CHAPTER 1 – INTRODUCTION

The Central and South Florida Project is one of the world's largest water management efforts. It covers 18,000 square miles, encompassing 1.5 million acres of remnant Everglades, 700,000 acres of agriculture, and a rapidly growing population of over 6 million (**Figure 1.1**). Approximately 1,500 miles of project canals and more than 200 primary structures exert control over all water associated with the remnant Everglades which today consist of a compartmentalized system of state managed Water Conservation Areas in the north bordered by Everglades National Park in the south.

Everglades National Park was the first national park to be established to preserve purely biological resources – to protect the unique resources of the Everglades subtropical ecosystem – and has subsequently been designated as a World Heritage site, an International Biosphere Reserve, and a Wetland of International Importance (Ramsar Convention). The importance of the greater Everglades to its inhabitants, to the nation, and to the world, is reflected in the historic 1996 decision by the U. S. Congress to specifically mandate the ecological restoration of the remaining Everglades in its reauthorization of the "Central and South Florida Project for Flood Control and Other Purposes", resulting in the implementation of the Comprehensive Everglades Restoration Plan – currently the world's largest ecosystem restoration effort.

Ecosystem restoration requires knowledge of the ecosystem state at two different times—prior to anthropogenic alteration and the current, altered condition. Additionally, restoration requires enough detail to identify the critical differences between these snapshots in time, and enough temporal history to clearly separate the *signal* of anthropogenic change from the *noise* of naturally occurring change.

This study sets out to answer some of these questions for the Everglades. Specifically, we endeavor to characterize the ecosystem before alteration from a landscape perspective, explain how and when it changed, and how it previously varied over time under natural, pre-development conditions. Scientific and historical approaches are integrated to create a comprehensive picture of the pre-drainage Everglades thereby providing baseline information for ongoing ecological restoration efforts.

APPROACH

The principal objectives of this study were to:

1) Provide comprehensive documentation and compilation of historical sources of hydrologic and landscape information for the Everglades ecosystem.
2) Document changes that occurred within the Everglades between the time of first drainage, 1880, and time of first system-wide, scientific mapping in 1940.
3) Identify and characterize the principal pre-canal drainage landscapes of the Everglades and bordering areas: their spatial extents, vegetation, soils, topography and hydrology.
4) Estimate pre-drainage hydrology in terms of hydroperiods and long-term average annual high and low water depths for each landscape.
5) Estimate pre-drainage patterns of water flow.

The objective of creating a sourcebook of primary historical sources, many of which are either unpublished or of limited access, is reflected in the extensive endnotes, reproductions of early photographs and maps, aerial photographs, and appendices. As much as possible, we have endeavored to make available to the reader the same primary information used to draw our conclusions.

Throughout this report, the terms "pre-drainage" and "pre-canal" are used as shorthand for "pre-canal drainage," meaning the condition of the Everglades under natural drainage alone, prior to construction of any canals. In particular, we focus on the period from approximately 1820 to 1880. In our opinion, there exists a wealth of information and numerous observations regarding conditions in the pre-drainage Everglades in the mid-19th Century

Prior Studies

Several system-wide studies of pre-drainage landscapes and hydrology provided background for our analysis of the pre-drainage system. Davis *et al.* (1994), a direct predecessor to this work, used vegetation and soil surveys from the 1940's (Davis, 1943; Jones *et al.*, 1948), as well as historical accounts, to estimate the spatial extent of pre-drainage landscapes. Costanza (1975) produced an estimated vegetation map of South Florida for ca. 1900, based on his hindcasting of the Davis (1943) vegetation map. Useful historical information was extracted from the geologic treatise, Water Resources of Southeastern Florida (Parker *et al.*, 1955). Parker's subsequent effort to quantify pre-drainage Everglades hydrology (Parker, 1974) was also consulted. Early histories painted a qualitative picture of the Everglades in addition to suggesting relevant primary sources (Dovell, 1942; 1947a; 1947b; Tebeau, 1973; Meindl, 1996).

Studies of specific sub-regions also contributed to our approach. Robertson (1962) applied an approach similar to this study to a single historical account, extracting useful scientific information on wading birds once found in southern Everglades National Park. Gunderson (1989) quantified previous hydropatterns within Everglades National Park using hydrologic measurements beginning in 1954. D. F. Austin and his students used various historical sources, including original Government survey notes and 1940 USDA aerial photos, to delineate pre-drainage vegetation at several points within the Eastern Flatwoods landscape. (Austin 1976; Austin and Coleman, 1977; Austin and Richardson, 1977; Austin; Richardson, 1977; Steinberg 1980).

Historical Ecology

Restoration requires knowledge of the original; in this case, knowledge of the different types and extents of soils, vegetation communities, topographic sub-regions, and hydrologic regimes existing in the Everglades before anthropogenic drainage. Quantitative descriptions of the pre-drainage hydrology are particularly important. As a vast, shallow, peat-based wetland, the flows, depths, and timing of water passing into and through the Everglades are critical ecosystem processes (White, 1994). Knowledge of hydrology is important for practical reasons as well: alterations in hydrological management form one of the main tools available to restore the Everglades. The other main tool, alterations in water chemistry of Everglades inflows, is obviously closely linked to hydrology.

Accurate description of the pre-drainage Everglades is not a straightforward task. Intensive drainage efforts began in the 1880s with initial lowering of water levels in Lake Okeechobee, an important source of Everglades water. Drainage efforts intensified in 1906, whereas the earliest scientific mapping of the Everglades as a whole began much later, in the 1940s. As we show in this study, the intervening 60 years of managed drainage had, by then, already substantially altered the ecosystem. The comprehensive studies of the 1940s (Davis, 1943; Jones et al. 1948; Parker et al. 1955) represent the Everglades as they appeared at that time. Although such investigations may be considered as “baseline” studies, they are not representative of pre-drainage conditions.

The research reported here is therefore an exercise in historical ecology. It is an attempt to paint a picture, as scientifically and quantitatively as possible, of the main landscapes of the pre-drainage Everglades as they existed during the period from 1820 to 1880. The authors explicitly recognize that the picture painted here is a hypothesis. Unlike other fields of science, we cannot design experiments to test, nor can we even directly observe the original system. Nevertheless, we can proceed in a scientific manner by proposing hypotheses or models of the pre-drainage system and then testing these by comparison with available primary information. As for any other part of science, we cannot prove the hypothetical models to be correct; we can only show how well they compare to the available information. Each additional consistency increases confidence in the model, whereas each discrepancy diminishes confidence.

SCOPE

How representative is this period of study (the mid-19th Century Everglades) given the importance of change in the system? While a detailed answer is beyond the scope of this study, paleological studies of soil cores (Dachnowski-Stokes, 1930; Cohen and Spackman, 1974; Gleason et al. 1984; Willard, 1997) suggest that 19th century conditions may have been generally representative of the preceding several centuries. On a more recent time scale, the historical literature provided comparable observations for certain locations at multiple pre-drainage times (e.g. in the 1840s and again in the 1870s). The extensive research efforts of the 1940s provided another although post-drainage, time point of observation. We were frequently impressed by the consistency of observations of the same landscape, across different time periods and different observers. Drainage and development did not remove all traces of the pre-drainage landscapes. Although spatial extents and plant community composition of the landscapes had changed substantially by the 1940s (**Chapter 3**), frequently the relation to the original landscapes was still clearly recognizable.

The most obvious effects of 80 years of drainage are hydrological. More subtle, but we feel equally important, are the lasting changes in landscape topography. This includes both large-scale regional decreases in elevation and fine-scale changes in microtopography. Flattening of peat microtopography was of particular concern. We focused on landscapes to understand the original interaction between hydrology and topography, as well as to understand the changes that produced the landscapes seen today.

Characterization of Historical Landscapes

For the purposes of this research, a landscape is considered to be a distinct combination of vegetation, soil, topography, and hydrology, recognizable at the scale of miles (**Figure 1.2**). The largest pre-drainage landscape, ridge and slough, formed a characteristic, patterned mosaic which we addressed at the scale of hundreds of feet. At the regional (whole basin) scale, particular attention was paid to the overall hydrological functioning of the system; based on inflows from Lake Okeechobee and outflows to Florida Bay, Biscayne Bay, and the Atlantic Ocean. At the more local, mosaic scale, attention was focused on the relationship between landscape microtopography and seasonal variations in pre-drainage water depths.

Current Everglades restoration efforts include “getting the water right” with the ulitmate goal being ecological restoration, that is, restoration of selected aspects of the original pre-drainage landscapes. Pre-drainage flora and fauna of the Everglades appear to have been closely adapted to South F1orida’s unusual combination of vast, flat wetlands with strong annual cycles of rising and falling water levels and flowing water. Particularly because these landscapes have undergone substantial post-drainage changes, successful restoration requires two components: (1) a detailed, quantitative picture of pre-drainage characteristics of the different landscapes, and (2) a mechanistic understanding of any physical processes responsible for maintaining the landscape characteristics.

In characterizing the various landscapes, flora was emphasized over fauna. This emphasis in part reflects the greater abundance of floristic information in the historical records and is a reflection of the authors' areas of expertise.

Geographic Range and Areas

The principal geographic focus of this research was on the open, non-forested portions of the Everglades, from the Custard Apple Swamp fringing the southern shore of Lake Okeechobee, to the dense Sawgrass Plains of the northern or “Upper Glades” and the varied Ridge and Slough landscape forming the “Lower Glades” (**Plate 13**). The Ochopee and Rockland Marl Marshes bordering the northwest and southeast flanks of Shark River Slough were also studied. Sheet flow occurs through the Marl Transverse Glades, which are seasonally connected the Rockland Marl Marsh area with the Perrine Marl Marsh. Therefore, the latter area was studied as well, though in less detail. The mangrove areas along the coasts were not included in this study.

The upland areas bordering the Everglades on the eastern side were investigated because of their important role as rim, controlling water levels within, and outflow from, the Everglades, (**Figure 1.3**, **Plate 10**). The Eastern Flatwoods formed the northern portion of the eastern border. Further south, water flowed out of the Everglades through three different types of low points in the eastern rim: the Peat Transverse Glades, the coastal rivers piercing the Atlantic Coastal Ridge, and the Marl Transverse Glades separating the various Everglades Keys.

The landscapes along the western border of the Everglades, the Western Pine Flatwoods and the Big Cypress were investigated only in sufficient detail to locate the pre-drainage border.

Analysis and Interpretation of Historical Information

As we examined the historical literature, we found that the number and nature of the different landscapes was quite clear from consistent descriptions in multiple sources. At the same time, the extents of these landscapes suggested by soils and vegetation maps from the 1940s (**Plate 11** and **Plate 4**) differed substantially from the extents suggested by historical sources from the 1800s. The research therefore proceeded in three steps: (1) characterization of each of each of the pre-drainage landscapes, (2) identification or "hindcasting" of the pre-drainage extents of the landscapes, and (3) assignment of hydrologic observations to the appropriate pre-drainage landscape based on location.

Because the landscapes were defined on the basis of multiple sources of information -- pre-drainage soils, vegetation communities and topography -- they provide the most reliable units for mapping the pre-drainage hydrology.

Organic peat soils ("Histosols") originally covered much of the pre-drainage Everglades landscapes, and defined their surface elevations. These peat soils could form and persist only because the Everglades were formerly wetlands with standing water typically present during all or nearly all of the year. Within the vastness of these wetlands, slight variations in the elevation of the peat surface were extremely important in permitting development of a diversity of hydrologic regimes and habitats. The interaction between the varied peat elevations (microtopography) and the annual rise and fall in water depths was a key defining element of the pre-drainage Everglades. In addition, it appears very likely that the spatial patterns formed by the microtopography both influenced and were influenced by patterns of water flow (**Chapter 5**).

HYDROLOGY

As our understanding of patterns of post-drainage changes in the Everglades developed, particular attention was given to elucidating the physical driving forces that most likely produced or maintained the original Everglades landscapes. An important aspect of our research was to develop some working hypotheses concerning one of these primary driving forces -- historical hydrologic conditions in the Everglades.

Quantification of the pre-drainage hydrology of the Everglades presents multiple challenges. First, standard hydrologic information, such as time series measurements of stage, velocity, or discharge, do not exist for the pre-drainage system (i.e., prior to 1880). The earliest systematic, comprehensive studies began in 1940 (Parker *et al.* 1955; Parker 1974). Second, Everglades hydrology has always been highly variable--both seasonally, as water levels rose and fell with each year's wet and dry season (Strobel, 1836, in Hammond 1961; Stewart 1907); and interannually, as rainfall deviated substantially from year to year (**Figure 1.4)**. Third, to be meaningful, pre-drainage hydrologic conditions should not be roughly estimated. Differences in average water level as small as 3 to 6 inches are ecologically significant in South Florida, resulting in distinct vegetation communities (Harshberger 1914; Davis 1943a; Kolpinski and Higer 1968; McPherson 1973).

One might conclude that the above challenges are insurmountable; that the nature and hydrology of the pre-drainage Everglades landscapes can never be adequately quantified. The authors of this report do not support that conclusion. A substantial body of direct and indirect hydrological observations – well beyond the simply anecdotal – is available. In spite of different observers, different times, and different locations, remarkable consistency was found. In addition to these direct observations, the pre-drainage hydrology left a distinct mark on the soils, vegetation, and topography of this vast wetland. Numerous and consistent observations of these landscape characteristics allowed us to further sharpen our picture of the pre-drainage hydrology. After reading, mapping, and cross-checking more than 500 original sources, we conclude that significant aspects of the pre-drainage Everglades *can* be accurately described.

All historical sources were combed for four types of hydrologic observations: (1) water depths; (2) timing and duration of surface ponding (or below ground water tables); (3) flow directions; and (4) flow velocities. Of these, observations of water depth were the most plentiful.

A number of observations of flow direction were also found, as well as descriptions of "perceptible flow." Only a few numerical estimates of flow velocity were found. Quantitative estimates of average hydroperiod (number of days per year of surface ponding) were not found *per se*, but narrative accounts of specific locations often included qualitative descriptions of the typical (or exceptional) durations of annual surface ponding.

All historical observations were located in space and time. Those that could be located precisely were weighed more heavily. Observations were classified according to the landscapes described previously, and according to time of year, that is, timing within the wet or dry seasons. Remarkably, for an environment of such difficult access, we found that the large majority of the historical observations could be located with considerable detail, often to within a square mile or even less, and usually to a specific day.

Specifically, for each landscape we focused on identification of the long-term (30-50 year) average values for the annual low and annual high water depths, and on long-term average hydroperiods. The reasons for this focus are discussed in the following sections.

Annual Low and Annual High Water Depths

Water levels in the Everglades are distinctly seasonal, driven by the strong seasonality in south Florida rainfall (**Figure 1.4**). This was recognized quite early during exploration of this area, as typified in the following quote from 1836:

> "During the rainy season, ... the water collects in these low spots, and, not having easy access to the sea, rises to considerable heights and overflows the adjacent country for miles, leaving only the higher points of land visible. During the dry seasons, on the contrary, when the everglades, lakes and inland ponds, having had sufficient time to pour their contents into the ocean--the surface of the soil is made visible--the banks of the rivers are observed for many feet above the surface of the water, and the whole aspect of the country is changed." (Dr. Benjamin Strobel, 1836, in Hammond 1961).

On average, the wet season extends from approximately June through October; the dry season from November through May (Herr 1943; Corps of Engineers 1949; Parker *et al.* 1955; Sculley 1986). However, dates vary somewhat depending on the sources of data. Duever et al. (1994) indicate a rainy season from approximately May 15 through October 31. Water levels in the Everglades rise and fall with the presence or absence of precipitation. On average, the maximum water depth occurs in October; the minimum in May.

A linear increase and decrease in water depth during the wet and dry seasons was assumed, resulting in a sawtooth-shaped long-term average hydrograph (**Figure 1.5**). The sawtooth shape of linear rises and falls applies only to those landscapes which are inundated throughout the year. For landscapes in which the water surface declines below ground, the effect of soil porosity causes the slope of the rise and fall to become steeper during the period when the water table is below ground.

This long-term average hydrograph provides a context for interpreting historical observations of water depths. An observation made on February 1, for example, which falls halfway through the (average) course of the dry season, would be expected to show a water depth approximately halfway between the average annual high and low water depths.

Water Depths: Means and Variances

The hydrographs discussed in the previous section are based on long-term averages – 30 to 50 years, or more. The almost exclusive emphasis on averages in this research, rather than on variability, in no way reflects the relative ecological importance of hydrologic averages versus hydrologic variability. Plant and animal communities of South Florida are influenced both by the average hydrology, and by the deviations around those averages (DeAngelis and White 1994; Duever *et al.* 1994; Davis and Ogden 1994). The plant ecologist John H. Davis clearly recognized this:

> "The former overflow [from Lake Okeechobee] was at no times a consistent amount any more than rainfall conditions now are a consistent amount. The extreme conditions of wetness and dryness, great to no overflow, respectively, made the Everglades marshes alternately wet or dry and no average conditions should be considered as typical. The vegetation was of the type that could withstand these extreme conditions." (Davis 1943a, p.278)
> "...there can be no ideal average water conditions of the Everglades because none formerly existed." (Davis 1943a, p.279).

The focus on averages in this research simply reflects the available information concerning pre-drainage conditions. The historical record clearly indicates the occurrence of varying wetter and drier years, but quantitatively it did not warrant statistical estimates of that variability. In contrast, the landscape observations as well as numerous direct observations of water depth provided ample information for estimating long-term means.

Appropriate restoration of Everglades hydrology will require estimates of pre-drainage variances as well as of means. The mean values supplied by this study should be supplemented by variance information from modeling exercises.

Regional hydrologic models (e.g., Fennema *et al. 1994;* Van Zee *et al. 1996)* transform climatic variance into hydrologic variance, and may provide useful estimates of pre-drainage hydrologic variance. We note however that the scale of the above regional models excludes the hydrologically important patterns of microtopography. The influence of this scale effect on hydrologic variance is as yet unknown. Means supplied by this study may be useful for evaluation of comparable means calculated by the regional hydrologic models.

Water Depths and Hydroperiods

Both water depths and the duration of continuous ponding (hydroperiod) influence the distribution of plant and animal communities in South Florida. This study emphasizes water depths for the practical reason that measurements of water depth were available in the pre-drainage historical record; actual measurements of hydroperiod were not. The absence of hydroperiod measurements is not surprising; hydroperiods cannot be measured directly, rather they must be calculated from a long term series of daily measurements of water depth made at the same location. Such systematic measurements did not become available until the *1940s,* well after the initiation of drainage.

The pre-drainage water depth observations that we gleaned from historical records were also not collected systematically. However, by stratifying the available observations by time of year and by landscape within the Everglades, patterns were recognized within the data. Additional stratification of the observations by antecedent rainfall conditions might have further clarified the underlying patterns. This was done qualitatively, but not quantitatively, because of the limited rainfall measurements available prior to the *1890s.* Future studies might be able to refine our hydrologic estimates by using proxy variables such as tree rings or coral growth as a means of extending the rainfall record.

Pre-drainage hydroperiods for the Everglades landscapes were estimated by synthesis of information from multiple sources. Historical descriptions and landscape information, particularly soils and vegetation, were combined with the estimated average annual high and low water depths to estimate hydroperiods (see also **Figure 1.5**).

Water Depths and Water Elevations

Wetland water levels can be defined in either relative or absolute terms, that is, as depth of water above the local ground surface, or as elevation of the water surface above mean sea level. If the elevation of the ground surface has been measured, water depths can be easily converted to elevations. In the Everglades, such conversions are complicated by two factors relating to the ground surface elevation. First, the difficulty of access and the soft peat soil surface makes surveying difficult. Second, the ground surface elevation throughout most of the Everglades–anywhere that peat soil was originally present–has been changing continuously since the onset of drainage. The changes in elevation range between 1 and about 12 feet. In the Everglades of the last 100 years, the changes in ground, and hence water, elevation have been greater than the changes in water depth.

The present research focuses on water depths for this reason and because water depths, rather than elevations, are what pre-drainage eyewitnesses actually observed. A visitor to the Everglades stood at a usually unknown elevation above sea level, but in a most obvious depth of water, whether up to the knees or waist. Except for the Everglades Keys and Rockland Marl Marsh area, we have not attempted to convert depths into elevations.

Ecologically, the focus in this research on water depths rather than on absolute elevations is not a significant limitation. Many important biological processes in the Everglades in fact depend primarily on local water depth, and--except for the important influence of water flow--are largely independent of absolute elevation.

CHAPTER ORGANIZATION

These objectives, and the special problems encountered in this research are reflected in the chapter organization. As a wide variety of non-traditional sources were consulted, Chapter 2 details these sources by type, and notes particular methods of analysis. Chapter 3 summarizes the chronology of drainage during this period and was necessitated by the sixty year gap between the initiation of drainage in 1880 and the earliest synoptic, system-wide scientific mapping of the Everglades, around 1940. Chapter 3 also documents the extensive and substantial changes brought about by this drainage. A systematic understanding of these changes permitted the extensive 1940s information to contribute to a better understanding of the different, but related pre-drainage landscapes. Identification of the time courses of changes also helped identify driving forces which were most likely to have maintained the original system.

Chapter 4 addresses the landscapes that formed the pre-drainage Everglades wetlands and surrounding uplands. The descriptions of soils, vegetation, microtopography, and hydrological information for each landscape are based on synthesis of all available primary historical sources applicable to the landscape. Annotated quotes from the historical sources have been included as chronologically arranged endnotes. Sufficient annotation has been included to allow the endnote sections for each landscape to be read on their own. Historical photographs were included when available. For landscapes whose extents differ substantially from those mapped during the 1940s studies, the basis for mapping was described either within the landscape description or in Chapter 3.

This document ends with a synthesis chapter. Chapter 5 integrates information presented in previous chapters to develop a system-wide picture, or conceptual model, of pre-drainage Everglades hydrology, including water depths, water elevations (where possible), regional flow patterns, and the interaction of surface water flow with landscape microtopography. In conclusion, and in the spirit of reducing uncertainty in the conceptual hydrologic model proposed in Chapter 5, the authors provide recommendations for specific hydrologic research in support of improved understanding and hydrologic modeling of the pre-drainage Everglades system.

CHAPTER 1 FIGURES

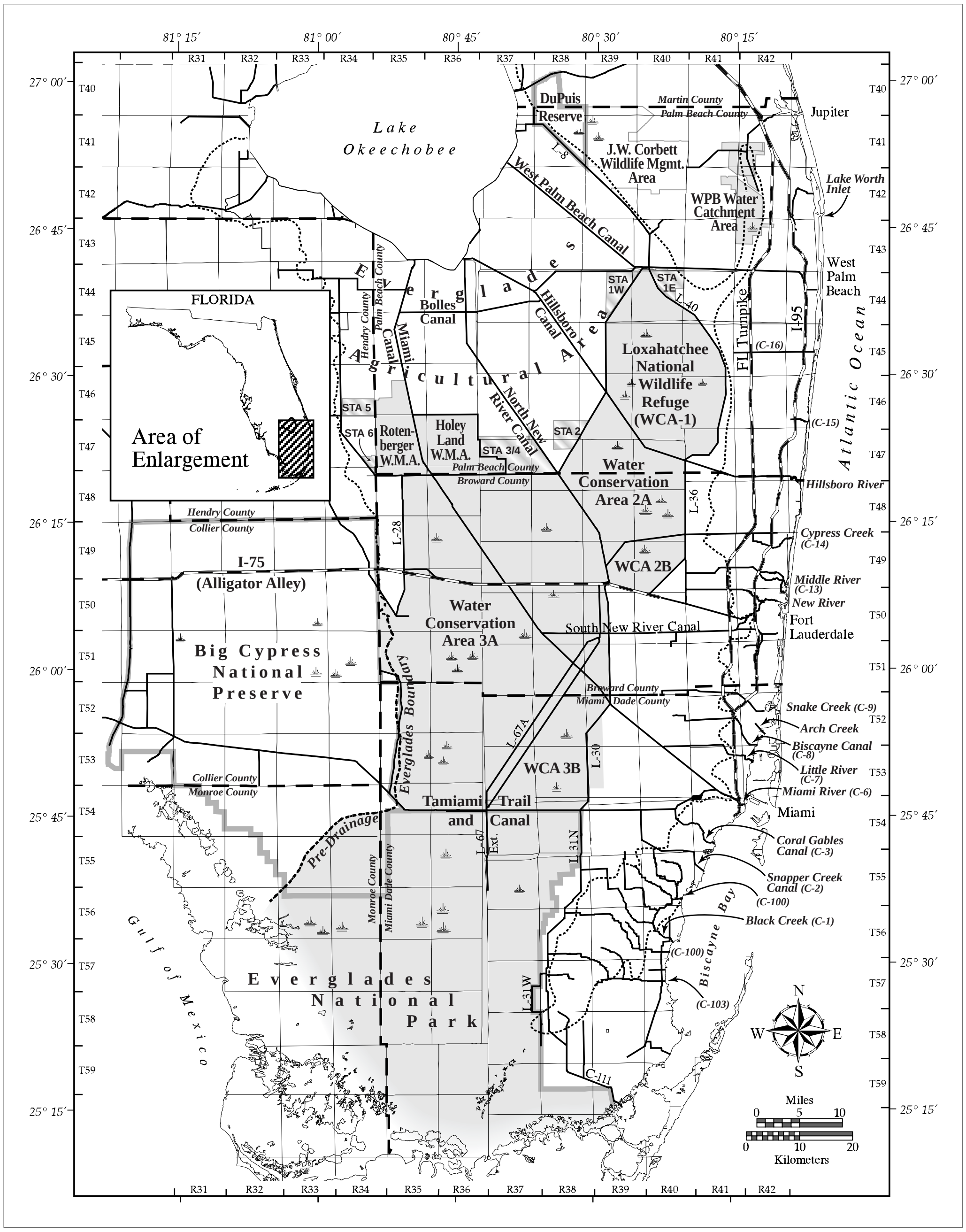

Figure 1.1 Location of Major Canals, levees and land units present in South Florida in 2000. Remnant Everglades freshwater wetlands are shaded gray. Diagonally shaded Stormwater Treatment Areas (STAs) are in various stages of completion.

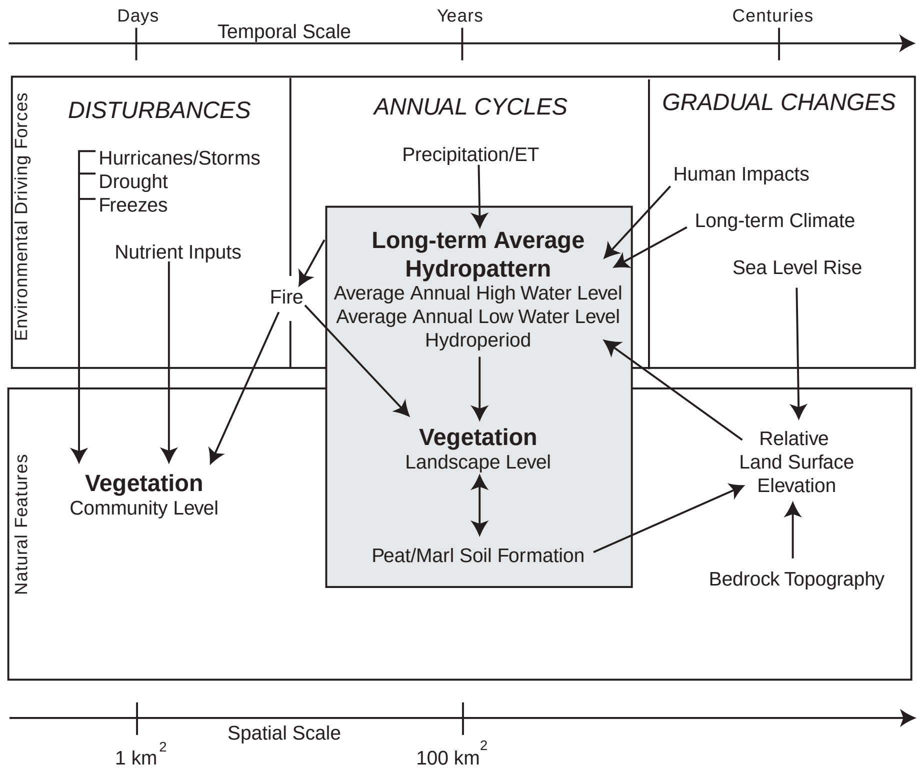

Figure 1.2 Temporal and Spatial Scales in the Everglades. Scales of focus of this study are shown in Gray (Modified from DeAngelis and White 1994).

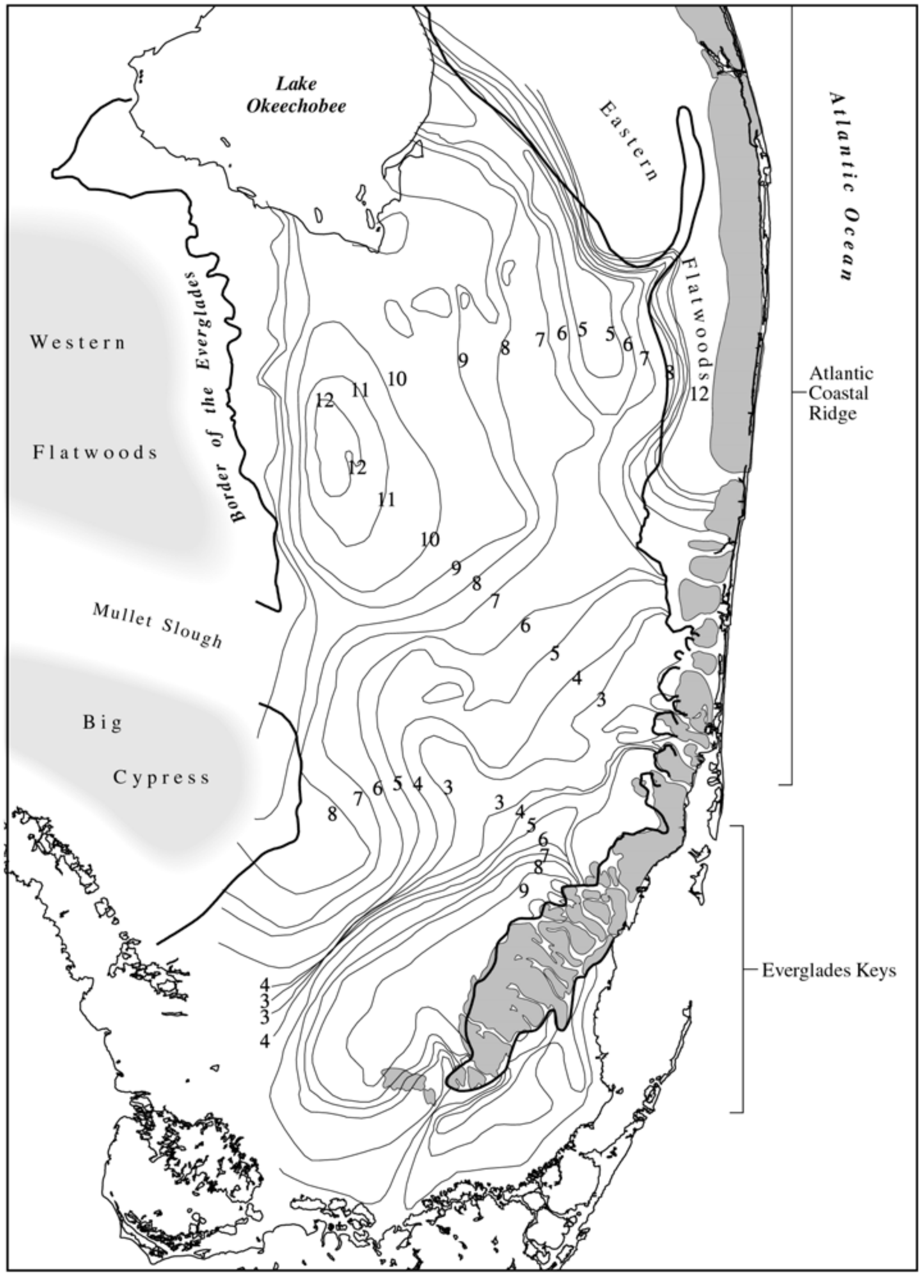

Figure 1.3 The Everglades basin and bordering uplands. Contours show bedrock elevation in feet above Punta Rassa datum (Jones et al. 1948, supplemented by Parker et al. 1955). Eastern shaded areas indicate higher ground exposed during geological periods of lower sea level (Leach *et al*. 1971).

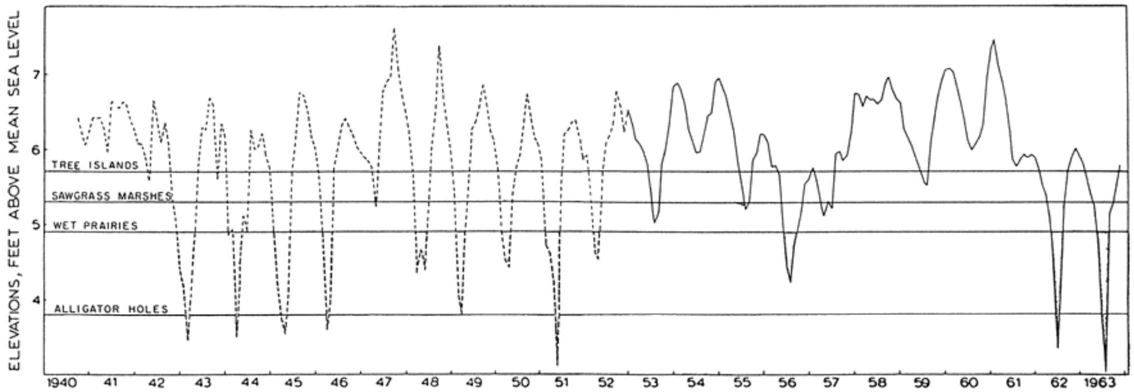

Figure 1.4 Time series of water elevations (stage) at the P-33 gauge, Shark River Slough (Everglades National Park), showing annual range of about 2 feet. Compare with ground surface elevations of four major habitats, differing from each other by as little as 0.5 feet. Ground surface was determined by averaging along transects through each habitat. Post drainage measurements were made during 1968 The pre-1953 stage was determined by regression. (From Kolipinshi and Higer, 1969).

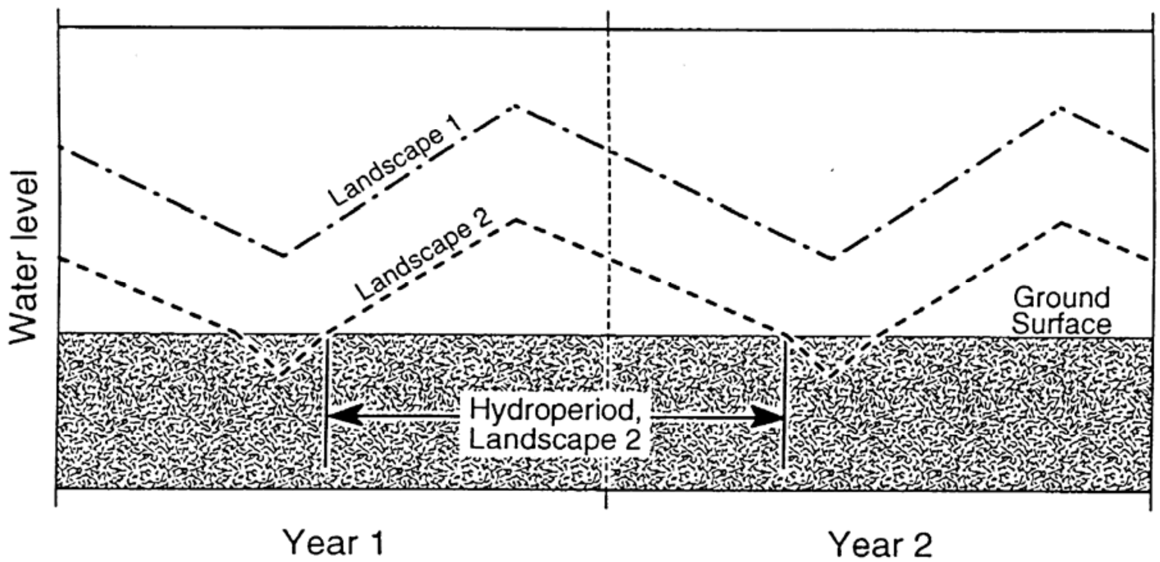

Figure 1.5 Relationship of Hydroperiod to hydrograph for two representative Everglades landscapes. Landscapes 1 and 2 have 12-month and 10-month hydroperiods, respectively.