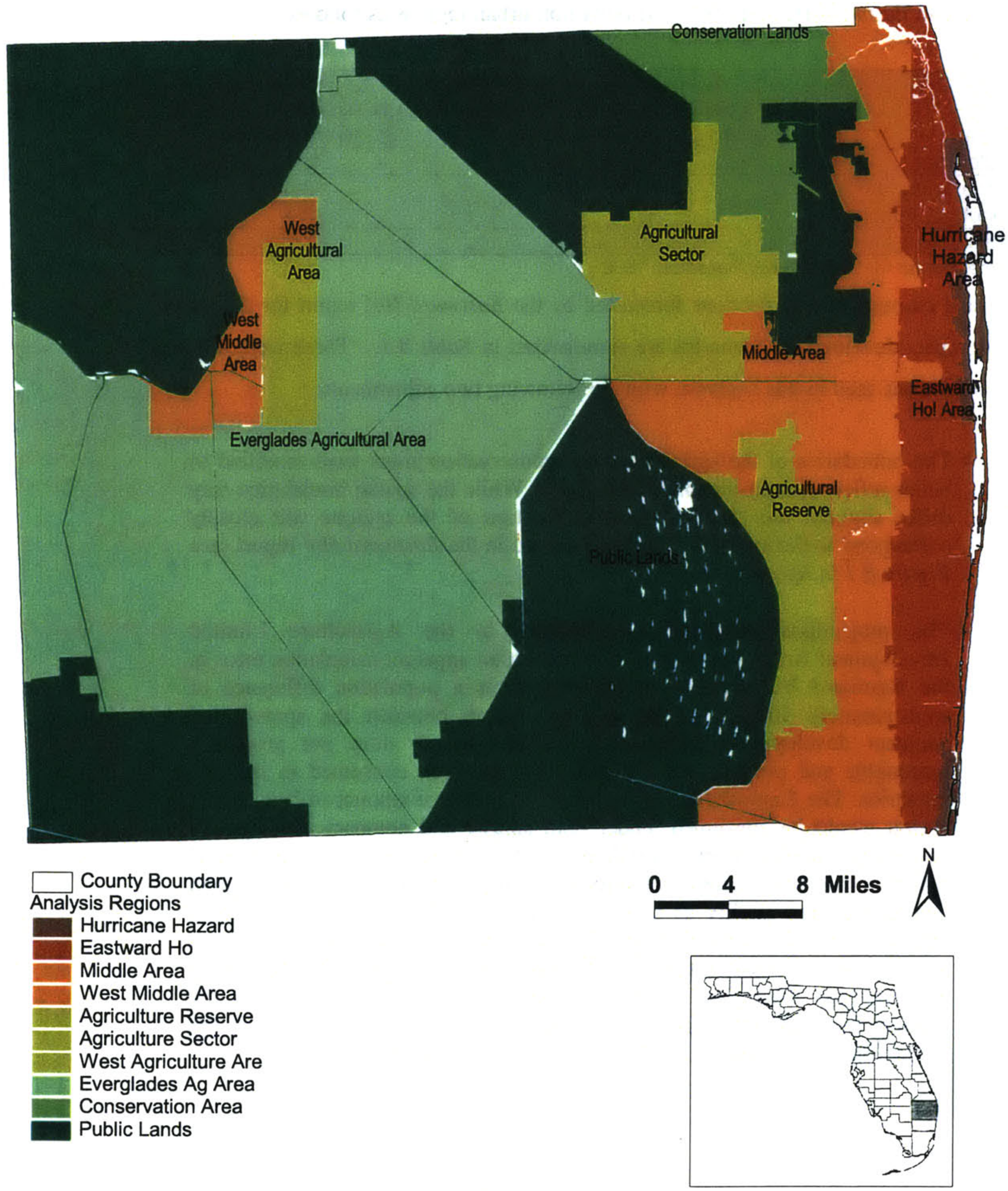
Source: Center for Urban Policy Research. 1999.

The land consumption projections forecasted by the *Eastward Ho*! report for the sprawl and compact development scenarios are summarized in *Table 4.1*. These were the land use projections used in this analysis, with the following two adjustments:

- The boundaries of the agricultural and conservation areas were modified to better reflect current planning boundaries. While the spatial boundaries may differ slightly, the size and general location of the regions still closely correspond to the analysis regions described in the *Eastward Ho!* report (*see Figure B.1 in Appendix B*).

- The projections for land consumption in the Agriculture Limited Development Areas were adjusted to correct an apparent calculation error in the *Eastward Ho!* report. The study projects a population difference of approximately 100,000 people for the region between the sprawl and compact development scenarios by 2020. But, it does not project a reasonable and proportional difference in land area consumed in the two scenarios. The *Eastward Ho!* projection that the same amount of land in that region would be consumed, under both sprawl and compact development conditions, would require densities of 10 units/acre under the sprawl condition in the Limited Development Agricultural Areas. Such high densities do not qualify as sprawl and are unlikely to occur in that area. Furthermore, the *Eastward Ho!* land consumption estimates under the sprawl scenario are not consistent with the numbers that would result from the study methodology. Therefore, projected residential land consumption for the Limited Development Agricultural Areas was recalculated according to the methodology described in the *Eastward Ho!* report as follows:

Figure 4.1: Analysis Regions in Palm Beach County



Sources: Burchell 1999 and South Florida Water Management District 1997.
Ambika Anand Prokop. Dept. of Urban Studies & Planning. Massachusetts Institue of Technology. May 2001.

TABLE 4.1: PROJECTED LAND CONSUMPTION IN PALM BEACH COUNTY (1995-2020)

Region	Description	Acres consumed with sprawl development	Acres consumed with compact development	Difference	% difference with compact development
Eastward Ho!	The current boundary of urban development, including most coastal area, but excluding beaches and high hazard coastal areas. Under sprawl development patterns, this area would experience modest growth, while under the compact development model, this would be an area of encouraged growth.	9,066	15,581	6,515	72%
Hurricane Hazard	The strip of land on the coast which is vulnerable to strong hurricane winters. Despite the hazards, the area is desirable for development due to its oceanfront location. Under sprawl development patterns the area will grow, but under the compact development scenario, this would be an area of limited development, with infill and high density development encouraged.	1,210	629	-581	-48%
Middle Area: **East Middle Area &** **West Middle Area**	The suburban/rural area which is currently experiencing rapid conversion of vacant and agricultural lands to commercial and residential development. Under current sprawl development patterns, 62% growth is expected in the East Middle Area, while little is expected in the economically depressed areas of the West Middle Area. Under the compact development scenario, this region is an area of managed growth in which new development occurs in specific centers where adequate infrastructure is provided. Investment is also made in the West Middle Area.	34,672	37,130	2,458	7%
Agricultural Area: **Limited Development Area (Agricultural Reserve, Agricultural Sector, Western Agricultural Area)** **& No Development Area (Everglades Agricultural Area)**	Agricultural lands which are sparsely settled but are experiencing considerable development pressure. Under current trends, the Agricultural Reserve and Sector Areas will experience a rate of growth higher than the Middle Areas, with a projected 234% population increase and a more modest 34% job increase. Under the compact scenario, the Agricultural Reserve and Sectors Areas will be allowed limited growth with new development occuring in existing locations or new centers. Remaining agricultural lands in the Everglades Agricultural Area will be protected for aquifer recharge and agricultural use.	53,009	9,424	-43,585	-82%
Conservation Area	Privately held wetlands and other environmentally sensitive lands. Currently these areas are experiencing some development pressures, with projected population growth of 41%. Under the compact development scenario, no growth would be allowed.	13,997	0	-13,997	-100%
Public Lands	Publicly held areas including natural habitats used for state parks, wetland ecosystems, aquifer recharge, wildlife management, and Indian reservations. Currently, no development occurs here, and none is projected under the compact development scenario.	0	0	0	-
Total		**148,181**	**59,551**	**-88,630**	-60%

Land consumption	**= (units /density) + platting coefficient (units/density)**
Sprawl scenario:	= (56,877 units/1.3 du/acre) + 0.2 x (56,877 units/1.3 du/acre) **= 52,501 acres (not 4,760 acres projected by report)**
Compact scenario:	= (5,950 units/0.8 du/acre) + 0.2 x (5,950 units/0.8 du/acre) **= 8,925 acres (not 4,760 acres projected by report)**

These adjustments significantly change the results of both this study and the *Eastward Ho! report* by projecting an even greater difference in land consumption between sprawl and compact development, than originally indicated. These calculation errors were very significant because they affected growth estimates in the Agriculture Limited Development Area, the region experiencing the greatest development pressure in Palm Beach County.

This last modification, notwithstanding, the generalized spatial patterns predicted by the *Eastward Ho! Development Futures* report corresponded to the analysis and goals set by the Managed Growth Tier System adopted by Palm Beach County Planning Division (*see Chapter 3 for details*). Based on their analysis of these patterns, both the County Planning Division and the *Eastward Ho!* authors embrace the compact development scenario as the preferred form of future urban development.

Methodology for Calculating Aquifer Recharge

To assess the impact on water storage of the two growth scenarios projected by the *Eastward Ho!* report, this study projects the spatial distribution of future urban development and models how much aquifer recharge would occur under the new land use scenarios. Figure 4.2 illustrates the general model used to determine aquifer recharge using the ESRI ArcView 3.2 Geographic Information Systems (GIS) application.

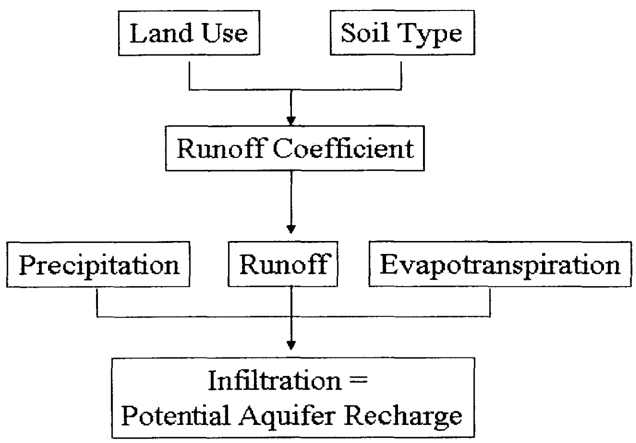


Figure 4.2: GIS Determination of Aquifer Potential Aquifer Recharge

The following specific steps are used in the GIS analysis:

<u>Spatial projection of future land use</u>

Step 1: Divide the 1995 GIS land use coverage into the different analysis regions. This coverage is the basis for the *Eastward Ho! Development Futures* study and has been divided into the following analysis regions: Eastward Ho Area, Middle Area, Hurricane Hazard Area, Agricultural Areas, Conservation Area, and Public Lands.

Step 2: Identify parcels of land available for development in each region. The following categories of land are considered available for development: vacant land, agriculture and rangelands, barren lands (mostly beaches), uplands, and wetlands. Current land uses classified as residential, commercial, institutional, recreational, transportation, communications, or utilities are considered unavailable for development.[1]

Step 3: Eliminate any "developable parcels" which lie within conservation areas. Public lands, priority acquisition sites, wellfield protection zones, or the 100-year floodplain can be classified as conservation areas. These areas either have high value as natural habitats, aquifer recharge areas, or are prone to flooding, and therefore should not be developed.

Step 4: Select enough "developable parcels" to meet the land consumption values for the two development scenarios estimated by the *Eastward Ho! Development Futures* report. The following assumptions are used:

- New development is more likely to occur closer to existing development and infrastructure.

- Parcels are developed in the following order of priority: vacant, agriculture and rangeland, barren lands, uplands, and wetlands. Vacant lands are used first, as their development does not require displacement of existing uses.

- For a best case scenario for protection of natural habitats, agriculture and rangelands ware assumed to be developed before uplands, barren lands, and wetlands. The latter are protected for their habitat value and for water storage. In reality, developing upland forest and barren lands before agriculture and rangelands is more likely since there is no associated economic loss or displacement involved with developing "virgin land." However, due to the high value and potential for development of agricultural lands close to urban areas, many farmers have sold their lands for development. This provides the farmers greater economic return than continued agricultural production. In recent years, 51% of the acreage used for new residential and nonresidential development has come from former agricultural lands (Burchell 1999). This suggests that agricultural lands have a strong likelihood of being developed before uplands or barrier lands in the future. Wetlands are heavily regulated by federal laws and their development require mitigation, so these lands are likely to be developed last.

[1] While industrial lands can be redeveloped to meet land consumption needs, these land uses are not considered for development for this study, since the status of these lands and the economic ramifications of redevelopment are unclear. Furthermore, developers often shy away from industrial lands, as these may require contaminant remediation.

In each region, sufficient land is identified for development to come within 10 acres of the *Eastward Ho!* projected land consumption estimates for either future development scenario. In some regions, it is impossible to meet the development quota without intruding upon floodplains, wellfield protection zones, priority acquisition areas, or conservation areas. In these cases, small isolated pieces of open space are identified for new urban development before larger areas of open space, based on the principle that larger tracts of land support more biodiversity (greater numbers and types of species) and, therefore, are more ecologically valuable. Specific results regarding the identification of "developable" lands in each region are summarized in Table C.1 in Appendix C.

Step 5: Assign a new land use for each parcel selected for future urban development. New land uses are identified either as high-, medium-, or low-density residential or as high- or low-intensity commercial, based upon the following definitions:

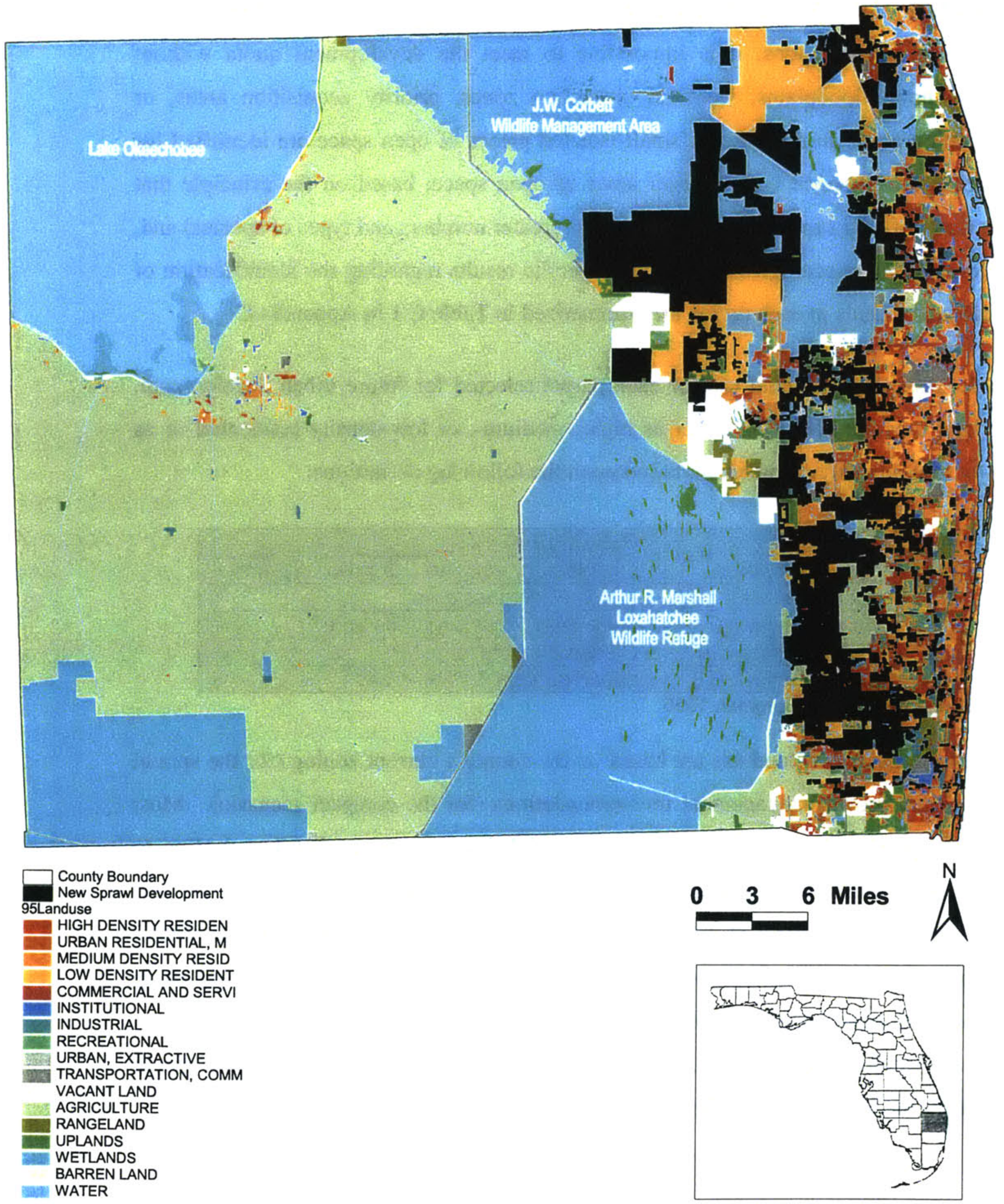
Land Use Category	Definition
Low Density Residential	Less than or equal to 1 dwelling unit/acre
Medium Density Residential	1-5 dwelling units/acre
High Density Residential	More than 5 dwelling units/acre
Low Intensity Commercial	Offices & institutions
High Intensity Commercial	Urban centers & retail areas

Source: Adamus & Bergman 1995.

The projections of new land use are based on the county's current zoning (for the sprawl scenario) and growth management recommendations (for the compact scenario). Most new development is residential. New commercial development is distributed close to existing commercial development and/or near major roadways. Furthermore, no new nonresidential development is assigned to industrial use, as economic forecasts predict more growth in the service industries (Burchell 1999). The distribution of new land use in each region is summarized in Table C.2 in Appendix C.

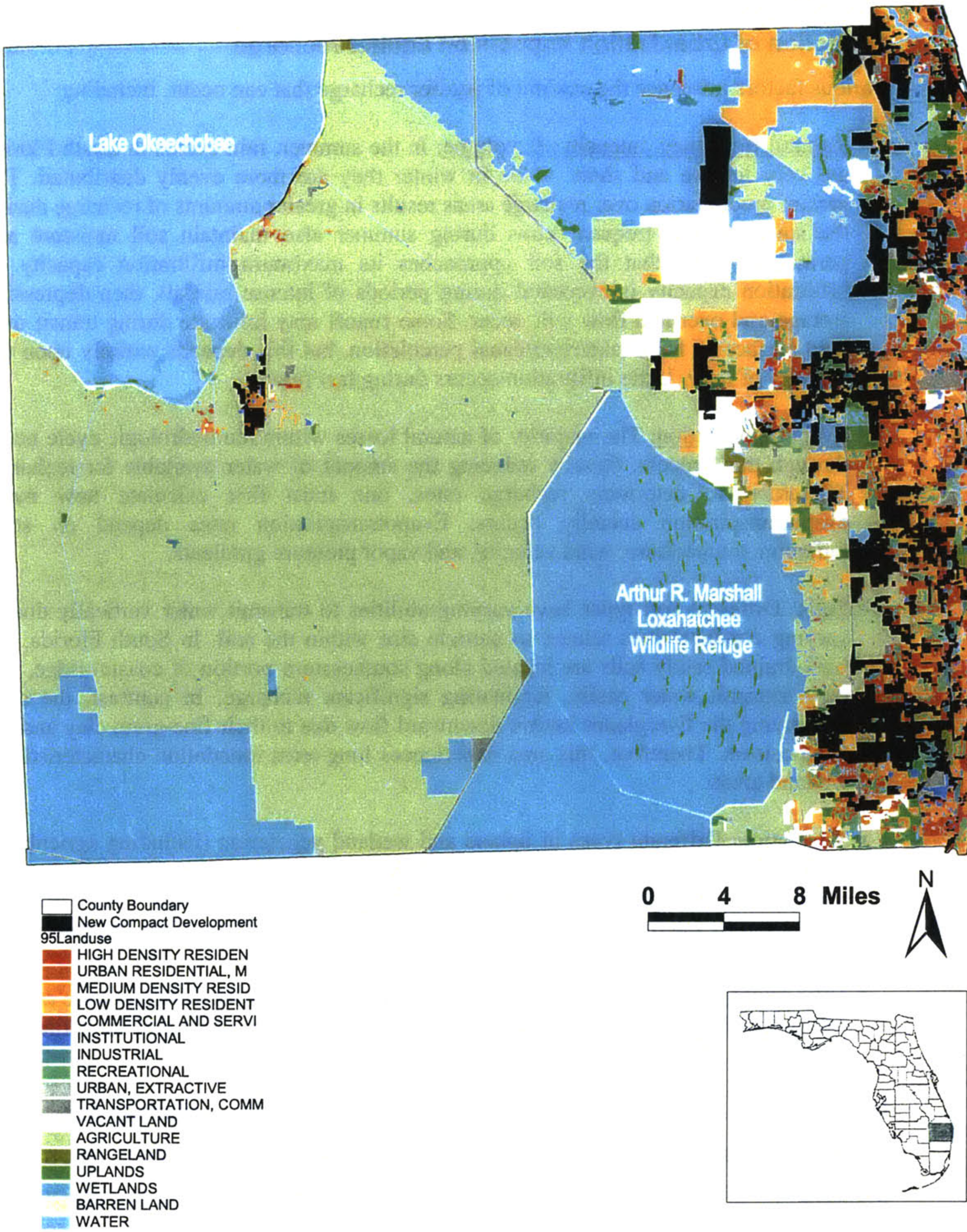
Figures 4.3 and 4.4, respectively, show the spatial distribution of projected land use in 2020 under the sprawl development and compact development scenarios.

Figure 4.2: Projected New Sprawl Development in Palm Beach County (1995-2020)



Base Map: South Florida Water Management District. 1995 Land Use Coverage.
Ambika Anand Prokop. Dept. of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.

Figure 4.3: Projected New Compact Development in Palm Beach County (1995-2020)



Base Map: South Florida Water Management District. 1995 Land Use Coverage.
Ambika Anand Prokop. Dept. of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.

Projection of urbanization impacts on aquifer recharge

Various factors influence the amount of aquifer recharge that can occur, including:

- Rainfall frequency, intensity, & volume: In the summer, rain events in South Florida are very intense and short, while in winter they are more evenly distributed. The greater precipitation over recharge areas results in greater amounts of recharge during the summer. The frequent rains during summer also maintain soil moisture and permeability, so that the soil approaches its maximum infiltration capacity. If infiltration capacity is exceeded during periods of intense rainfall, then depression storage and overland flow will occur. Some runoff may infiltrate during transit over land surface or from lake/river/canal percolation, but this depends entirely upon the velocity of flow. Little infiltration occurs during fast flows.

- Evapotranspiration: The majority of natural losses within the hydrologic cycle occur through this process, thereby reducing the amount of water available for recharge. Therefore, to determine recharge rates, one must first calculate how much evapotranspiration actually occurs. Evapotranspiration rates depend on solar radiation, temperature, wind velocity, and vapor pressure gradients.

- Soils: Different soil types have varying abilities to transmit water vertically due to varying conductivities related to particle size within the soil. In South Florida, the well-drained sandy soils are located along southeastern portion of coastal ridge, and they transmit water easily, facilitating significant recharge. In contrast, the soils underlying the Everglades inhibit downward flow due to their fine-grain clay and silt composition. Therefore, this area experiences long-term inundation characteristic of wetland areas.

- Vegetation: Different types of upland and wetland vegetation (including agricultural crops) vary in water consumption and transpiration rates. The majority of water transmitted through vegetation is evapotranspired. Vegetation also impedes infiltration by intercepting some rainfall, which then evaporates to the atmosphere.

- Topography: The flat shallow gradient of South Florida favors recharge since rainfall can accumulate in shallow depressions, maximizing the time available for infiltration to occur.

In this study, potential aquifer recharge is determined by evaluating how much precipitation is available to infiltrate to the deep aquifer after runoff and evapotranspiration has occurred (*see Figure 4.5*). Potential recharge is calculated using the following formula:

I = P – Q – ET

Where:

I = infiltration (or recharge)

P = precipitation

Q = runoff

ET = evapotranspiration

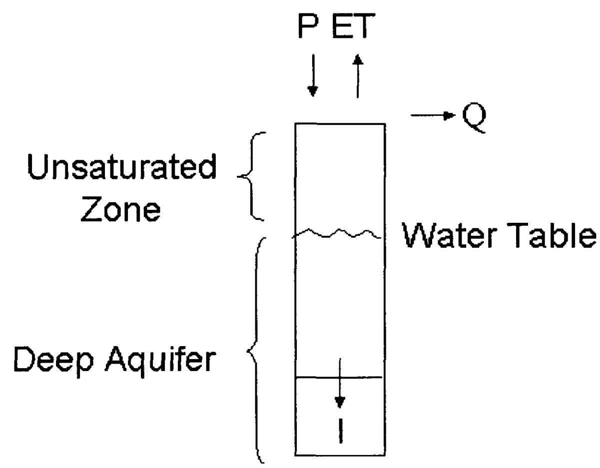


Figure 4.5: Infiltration in a sample soil column

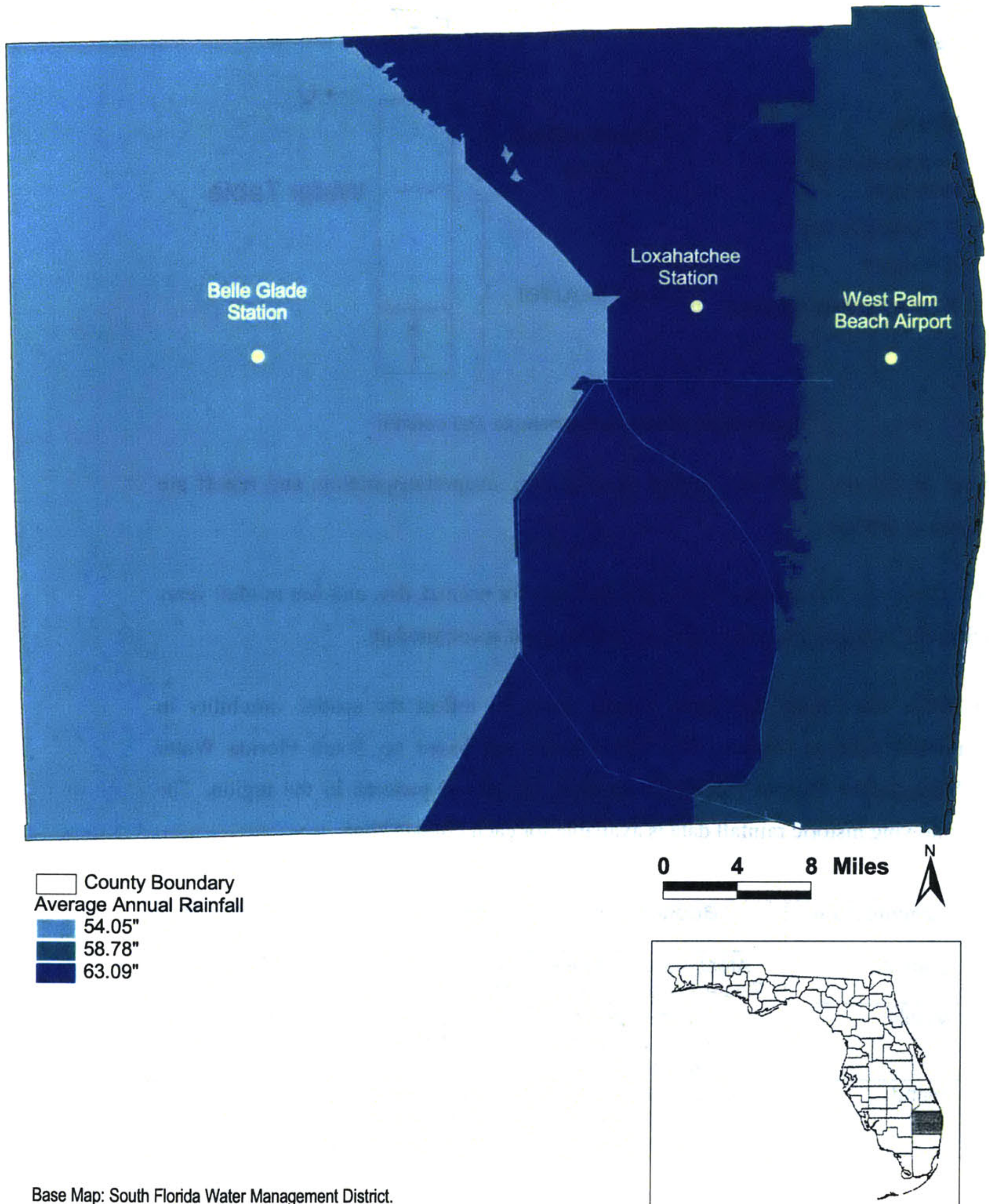
In order to calculate recharge, annual precipitation, evapotranspiration, and runoff are estimated as follows:

Step 1: Determine the average annual precipitation for normal, dry, and wet rainfall years to reflect the range of variability that the system must accommodate.

- Divide the county into three climate zones to reflect the spatial variability in rainfall patterns (*Figure 4.6*). These zones are based on South Florida Water Management District (SFWMD) analysis of rainfall patterns in the region. The following historic rainfall data is available for each climate zone:

Climate Zone	Boundaries	Rain Gauge	Period of Data
Coastal	Areas east of State Route 7 in the County	West Palm Beach International Airport	1948-2000
Middle	Loxahatchee Wildlife Refuge and areas to the north	Loxahatchee Station	1948-1988 & 1991-2000
Inland	Everglades Agricultural Area and Lake Okeechobee	Belle Glade Experimental Station	1924-2000

Figure 4.6: Climate Zones & Rainfall Stations in Palm Beach County



Base Map: South Florida Water Management District.
Ambika Anand Prokop. Dept. of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.

- Examine the historical rainfall data collected from the rain gauge in each zone. Figures 4.7 - 4.9 show the average annual precipitation in each zone. Figures 4.10 - 4.12 demonstrate the high variability in annual precipitation, as evidenced by the frequent occurrence of dry and wet years. The graphs also show that extreme events vary spatially as well as temporally. For example, a dry year in one climate zone may have been a normal rainfall year in another climate zone.

- Determine the average annual rainfall for normal, wet, and dry conditions in each climate zone as follows:
  - Normal rainfall year: the mean of precipitation levels for the entire rainfall record.
  - Wet year: the mean of precipitation levels from the years in the highest quartile
  - Dry year: the mean of precipitation levels from the years in the lowest quartile

This analysis yielded the following results:

Climate Zone	Average Annual Rainfall during Normal Year (inches)	Average Annual Rainfall during Wet Year (inches)	Average Annual Rainfall During Dry Year (inches)
Coastal	58.78	78.59	38.59
Middle	63.13	79.85	47.32
Inland	54.93	72.05	39.58

*note: missing values in the rainfall record were recorded as 0.

Figure 4.7: Average Annual Precipitation in Coastal Climate Zone (1949-2000)

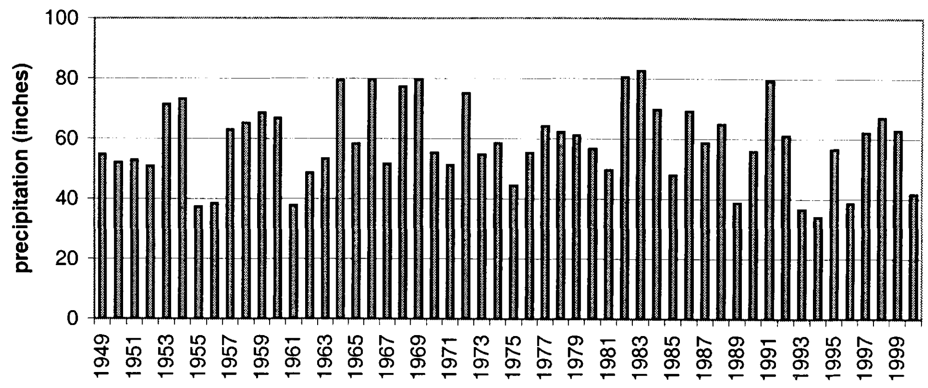


Figure 4.8: Average Annual Precipitation in Middle Climate Zone (1949-1989 & 1991-2000)

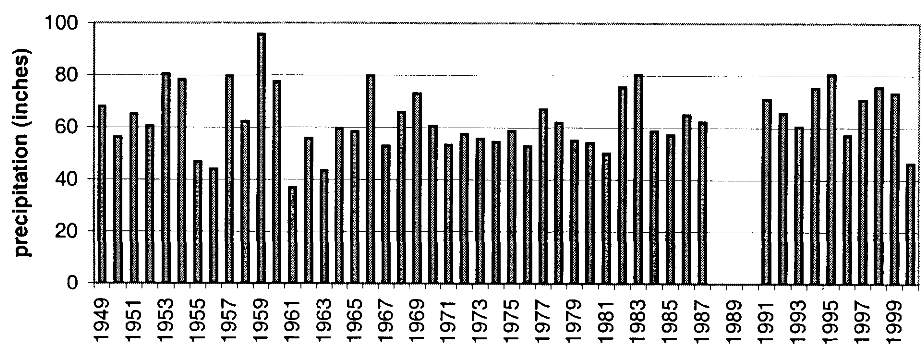
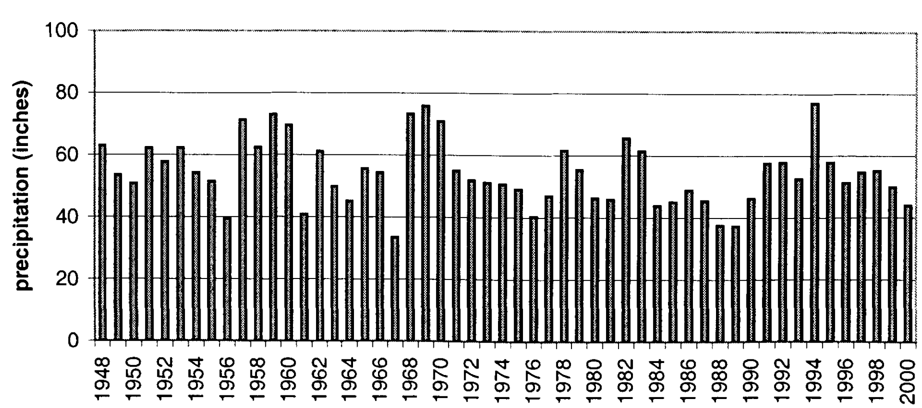


Figure 4.9: Average Annual Precipitation in Inland Climate Zone (1948-2000)



Source: National Climatic Data Center 2000

Figure 4.10: Deviation from Average Annual Precipitation in Coastal Climate Zone (1949- 2000)

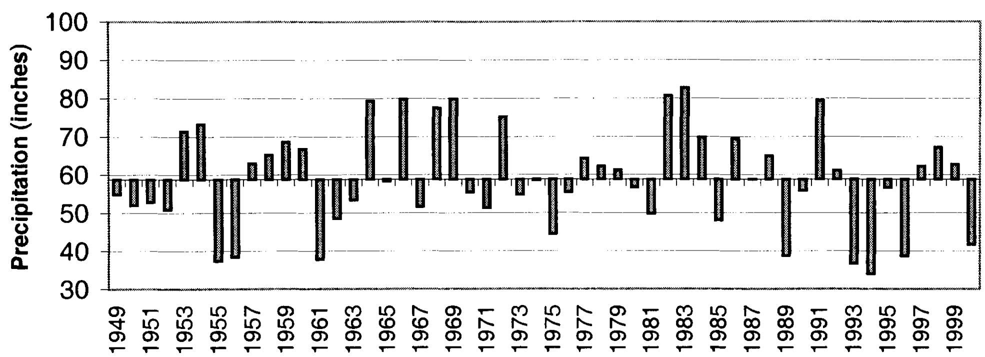


Figure 4.11: Deviation from Average Annual Precipitation in Middle Climate Zone (1949-1989 & 1991-2000)

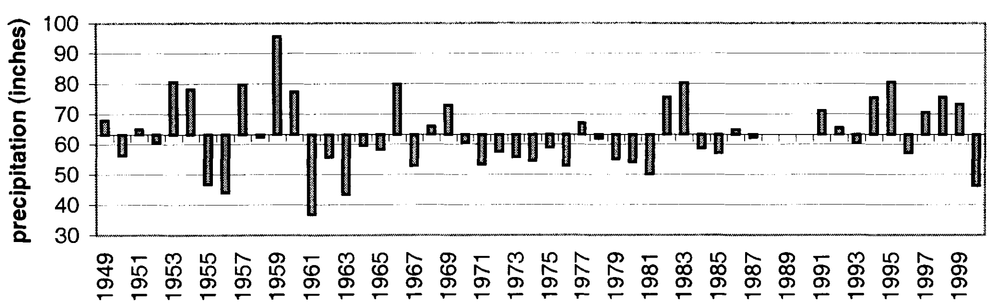
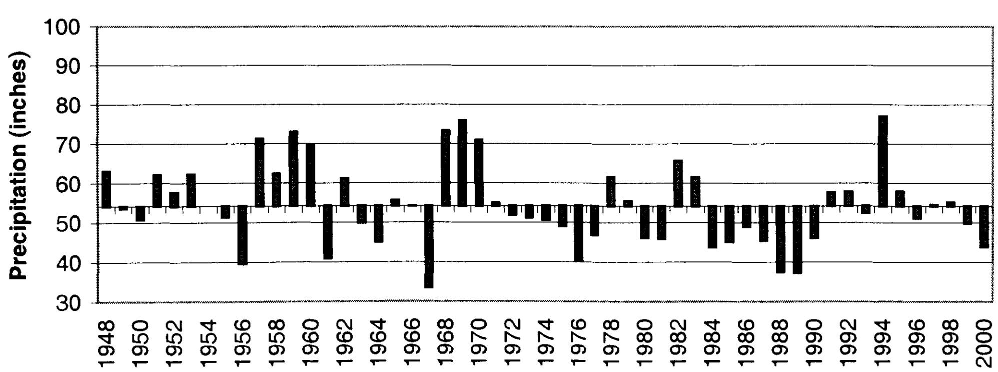


Figure 4.12: Deviation from Average Annual Precipitation in Inland Climate Zone (1949-2000)



Source: National Climatic Data Center 2000

Step 2: Calculate the average annual evapotranspiration for normal, wet, and dry years in each climate zone. Evapotranspiration accounts for the amount of water which is absorbed by vegetation and transpired back to the atmosphere (*see Chapter 2 for details*). It is very difficult to determine evapotranspiration without actually measuring it. Since adequate experimental data is not available, the following approximations and formulas are used to derive an estimate of evapotranspiration in each climate zone:

- Examine the historic evaporation data. This data represents "open pan" data and reflects the amount of water which evaporates from an open pan of water. Adequate evaporation data is available only for the Belle Glade Experimental Station in the inland climate zone.

- Calculate Potential Evapotranspiration (PET). PET is equivalent to the water loss that occurs if there is adequate water supply for the vegetation. Open pan evaporation data is used as a measure of PET for the inland climate zone. Since no open pan evaporation data is available for the other climate zones, PET for these zones is calculated based on the Malmstrom formula (Dingman 1994):

$$PET_m = .409[e_{sat}(T)]$$

where:
PET_m is expressed in cm/mo
e_{sat} = saturated vapor pressues = $6.11 \exp[17.3T/(T+237.3)]$
T = Temperature, expressed in degrees Celsius.

As expressed by the Malmstrom formula, PET is largely a function of temperature and humidity.

- Calculate Actual Evapotranspiration (AET). The difference between potential evapotranspiration (PET) and actual evapotranspiration (AET) is the availability of water in the soil. If water supply is inadequate for evapotranspiration, the deficit is drawn from soil moisture storage. AET was calculated using the Thornthwaite Water-Balance Model (Dingman 1994):

If $P > PET$,

$$\Theta_m = P - PET + \Theta_{m-1}$$
$$AET_m = PET_m$$

Note: When precipitation exceeds potential evapotranspiration, there is unlimited moisture availability due to abundant rainfall, so actual evapotranspiration is equivalent to potential evapotranspiration.

If P < PET,
$\Theta_m = \Theta_{m-1} \exp [-(PET_m - P_m)/ \Theta_{max}$[2]
$AET_m = P + \Theta_{m-1} - \Theta_m$

where: P = monthly precipitation
PET = Potential Evapotranspiration = open pan evaporation
AET = Actual Evapotranspiration
Θ = soil water storage

- Adjust the calculated AET values for different vegetation types. Since each vegetation type evapotranspires different water amounts, the calculated AET values are adjusted using ratios of evapotranspiration data collected from experiments conducted by the Agricultural Service from 1934-38 at the Belle Glade Experimental Station (*see Appendix D*). The results show differences in AET for sugar cane, grass and bare soil. By using ratios reflecting these differences, the calculated AET values for each climate zone are adjusted as follows:
-

Climate Zone	**Land Cover & corresponding vegetation type**	**AET adjustment for vegetation type**
Inland	Primarily agriculture: sugar cane	$AET_{sugar\ cane} = .759\ AET_{grass}$
Middle	Primarily rural: grass	No adjustment: grass AET is relatively high so calculated AET value used
Coastal	Primarily urban: bare soil	$AET_{bare\ soil} = .67\ AET_{grass}$

- Determine the average annual evapotranspiration. Based on the designation of wet and dry years from the analysis of rainfall patterns, average AET values for wet and dry conditions in each climate zone were also calculated by summing the adjusted calculations of monthly evapotranspiration in each climate zone (*see Figures 4.13-4.15: Calculated Annual Evapotranspiration*). Tables E.1-E.3 in Appendix E summarize the results of the analysis of annual precipitation and evapotranspiration patterns in each climate zone under normal, wet, and dry conditions.

[2] Maximum soil water storage (Θ_{max}) occurs when soil is saturated. Since the rainfall record began in 1948, a year of heavy floods, the ground would have been saturated in December of 1948 after the rainy season. Therefore, the calculations began with this month. It is also assumed that all the soil pores would be filled with water at this time, and therefore the soil water storage in this month would equal soil porosity. The soils in the coastal climate zone are primarily sandy soils with a porosity of 0.395 (Dingman 1994), and the soils in the middle and inland climate zones are primarily muck soils with a porosity of 0.8 (Heid 1997). These values were used for maximum soil storage in a representative 1m soil column for December 1948. Data for the middle climate zone is not available for the period of 1988-1990, so the monthly soil storage values calculated for the coastal climate zone nearby is used.

Figure 4.13: Average Annual Evapotranspiration in Coastal Climate Zone (1949-2000)

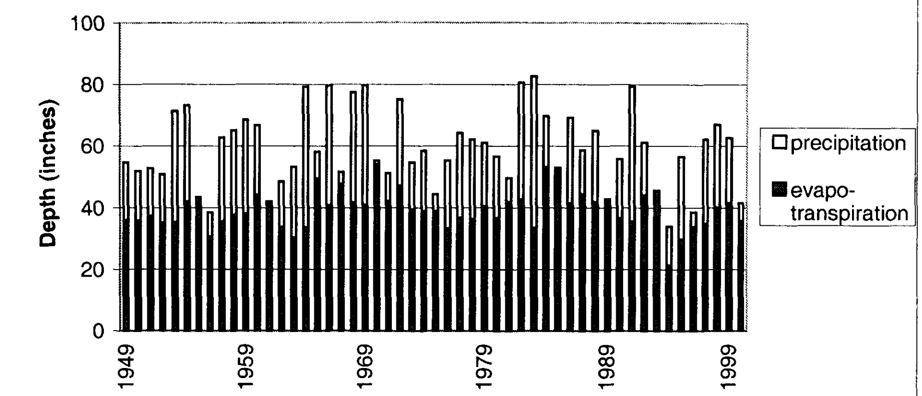


Figure 4.14: Average Annual Evapotranspiration in Middle Climate Zone (1949-1988 & 1991-2000)

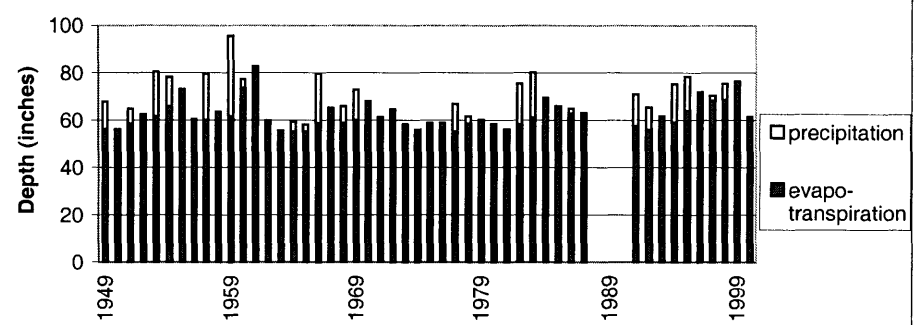
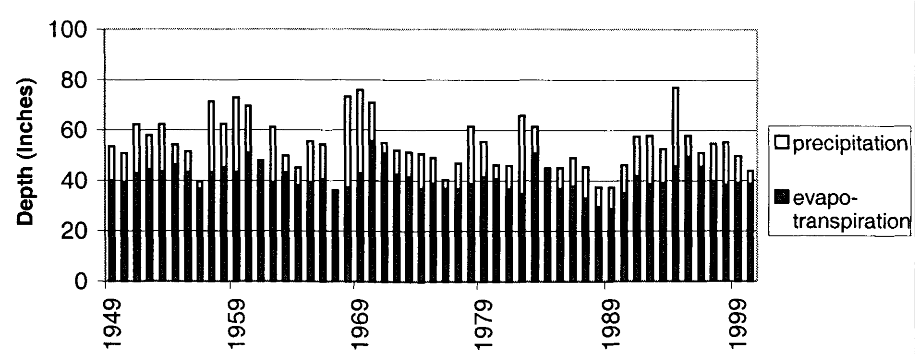


Figure 4.15: Average Annual Evapotranspiration in Inland Climate Zone (1949-2000)



Source: National Climatic Data Center 2001

Step 3: Calculate runoff generated under each land use scenario (1995 Base Case, 2020 Sprawl Scenario, and 2020 Compact Scenario).

- Assign a hydrologic soil type to each land use parcel. This is done using soil data for the county, wherein soil types are defined as follows:

Hydrologic Group	Description	Infiltration Capacity
A	Deep, well to excessively drained sands and gravels	High
B	Moderately fine to moderately coarse-grained soil (eg sandy loam)	Moderate
C	Moderately fine to fine-grained soils	Low
D	Clay soils with high swelling potential, soils with a permanent high-water table, soils with a clay layer near the surface, shallow soils over impervious bedrock	Very Low

The GIS soil coverages are obtained from the National Soil Conservation Service. For soil designations classified as B/D or C/D in the GIS soil coverage, soil surface texture and drainage maps were referenced to determine the likely infiltration capacity (*see Figures F.1-F.3 in Appendix F*). In general, soils in the inland climate zone and the northern part of the middle climate zone were assigned to the "C" hydrologic group, due to the presence of muck and poorly drained soils in the region. Soils in the southern middle climate zone and the coastal climate zone were assigned to the "B" hydrologic group, due to the presence of sandy soils.

- Determine a runoff coefficient for each parcel using the following values:

Land Use Category	Hydrologic Group A	Hydrologic Group B	Hydrologic Group C	Hydrologic Group D
Low Density Residential	.25	.30	.35	.40
Medium Density Residential	.30	.37	.43	.50
High Density Residential (including mobile homes)	.50	.57	.63.	.70
Low Intensity commercial	.60	.70	.80	.90
High Intensity Commercial	.65	.75	.85	.95
Industrial	.60	.70	.80	.90
Transportation & Communications	.65	.75	.85	.95
Agriculture (all types)	.15	.23	.32	.40
Mining	.20	.30	.40	.50
Recreation, Open Space (barren land, vacant land, upland forest), Rangelands	.10	.17	.23	.30
Wetlands	.10	.17	.23	.30

Source: Adamus & Bergman 1995.

- Calculate inches of annual runoff for each point on the ground during normal, wet, and dry conditions using the formula:

Annual Runoff = Coefficient x Average Annual Precipitation[3]

[3] While most formulas incorporate rainfall intensity (in inches/hour) into the calculation of runoff equation, this analysis adopts a different approach. Since the objective is to estimate the percentage of rainfall which will discharge off-site on an annual time scale, the runoff coefficient is used as an estimate of that percentage. Clearly, this is an oversimplification of the actual situation. Runoff depends on the rainfall intensity and level of ground saturation, and this interpretation of the formula does not account for it. Therefore, such a simplification, may underestimate runoff volumes.

Step 4: Calculate the annual recharge generated in each land use scenario (1995 Base Case, 2020 Sprawl Scenario, and 2020 Compact Scenario). Recharge values are calculated for all land areas except water bodies using the following formula:

Recharge = Precipitation – Runoff – Evapotranspiration

Step 5: Convert any negative recharge values to 0. This occurs when all available precipitation which infiltrates the ground is used for evapotranspiration (i.e. P-Q > AET), so that none is available for aquifer recharge. This assumption also implies that the process of evapotranspiration does not draw water from the deep aquifer. Such a situation is likely since the roots of most vegetation do not penetrate that deep, and evapotranspiration usually occurs in the top 25 cm of soil. When evapotranspiration draws all available water from the unsaturated zone, the process ceases.

Step 6: Recalculate the recharge accounting for stormwater management regulations for new development. Pursuant to the Water Resources Act of 1972 (Florida Statutes Chapter 373), new developments built since 1974 are subject to surface water management regulations which seek to alleviate flooding and water quality deterioration.[4] To alleviate flooding, new developments are permitted to discharge a certain volume of water into the canal system based on a formula for each drainage basin. The discharge regulations are more permissive for nonflood conditions than flood conditions. To prevent deterioration of water quality, regulations require that the first one inch of precipitation be detained on site to be treated through vegetated areas which filter the water.

These stormwater regulations have a significant impact on the amount of water that can discharge off-site and, therefore, the amount of water available for infiltration, it is important to incorporate these effects into this analysis. The nonflood conditions are more relevant to this analysis as water supply is not so critical during wet years. To be

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[4] The regulations are defined in the Chapters of the Florida Administrative Code and the Basis of Review: Chapters 40E-41: Surface Water Management Basin & Related Criteria and Environmental Resource Permitting, Section 5.

conservative, the study accounts for the one inch detention regulations, as they appeared to be more restrictive than the discharge regulations for nonflood conditions. The assumption is made that 100% of the water that is detained infiltrates in the ground, rather than ultimately draining into the canals.

Runoff values are recalculated to account for stormwater regulations as follows:

- Assume one rainfall event per day.
- Determine the amount of precipitation "permitted" to runoff (P_{runoff}).
  - If daily precipitation <1", $P_{runoff} = 0$
  - If daily precipitation >1", $P_{runoff} = P-1"$
- Sum daily precipitation subject to runoff to give annual amount of precipitation subject to runoff.
- Recalculate annual runoff under the stormwater management regulation as follows:
  Annual runoff permitted = Coefficient x Annual Precipitation subject to runoff
- Recalculate annual recharge incorporating new runoff values:
  Recharge = Precipitation – Runoff permitted - Evapotranspiration

These stormwater regulations are applied to all projected new developments. They are also applied to all urban developments in the Middle Area region, where development has taken place subsequent to the adoption of the 1970 stormwater regulations. All other areas maintain the recharge values calculated in the nonregulated stormwater management scenario.

Chapter 5: Analysis

Impact of Compact Development on Aquifer Recharge

Overview

Since water storage in aquifers and surface reservoirs is key to resolving the problem of water supply in South Florida, this study analyzed the impact of compact versus sprawl development on aquifer recharge. The results of this analysis indicate that the policy of encouraging compact development in urban areas does not always produce greater benefits to aquifer recharge than sprawl development. In fact, compact development in the "wrong" place can have more harmful consequences than sprawl development in the "right" place, suggesting that the general assumption that compact development is preferable to sprawl development may not withstand scrutiny. The case of Palm Beach County illustrates that such planning paradigms must be calibrated to respond to the physical characteristics of the particular region: simply put, these policies must be adapted to place-specific conditions.

This study suggests that the combination of implementing stormwater regulations and locating new urban developments on impervious soils with low recharge potential can mitigate potential reductions in aquifer recharge, even in new sprawl developments. The advantage of compact development in Palm Beach County is not that it benefits recharge, but that it preserves more lands to be used as surface water storage areas. Thus, compact development should not be automatically channeled to existing urban areas; rather, it should be encouraged in areas with low recharge and surface water storage potential. In the case of Palm Beach County, this may actually mean concentrating development in clusters in the suburban and rural areas of the county's northern regions, rather than building in the existing metropolitan areas which contain soils with high recharge potential. This approach, however, runs counter to the county's current policy of limiting growth in outlying areas and encouraging investment in the existing urban core.

This study also indicates that the benefits of compact development on aquifer recharge are dwarfed by the projected increases in urban water demand. Therefore, the region's growth management and "sustainable Florida" agenda cannot rely solely on policies that encourage compact development to resolve the competition for water between the growing urban population and the diminished natural systems. Stringent water conservation strategies will still be needed.

These results suggest the following general principle for land use planning:

- Compact development does not necessarily yield greater aquifer recharge rates, and sometimes it yields lower recharge rates than sprawl development: the potential benefits of compact development to aquifer recharge depend entirely on where the new development occurs.
- Stormwater regulations *which require infiltration* can mitigate potential reductions in recharge of *both* compact and sprawl development, so that the differences between them are insignificant.
- Compact development will allow for the protection of existing water conservation areas and acquisition of new surface water storage areas and buffer zones.
- The benefits of future compact development to aquifer recharge are very small compared to projected increases in future water consumption; compact development alone cannot address the looming shortage of water in the region.

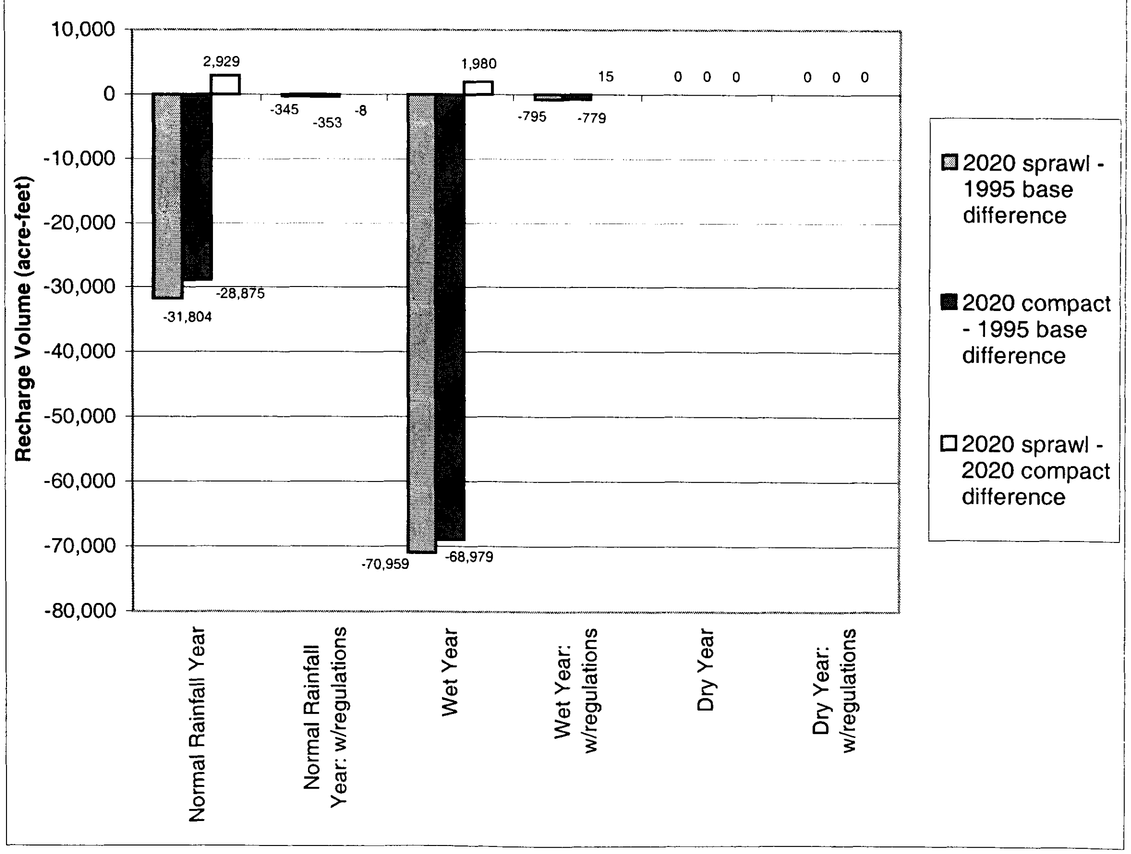
When applied to the Palm Beach County, these principles yield the following planning recommendations:

- Compact development should be the preferred form of new development. However, the location of compact development should be based on detailed analysis of the location of permeable soils and recharge areas.
- Compact development in regional clusters on land with low recharge potential should be encouraged by the strategic provision of infrastructure including utilities, roads, and schools.
- Any significant recharge areas, which in Palm Beach County are primarily in the urbanized areas, should be protected as open space amenity zones.
- Stormwater regulations must be written to encourage retention and infiltration, rather than detention and subsequent discharge.
- All new developments should be designed to infiltrate the maximum amount of stormwater possible.
- The regional growth management plan must address water consumption in addition to promoting compact development.

Results of Aquifer Recharge Calculations

Because the study methodology involved numerous simplifications and assumptions to determine annual aquifer recharge, the <u>differences</u> in projected recharge under each urban development scenario, rather than projections of total recharge, are most meaningful in analyzing which scenario confers the most benefits to regional water storage capacity. Figure 5.1 summarizes the projected differences in total annual recharge between the 1995 base case scenario, the 2020 sprawl development scenario, and the 2020 compact development scenario.

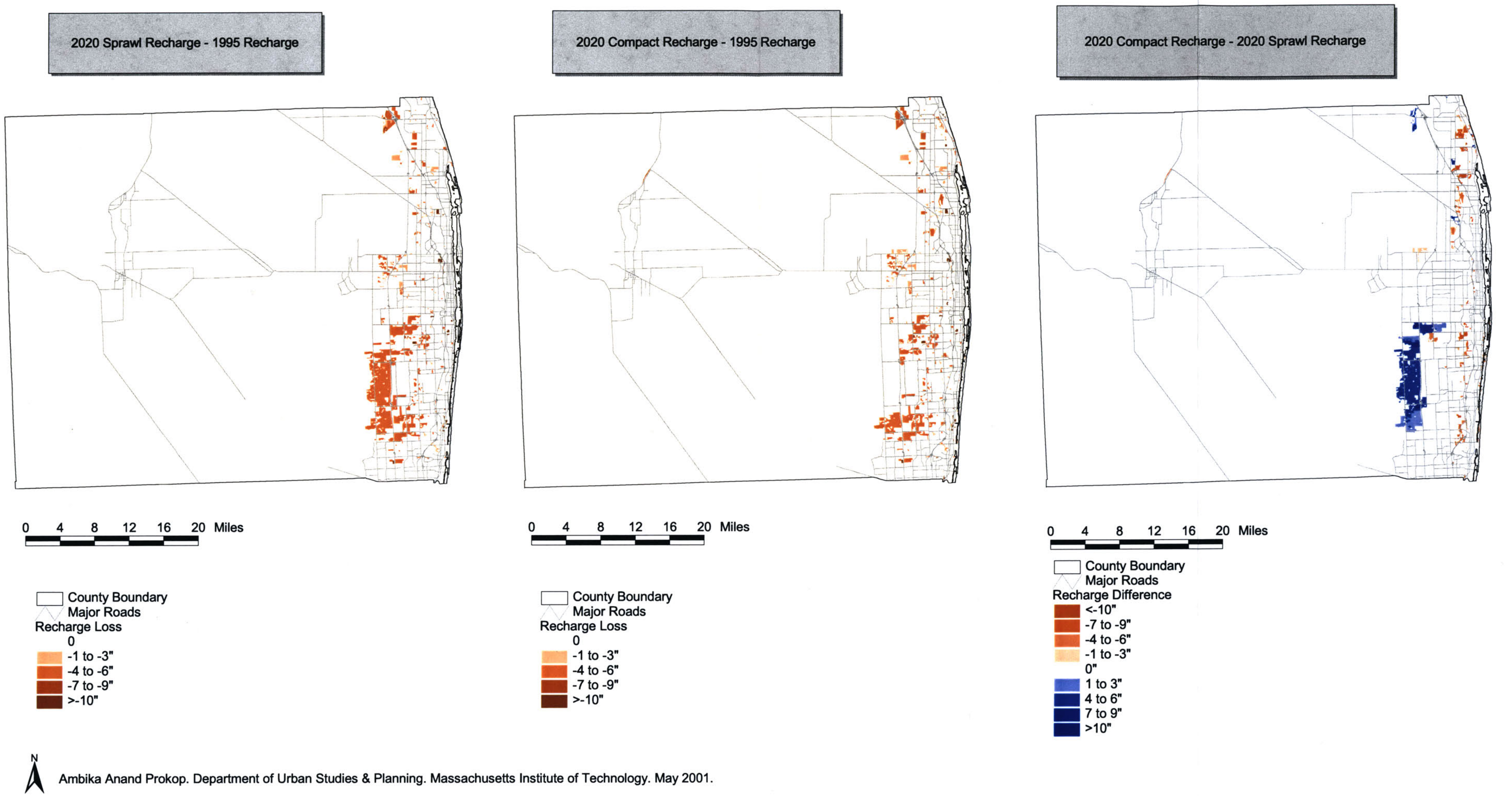
Figure 5.1: Projected Differences in Annual Recharge in Palm Beach County



Figures 5.2 & 5.3 map the spatial distribution of differences in annual recharge in Palm Beach County under normal rainfall conditions, as they would occur with and without the implementation of stormwater regulations for new development. Figures 5.4 & 5.5 depict differences in recharge under heavy rainfall conditions. The maps accounting for stormwater regulations represent a more accurate recharge scenario, as Stormwater regulations have been in place in Palm Beach County since 1974. The maps of recharge during dry years are not included because the calculations indicate that no recharge would occur under these conditions in any of the three scenarios, since rainfall is so low and evapotranspiration so high.

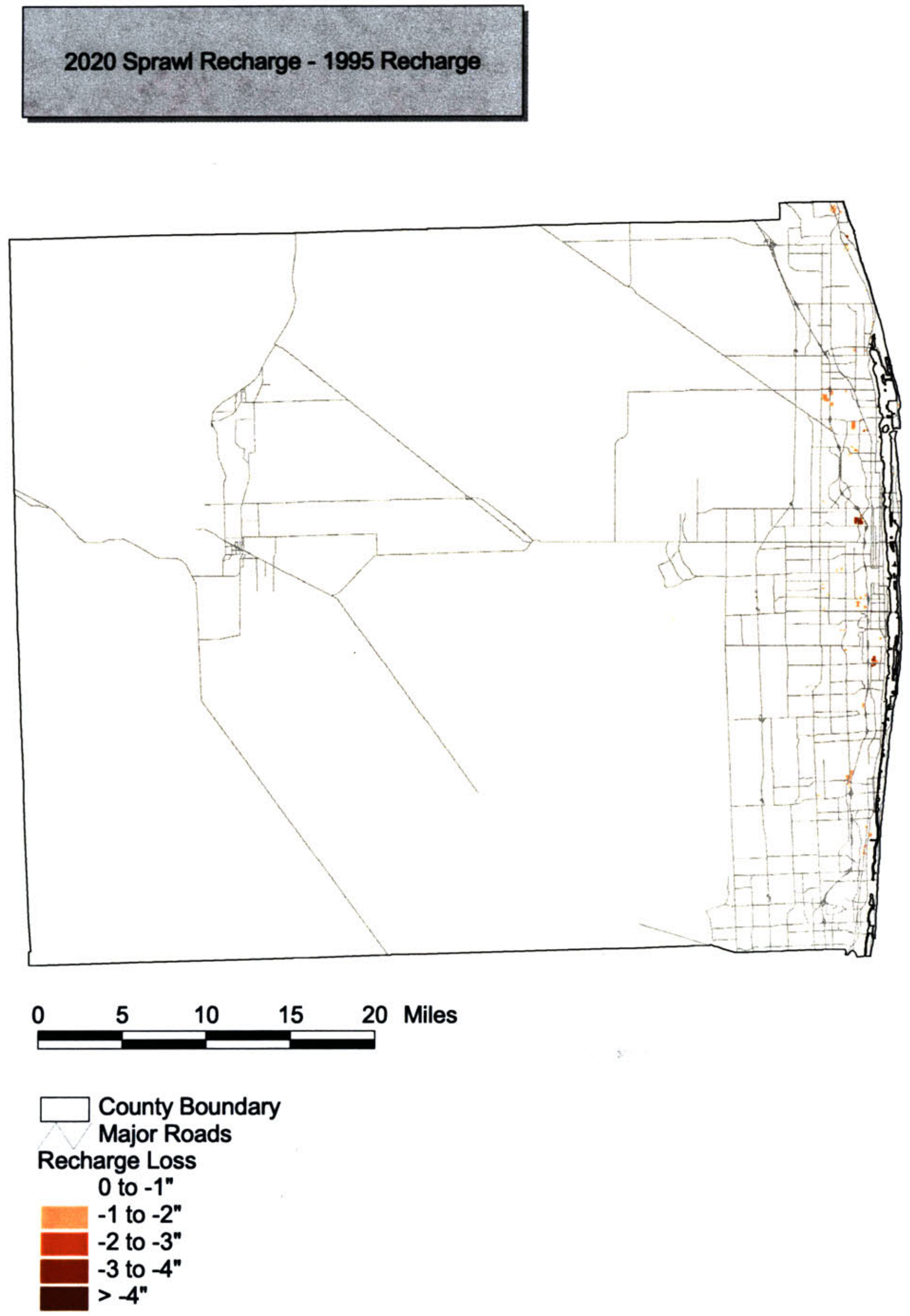
These results do have some limitations, however. Given that the study was conducted on a regional spatial scale and annual time scale, the analysis was too coarse to capture the many variations which may significantly affect recharge estimates. Most significantly, the projections of evapotranspiration and runoff discharged under stormwater regulations involved simplifying assumptions and estimates. However, all of the assumptions were applied consistently to each scenario, and therefore the conclusions about the differences in recharge between each scenario should remain valid. Appendix G provides a more detailed explanation of potential errors in this analysis.

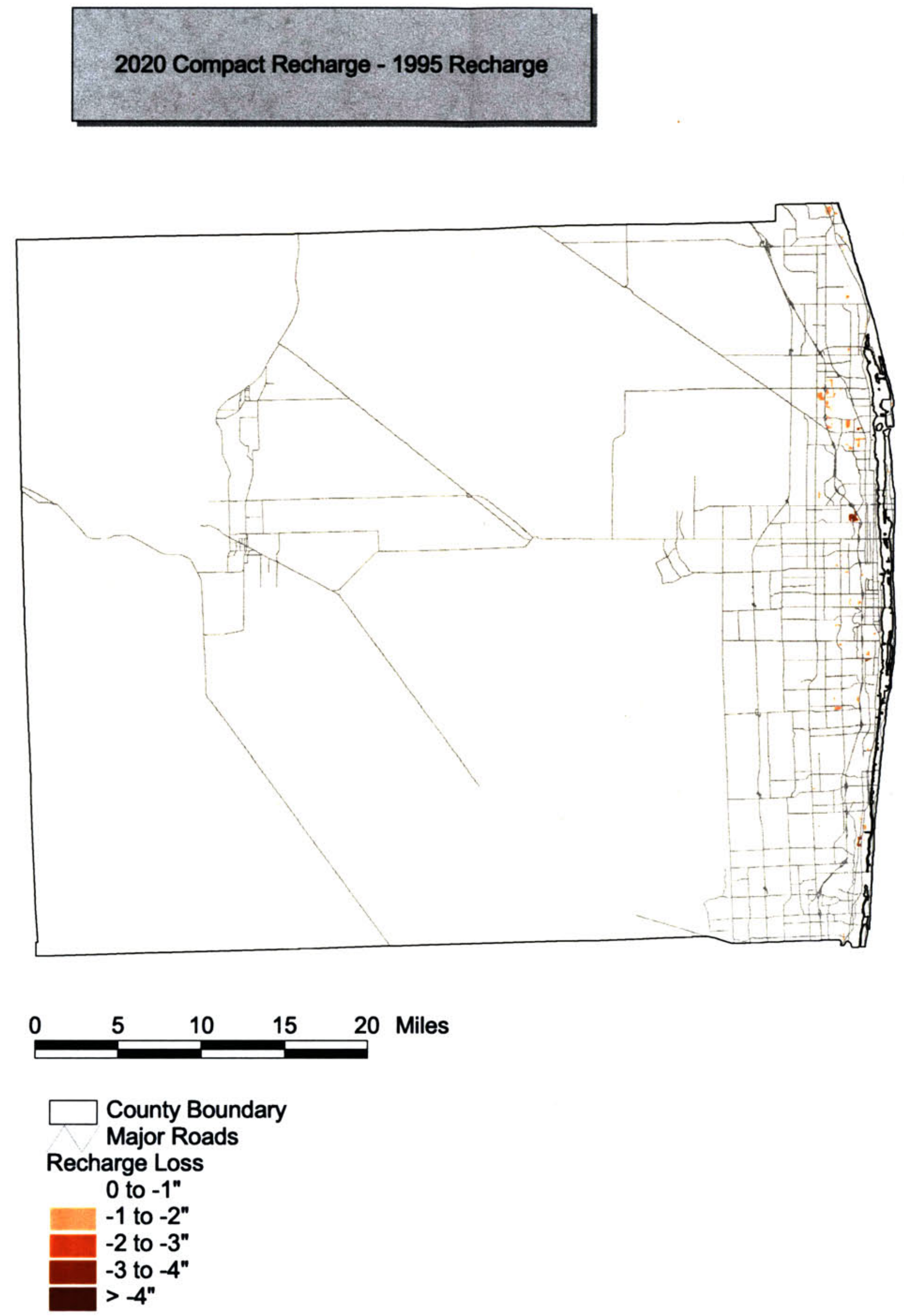
Figure 5.2: Projected Annual Recharge Differences during a Normal Rainfall Year (Without Stormwater Regulations)

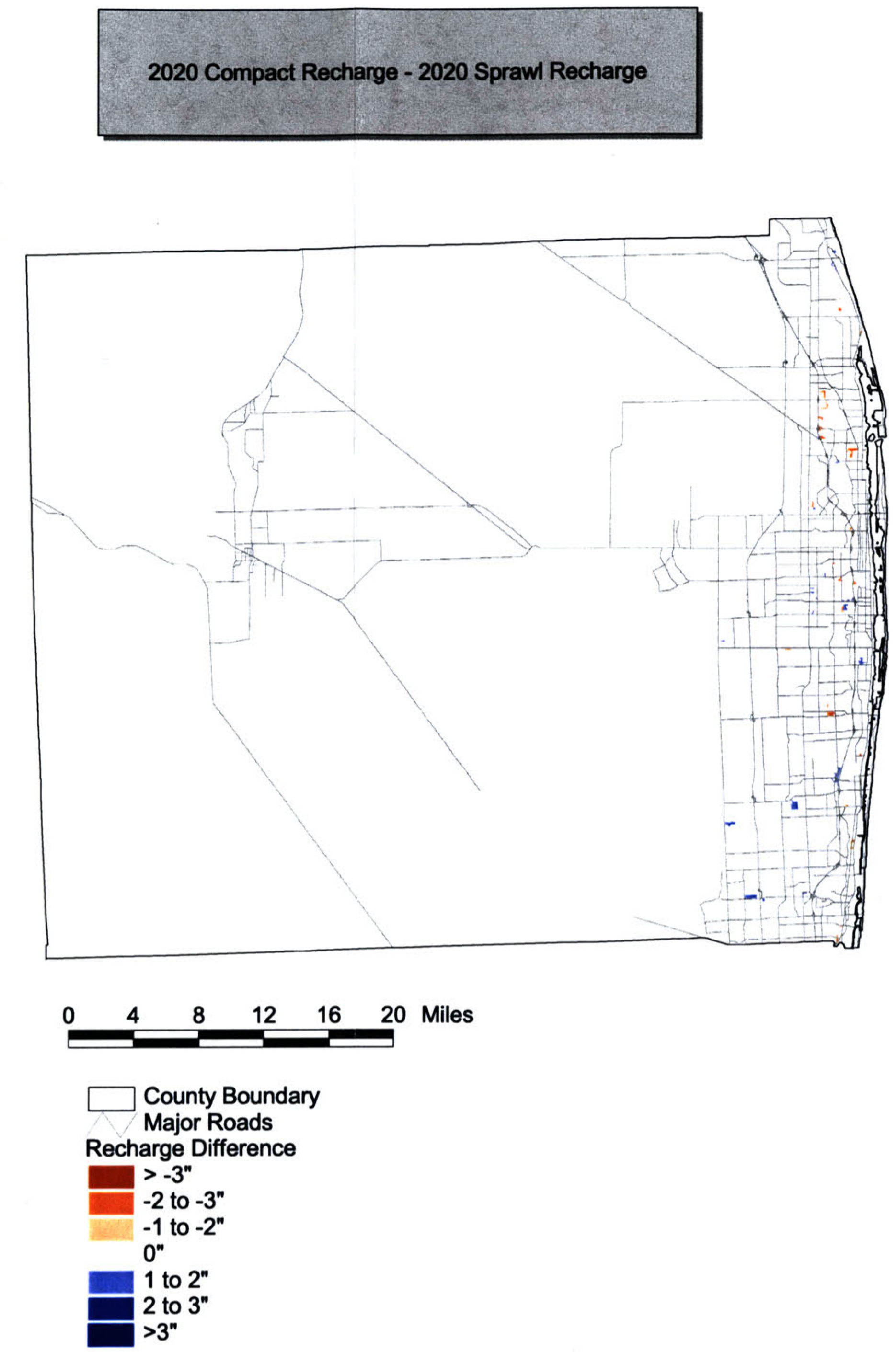


Ambika Anand Prokop. Department of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.

Figure 5.3: Projected Annual Recharge Differences During Normal Rainfall Year (with Stormwater Regulations)

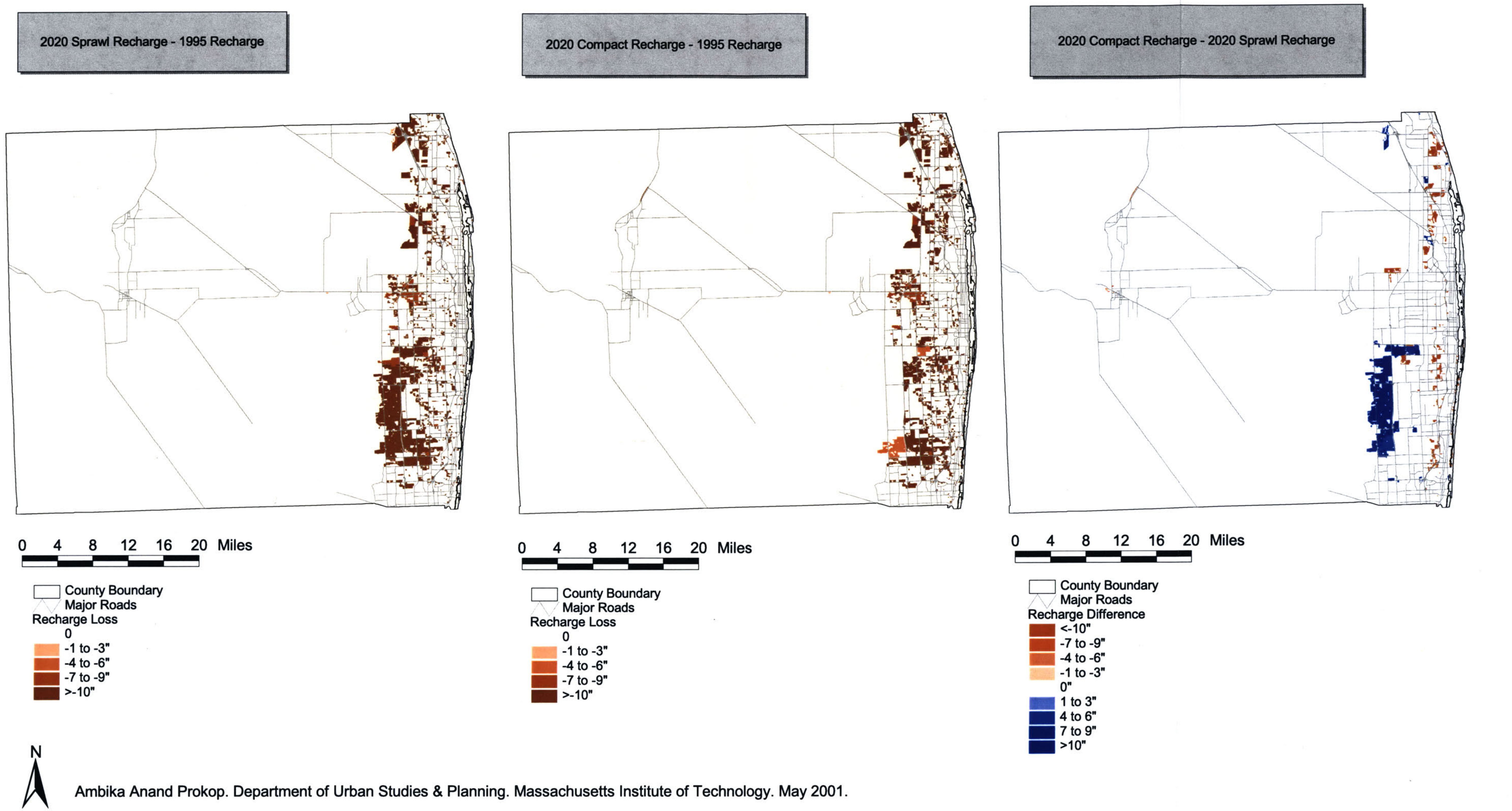






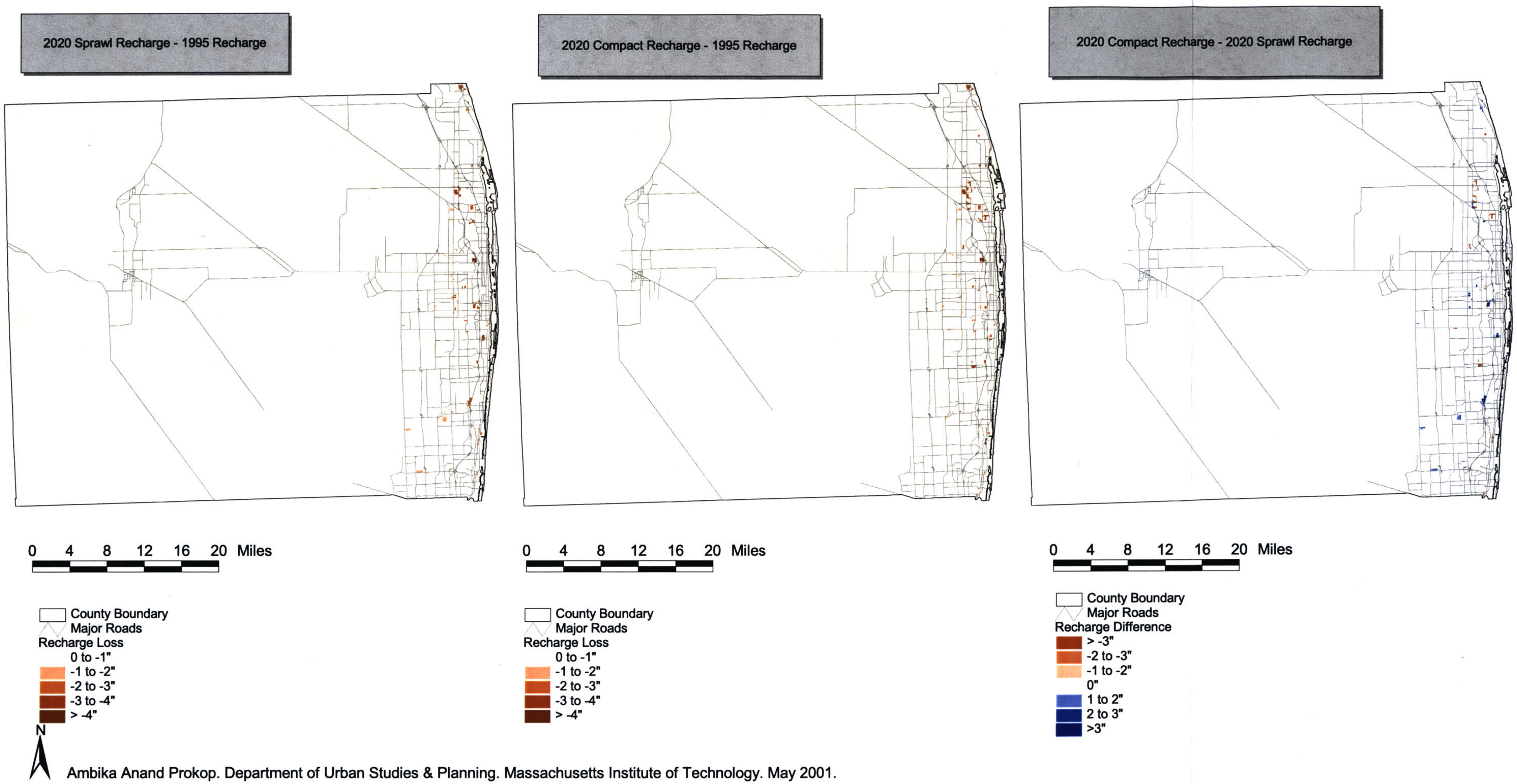
Ambika Anand Prokop. Department of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.

Figure 5.4: Projected Annual Recharge Differences during Wet Year (without Stormwater Regulations)



Ambika Anand Prokop. Department of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.

Figure 5.5: Projected Annual Recharge Differences during Wet Year (with Stormwater Regulations)



Ambika Anand Prokop. Department of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.

Planning Implications

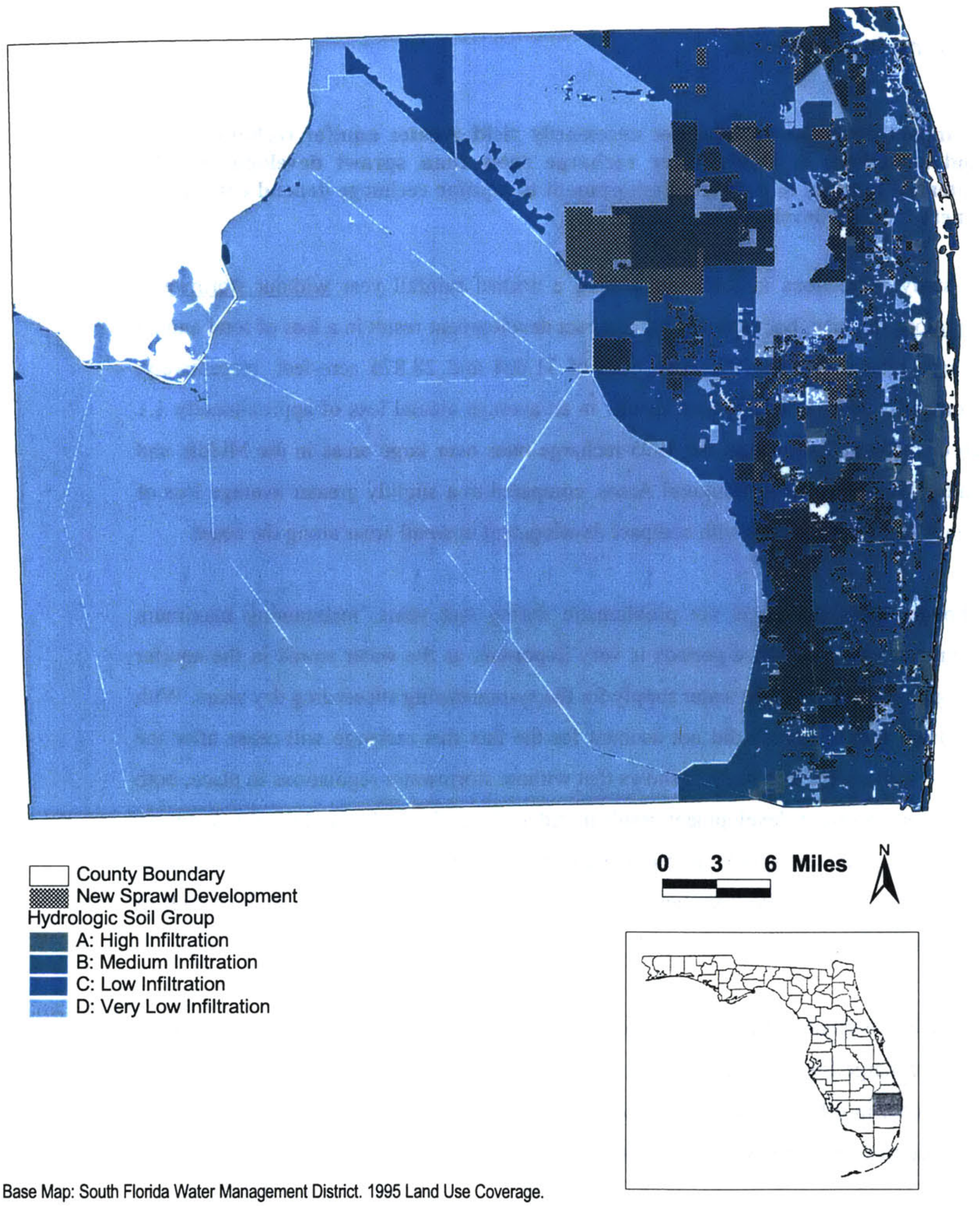
- **Compact development does not necessarily yield greater aquifer recharge rates, and sometimes it yields lower recharge rates than sprawl development: the potential benefits of compact development to aquifer recharge depend entirely on where the new development occurs.**

The study projections indicate that during a normal rainfall year without stormwater regulations in place, both sprawl and compact development result in a loss of total annual recharge relative to the 1995 base case of 31,804 and 28,875 acre-feet, respectively. Specifically, sprawl development results in an average annual loss of approximately 1.1 inch of recharge depth from the 1995 recharge rates over large areas in the Middle and Limited Development Agricultural Areas, compared to a slightly greater average loss of 1.2 inch of recharge depth with compact development in small areas along the coast.

Although water storage is not problematic during wet years, maintaining maximum recharge rates during these periods is very important, as the water stored in the aquifer during a wet year provides water supply for the system during succeeding dry years. With the caveat that this study did not account for the fact that recharge will cease after the ground is saturated, this analysis shows that without stormwater regulations in place, both sprawl and compact development result in reduced aquifer recharge during a wet year. During wet years, the sprawl development pattern results in an average loss of 2.87 inch of recharge depth, while compact development results in a reduction of 3.33 inch of recharge depth.

It may be surprising that especially during wet years compact development results in higher recharge loss than sprawl. But compact development in Palm Beach County will likely occur in urbanized areas situated on permeable soils, while sprawl development is projected to occur to the west, where soils are less permeable (*see Figures 5.6 and 5.7*).

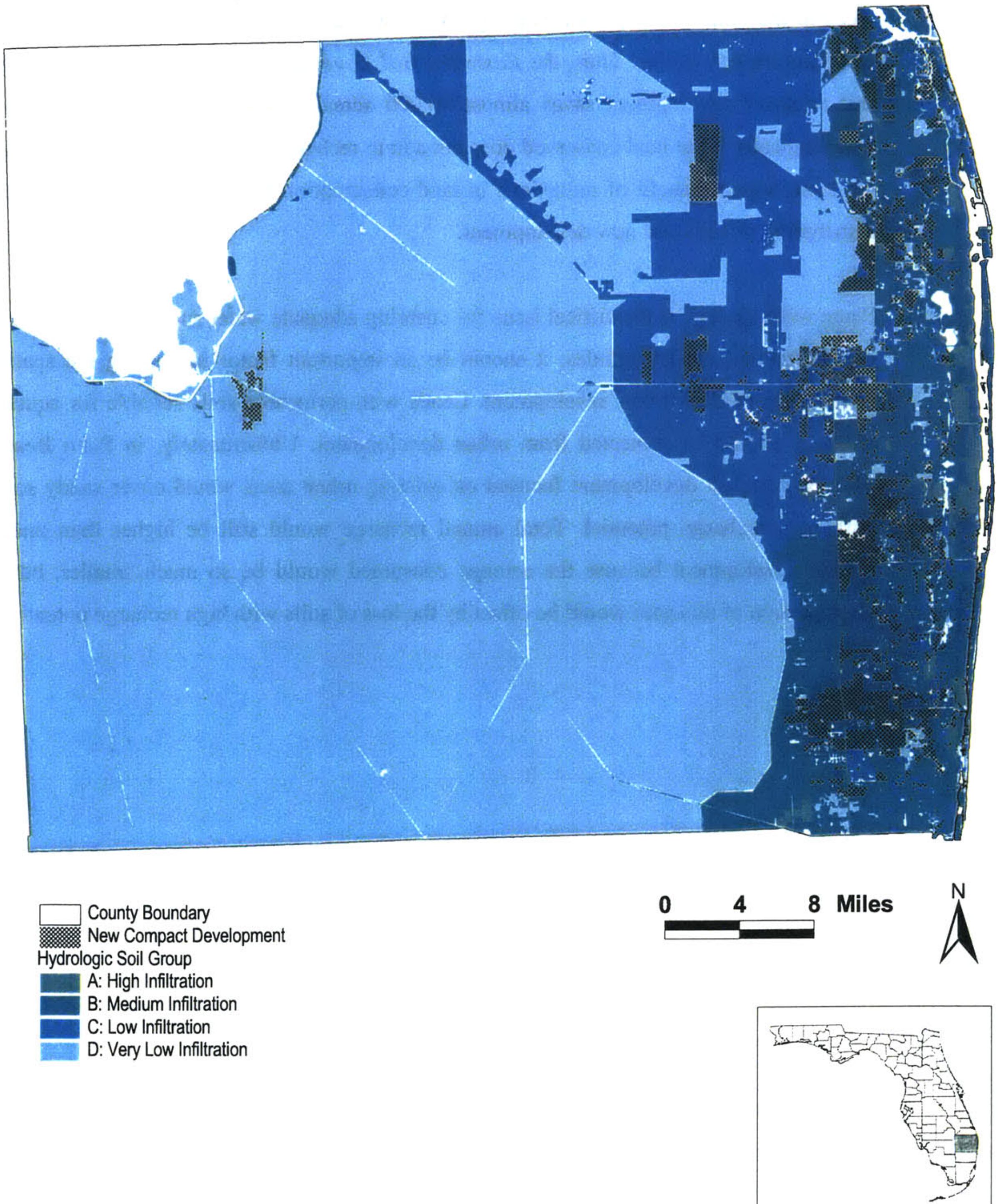
Figure 5.6: Relationship between Sprawl Development & Soil Permeability in Palm Beach County



Base Map: South Florida Water Management District. 1995 Land Use Coverage.

Ambika Anand Prokop. Dept. of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.

Figure 5.7: Relationship between Compact Development & Soil Permeability in Palm Beach County



Base Map: South Florida Water Management District. 1995 Land Use Coverage.
Ambika Anand Prokop. Dept. of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.

This result demonstrates the importance of considering the spatial distribution of recharge areas in the county. Simply calculating how much land is consumed in aggregate will yield incomplete results. Thus, the *Eastward Ho! Development Futures* study's findings that compact development saves almost 90,000 acres of land may have little impact hydrologically if the land conserved does not add to recharge potential. Any evaluation of the hydrological benefit of reductions in land consumption must account for the spatial distribution of soils and new development.

Since water storage is the critical issue for ensuring adequate water supply for the human population and the Everglades, it should be an important factor in guiding the spatial distribution of new urban development. Lands with permeable soils suitable for aquifer recharge should be protected from urban development. Unfortunately, in Palm Beach County, compact development focused on existing urban areas would cover sandy soils with high recharge potential. Total annual recharge would still be higher than under sprawl development because the acreage consumed would be so much smaller, but a large portion of this gain would be offset by the loss of soils with high recharge potential.

- **Stormwater regulations *which require infiltration* can mitigate potential reductions in recharge of *both* compact and sprawl development, so that the differences between them are insignificant.**

The implementation of stormwater regulations which require on-site retention of the first one inch of rainfall effectively prevents reduction of recharge rates due to new development, regardless of the form it takes. The results indicate almost no difference between the 1995 base case recharge and the compact or sprawl recharge rates. The regulations reduced recharge loss to almost zero in both cases. This suggests that sprawl development may not adversely impact aquifer recharge if stormwater regulations are in place.

The results occur only under the assumption that 100% of the water detained on site infiltrates into the soil. The stormwater regulations will have no positive impact on aquifer recharge unless they require infiltration rather than temporary detention and subsequent release of the water into the canal system at a later time. In general, stormwater regulations in South Florida are designed for flood control and for water quality protection, rather than to allow aquifer recharge. Flood control regulations are designed to limit off-site discharge during peak flows. This can be achieved by various measures, including:

- permanently retaining the water on site in a depression so that it infiltrates the ground rather than being discharged off-site
- temporarily detaining the water on site and releasing it after the peak storm discharge has passed
- storing the water in a holding tank
- capturing the rainfall on a rooftop garden where it will irrigate the rooftop plants and evaporate the water back to the atmosphere.

Of these methods, only the first actually serves purposes of enhancing recharge; the others simply delay removal of the water off-site by various means, without giving adequate opportunity for the water to infiltrate. The water quality regulations are however more likely to facilitate enhanced infiltration because they often require the flow of stormwater through vegetated areas before being discharged off-site. This slow movement of water through the vegetation allows infiltration. Because water storage is such a critical issue in South Florida, planners and engineers should recognize that stormwater regulations should not only address flood control and water quality concerns, but aquifer recharge as well. To this end, regulations should require stormwater retention which allows the water to infiltrate the ground and recharge the aquifer.

- **Compact development will allow for the protection of existing water conservation areas and acquisition of new surface water storage areas and buffer zones.**

Without stormwater regulations, the loss of recharge due to sprawl development in the Agricultural Reserve Area near the Arthur R. Marshall Loxahatchee Wildlife Refuge and Water Conservation Area could be very damaging due to potential seepage problems. The Loxahatchee refuge is a key water storage area in the C&SF Project. Maintenance of its water levels is important not only for water storage, but also to support its plants and animals. Seepage, in which groundwater flows from a higher gradient to a lower gradient, could occur if groundwater levels in the refuge are higher than groundwater levels in the adjacent areas. Currently, the adjacent areas consist of agricultural lands, and groundwater historically flowed from these areas into the reserve. However, the direction of this flow has changed as water was withdrawn from local wellfields to support the urban population (Miller 1988). If the Agricultural Reserve Area is urbanized and recharge is reduced, groundwater levels are likely to drop, and this could cause seepage from the refuge. However, if sprawl development does occurs, stormwater regulations which require infiltration could address this problem.

Nevertheless, even with stormwater regulations in place, sprawl development in this area could negatively impact regional water storage potential because the Agricultural Reserve Area has been identified as a potential surface water storage area in the Comprehensive Everglades Restoration Plan (South Florida Water Management District 1998). Utilizing these lands as surface reservoirs will not be possible if urban development occurs there. Even if limited development occurs, the area will require a significant buffer zone so that little seepage occurs. This study suggests that a clear hydrologic benefit of compact development is its preservation of water storage capacity at the Loxahatchee Refuge and potential future water storage areas. For this reason, compact development is the preferred form of development in the county.

- **The benefits of future compact development to aquifer recharge are very small compared to projected increases in future water consumption; compact development alone cannot address the looming shortage of water in the region.**

How changes in urban form (i.e. compact versus sprawl development) affect aquifer recharge can be evaluated by analyzing a projected regional water budget which incorporates these changes. Figures 5.7a & 5.7b show current and projected inflows and outflows of water in the lower east coast region of South Florida. With stormwater regulations in place, during a normal rainfall year, aquifer recharge in 2020 is at almost the same level as in 1995 under both sprawl and compact scenarios. Even if no stormwater regulations were in place, sprawl development would decrease aquifer recharge (storage) by 10% while compact development would decrease recharge by 9%.

To put this in context, urban water consumption in Palm Beach County is expected to increase 48%, while agricultural water demand in Palm Beach County is expected to decrease 11% (*see Figure 5.8*). This follows the historical trends of increasing urban water demand and decreased agricultural demand over the last 20 years (*see Figure 5.9*). Even if all of the savings from reduced agricultural water consumption are redirected to supply the additional county urban water demand, a deficit of .06 million acres remains. The *Eastward Ho! Development Futures* report suggests that compact development reduces water demand because residential lot sizes are smaller and have lower irrigation requirements (Burchell 1999). The study projects a savings of .003 million acre-feet under the compact development pattern, which is only a 2% savings in projected urban demand in the county. With stormwater regulations in place, neither compact nor sprawl development reduces the amount of water supply in aquifer recharge. But neither form significantly reduces the amount of water consumed either.

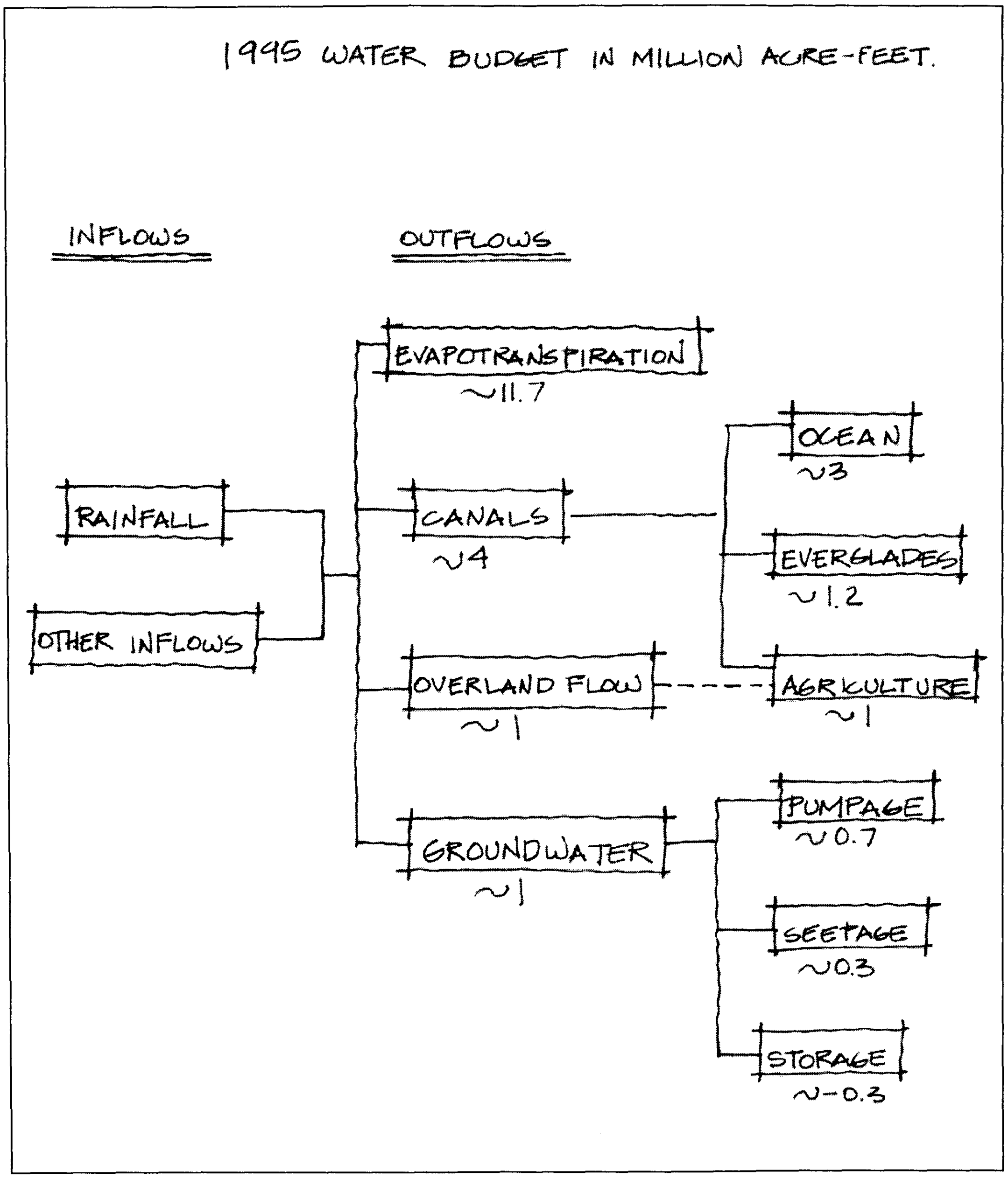


FIGURE 5.7a: 1995 South Florida Water Budget

Source: South Florida Water Management District 2000

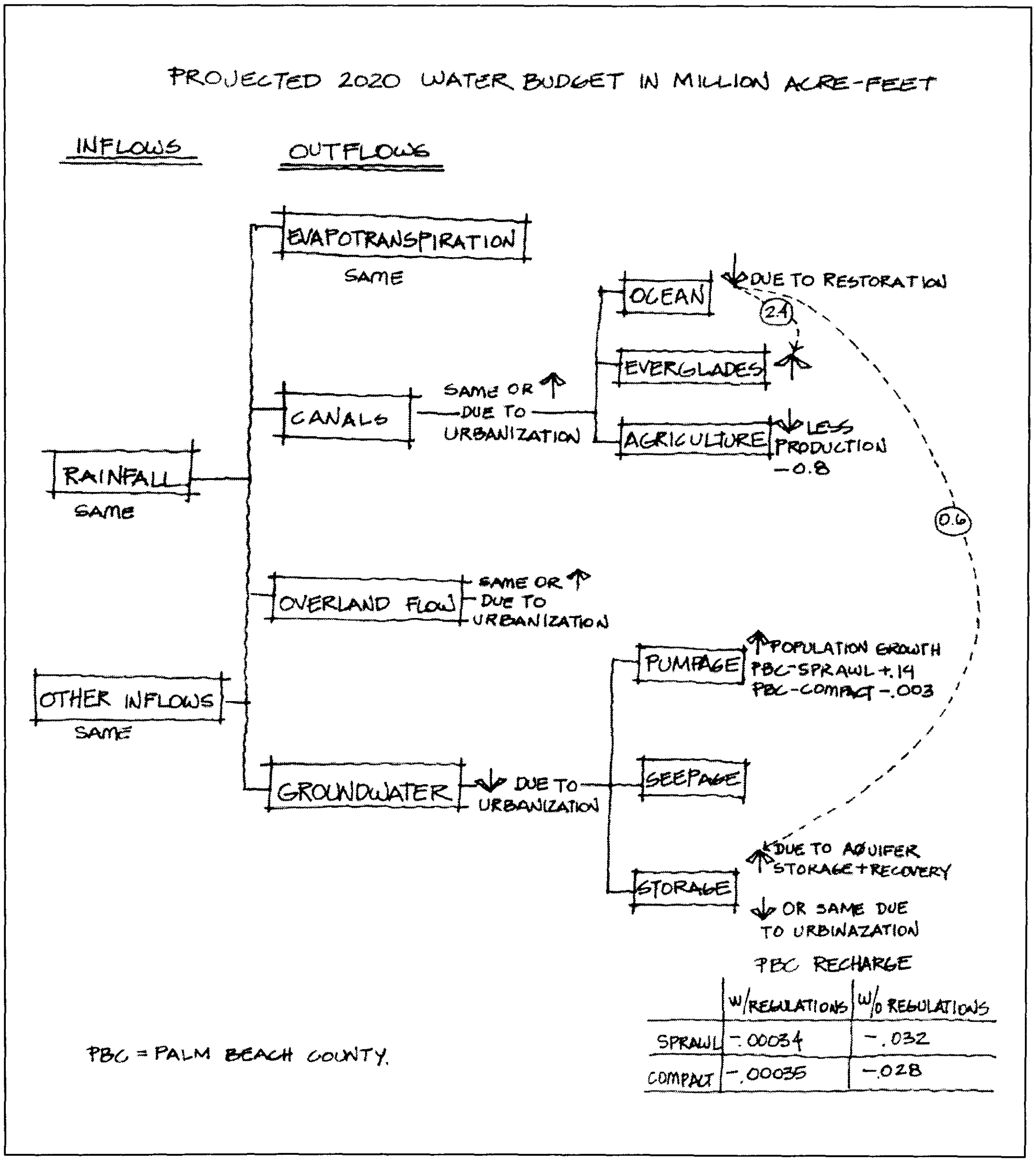
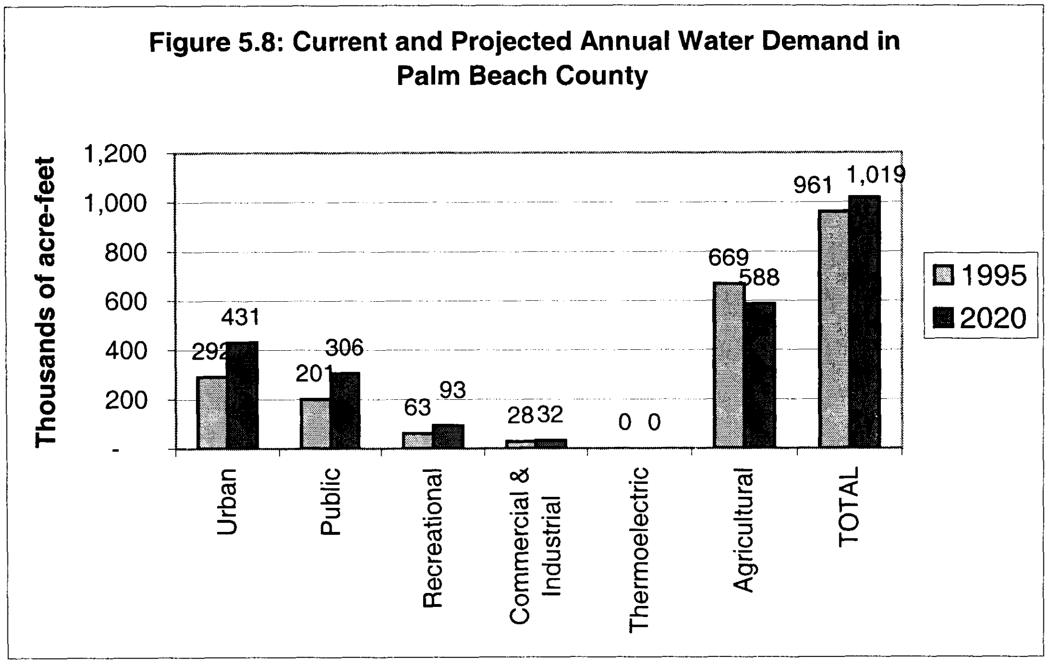
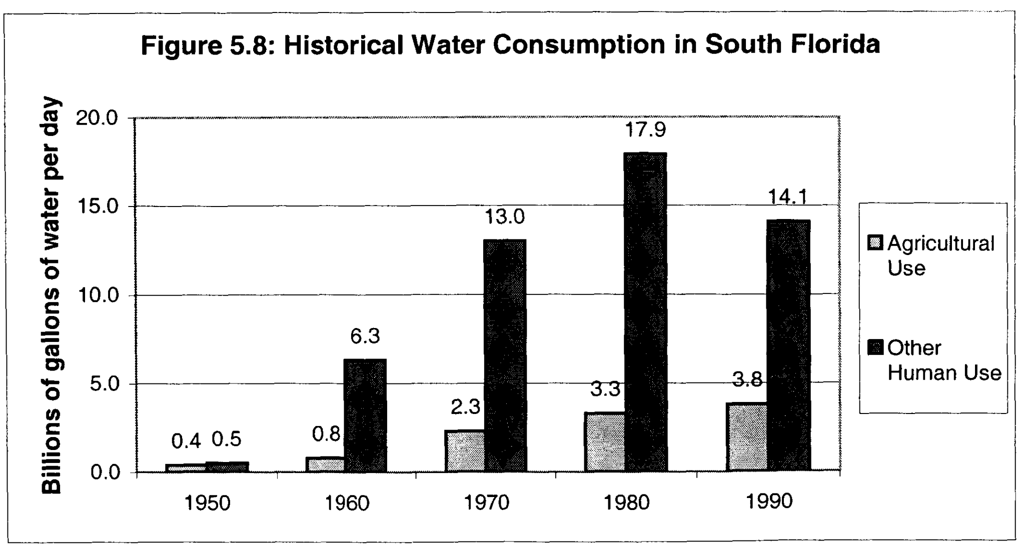


FIGURE 5.7b: Projected 2020 South Florida Water Budget

Source: South Florida Water Management District 2000

Source: South Florida Water Management District 2000





These results support the conclusion that the region's ability to provide adequate water for human, agricultural, and natural systems depends heavily on recapturing and storing water that is currently discard to the ocean through the canal system. This will add an additional 3 million acre-feet of water to the region as a whole. The success of the plan depends on finding storage capacity, which is determined in part by urban form. The location of compact development in Palm Beach County will allow more lands to be allocated to surface water storage and will help prevent losses of water from surface reservoirs due to seepage. But the variable of human water consumption is just as, if not more important to the success of the plan because plant and animal populations of the Everglades and the human population of Southeast Florida will share the recaptured water. Unofficially, the current plan allocates 80% of the recaptured water to the Everglades and 20% to human populations (Boston Globe 2001). Assuming that adequate storage is secured, the recaptured water will add .6 million acre-feet to the urban water supply of the entire region, which must be divided among the counties. However, should this supply fail to meet urban needs especially during periods of drought, water could be diverted from the Everglades and threaten its restoration. As it is, the current 80% allocation will only meet 90% of the predrainage levels in the Everglades. Thus, even if the CERP plan does achieve adequate water storage capacity, which is uncertain, population growth and the related human consumption can still threaten the success of the restoration plan. While compact development slightly reduces residential urban consumption, this reduction is not large and only slightly offsets the impact of increased population growth by 2020.

Design and Planning Recommendations

- **Compact development (i.e. higher density development) should be the preferred form of new development. However, the location of compact development should be based on a fine-grain analysis of the location of permeable soils and recharge areas.**

Many of the permeable sandy soils and recharge areas in Palm Beach County are located along the urbanized coast and the highly productive Biscayne aquifer situated to the south. These areas must be protected from new development, even compact development. Rather, new compact development should be clustered in areas throughout the county which have low recharge potential. Such areas with less permeable soils are located to the west in existing rural and suburban areas of the county. This recommendation contradicts the county's current planning initiatives, which seek to redirect growth from the western areas to the eastern urban core.

- **Compact development in regional clusters on land with low recharge potential should be encouraged by the strategic provision of infrastructure including utilities, roads, and schools.**

Another strategy of growth management and the "urban side of Everglades restoration" could permit the provision of infrastructure to sustain only the number of people that can be supported by the groundwater capacity of the local wellfield. This would provide some security that the needs of the growing urban population would not draw water away from the supply intended for the Everglades. Alternatively, the county could regulate growth by issuing a limited number of permits for private wells based on the capacity of the local groundwater storage. The advantage of providing a centralized system, however, is that the overseeing body retains control over water supply, quality, and price, all of which may be important for water management during droughts.

- **Any significant recharge areas, which in Palm Beach County are primarily in the urbanized areas, should be protected as open space amenity zones.**

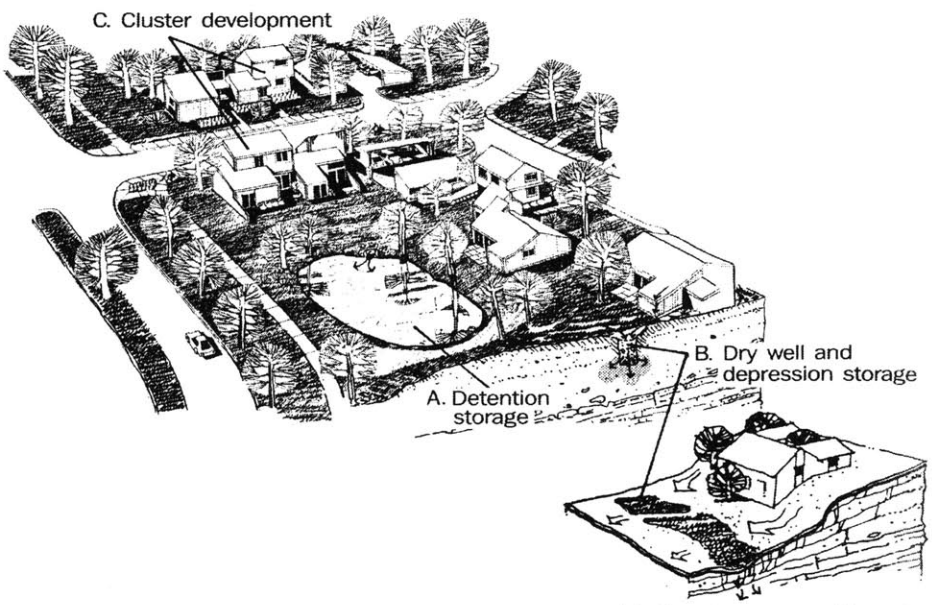
Given the demand for natural and recreational open space, lands with high recharge potential should be zoned for these uses. Furthermore the county should direct land acquisition funds to the purchase of these lands as conservation areas and provide tax incentives for municipalities to purchase and maintain these areas. In all cases, strict controls on fertilizers and other contaminants must be implemented to protect the quality of water recharging the aquifer.

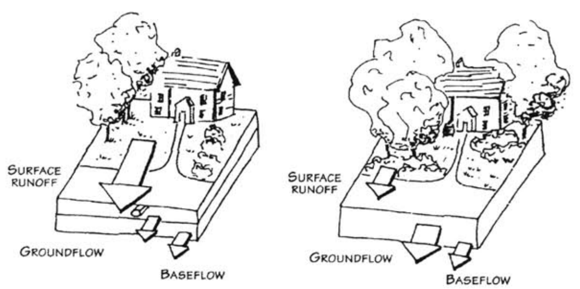
- **Stormwater regulations must be written to encourage retention and infiltration, rather than detention and subsequent discharge.**

Such regulations would require that water slowly flow through vegetated areas rather than stand in lined depressions or underground storage tanks. If the water must be piped and held off-site, it should be discharged to areas with high recharge potential. These areas could be designated as "recharge parks" that also serve as public open space amenities. Without stormwater regulations to allow for infiltration, new development will definitely diminish recharge capacity, which the region can ill afford.

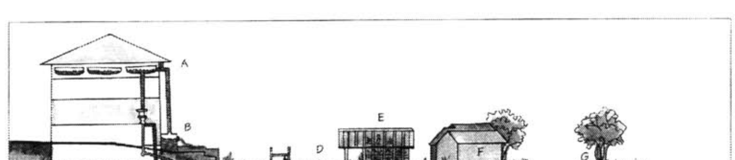
- **Although ideally, new developments would be located on areas with low recharge potential, all new developments should still be designed to infiltrate the maximum amount of stormwater possible.**

Achieving maximum infiltration should be considered at all scales of design, including the single-family house, the neighborhood, and the larger community. New structures should be disconnected from the stormwater system, and stormwater discharged to open space on-site. Figure 5.10 represents some examples of architectural and site design strategies which allow infiltration. Low-density developments may provide more flexibility for maximizing infiltration as these developments usually have larger areas of open space. Developers could be given incentives such as lower exaction fees or tax credits for designs which achieve recharge benefit.





A simple retrofit "disconnect" and revegetation at an individual residence alters the contribution of the lot to the watershed's hydrology. Drawing by charrette team.



The sequence of drainage features proposed for the Sterrett School site. A: Roof runoff is routed to attic bladders and school-side cisterns and used for toilet flushing and irrigation. B: Overflow from cisterns runs along the "art creek" (represented here on the east side of the building). C: Graywater from fixtures could be routed to the greenhouse for bioremediation; blackwater is routed to sewers. D: Art creek and field runoff passes along a vegetated swale around the play field. E: A greenhouse puts some runoff water to productive and educational use. F: Runoff continues along a naturalized surface channel between the houses east of the school. G: Removing the street embankment allows the open channel to continue to a cascade into Fern Hollow. Drawing by Jen Uncapher, RMI, after drawing by charrette team.

FIGURE 5.10: Site Design Strategies Which Maximize Infiltration

Sources: Marsh 1997, Ferguson 1999

- **The regional growth management plan must address water consumption in addition to promoting compact development.**

The management of water consumption could take many forms, including using the availability of local groundwater resources to determine how and where new development should occur. Design regulations such as Palm Beach County's policy that reclaimed water must be used for the landscape irrigation needs of all new developments are critical. Such policies are particularly important because the county contains 135 golf courses, which have high water requirements (Sharma 2001). Another strategy could involve increasing the incremental cost of water to discourage excessive consumption. Numerous interventions are possible, but promotion of compact development alone will not be sufficient.

Chapter 6: Conclusion

The Future of the Everglades...

The current water shortage in South Florida has underscored the conflict between human and natural populations centered around where, when and how water flows. While the human population of the region has grown at an extraordinary rate over the last 50 years and continues to expand, indigenous plant and animal populations are dying due to the manipulation of the hydrologic regime to suit human needs. Currently, efforts are underway to restore a regime more closely calibrated to the needs of the natural system. However, these efforts must take into account the needs of the growing urban population, since the man and nature in South Florida are linked by a common reliance on a limited water supply.

Implicit in the promotion of compact development as the "urban side of Everglades restoration" is the notion that adopting this new form of urban development will help make regional growth compatible with ecosystem restoration. However, this study suggests that the benefits of compact development to the regional water storage capacity so critical to ecosystem restoration, are not as great as might be expected. While compact development does confer some benefits to regional water storage capacity, its impacts (both potential benefits and potential harms) depend on the physical characteristics, particularly the geology, of the specific area being developed. In Palm Beach County, compact development benefits recharge primarily by protecting existing water conservation areas and by facilitating the acquisition of additional surface water storage sites.

This analysis produces two striking results:

- Sprawl development does not diminish recharge significantly more than compact development in Palm Beach County, since sprawl development is occurring primarily on less permeable soils, while compact development is occurring on permeable soils.
- With stormwater regulations in place, the loss of recharge from both sprawl and compact development is insignificant. This suggests that stormwater regulations

requiring infiltration can largely mitigate the negative impacts of both compact and sprawl urban developments on aquifer recharge.

The most important finding of this thesis is that the positive and negative impacts of compact or sprawl development on aquifer recharge pale in comparison to the magnitude of future growth in water demand. This suggests that planners and politicians cannot simply adopt compact development, the current preoccupation of "smart growth" and "sustainable development" as a silver bullet for looming water shortages. Before investing heavily in such policies, one must understand their place-specific implications to determine if their adoption will achieve the desired benefits. In South Florida, where securing adequate water supply for the human and nonhuman inhabitants of the Everglades has proved challenging, careful planning of the hydrology of the region is the key to achieving sustainability. While compact development may prove to have important hydrologic value in some areas, the implementation of multiple strategies to store adequate water for the system is much more important. Through careful reengineering of canals, intelligent placement of cities, and conservative use of water, the Everglades in its entire expanse – that which remains and that which has been changed forever– may achieve a new equilibrium between its human and nonhuman populations.


I TOLD YOU WE SHOULDN'T BUILD SO CLOSE TO THE EVER-GLADES!...
Sports
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Appendices

Loss of 1.5 million acres of the original Everglades due to drainage and development - 148,260 acres custard apple and wetland swamps destroyed - 289,110 wet prairie destroyed - 30,000 cypress forest destroyed - 897,000 acres saw-grass slough community destroyed - 146,000 acres marsh destroyed
Alteration of the hydrologic regime of the remaining wetlands - dams permanently flooded upstream areas, thereby modifying those habitats; - canals diverted water that flowed through the Everglades to other areas, lowering water levels in the park; - flood control measures altered the periods of inundation so that the hydroperiod is shorter than what it once was. Furthermore, stored water is released to agricultural areas at different times than the natural hydrologic regime would dictate; - flows are higher during the wet season and lower during the dry season.
Lowering of the water table by 6 feet due to water withdrawal for urban and agricultural areas - increased fires, since soil which was once inundated is now exposed; - increased soil subsidence; - salt water intrusion which threatens habitats and municipal water supplies; - inadequate freshwater supply for agriculture, urban areas, and natural areas.
Nutrient loading due to agriculture and polluted urban runoff - high levels of phosphorus, nitrogen, chlorine, sodium, and metals such as mercury, from fertilizers, pesticides, urban emissions, landfill and septic tank seepages, and industrial wastes; - proliferation of some species and decline of others which have adapted to low nutrient levels.
Decline of natural habitat and native plant and animal species adapted to these habitats - 68 species listed as endangered or threatened, including the Florida panther, American crocodile, and the snail kite; - 93% decline in wading bird species, from 265,000 to 18,500; - The spread of invasive exotics over 1.3 million acres of land.

Sources: National Park Service 1999, McPherson & Halley 1997, Boston Globe 2001

Step 1: Divide county into "analysis regions" *(see Figure B.1: Eastward Ho! Analysis Designations for Palm Beach County).*

Step 2: **Develop population and employment projections for each region under each scenario** using U.S. Census data, University of Florida Bureau of Economic and Business Research data, building permit data, and interviews with county, local, and regional planners.
(*see Table B.1-B.3: Population, Household & Employment Projections*)

- Standards for sprawl development: use existing growth trends
- Standards for compact development: redirect a percentage of growth to the Eastward Ho! Area as follows:

Region	% Population & Household Growth Redirected	% Job Growth Redirected
Middle Area	20%	33%
Agricultural Areas	90%	33%
Hurricane Hazard	50%	40%
Conservation Areas	100%	100%

Step 3: **Convert population and employment projections to demand for lands and structures** in each region.

a. Residential demand:

i. **Determine number and type of residential units required** to support expected 1995-2020 population growth using area-specific overall vacancy rates.
(see Table B.4: Projected Average Household Size, Table B.5: Projected Demand for Residential Units & Table B.6:Projected Residential Distribution)

ii. **Determine density (ie dwelling units/acre) for each unit type** in each region using following standards: *(see Table B.7: Projected Average Residential Densities)*

- Sprawl development scenario: use recent distribution of housing densities and development types in last 5 years
- Compact development scenario:
  - increase density of new homes in Eastward Ho! area 20%
  - decrease density 40% in peripheral areas (Agricultural and Conservation Areas)
  - encourage clustering for 20% development

ii. Determine total demand for residential land

- **Required land for dwelling units**:

Acres for dwelling units = # units needed/density (units/acre)

- **Required additional land for roads, street hardware, utilities, and open space:**

  Additional acres = platting coefficient * acres for each dwelling type

Housing type	Platting coefficient
Multifamily	.1
Single family attached/duplex	.15
Single family detached	.2

- **Total residential demand = acreage for dwelling units + acreage for additional land** *(see Table B.8: Projected Land Consumption for Residential Development)*

b. Nonresidential demand:

i. **Convert employment growth by sector to number and type of structures needed** as follows:

Employment Type	Structure Type
Manufacturing	Distribution, warehouse (100%)
Wholesale/retail	Retail (70%), warehouse (30%)
Services	Retail (70%), office (30%)
Government	Office (100%)
Fire	Office (100%)
Mining/construction	Distribution/warehouse (60%), office (40%)
Public transportation	Distribution/warehouse (70%), office 30%)

ii. **Determine number of employees housed in each structure.**

iii. **Calculate total square footage required for each building type** *(see Table B.9: Projected Demand for Nonresidential Structures)*:

Total square footage required = # employees * ft^2/employee

Structure type	ft^2 per employee	Average building size (ft^2)
Office	333	25,000
Retail	400	10,000
Distribution/warehouse	667	10,000

iv. **Determine number of each structure type required:**

Number of buildings required = total square footage/average building size

v. **Determine density (FAR[1]) for each building type** in each scenario. Values are based on zoning and discussions with planners and national commercial realtors. (*see Table B.10: Projected Nonresidential Densities*)

[1] FAR (floor to area ratio) is a measure of density which represents the typical lot coverage that occurs in an area due to natural restrictions, setback requirements, etc. FAR varies by development patterns (urban, suburban, rural) rather than use (retail, office, distribution, warehouse).

- Sprawl development: based on historical trends of density and development type in the last 5 years.
- Compact development:
  - 20% increased densities or 1.2 times the existing FAR in Eastward Ho area and 10% increase in Hurricane Hazard Area
  - 20% decrease in Middle Areas and 40% FAR decrease in Agriculture, Conservation, and Public Areas.

vi. Determine total demand for nonresidential land

i. **Required land for structures**:

Total acreage required = lot size per structure * number structures needed
Lot size per structure = building size/FAR

ii. **Required additional land for roads, street hardware, utilities, inefficiencies in landscape design, required public open space**:

Additional acres = platting coefficient * acres for each structure type

Structure type	Platting coefficient
Office	.2
Retail	.05
Distribution/warehouse	.15

iii. **Total nonresidential demand = acreage for structures + acreage for additional land** *(see Table B.11: Projected Land Consumption for Nonresidential Development)*

Step 4: **Determine the amount of developable land available** in each area through evaluation of 1995 GIS land use maps.

a. Use ratios to determine amount of land of each land-use type available for development:
   - open land almost fully available
   - water bodies excluded

b. Use development ceiling with development standards for residential and nonresidential density to determine the amount of residential and nonresidential growth possible in each area.

Step 5: **Compare 2020 projections with 90% ceiling and reassign any growth which exceeds ceiling to another area.**

Step 8: **Determine the infrastructure requirements for water and sewer** *(see Table B.12: Projected Water & Sewer Demand & Table B.13: Projected Water Demand)*

a. Water demand proportional to:
   - Number of people in dwelling unit or per 1000 ft^2 for nonresidential
   - Extent of residential lawn coverage.

b. sewer demand is proportional to the number of gallons of occupant-driven water consumption which is retained in the system and must be disposed of (65-86% of water consumption)

Step 9: Summarize results of land, infrastructure, and fiscal savings *(see Table B.14: Projected Impact of Compact Development in Palm Beach County)*

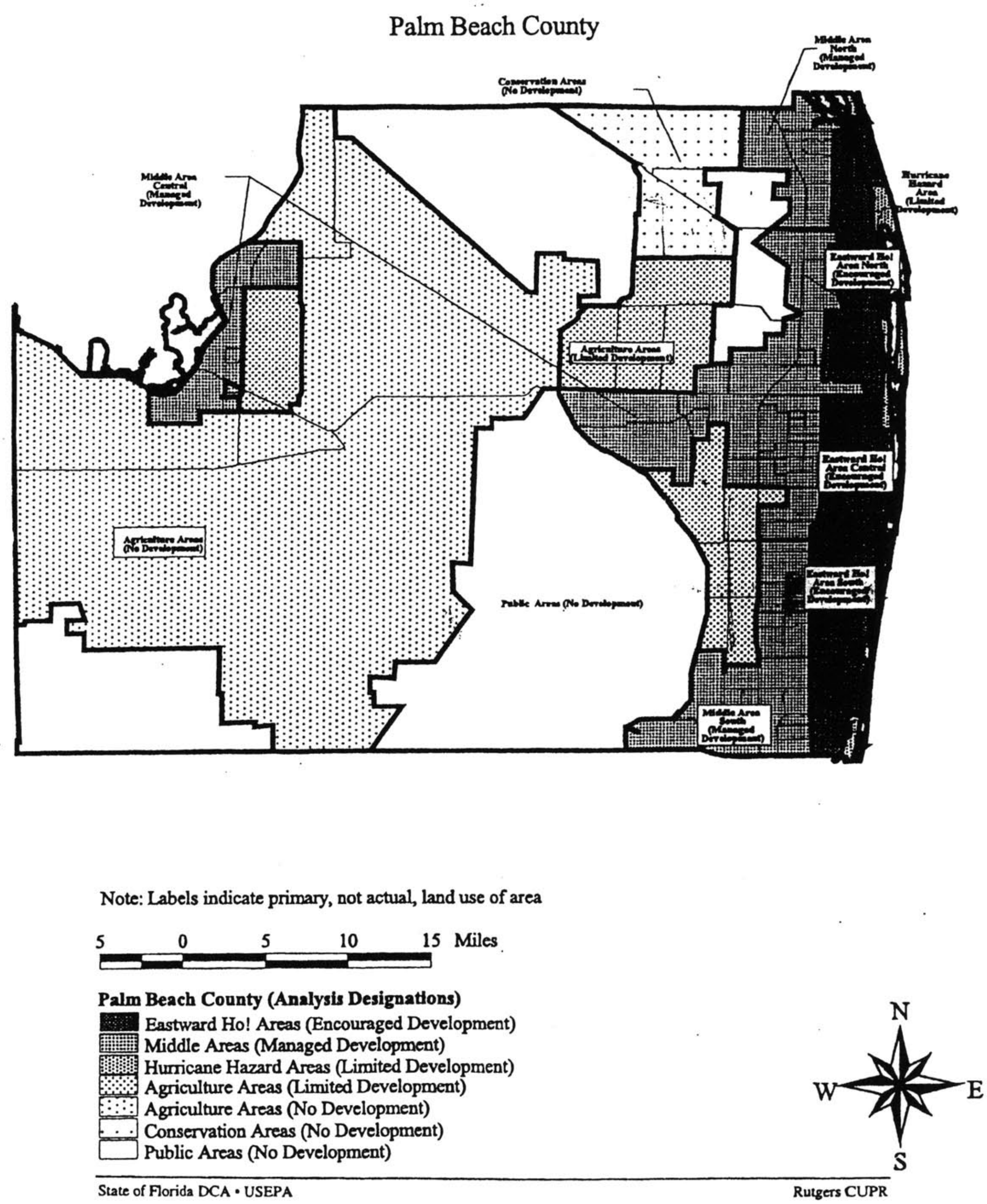


Figure B.1: Eastward Ho! Analysis Regions for Palm Beach County

PALM BEACH COUNTY POPULATION AND EMPLOYMENT PROJECTIONS

Table B.1: POPULATION PROJECTIONS

Region	1995	sprawl: 2020	difference	%change	compact: 2020	difference	%change	% redirected with compact development
Eastward Ho!	380,931	492,502	111,571	29%	661,207	280,276	74%	151%
Middle	436,892	709,522	272,630	62%	654,996	218,104	50%	-20%
Hurricane Hazard	82,705	90,836	8,131	10%	86,771	4,066	5%	-50%
Agricultural	50,459	167,669	117,210	232%	62,414	11,955	24%	-90%
Conservation	11,816	16,675	4,859	41%	11,816	-	0%	-100%
Public	-	-	-	-	-	-	-	0%
Total	962,803	1,477,204	514,401	53%	1,477,204	514,401	53%	

Table B.2: HOUSEHOLD PROJECTIONS

Region	1995	sprawl: 2020	difference	%change	compact: 2020	difference	%change	% redirected with compact development
Eastward Ho!	160,492	208,376	47,884	30%	278,879	118,387	74%	147%
Middle	187,860	304,868	117,008	62%	283,369	95,509	51%	-18%
Hurricane Hazard	42,918	46,407	3,489	8%	44,663	1,745	4%	-50%
Agricultural	17,956	68,261	50,305	280%	23,087	5,131	29%	-90%
Conservation	3,995	6,080	2,085	52%	3,995	-	0%	-100%
Public	-	-	-	-	-	-	-	0%
Total	413,221	633,992	220,771	53%	633,993	220,772	53%	

Table B.3: EMPLOYMENT PROJECTIONS

Region	1995	sprawl: 2020	difference	%change	compact: 2020	difference	%change	% redirected with compact development
Eastward Ho!	169,100	314,551	145,451	1	377,859	208,759	123%	44%
Middle	136,289	238,474	102,185	1	202,710	66,421	49%	-35%
Hurricane Hazard	58,309	112,566	54,257	1	93,576	35,267	60%	-35%
Agricultural	31,772	42,709	10,937	0	38,221	6,449	20%	-41%
Conservation	1,138	5,204	4,066	4	1,138	0	0%	-100%
Public	0	0	0	-	0	0	-	0%
Total	396,608	713,504	316,896	1	713,504	316,896	80%	

Source: Eastward Ho! Development Futures. Center for Urban Policy Research, Rutgers University , 1999

PROJECTIONS FOR RESIDENTIAL DEMAND IN PALM BEACH COUNTY (1995-2020)

Table B.4: PROJECTED AVERAGE HOUSEHOLD SIZE (1995-2020)

Housing Type	Sprawl: persons/unit	Compact: persons/unit
single-family detached	2.91	3.13
single-family attached	2.08	2.2
2-4 units	1.89	2.04
multifamily	1.75	1.89

Table B.5: PROJECTED DEMAND FOR RESIDENTIAL UNITS (1995-2020)

Region	sprawl: # units	compact: # units	difference	% difference with compact development
Eastward Ho	55,583	135,973	80,390	145%
Middle	136,122	111,201	-24,921	-18%
Hurricane Hazard	4,480	2,240	-2,240	-50%
Agricultural	56,877	5,950	-50,927	-90%
Conservation	2,301	0	-2,301	-100%
Total	255,363	255,364	1	0%

Table B.6: PROJECTED RESIDENTIAL DISTRIBUTION IN PALM BEACH COUNTY

	Percent Distribution with Sprawl Development					Percent Distribution with Compact Development				
Region	single family	townhouse	2-4 unit	5+unit condo	5+unit rental	single family	townhouse	2-4 unit	5+unit condo	5+unit rental
Eastward Ho	34%	19%	12%	17%	17%	33%	28%	1%	19%	19%
Middle	40%	18%	10%	15%	16%	62%	16%	2%	10%	10%
Hurricane Hazard	34%	18%	12%	16%	20%	37%	20%	3%	18%	23%
Agricultural	100%	-	-	-	-	100%	-	-	-	-
Conservation	100%	-	-	-	-	100%	-	-	-	-
County Average	62%	18%	11%	16%	18%	66%	21%	2%	16%	17%

Table B.7: PROJECTED AVERAGE RESIDENTIAL DENSITIES

	Units/acre with Sprawl Development					Units/acre with Compact Development				
Region	single family	townhouse	2-4 unit	5+unit condo	5+unit rental	single family	townhouse	2-4 unit	5+unit condo	5+unit rental
Eastward Ho	7.5	10	10	10	10	9	12	12	18	12
Middle	4	6	6	9	6	3.2	4.8	4.8	7.2	4.8
Hurricane Hazard	5	10	10	22.5	15	5.5	11	11	24.8	16.5
Agricultural	1.3	-	-	-	-	0.8	-	-	-	-
Conservation	0.2	-	-	-	-	0.1	-	-	-	-
Total	3.6	8.7	8.7	13.8	10.3	3.7	9.3	9.3	16.7	11.1

Table B.8: PROJECTED LAND CONSUMPTION FOR RESIDENTIAL DEVELOPMENT

Region	Acres consumed in Sprawl	Acres consumed in Compact	Difference	% difference with compact development
Eastward Ho	7,102	13,702	6,600	92.9%
Middle	32,106	35,045	2,939	9.2%
Hurricane Hazard	626	284	-342	-54.6%
Agricultural*	52,501	8,925	-43,576	-83.0%
Conservation	13,808	0	-13,808	-100.0%
Total	**106,143**	**57,956**	**-48,187**	**-45.4%**

*Note: numbers revised from original Eastward Ho! report projections for the Agricultural Areas of 5268 and 5259 acres consumed for Sprawl and Compact Development scenarios, respectively.

Source: Eastward Ho! Development Futures. Center for Urban Policy Research, Rutgers University, 1999.

PROJECTIONS FOR NONRESIDENTIAL DEMAND IN PALM BEACH COUNTY (1995-2020)

Table B.9: PROJECTED DEMAND FOR NONRESIDENTIAL LAND

Region	Sprawl: ft^2	Compact: ft^2	difference	% difference with compact development
Eastward Ho	65,353,000	93,799,000	28,446,000	43.5%
Middle	45,913,000	29,844,000	-16,069,000	-35.0%
Hurricane Hazard	24,378,000	15,846,000	-8,532,000	-35.0%
Agricultural	4,914,000	2,898,000	-2,016,000	-41.0%
Conservation	1,827,000	0	-1,827,000	-100.0%
Total	**142,385,000**	**142,387,000**	**2,000**	**0.0%**

Table B.10: PROJECTED NONRESIDENTIAL DENSITIES

	FAR with Sprawl Development			**FAR with Compact Development**		
Region	retail	office	industrial/ warehouse	retail	office	industrial/ warehouse
Eastward Ho	0.9	0.9	0.6	1.08	1.08	0.72
Middle	0.45	0.45	0.5	0.36	0.36	0.4
Hurricane Hazard	1.13	1.13	0.75	1.24	1.24	0.83
Agricultural	0.23	0.23	0.5	0.14	0.14	0.3
Conservation	0.23	0.23	0.5	0.14	0.14	0.3
County Average	0.59	0.59	0.57	0.59	0.59	0.51

Table B.11: PROJECTED LAND CONSUMPTION FOR NONRESIDENTIAL DEVELOPMENT

Region	Acres consumed in sprawl	Acres consumed in Compact	Difference	% difference with compact development
Eastward Ho	1,964	1,879	-85	-4.3%
Middle	2,566	2,085	-481	-18.7%
Hurricane Hazard	584	345	-239	-40.9%
Agricultural	508	499	-9	-1.8%
Conservation	189	0	-189	-100.0%
Total	**5,811**	**4,808**	-1,003	**-17.3%**

Source: Eastward Ho! Development Futures. Center for Urban Policy Research, Rutgers University, 1999.

UTILITY PROJECTIONS IN PALM BEACH COUNTY

Table B.12: PROJECTED WATER AND SEWER DEMAND (1995?)

Structure Type	water	sewer
Residential	**Demand (gallons/person/day)**	
single family detached	100	65
single-family attached	85	56
2-4 units	85	56
5+ units (condo)	75	52
5+ units (rental)	75	52
Nonresidential	**Demand (gallons/1000ft^2)**	
office	100	86
retail	200	172
industrial/warehouse)	180	155

Table B.13: ANNUAL PALM BEACH COUNTY PROJECTED WATER DEMAND

Region	KGY with Sprawl	KGY with Compact	Difference	% difference with compact development
Eastward Ho	7,071,275	13,604,569	6,533,294	92.4%
Middle	11,535,255	8,745,450	-2,789,805	-24.2%
Hurricane Hazard	1,520,374	944,472	-575,902	-37.9%
Agricultural	4,531,385	563,875	-3,967,510	-87.6%
Conservation	271,509	0	-271,509	-100.0%
Total	**24,929,798**	**23,858,366**	-1,071,432	**-4.3%**

Source: Eastward Ho! Development Futures. Center for Urban Policy Research, Rutgers University, 1999.

TABLE B.14: PROJECTED IMPACT OF COMPACT DEVELOPMENT IN PALM BEACH COUNTY

	Acres of lands saved			Land miles saved		Roadway costs saved	
Region	Total	Agricultural lands	Fragile lands	Local roads	State roads	Local costs ($000)	State costs ($000)
Eastward Ho	-6,515	-322	-1,091	-522	-14	-421,608	-12,130
Middle	-2,457	-1,518	-161	218	12	154,240	8,249
Hurricane Hazard	580	0	68	0	0	0	0
Agricultural	9	18	-2	2,580	0	1,127,969	0
Conservation	13,996	4,298	6,806	91	4	39,394	1,949
Total	**5,613**	**2,476**	**5,620**	**2,367**	**2**	**899,995**	**-1,932**

	Potable water saved			Sewer water saved			Development costs saved		
Region	Water demand (KGY)	Water hookups (E)	Water cost ($000)	Sewer demand (KGY)	Sewer hookups	Sewer cost ($000)	Average housing costs	Nonresidential costs ($000/ft^2)	Annual fiscal impact ($000)
Eastward Ho	-6,533,294	-34,885	-41,862	-4,679,996	-34,885	-34,885	21,171	2,906	50,697
Middle	2,789,806	20,657	24,788	1,978,224	20,657	20,657	-21,393	-4,755	-10,639
Hurricane Hazard	575,902	2,068	2,482	467,826	2,068	2,068	3,606	1,698	3,875
Agricultural	3,967,510	51,965	83,086	2,597,864	51,965	72,693	-31,460	-10,490	-19,817
Conservation	271,509	2,433	3,840	196,251	2,433	3,353	246,039	84,704	-1,809
Total	**1,071,433**	**42,238**	**72,334**	**560,169**	**42,238**	**63,886**	**217,963**	**74,063**	**22,307**

Source: Eastward Ho! Development Futures. Center for Urban Policy Research, Rutgers University, 1999.

Table C.1: PROJECTED CONVERSION OF LANDS FOR NEW URBAN DEVELOPMENT IN PALM BEACH COUNTY (1995-2020)

REGION	Land Use Converted	1995 acreage includes environmentally sensitive lands	Acres converted	encroachment on environmentally sensitive lands	Notes
Eastward Ho Sprawl Development	vacant land	6,666.4	4,481.5	yes - floodplains, wellfield zones, conservation areas, and priority acquisition sites	
	agricultural	2,786.0	1,991.4		
	rangeland	3,658.4	383.9		
	upland forest	6,916.5	2,207.8		
	wetlands	925.5	-		
	barren	46.2	-		
need 9,066 acres	**total**	20,999.0	**9,064.6**		
Eastward Ho Compact Development	urban open land	6,666.4	6,096.7	yes - floodplains, wellfield zones, conservation areas, and priority acquisition sites	
	agricultural	2,786.0	2,447.6		
	rangeland	3,658.4	2,356.3		
	upland forest	6,916.5	4,160.7		
	wetlands	925.5	457.8		
	barren	46.2	46.2		
need 15,582 acres	**total**	20,999.0	**15,576.0**		
Hurricane Hazard Sprawl Development	urban open land	103.4	103.4	yes - floodplains	Could not meet Eastward Ho! Study acreage requirement without redeveloping industrial lands in this area.
	agricultural	7.2	7.2		
	rangeland	-	-		
	upland forest	529.4	172.1		
	wetlands	93.2	37.6		
	barren	425.1	425.1		
need 1,210 acres	**total**	1,158.3	**745.4**		
Hurricane Hazard Compact Development	urban open land	103.4	103.4	yes - floodplains	
	agricultural	7.2	7.2		
	rangeland		-		
	upland forest	529.4	172.1		
	wetlands	93.2	-		
	barren	425.1	354.2		
need 629 acres	**total**	1,158.3	**636.9**		
East Middle Area Sprawl Development	urban open land	19,838.3	10,538.7	yes - floodplains, wellfield zones, conservation areas, and priority acquisition sites	In this scenario, 100% of projected development for the Middle Area occurs in East Middle Area.
	agricultural	37,832.3	13,717.5		
	rangeland	1,897.6	743.7		
	upland forest	16,080.7	9,126.4		
	wetlands	11,642.1	550.9		
	barren	4.2	4.2		
need 34,672 acres	**total**	87,295.2	**34,681.4**		
East Middle Area Compact Development	urban open land	19,838.3	11,030.2	yes - floodplains and wellfield zones	In this scenario, 95% of projected development for the Middle Area occurs in East Middle Area.
	agricultural	37,832.3	13,791.6		
	rangeland	1,897.6	743.7		
	upland forest	16,080.7	9,147.2		
	wetlands	11,642.1	550.9		
	barren	4.2	4.2		
need 35,273.5 acres	**total**	87,295.2	**35,267.8**		
West Middle Area Sprawl Development	urban open land	316.8	-	none	In this scenario, none of the projected development for the Middle Area occurs in the West Middle Area.
	agricultural	21,642.2	-		
	rangeland	27.4	-		
	upland forest	67.7	-		
	wetlands	111.0	-		
	barren	114.9	-		
need 0 acres	**total**	22,280.0	-		
West Middle Area Compact Development	urban open land	316.8	286.9	none	In this scenario, 5% of the projected development for the Middle Area occurs in the West Middle Area.
	agricultural	21,642.2	1,478.3		
	rangeland	27.4	27.5		
	upland forest	67.7	-		
	wetlands	111.0	-		
	barren	114.9	21.9		
need 1,856.5 acres	**total**	22,280.0	**1,839.0**		

REGION	Land Use Converted	1995 acreage inc/environmentally sensitive lands	Acres converted	encroachment on environmentally sensitive lands	Notes
Agricultural Reserve	urban open land	2,110.6	846.7	yes - wellfield zones	In this scenario, 36% of the
Sprawl Development	agricultural	21,512.7	18,435.6		projected development for the
	rangeland	321.3	110.6		Agricultural Area occurs in
	upland forest	1,954.6	965.0		Agricultural Reserve Area.
	wetlands	7,025.6	232.3		Avoided impinging upon
	barren	-	-		Loxahatchee Refuge.
need 21,825 acres	**total**	32,924.8	**21,834.4**		
Agricultural Reserve	urban open land	2,110.6	-	none	
Compact Development	agricultural	21,512.7	3,892.1		
	rangeland	321.3	48.7		
	upland forest	1,954.6	-		
	wetlands	7,025.6	-		
	barren	-	-		
need 3,954 acres	**total**	32,924.8	**3,940.8**		
Agricultural Sector	urban open land	20,091.5	15,826.0	yes - floodplains	In this scenario, 64% of the
Sprawl Development	agricultural	18,389.0	14,703.1		projected development for the
	rangeland	-	-		Agricultural Area occurs in
	upland forest	2,781.7	663.1		Agricultural Sector.
	wetlands	538.6	-		
	barren	-	-		
need 31,184 acres	**total**	41,800.8	**31,192.2**		
Agricultural Sector	urban open land	20,091.5	1,754.6	yes - floodplains	
Compact Development	agricultural	18,389.0	2,906.5		
	rangeland	-	-		
	upland forest	2,781.7	526.3		
	wetlands	538.6	295.6		
	barren	-	-		
need 5,470 acres	**total**	41,800.8	**5,483.0**		
Conservation Area	urban open land	317.7	317.7	yes - floodplains,	Could not meet Eastward Ho!
Sprawl Development	agricultural	6,973.2	6,973.2	wellfield zones,	Study acreage requirement
	rangeland	271.7	271.7	conservation areas,	without redeveloping industrial
	upland forest	814.4	814.4	and priority	lands in this area.
	wetlands	24,708.9	587.4	acquisition sites	
	barren	-	-		
need 13,997 acres	**total**	33,085.9	**12,635.2**		
Conservation Area	urban open land	236.2	-	none	
Compact Development	agricultural	6,973.2	-		
	rangeland	271.7	-		
	upland forest	814.4	-		
	wetlands	24,708.9	-		
	barren	-	-		
need 0 acres	**total**	33,004.4	-		

TABLE C.2: PROJECTED DISTRIBUTION OF NEW RESIDENTIAL & NONRESIDENTIAL LAND DEVELOPMENT CONSUMPTION IN PALM BEACH COUNTY (1995-2020)

	Residential Development					
Region	**Acres consumed in sprawl scenario**	**Sprawl residential densities**	**Acres consumed in compact scenario**	**Compact Residential densities**	**Difference in land consumption**	**% difference with compact development**
Eastward Ho	7,102	high	13,702	high	6,600	93%
East Middle Area	32,106	medium	33,293	medium	1,187	4%
West Middle Area	0	medium	1,752	medium	1,752	100%
Hurricane Hazard	626	high	284	high	-342	-55%
Agricultural Reserve	21,825	medium	3,954	low	-17,871	-82%
Agricultural Sector	31,184	medium	5,470	low	-25,714	-82%
Conservation	13,808	low	0	low	-13,808	-100%
Total	**106,651**		**58,455**		-48,196	-45%

	Nonresidential Development					
Region	**Acres consumed in sprawl scenario**	**Sprawl commercial intensities**	**Acres consumed in compact scenario**	**Compact commercial intensities**	**Difference in land consumption**	**% difference with compact development**
Eastward Ho	1,964	high	1,879	high	-85	-4%
East Middle Area	2,566	low	1,981	low	-585	-23%
West Middle Area	0	low	104	low	104	100%
Hurricane Hazard	584	high	345	high	-239	-41%
Agricultural Reserve	300	low	294	low	-6	-2%
Agricultural Sector	208	low	205	low	-3	-1%
Conservation	189	low	0	low	-189	-100%
Total	**5,811**		**4,808**		-1,003	-17%

TABLE 10.—EVAPORATION AND TRANSPIRATION FROM TANKS AND OPEN PAN FOR YEAR 1934, EVERGLADES EXPERIMENT STATION, BELLE GLADE, FLORIDA.

Month	Wind Motion	Average Depth to Water	Evaporation and Transpiration				Rainfall	Mean Tempera-ture
			Cane Tank 1	Cane Tank 2	Bare Soil Tank 3	Open Pan		
	Miles	Feet	Inches	Inches	Inches	Inches	Inches	F. °
Jan.	4,600	2.05	1.95	2.36	2.39	3.63	0.14	63.8
Feb.	5,070	1.94	2.63	2.66	2.86	3.69	1.91	62.3
Mar.	5,650	1.87	2.91	2.91	3.38	5.56	7.10	66.4
Apr.	4,950	1.61	4.62	4.41	4.62	6.96	3.11	70.2
May	4,100	1.76	3.66	4.00	3.97	6.40	5.20	75.3
June	3,860	1.37	5.37	5.28	4.59	6.19	10.15	78.5
July	3,330	1.66	7.32	6.60	4.65	7.12	10.09	79.2
Aug.	3,410	1.35	6.51	5.49	4.74	6.70	12.41	80.0
Sept.	3,540	1.67	5.67	5.16	3.69	5.77	7.44	79.6
Oct.	3,980	1.93	5.61	5.30	3.41	5.73	3.22	76.1
Nov.	4,250	1.99	3.48	3.57	2.31	4.03	0.65	68.0
Dec.	4,220	1.96	1.67	1.58	2.05	3.49	0.82	63.8
Year	50,960	1.76	51.40	49.32	42.65	65.27	62.24	71.9

Note.—Cane in Tank 1 was a large barrel type (P.O.J. 2725) and that in Tank 2 was a medium barrel type (Co. 281). Both canes were planted Feb. 1, 1934, and were cut Dec. 13, 1934, following a hard freeze on Dec. 12. Cane in Tank 1 produced 46.4 tons per acre and that in Tank 2 produced 33.0 tons per acre. Tank 3 contained bare soil without shade. Tanks 1 and 2 were surrounded with cane on the outside, for a windbreak.

TABLE 11.—EVAPORATION AND TRANSPIRATION FROM TANKS AND OPEN PAN FOR YEAR 1935, EVERGLADES EXPERIMENT STATION, BELLE GLADE, FLORIDA.

Month	Wind Motion	Average Depth to Water	Evaporation and Transpiration					Rainfall	Mean Tempera-ture
			Cane Tank 1	Cane Tank 2	Bare Soil Tank 3	Alfalfa Tank 4	Open Pan		
	Miles	Feet	Inches	Inches	Inches	Inches	Inches	Inches	F. °
Jan.	5,179	1.80	0.93	0.87	2.08	1.74	3.81	0.30	63.4
Feb.	4,143	1.78	1.76	1.62	2.24	2.46	4.25	1.32	63.1
Mar.	5,087	1.79	1.98	1.64	2.94	2.23	6.52	0.41	68.8
Apr.	4,434	1.38	3.15	4.86	3.81	3.06	7.50	5.32	71.1
May	4,073	1.82	2.94	2.73	2.79	4.22	8.84	1.08	76.1
June	2,990	1.46	4.11	4.14	3.54	5.01	6.55	8.45	77.3
July	3,851	1.67	5.83	6.26	4.16	6.70	7.38	6.37	79.3
Aug.	2,956	1.55	6.54	7.16	4.37	7.28	7.02	6.54	80.1
Sept.	4,111	1.28	5.64	5.28	5.55	3.69	5.54	10.88	79.1
Oct.	4,898	1.36	5.30	5.46	3.81	3.60	5.37	5.71	75.9
Nov.	4,148	1.82	5.25	4.11	1.50	2.49	4.32	0.36	69.0
Dec.	4,820	1.65	3.08	2.42	2.42	2.64	3.50	2.07	56.4
Year	50,690	1.61	46.51	46.55	39.21	45.12	70.60	48.81	71.6

Note.—Cane in both tanks was the same type as in previous year. Soil was covered with dry cane leaves until Jan. 21, thus reducing evaporation for a period of three weeks. Cane growth was stopped by killing frost o Dec. 1 and crop was harvested on Jan. 14, 1936. Cane in Tank 1 was retarded by wireworms. The yield was 42.0 tons per acre. Tank 2 was replanted on April 15, because of wireworm damage. The cane yield was 28.6 tons per acre.

Tank 3 contained bare soil partially shaded by cane around the outside, but the shade was not equivalent to usual cane field conditions.

Tank 4 had soil substantially bare prior to April 15 when alfalfa was planted. At first the alfalfa made good progress, but the stand deteriorated during the summer, and only a scattered growth remained in the fall; hence the drop in evaporation.

TABLE 12.—EVAPORATION AND TRANSPIRATION FROM TANKS AND OPEN PAN FOR YEAR 1936, EVERGLADES EXPERIMENT STATION, BELLE GLADE, FLORIDA.

Month	Wind Motion	Av. Depth to Water in Ft.		Evaporation and Transpiration					Rainfall	Mean Temperature
		Tanks 1, 3 & 4	Tank 2	Cane Tank 1	Sawgrass Tank 2	Bare Soil Tank 3	Grass Tank 4	Open Pan		
	Miles			Inches	Inches	Inches	Inches	Inches	Inches	F. °
Jan.	4410	1.38	*	1.43	*	1.20	2.67	4.18	1.91	65.1
Feb.	4994	1.21	*	1.02	*	1.12	2.87	3.81	4.04	63.5
Mar.	5050	1.42	*	1.64	*	2.08	4.34	6.22	2.40	65.5
Apr.	4520	1.47	0.72	3.48	2.79	3.54	6.80	7.68	1.96	70.6
May	4709	1.24	0.75	5.55	3.22	4.43	5.24	7.40	6.39	73.8
June	3526	1.00	0.59	5.94	4.86	4.56	4.86	5.94	18.61	77.0
July	3943	1.47	1.00	6.45	5.42	4.94	7.28	7.37	6.09	81.1
Aug.	3337	1.46	1.00	5.36	6.60	4.74	5.95	6.54	5.33	80.6
Sept.	2707	1.31	0.97	3.87	5.43	3.78	4.38	4.92	5.84	79.3
Oct.	3509	1.46	1.08	3.56	4.25	1.89	3.44	5.15	1.65	78.1
Nov.	3755	1.14	0.86	2.76	4.86	2.76	2.13	4.28	9.17	68.0
Dec.	3850	1.42	1.02	2.70	4.06	0.93	1.95	3.13	1.18	67.0
Year	48,310	1.33	—	43.76	—	35.97	51.91	66.62	64.57	72.5

Note.—Cane (F31-1037) was cut Dec. 29, 1936. Yield of mill cane was 28.4 tons per acre and 205 lbs. of 96° sugar per ton.

Sawgrass was set in Tank 2 on Mar. 3. By May 1 old sawgrass had died down and new sprouts appeared. Stand did not reach full size until Nov. Thereafter a good stand was maintained.

Soil in Tank 3 was partially shaded during year by cane around tank.

Tank 4 was planted to Alfalfa on Jan. 29. Stand died down by summer and was mostly grass and weeds during last half of year.

*No record.

TABLE 13.—EVAPORATION AND TRANSPIRATION FROM TANKS AND OPEN PAN FOR YEAR 1937, EVERGLADES EXPERIMENT STATION, BELLE GLADE, FLORIDA.

Month	Wind Motion	Av. Depth to Water in Ft.		Evaporation and Transpiration					Rainfall	Mean Temperature
		Tanks 1, 3 & 4	Tank 2	Cane Tank 1	Sawgrass Tank 2	Bare Soil Tank 3	Mulch Soil Tank 4	Open Pan		
	Miles			Inches	Inches	Inches	Inches	Inches	Inches	F. °
Jan.	4076	1.28	0.77	1.73	5.61	1.75	0.53	4.44	2.97	70.8
Feb.	4283	1.47	1.05	2.46	4.93	2.91	0.66	3.86	1.21	64.7
Mar.	4235	1.49	1.06	3.36	6.24	3.78	0.71	5.30	5.87	66.1
Apr.	4037	1.18	0.84	4.63	7.53	4.26	1.06	6.30	6.00	70.0
May	3275	1.38	1.04	5.85	9.64	4.54	1.05	7.77	3.38	74.0
June	2978	1.12	0.77	4.33	7.05	4.53	1.18	6.70	7.74	78.3
July	2914	1.38	0.96	5.43	9.95	5.09	2.05	6.66	7.65	79.7
Aug.	2853	1.31	0.88	5.24	8.80	4.99	1.48	6.02	7.89	80.6
Sept.	2812	1.26	0.95	4.79	8.93	4.38	1.39	5.58	8.35	78.9
Oct.	3345	1.30	0.93	3.44	7.60	3.20	1.10	4.93	4.92	73.8
Nov.	4418	1.40	0.93	2.49	4.14	1.44	0.55	3.76	2.08	67.1
Dec.	4275	1.52	0.99	1.67	3.62	1.41	0.43	3.12	0.38	63.2
Year	43,501	1.34	0.93	45.42	84.04	42.28	12.19	64.44	58.44	72.3

Note.—Cane (F31-1037) was cut Dec. 17. Yield of cane was 20.0 tons per acre and 219 lbs. of 96° sugar per ton. Stand was poor probably due to wire worms. Sawgrass fully grown and shaded by cane around tank. Stand probably equal to average in Glades. Bare soil partially shaded by cane around tank. About 4 inches of cane leaves used for mulch on Tank 4.

TABLE 14.—EVAPORATION AND TRANSPIRATION [illegible] TANKS AND OPEN PAN FOR YEAR 1938, EVERGLADES EXPERIMENT STATION, BELLE GLADE, FLORIDA.

Month	Wind Motion	Av. Depth to Water in Ft.		Evaporation and Transpiration					Rainfall	Mean Temperature
		Tanks 1, 3 & 4	Tank 2	Cane Tank 1	Sawgrass Tank 2	Grass Tank 3	Mulch Soil Tank 4	Open Pan		
	Miles			Inches	Inches	Inches	Inches	Inches	Inches	F. °
Jan.	4140	1.60	0.78	[illegible]	4.01	*	0.56	3.69	0.46	62.5
Feb.	4685	1.45	0.90	[illegible]	4.17	2.87	0.59	4.22	1.14	65.4
Mar.	3833	1.43	1.02	[illegible]	6.49	4.93	0.43	5.85	1.87	68.9
Apr.	4300	1.51	1.04	[illegible]	7.32	5.27	0.46	6.78	0.32	69.8
May	3224	1.37	0.92	[illegible]	7.69	6.98	0.76	6.66	4.52	75.8
June	2913	1.39	0.90	3.93	7.59	7.26	1.11	6.50	5.44	77.6
July	3188	1.26	0.94	[illegible]	6.72	5.63	1.65	6.64	8.85	79.0
Aug.	3062	1.45	1.00	[illegible]	7.05	5.80	0.59	6.75	2.65	79.8
Sept.	2961	1.36	0.88	[illegible]	5.99	4.65	1.08	5.92	10.09	78.6
Oct.	4220	1.43	0.95	[illegible]	5.09	4.34	0.78	5.34	2.78	72.5
Nov.	3663	1.39	0.90	[illegible]	3.48	3.57	0.81	4.08	2.66	71.2
Dec.	3554	1.50	0.96	[illegible]	2.25	2.69	0.28	3.36	0.21	63.7
Year	43,743	1.43	0.93	[illegible]	67.85	53.99	9.10	65.79	40.99	72.1

Note.—Cane (F31-436) was planted last week of Dec., [illegible] cut Jan. 3, 1939. Yield was 37.4 tons per acre. Both Cane Tank 1 and Mulch Tank 4 were covered with a heavy layer of cane trash during [illegible] year. The difference between the total evaporations of the 2 tanks or 25.93 inches is roughly the transpiration loss through the cane. This am[illegible] to 78.4 pounds of water per pound of mill cane, and 763 pounds of water per pound of 96° sugar.

The sawgrass in Tank 2 was surrounded by cane for n[illegible] tank. The stand of sawgrass was below normal during the last half of year. Tank 3 was planted to Bahia grass in January. The grass was n[illegible] during the year.

*No record.

Source: U.S. Department of Agriculture

Table E.1: SUMMARY OF ANNUAL PRECIPITATION AND EVAPOTRANSPIRATION IN COASTAL CLIMATE ZONE (1948-2000)

ALL YEARS

Year	Prcp	ET	ET/P	Potential Recharge
1949	54.80	36.03	0.66	18.77
1950	51.97	35.84	0.69	16.13
1951	52.83	37.39	0.71	15.44
1952	50.87	35.22	0.69	15.65
1953	71.38	35.37	0.50	36.01
1954	73.21	42.05	0.57	31.16
1955	37.31	43.44	1.16	-6.13
1956	38.40	30.67	0.80	7.73
1957	62.93	35.62	0.57	27.31
1958	65.18	37.70	0.58	27.48
1959	68.61	38.10	0.56	30.51
1960	66.77	44.28	0.66	22.49
1961	37.76	42.13	1.12	-4.37
1962	48.56	33.80	0.70	14.76
1963	53.31	30.39	0.57	22.92
1964	79.30	33.65	0.42	45.65
1965	58.26	49.59	0.85	8.67
1966	79.75	40.97	0.51	38.78
1967	51.54	47.68	0.93	3.86
1968	77.42	41.70	0.54	35.72
1969	79.75	41.04	0.51	38.71
1970	55.28	54.23	0.98	1.05
1971	51.31	42.13	0.82	9.18
1972	75.15	47.24	0.63	27.91
1973	54.74	39.58	0.72	15.16
1974	58.46	38.89	0.67	19.57
1975	44.40	39.10	0.88	5.30
1976	55.32	33.38	0.60	21.94
1977	64.26	36.64	0.57	27.62
1978	62.21	36.41	0.59	25.80
1979	61.18	40.60	0.66	20.58
1980	56.67	36.78	0.65	19.89
1981	49.74	41.88	0.84	7.86
1982	80.62	42.69	0.53	37.93
1983	82.71	33.56	0.41	49.15
1984	69.79	53.23	0.76	16.56
1985	47.99	53.09	1.11	-5.10
1986	69.31	41.51	0.60	27.80
1987	58.69	44.44	0.76	14.25
1988	64.91	41.78	0.64	23.13
1989	38.66	42.87	1.11	-4.21
1990	55.81	36.59	0.66	19.22
1991	79.36	35.64	0.45	43.72
1992	61.11	44.02	0.72	17.09
1993	36.56	45.51	1.24	-8.95
1994	33.94	21.34	0.63	12.60
1995	56.57	29.85	0.53	26.72
1996	38.57	33.78	0.88	4.79
1997	62.13	34.74	0.56	27.39
1998	67.05	40.22	0.60	26.83
1999	62.73	41.59	0.66	21.14
2000	41.67	35.80	0.86	5.87
average	**58.78**	**39.46**	**0.70**	**19.33**

WET YEARS

Year	Prcp	ET	ET/P	Potential Recharge
1953	71.38	35.37	0.50	36.01
1954	73.21	42.05	0.57	31.16
1964	79.30	33.65	0.42	45.65
1966	79.75	40.97	0.51	38.78
1968	77.42	41.70	0.54	35.72
1969	79.75	41.04	0.51	38.71
1972	75.15	47.24	0.63	27.91
1982	80.62	42.69	0.53	37.93
1983	82.71	33.56	0.41	49.15
1991	79.36	35.64	0.45	43.72
average	**77.87**	**39.39**	**0.51**	**38.47**

DRY YEARS

Year	Prcp	AET	AET/prcp	Recharge
1955	37.31	43.44	1.16	-6.13
1956	38.40	30.67	0.80	7.73
1961	37.76	42.13	1.12	-4.37
1975	44.40	39.10	0.88	5.30
1989	38.66	42.87	1.11	-4.21
1993	36.56	45.51	1.24	-8.95
1994	33.94	21.34	0.63	12.60
1996	38.57	33.78	0.88	4.79
2000	41.67	35.80	0.86	5.87
average	**38.59**	**37.18**	**0.96**	**1.40**

Table E.2 : SUMMARY OF ANNUAL PRECIPITATION AND EVAPOTRANSPIRATION IN MIDDLE CLIMATE ZONE (1948-2000)

ALL YEARS

Year	Prcp	Evapotran	P/ET	Potential recharge
1949	67.91		0.00	67.91
1950	56.17	55.77	0.99	0.40
1951	64.97	58.64	0.90	6.33
1952	60.48	62.45	1.03	-1.97
1953	80.61	61.67	0.77	18.94
1954	78.23	65.86	0.84	12.37
1955	46.69	73.10	1.57	-26.41
1956	43.93	60.47	1.38	-16.54
1957	79.66	60.14	0.75	19.52
1958	62.32	63.64	1.02	-1.32
1959	95.63	61.75	0.65	33.88
1960	77.3	73.69	0.95	3.61
1961	36.64	82.82	2.26	-46.18
1962	55.7	59.93	1.08	-4.23
1963	43.31	55.66	1.29	-12.35
1964	59.46	55.27	0.93	4.19
1965	58.23	55.23	0.95	3.00
1966	79.76	58.69	0.74	21.07
1967	52.9	65.23	1.23	-12.33
1968	65.87	58.68	0.89	7.19
1969	72.91	60.10	0.82	12.81
1970	60.47	68.07	1.13	-7.60
1971	53.22	61.27	1.15	-8.05
1972	57.44	64.73	1.13	-7.29
1973	55.7	58.34	1.05	-2.64
1974	54.46	56.03	1.03	-1.57
1975	58.78	58.14	0.99	0.64
1976	52.86	58.81	1.11	-5.95
1977	67.02	55.16	0.82	11.86
1978	61.75	58.58	0.95	3.17
1979	54.95	60.34	1.10	-5.39
1980	54.04	58.50	1.08	-4.46
1981	50.1	56.24	1.12	-6.14
1982	75.5	58.35	0.77	17.15
1983	80.29	61.14	0.76	19.15
1984	58.6	69.52	1.19	-10.92
1985	57.08	66.03	1.16	-8.95
1986	64.86	62.95	0.97	1.91
1987	62.15	63.18	1.02	-1.03
1988	-	-	-	-
1989	-	-	-	-
1990	-	-	-	-
1991	70.97	57.56	0.81	13.41
1992	65.47	56.04	0.86	9.43
1993	60.37	61.78	1.02	-1.41
1994	75.39	59.15	0.78	16.24
1995	78.55	63.98	0.81	14.57
1996	57.05	71.99	1.26	-14.94
1997	70.58	68.37	0.97	2.21
1998	75.52	68.63	0.91	6.89
1999	73.17	76.44	1.04	-3.27
2000	46.21	61.54	1.33	-15.33
average	**63.09**	**62.28**	**1.01**	**2.07**

WET YEARS

Year	Prcp	Evapotran	P/ET	Potential recharge
1953	80.61	61.67	0.77	18.94
1954	78.23	65.86	0.84	12.37
1957	79.66	60.14	0.75	19.52
1959	95.63	61.75	0.65	33.88
1960	77.3	73.69	0.95	3.61
1966	79.76	58.69	0.74	21.07
1983	80.29	61.14	0.76	19.15
1984	58.6	69.52	1.19	-10.92
1994	75.39	59.15	0.78	16.24
1995	78.55	63.98	0.81	14.57
1998	75.52	68.63	0.91	6.89
average	**78.14**	**64.02**	**0.83**	**14.12**

DROUGHT YEARS

Year	Prcp	Evapotran	P/ET	Potential
1955	46.69	73.10	1.57	-26.41
1956	43.93	60.47	1.38	-16.54
1961	36.64	82.82	2.26	-46.18
1963	43.31	55.66	1.29	-12.35
1967	52.9	65.23	1.23	-12.33
1971	53.22	61.27	1.15	-8.05
1976	52.86	58.81	1.11	-5.95
1981	50.1	56.24	1.12	-6.14
2000	46.21	61.54	1.33	-15.33
average	**47.32**	**63.91**	**1.38**	**-16.59**

TableE.3 : SUMMARY OF ANNUAL PRECIPITATION AND EVAPOTRANSPIRATION IN INLAND CLIMATE ZONE: (1948-2000)

ALL YEARS

Year	Prcp	Evaptrans	P/ET	Potential recharge
1949	53.53	39.91	0.75	13.62
1950	50.78	39.25	0.77	11.53
1951	62.18	42.85	0.69	19.33
1952	57.75	44.28	0.77	13.47
1953	62.31	43.39	0.70	18.92
1954	54.18	46.16	0.85	8.02
1955	51.4	43.17	0.84	8.23
1956	39.55	36.64	0.93	2.91
1957	71.26	43.14	0.61	28.12
1958	62.4	45.10	0.72	17.30
1959	72.99	43.31	0.59	29.68
1960	69.5	50.87	0.73	18.63
1961	40.85	47.87	1.17	-7.02
1962	61.15	39.30	0.64	21.85
1963	49.87	43.01	0.86	6.86
1964	45.13	38.09	0.84	7.04
1965	55.56	39.28	0.71	16.28
1966	54.27	40.51	0.75	13.76
1967	33.51	36.02	1.07	-2.51
1968	73.29	37.18	0.51	36.11
1969	75.87	42.82	0.56	33.05
1970	70.9	55.67	0.79	15.23
1971	55.02	50.76	0.92	4.26
1972	51.99	42.38	0.82	9.61
1973	51.2	41.31	0.81	9.89
1974	50.64	36.84	0.73	13.80
1975	49.04	38.81	0.79	10.23
1976	40.31	36.74	0.91	3.57
1977	46.93	36.63	0.78	10.30
1978	61.51	38.57	0.63	22.94
1979	55.35	41.32	0.75	14.03
1980	46.18	40.60	0.88	5.58
1981	45.89	36.52	0.80	9.37
1982	65.6	34.65	0.53	30.95
1983	61.44	50.74	0.83	10.70
1984	43.81	44.96	1.03	-1.15
1985	45.1	36.85	0.82	8.25
1986	48.97	37.75	0.77	11.22
1987	45.48	33.02	0.73	12.46
1988	37.46	29.52	0.79	7.94
1989	37.28	28.87	0.77	8.41
1990	46.17	34.91	0.76	11.26
1991	57.57	41.74	0.73	15.83
1992	57.78	38.57	0.67	19.21
1993	52.49	38.88	0.74	13.61
1994	76.98	45.59	0.59	31.39
1995	57.85	49.43	0.85	8.42
1996	51.11	45.53	0.89	5.58
1997	54.57	39.76	0.73	14.81
1998	55.15	38.19	0.69	16.96
1999	49.85	39.06	0.78	10.79
2000	43.87	38.74	0.88	5.13
average	**54.05**	**40.87**	**0.77**	**13.19**

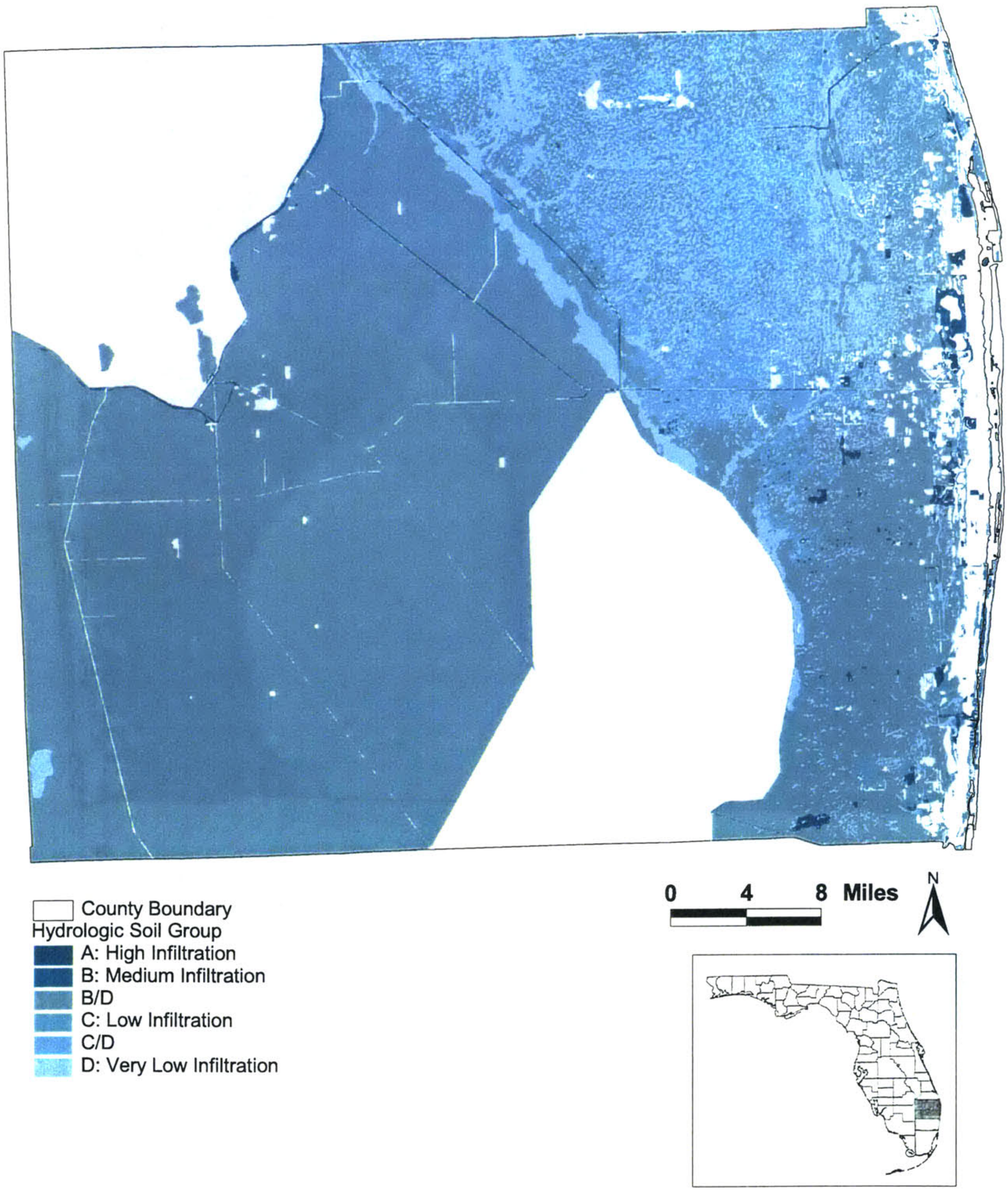
WET YEARS

Year	Prcp	Evaptrans	P/ET	Potential recharge
1957	71.26	43.14	0.61	28.12
1959	72.99	43.31	0.59	29.68
1960	69.5	50.87	0.73	18.63
1968	73.29	37.18	0.51	36.11
1969	75.87	42.82	0.56	33.05
1970	70.9	55.67	0.79	15.23
1982	65.6	34.65	0.53	30.95
1994	76.98	45.59	0.59	31.39
average	**72.05**	**44.15**	**0.61**	**27.90**

DRY YEARS

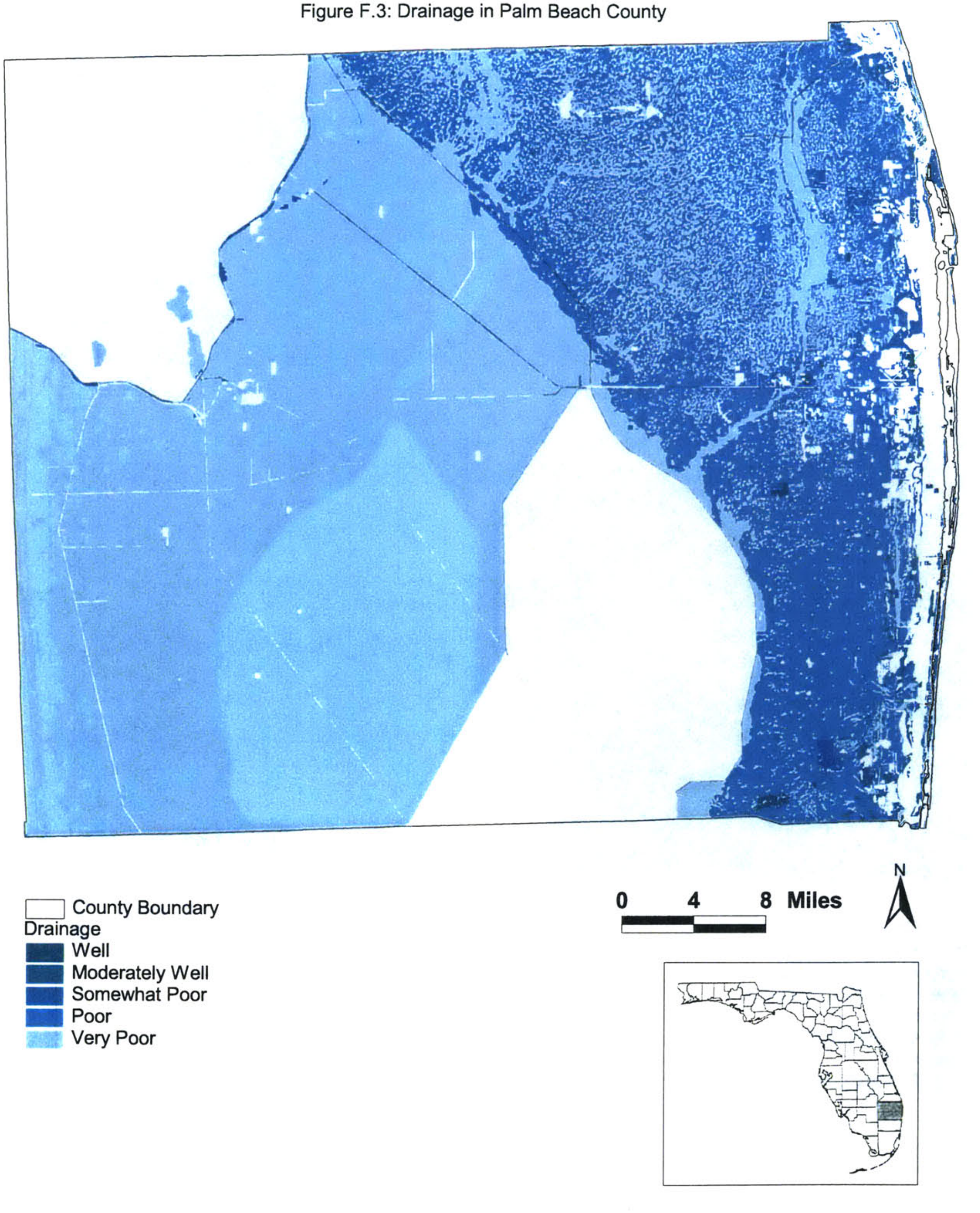
Year	Prcp	Evapotrans	P/ET	recharge
1956	39.55	36.64	0.93	2.91
1961	40.85	47.87	1.17	-7.02
1967	33.51	36.02	1.07	-2.51
1976	40.31	36.74	0.91	3.57
1984	43.81	44.96	1.03	-1.15
1988	37.46	29.52	0.79	7.94
1989	37.28	28.87	0.77	8.41
2000	43.87	38.74	0.88	5.13
average	**39.58**	**37.42**	**0.94**	**2.16**

Figure F.1: Hydrologic Soil Groups in Palm Beach County



Source: Florida Geographic Data Library. University of Florida.
Ambika Anand Prokop. Dept. of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.

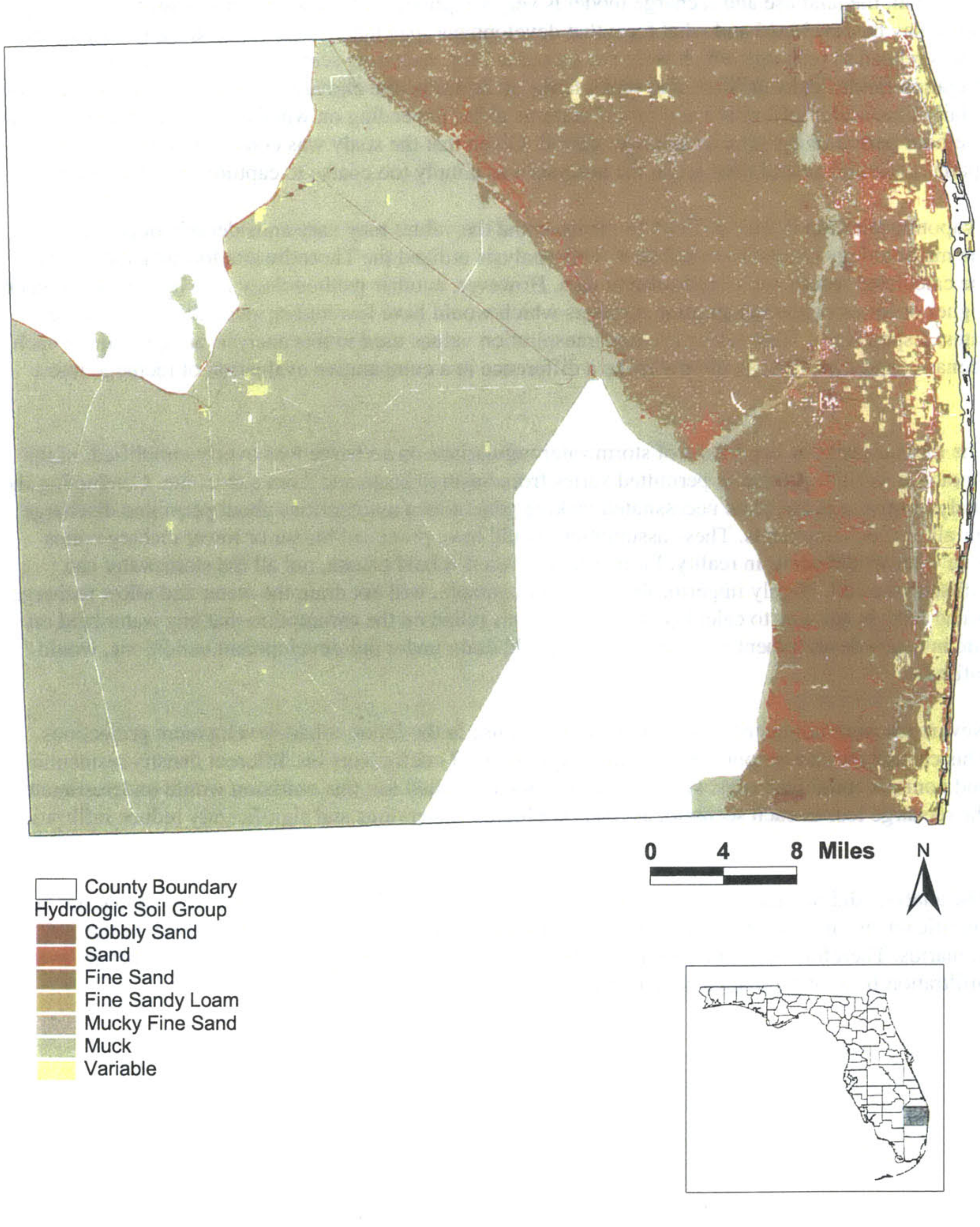
Figure F.3: Drainage in Palm Beach County



Source: Florida Geographic Data Library. University of Florida.

Ambika Anand Prokop. Dept. of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.

Figure F.2: Soil Surface Texture in Palm Beach County



Source: Florida Geographic Data Library. University of Florida.
Ambika Anand Prokop. Dept. of Urban Studies & Planning. Massachusetts Institute of Technology. May 2001.

The following potential sources of error may affect the results of this analysis:

- In general, the land use and recharge model is very simplistic. Numerous factors influence which lands may be developed and what form that development may take. There are also many outputs and inputs related to recharge which were not accounted for, including seepage from rivers, canals, irrigation fields, leaky utilities, and septic tanks. In addition, the climate patterns vary considerably on a daily time scale: infiltration and runoff patterns differ depending on whether rain falls intensely in a one hour period or lightly over a longer period. Given that the study was conducted on a regional spatial scale and annual time scale, the analysis was simply too coarse to capture these variations.

- Evapotranspiration is very difficult to measure and the values may vary considerably depending on the methodology chosen to calculate it. This analysis utilized the Thornthwaite formula and adjusted the calculated results with experimental data. However, another methodology may have yielded much higher or lower evapotranspiration numbers which would have lowered or increased the recharge rates, respectively. That said, the evapotranspiration values used in this analysis are constant in each scenario, and therefore should not make a difference in a comparative evaluation of recharge rates.

- The measurement of the impact of stormwater regulations on recharge was overly-simplified, as the amount of off-site discharge permitted varies from basin to basin and from site to site. Conducting the analysis on a regional scale necessitated making generalized assumptions about permitted discharge for all new developments. These assumptions could have produced higher or lower recharge rates than what would occur in reality. Furthermore, even if it held on site, not all the stormwater can infiltrate the soil. Highly impermeable soils, for example, will not drain the water and allow recharge. Since there is not way to calculate this, the analysis relied on the assumption that any water held on site in a new development in excess of what could drain under pre-development conditions, would infiltrate.

- New roads were not distributed as a separate land use in the future urban development projections. This change may be accounted for in the varying runoff coefficients for different density residential and nonresidential land uses. However, if it is not accounted for, this omission would underestimate the recharge loss in each scenario, as roads are highly impervious and significantly reduce infiltration.

- The analysis did not account for recharge from water bodies. However, this omission should not be significant, as land use should not affect infiltration capacity of the water bodies in any of the scenarios. Therefore, the final results of <u>differences</u> between recharge rates should not change, even if infiltration from water bodies is accounted for.

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Personal Communications

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