APPENDIX A

Descriptions of Natural System Hydrology from SFWMD Project Documentation

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FIGURES

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A.1: GREATER EVERGLADES

This section is excerpted from Chapter 5 (revised based on peer review comments) of the Draft Document *Pre-Drainage Everglades Landscapes and Ecology* by Christopher McVoy, Winifred Park Said, Jayantha Obeysekera and Joel VanArman (in prep). Chapter 5 is a synthesis from a comprehensive study conducted by SFWMD staff for the purpose of characterizing natural system landscapes and hydrology. Chapters 1-4 from the same document were not included in this appendix but can be accessed online if necessary at https://my.sfwmd.gov/hesm.

Chapter 5 -- Combining the Pieces

Introduction

The details of the previous chapters are like pieces of a puzzle that can be reconstructed in various ways. Some of these pieces are clear and precise, others are vague or missing. It was both challenging and stimulating to write this synthesis chapter, sections of which provoked impassioned discussion. After many years of thought, discussion, and peer-reviews, this story of Everglades hydrology before canal drainage presents a significantly improved model, but one that may never be validated without a time-machine. Rather, it should be viewed as pieces of a puzzle woven together to get a clearer picture. Focus too closely on just one section of this puzzle and one will see gaps and flaws, step back too far and the beauty of its complexity is lost.

Historical observations of the plants, animals, soils, fires, and the water that flowed through the Everglades raise a number of questions that need to be addressed to reconstruct pre-drainage Everglades hydrology, including the following:

- How deep were the waters of this system both in general and within each landscape?
- What were the general water flow patterns through the system and can flow volumes be estimated?
- Where did water enter, where did it leave, and at what elevations did overflows occur?
- How did water flows and depths influence the landscape patterns?
- To what extent did the bimodel seasonality of rainfall affect the flows, depths and hydroperiods across the landscape?

In this chapter, the diverse collection of historical sources introduced in Chapter 2, the post-drainage changes presented in Chapter 3, and the individual landscapes of Chapter 4, are combined with an interpretation of the post-drainage environment of the Everglades in relation to water management. Aerial photographs and satellite imagery, even though post-drainage, were particularly helpful in providing a spatial context for historical observations. These sources will be synthesized in this chapter to develop a conceptual model of pre-drainage Everglades hydrology, including water depths, flow directions, spatial patterns, and flows in and out of the Everglades. The time period covered by the conceptual model matches that of the rest of this study, namely the middle of the 1800's and perhaps as much as the preceding one or two centuries. Pre-historic conditions including the dynamic nature of the ecosystem are acknowledged, but no attempt is made to describe the hydrology of the Everglades prior to the mid-1800s, nor the approximately 5000 year-long process of peat accumulation.

One important aspect of pre-drainage (1800's) Everglades hydrology was not estimated in this study: the volumes of pre-drainage flows. While historical narratives and aerial photographs provide a strong record of pre-drainage flow directions and of the pre-drainage distribution of flows, quantitative observations of pre-drainage flow velocities are almost completely lacking. Cross-sectional areas of flow would be very useful to this discussion if not for the absence of pre-drainage velocity measurements. However, even without velocities and volumes, the maps of flow directions, a syntheses presented later in this chapter, provides considerable insight into pre-drainage hydrology of the Everglades system.

During development of the conceptual model, it became apparent that a relatively high level of detail and precision were embedded within the historical and post-drainage data despite the absence of formal time series measurements of stages or flows. This was possible, for the most part, because of the hydrologic simplicity of extremely flat, peat-based landscapes, and because of the hydrologic information implicit within the original vegetation communities, soils and landforms.

To build this conceptual model of pre-drainage hydrology, the first assumption is that the vegetation and peat microtopography of the pre-drainage Everglades were in equilibrium with, or closely "tuned to" the hydrologic driving forces originally present. The Sawgrass Plains is one such example of this "tuning" to hydrologic driving forces. The presence of an extensive plain dominated by sawgrass was dependent on a specific water regime that included an annual average rise and fall of water depths from about 1.5 feet above ground surface down to about 0.5 feet below. The rates of rise and fall were such that the period without standing water generally did not exceed 2-3 months. As discussed in Chapter 3, first-hand reports reinforce the impression of close tuning: within only a few years of lowering water levels, sometimes even more rapidly, drier species such as willow (*Salix*), elder (*Sambucus*) and careless weed (*Amaranthus australis*) spread into the sawgrass and the sawgrass stands were reported to "weaken". The often repeated observation that "Changes in elevation of only a few inches can have a great effect on the flora of Florida" (Taylor 1998) is another manifestation of the close "tuning" referred to here.

The "tuning" of this vegetation community to hydrologic conditions is particularly significant within the Everglades considering that it occurred on a sloped land surface off of which water was continually draining and evaporating. The pre-drainage water depths, and the annual rise and fall in those depths, was therefore the result of a balance between inflows and outflows; inflows from rainfall and Lake

Okeechobee, and outflows as surface runoff and evapotranspiration. The presence of the particular water depths that favored sawgrass thus depended on, at a minimum, the slope of the land, the hydraulic resistance of the vegetation, the atmospheric energy balance, and the duration and intensity of the rainy season. According to this “tuning” assumption, had any of these parameters been different, the resultant water depth regime would have favored a species other than sawgrass.

General characterizations of pre-drainage Everglades hydrology from previous studies (Parker *et al.* 1955; Parker 1974; Davis *et al.* 1994; Fennema *et al.* 1994) have highlighted the significance of outflows from Lake Okeechobee, southward flows of surface water, seasonal increases and decreases in water depth, and landscape-wide sheetflow. However, important details were elusive in these previous studies, including pre-drainage water depths, topography, flow directions, and the nature of the edges of the Everglades. Descriptions of pre-drainage hydrologic conditions have ranged from picturing an Everglades that dried out sufficiently for the peat soils to burn frequently (every five to fifty years), to an Everglades that was a vast flowing lake, retaining sufficient water even in dry years that large-scale peat fires occurred only once or twice in its 5,000-year history.

This study reinforces most aspects of these earlier studies, but differs due to the use of significantly improved descriptions of pre-drainage topography and landscape extents, and the explicit recognition of the directional, 3-dimensional microtopography of the Ridge and Slough landscape. In many cases, rather than introducing completely new concepts, we have simply resurrected old concepts that were prevalent among early observers, but were later forgotten as the Everglades became drastically altered by drainage.

Water Depths

Studies of wetlands and peat lands around the world (REFS) indicate that water depths, water flow and water chemistry were almost certainly the principal hydrologic driving forces that maintained, and perhaps originally created, the Everglades. Estimation of pre-drainage water depths is therefore a key part of understanding the Everglades. Fortunately, despite the absence of standard hydrologic time series data, a diverse wealth of other information is available from which to estimate water depths. These include numerous direct measurements (locations shown in **Figure A.1-1**) recorded by government land surveyors, depths recorded in the nightly logs of various cross-Everglades expeditions, general descriptions from first-hand pre-drainage observers, and depths that were inferred from a variety of sources. Sources of inference include the drafts and travel speeds of boats used in pre-drainage explorations and military navigation, pre-drainage soil types (as mapped in this study and estimated from Jones *et al.* 1948), hydrologic requirements and tolerances of wetland vegetation, and the likely frequency of pre-drainage peat (soil) fires, as estimated from soil cores and from the narrative record.

Within the Ridge and Slough landscape, the pre-drainage elevation differences between sloughs, ridges and tree islands is an important additional source of water depth information. For example, the frequent complaint in military and explorer narratives of not being able to find a tree island dry enough to sleep on or to make a fire, suggest that pre-drainage tree island elevations were two to four feet above the surrounding sloughs, and that water in the sloughs, when even with the tree islands, were two to four feet deep:

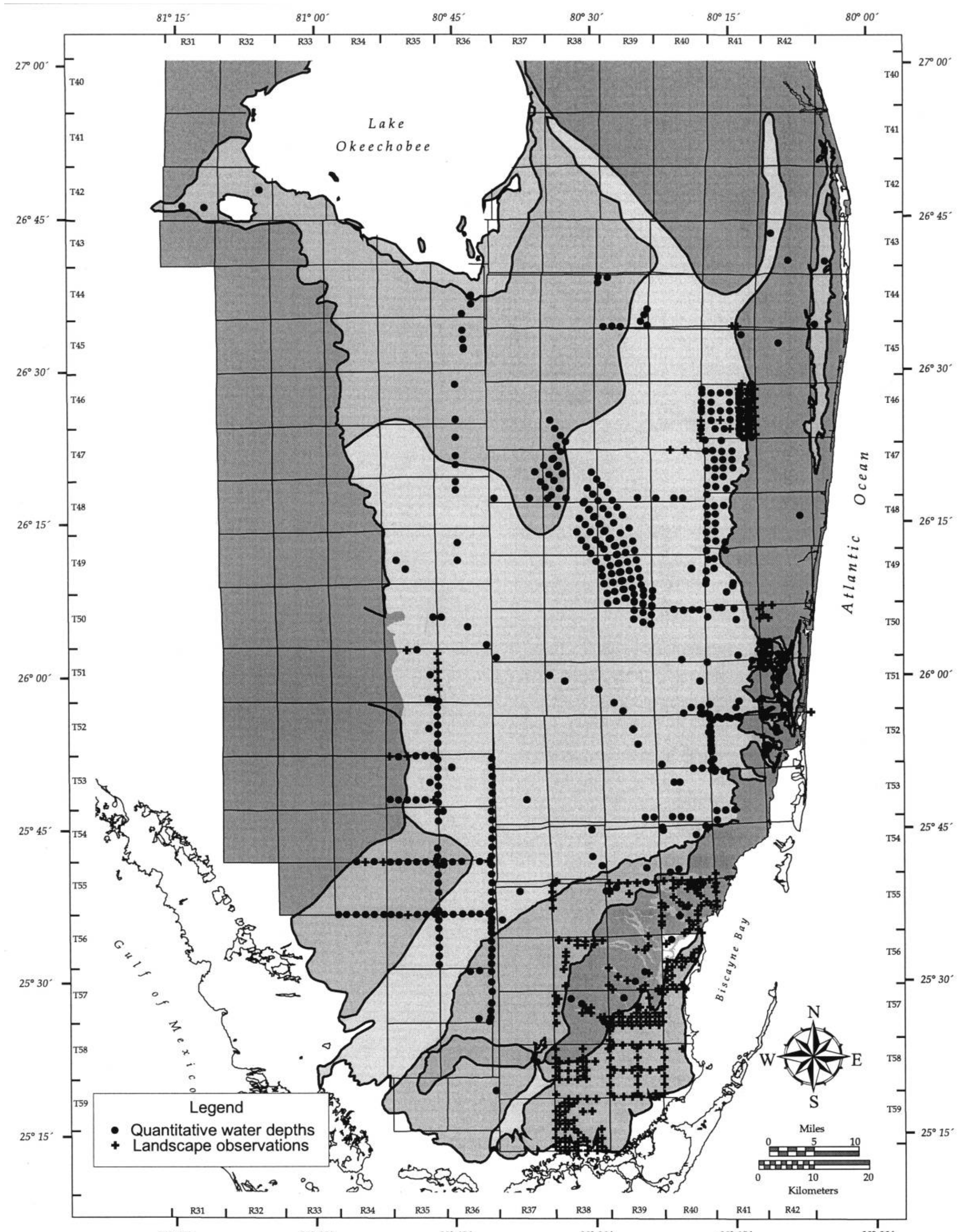


Figure A.1-1 Point observations of water depths and vegetation in the pre-drainage Everglades. Plus signs indicate soils, vegetation and/or qualitative hydrologic observations;

circles additionally include a quantitative water depth. Observations are from government township surveys, Everglades expeditions; and early scientific studies.

> "Scattered about in this sea of grass are islands of bushes and trees, called Keys. These Keys [tree islands] seem to owe their origin to an accumulation of vegetable matter which may appear some inches above water level, during the dry season becoming partially dry. During a night's sleep upon them one's bed is liable to settle to water level…" (Griswold 1896, p.54).

The present day Ridge and Slough landscape might also provide additional sources of information for estimating pre-drainage water depths, depending on whether present day depths and vegetation can be assumed equal to pre-drainage ones. This assumption is hard to accept in most places due to the fact that water management has impacted peat oxidation rates and has created artificial water depths across much of the remaining Everglades.

These types of impacts are known to alter wetland elevations. If this is also true in the Everglades, and all that has been presented so far would indicate that it is, then the idea that the present day microtopography of the Ridge and Slough landscape has flattened" relative to pre-drainage conditions becomes an educated conclusion. That is, both sawgrass ridges and the peat surfaces of tree islands have lost elevation relative to sloughs, either by peat oxidation or from outright peat fires, and current depths are not indicative of the "tuned" landscape of pre-drainage:

> "During recent times fires have been more frequent and of even greater intensity than previously as a consequence of lowered water levels due to ill-conceived drainage programs. This has resulted in altering or completely destroying many tree island communities, changing the composition of other plant communities, and has resulted in the loss of organic soils." (Loveless 1959, p.9)

> "These [early summer of 1956] fires completely destroyed many tree island communities by burning the peat substrate out from under the tree growth." (Loveless 1959, p.8)

Two characteristic pre-drainage water depths were estimated in this study for each landscape: the long term average annual high and long term average annual low. These estimates were arrived at using all available pre-drainage observations, synthesized using the following hypotheses:

1. The similarity of soils, vegetation and landscape patterning, presented in Chapters 3 and 4, indicate that water depths within the peat-based landscapes (Custard Apple Swamp, Sawgrass Plains and Ridge and Slough landscape) were uniform throughout, forming a single population. Similarly, water depths within the sloped Rockland and Ochopee Marl Marshes were hypothesized to decrease with lateral distance away from Shark Slough. (For the microtopographically varied Ridge and Slough landscape, this translated into several subpopulations: a subpopulation of uniform slough water depths, another one of different, but still uniform ridge water depths.)

2. The long term average pre-drainage hydrologic cycle is captured by two long term average water depths, an annual low water depth with an average date of mid-May, and an annual high water depth with an average date of min-October.
3. The long term average difference (“range”) between annual high and annual low is two feet (60 cm) throughout the Everglades.

Together, these three hypotheses define a simple long term average annual hydrograph: two line segments of slightly different slope, rising and falling each year between the average annual high and average annual low. For landscapes where the water drops below ground, soil porosity causes an apparent amplification of the range and distortion of the hydrograph shape. This is just appearance however; in terms of “free” water, the annual range is still two feet. The hypotheses of fixed timing of high and low, and fixed annual range throughout the Everglades landscapes reflects an assumption that regional climate drives both of these parameters.

Before discussing the process of adjusting the hydrographs to match the individual landscapes, it is appropriate to first substantiate the hypotheses listed above. The first hypothesis, that water depths were uniform across the peat-based Custard Apple Swamp, Sawgrass Plains and Ridge and Slough landscapes derives from two basic assumptions, one each for the downstream and transverse directions: (1) in the direction transverse to flow, peat accumulated levelly in equilibrium with a water surface leveled by gravity; and (2) in the downstream direction, the water surface was *not* level, but instead was parallel to the ground surface. The first assumption, that water and peat surface were level and parallel to each other in the transverse direction, derives from the observation that there is no consistent hydrodynamic force to make the water surface deviate from level, and since peat processes are likely to be regulated by water depths, the peat surface would tend to duplicate the water surface. The historical evidence points to the fact that a convex peat surface, as observed in some smaller wetlands, seems unlikely over the wide cross-sections of the pre-drainage Everglades.

The Rockland and Ochopee Marl Marshes are most indicative of this first assumption. These areas were once floodplain landscapes that sloped slightly upward away from each side of Shark Slough. As water elevations rose each year within Shark Slough, the water surface simply extended further and further outward onto the Marl Marshes (**Plate 17**). The level water surface over the sloped Marl Marsh land surfaces created a “wedge” of water. Surveyor’s field notes from townships that extend into the Rockland Marl Marsh appear to corroborate this, with indications of increasing water depths and corresponding soil and vegetation changes as Shark Slough was approached. In the downstream direction, the second assumption, the water surface was not leveled by gravity; instead, it sloped from the elevation of Lake Okeechobee, 20+ feet above sea level, to zero at Florida Bay. If the water had formed a wedge, deeper at either the up or downstream end, this would have created a depth gradient, which in turn would have created a vegetation gradient where zones of deep-water-tolerant species such as *Nymphae spp.* transitioned into less tolerant plants such as sawgrass. No evidence of this has been found; instead, the observed uniformity of pre-drainage vegetation upstream and downstream within each of the peat landscapes indicates that the water and ground surface planes were parallel in the direction of the flow axis.

Hypothesis 2, that the pre-drainage shape of long term average Everglades hydrographs could be captured by two points, occurring at fixed times of the year, and with a linear rise and fall between them, derives primarily from long term averaging of the seasonal climate, estimated from 60-100 years of south Florida weather records. Implicit within this hypothesis is the generalization that the rainfall rate is constant throughout the wet season and rates of natural drainage and evapotranspiration are constant throughout the dry season. Although it is recognized that a constant drainage rate is not strictly correct, in practice and for long term averages, the actual deviations from linear are small.

Why focus on long term averages? It is clear that South Florida experiences, and experienced, a range of weather from year to year. A “typical” or “average” year was and is the exception rather than the rule, where many years have been drier or wetter than average and decadal scale weather cycles are likely. Nevertheless this focus on long term averages was done for two reasons -- one biological and one practical. Biologically, wetland vegetation and peat soil processes over broad landscapes are influenced primarily by the long term, perhaps 20-50 year average water depths, rather than by the variations of any individual year. Examination of aerial photographs of the Everglades spanning 60 years shows large regions of homeostasis away from the direct influences of canals, levees, and structures. Practically, it is not possible to truly know the pre-drainage deviation from average because estimation of ranges and variances require a systematic data set of regularly timed measurements extending over multiple years, and such a data set does not exist.

Hypothesis 3, that the magnitude of the annual range (i.e., the difference between long term average annual high and low) was two feet, was derived from synthesis of observed pre-drainage depths and several topographic considerations. **Table A.1-1** lists narrative descriptions of pre-drainage Everglades water depths, generally not assigned to individual landscapes, but in almost all cases made by known first-hand observers. Some observers specifically stated an annual range, others only give an annual low and/or annual high. Aside from Shaler’s anomalous description of a five to eight foot annual range, the ranges, and also the difference between the estimates of the remaining annual high and annual low observations, all seem to indicate an annual range of about two to three feet.

Table A.1-1 Historical estimates of Everglades water depths: Low (dry season), other (unspecified season), high (wet season), and annual range (high- low).

Observer's Name and Occupation	Year	Low (ft)	Other (ft)	High (ft)	Range ft	Citation
Charles Vignoles, Civ. & Topo. Eng.	1823	0.5-2				Vignoles (1823a) Williams
John L. Williams, Atty. & Explorer Engineer	1837	2-4				(1837)
in Col. Harney's command	1841	2-4				Brooks (1880)
Buckingham Smith, U.S. Treas. Agt	1848	3-6				Smith (1848)
Gen. Harney, Seminole Wars	1848	2.5-6				Senate Doc. 89 (1911)
Lieut. Rogers, Seminole Wars	1848					Senate Doc. 89 (1911)
S.R. Mallory, Collector of Customs	1848					Senate Doc. 89 (1911)
J.C. Ives, Topog. Engineer	1856				2-3	Ives(1856b)
J. A. Henshall, U.S. Fish. Comm.	1882			2[2]		Reiger (1971)
W. Mickler, U.S. Deputy Surveyor	1885		0.5-5			Mickler (1885)
N.S. Shaler, Geologist/Geographer	1890	3	4-6[1]	4-6	5-8	Shaler (1890)
L. S. Griswold, Geologist	1896			2-5[3]	2	Griswold (1896)
William Dupuy, Writer	1908				3[4]	Dupuy (1908)
Samuel Sanford, Geologist, RR Eng.	1913				2; max 4	Matson & Sanford (1913)
John W. Harshberger, Plant Ecolog.	1914				2-3	Harshberger(1914)

[1] in channels only (unspecified time of year)
[2] on the "immense grassy plain... of dense saw grass" (average for the wet season)
[3] regarding Ochopee Marl area in western Everglades (T 56 R 36, T 57 R 36)
[4] "a difference of nearly three feet in its levels in the two seasons"

The 2-3 foot estimate of long term average annual range was made more credible through comparison with other known aspects of the pre-drainage Everglades, in particular the Ridge and Slough landscape microtopography, the recorded pre-drainage water depths (**Figure A.1-3**), and the cross-sectional elevations of Shark Slough, Rockland Marl Marsh and the Marl Transverse Glades. Taking an annual minimum of about one foot of water in sloughs as a given, based on indications of year-round persistence of water, suggests that a long term average annual range of 3 feet would have overtopped a number of the tree islands in most years. A range as high as 3 feet also would have placed 2.5 feet of water on top of sawgrass ridges at the end of the wet season. This seems to be deep enough to displace sawgrass and promote growth of slough species. Therefore, a value of 2 feet for the typical pre-drainage annual range seems most consistent with pre-drainage microtopography, vegetation and tree island heights.

Figure A.1-3 shows all available recorded pre-drainage water depths from the Ridge and Slough landscape found during the course of this study. The points in no way represent a systematic study; rather they are a random collection from many different observers and different years, and from an unidentified mix of ridge, slough, and possibly a few tree island locations. As a result, even the seasonal pattern of rise and fall is hard to discern. Nevertheless, most of the depths seem to be clustered in the one to three feet range. Like the elevations of ridges and tree islands, the clustering around one to three feet suggests that the annual range was about two feet.

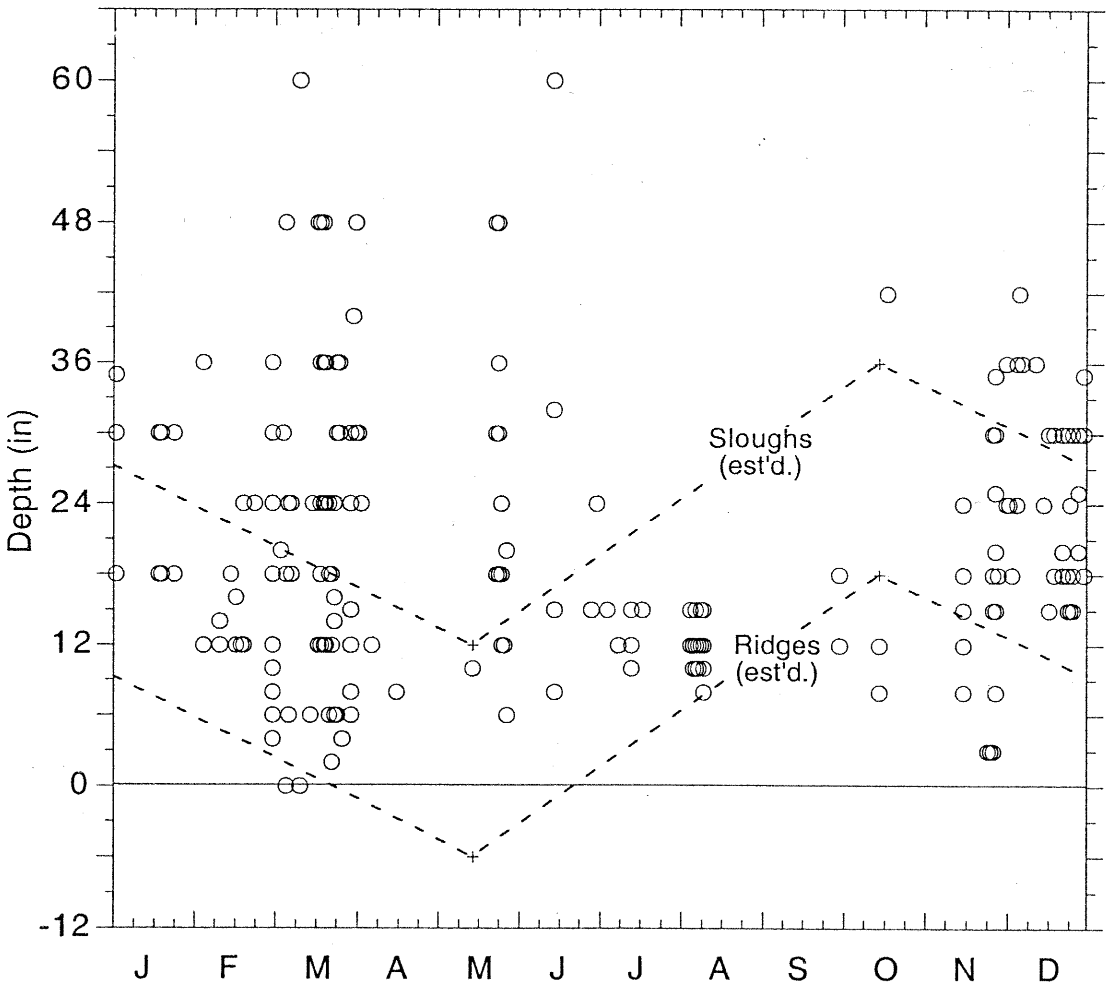


Figure A.1-3. Measured depths of water in the Ridge and Slough landscape, 1820 to 1920, plotted versus time of year. Locations shown in Figure A.1-1. Water depths in this landscape may have been measured in sloughs, in channels, or on sawgrass ridges. Dashed lines indicate hydropatterns estimated by authors for sloughs and for ridges; shown for comparison with measured points.

The relative elevation of the Marl Transverse Glades, which received water from the Shark Slough portion of the Ridge and Slough landscape, also appears to help constrain estimates of the annual range. The maximum average annual headwater depth at the western edge of the Marl Transverse Glades was one foot, a value consistent with marl soils and sparse sawgrass, would correspond to an average annual range of about two feet.

For comparison, **Table A.1-2** shows informal estimates of ranges extracted from post-drainage studies. The post-drainage, post-impoundment ranges from the Water Conservation Areas tend to be somewhat greater than the pre-drainage estimate of two feet, as might be expected. Overall, the estimate of two feet (60 cm) for the long term average annual range in water depths appears to be consistent with many features of the pre-drainage and even some post-drainage information.

Table A.1-2. Post-drainage estimates of average annual range in water depth (feet of water) for various locations in the Everglades.

Range (ft)	Location	Time Periods	Comments	Citations
1.5	Everglades	1940-1946	water budget analysis	Langbein in Parker *et al.* (1955)
1.8	Tamiami Trial, 40 Mile Bend	1940-1946	from hydrographs	Parker *et al.* (1955)
1.6	Tamiami Trial, Krome Road	1940-1943	from hydrographs	Parker *et al.* (1955)
2	Lake Okeechobee Stage	1916-1936	from hydrographs	Schrontz (1942)
2	Southern WCA 3	1951-1959	from hydrographs	Wallace *et al.* (1960)
2.5	WCA 2A	1980-1984		Worth (1988)
3.1***	ENP*; Ochopee Marls	1954-1985		Gunderson (1989)
2.3***	ENP; Perrine Marls	1954-1985		Gunderson (1989)
2.4***	ENP; Loxahatchee Peats	1954-1985		Gunderson (1989)
2 - 3	Gum Slough; Monroe County	1930-1950	field observations	Stone (1979)
1.7-2**	Lox. Nat. Wildlife Ref. (WCA1)	1953-1997	1-7 gage	This study
2.5-3**	Water Conservation Area 2A	1953-1997	2-17 gage	This study
2.5-3**	Water Conservation Area 3A	1953-1997	3-28 gage	This study
1.5-2**	Everglades National Park	1953-1997	P-33 gage	This study

* Everglades National Park.
**These estimates reflect only variation in above ground water depth; not water table
***not corrected for porosity

Under the above three hypotheses, the specific hydrograph for each pre-drainage landscape was estimated by adjusting the hydrograph up or down according to known aspects of the soils, vegetation, microtopography, and observed depths from each landscape. Hydroperiods, in turn, were estimated from the hydrograph. Results of this anthropologic synthesis are summarized in **Table A.1-3**.

Specific conclusions of this synthesis, starting with sloughs of the Ridge and Slough landscape, is that they were typically deep enough to maintain open water (i.e. few emergent species), allowing easy canoe passage; that adjacent tree islands were near but not generally lower than the annual maximum slough water depth, and that the sloughs typically did not completely dry out. The latter means that even during below average rainfall years, the average depth must have been high enough to prevent peat fires in the sloughs and carry water over into the next hydrologic cycle. This hydrology combined with the observed water depths (**Figure A.1-3**) points to an average annual minimum of one foot (30 cm) and an annual maximum of three feet (90 cm), which in turn was used to estimate average annual water depths on the sawgrass ridges of 1.5 feet less than in the sloughs. This is a drop in water table below the surface of the sawgrass peat that is consistent with sawgrass growth (Andrews 1957). As a corollary to hypothesis 1, these assumptions and observations indicate that water depths in the Sawgrass Plains were the same as those on the sawgrass ridges of the Ridge and Slough landscape, and that the Custard Apple Swamp was slightly deeper, 0.5 feet, than the Sawgrass Plains, reflecting the tendency for custard apple to be found in wetter locations than sawgrass.

Similarly, if all assumptions are true, then water depths on the sloped Rockland and Ochopee Marl Marshes bordering Shark Slough were in equilibrium with Shark Slough, and the mid-elevation depths of these marl marshes were about one foot higher than the sloughs. Accordingly, the maximum annual water depths were approximately one foot lower than in the sloughs, and the annual minimum was an extra 0.5 feet lower, reflecting the influence of the marl soil porosity.

Since the Perrine Marl Marsh was not as directly connected hydrologically to the main portion of the Everglades, and historical accounts suggest that it was somewhat drier than the Rockland Marl Marshes, then annual average water depths were estimated to be another 0.5 foot lower yet again.

The relation of present day to pre-drainage water depths is made complicated within the Water Conservation Areas by water management. The average depth over the year, the annual range of depths and the duration of deeper water have all changed. Over the years, these areas have been managed for environmental benefits, storage for excess flood waters and as reservoirs to provide water to coastal communities during dry periods. Therefore, even though the *average* water depths may be generally less than pre-drainage ones, during the wet seasons of the 1960’s and 70’s the water depths increased *above* pre-drainage depths due to mandated intentional storage of excess water. Correspondingly during dry periods, water levels were once (before the establishment of State mandated minimum flows and levels) allowed to decrease *below* pre-drainage water levels. Thus somewhat counter-intuitively, at the same time that average water depths are lower than pre-drainage depths, the present duration of tree island inundation may actually be longer than under pre-drainage conditions, even if the tree island elevation loss mentioned above had not occurred. Both the dry and the wet aspects of an increased annual range—lower water depths and longer inundations—have been associated statistically with changes in tree island species composition (Heisler et al. 2002).

The complex and varied post-drainage hydrologic history of almost a century of managed water levels—with, in some locations, several long cycles of alternately lowered, then raised water depths; changes to the timing and amplitude of annual rise and fall; and the reduction or diversion of water flow—have altered vegetation communities, often in ways that appear to have “weakened” the connection between water depths and vegetation. Davis *et al.* (1994) found substantial vegetation changes over a 25-year, post-drainage period, despite little change in average managed depths. To conclude: present day average water depths do not appear to be a reliable estimator of pre-drainage depths. It is estimated that average present day depths within sloughs are generally shallower than average pre-drainage slough depths, and that present day ranges—especially within the Water Conservation Areas—are generally greater. Overall, it is easy to concur with Parker (1974, p.29), who concluded that pre-drainage information “...all add[s] up to the judgment that, in pre-drainage days, the Everglades were generally either wet or flooded most of the time...”

Table A.1-3. Estimated long term average annual pre-drainage water depths and hydroperiods, 1800's prior to 1880.

Area	Average Annual Low (feet)	Average Annual High (feet)	Average Hydroperiod (months)
Everglades Landscapes:			
Custard Apple Swamp	0	2.0	11-12
Sawgrass Plains	-0.5*	1.5	9-10
Ridge and Slough (sloughs)	1.0	3.0	12
Ridge and Slough (ridges)	-0.5	1.5	9-10
Rockland Marl Marsh*	-0.5	2.0	8-9
Ochopee Marl Marsh*	-0.5	2.0	8-9
Perrine Marl Marsh**	-1.0	1.5	8-9

* Negative values indicate distance below ground surface.
** Water depths across these landscapes were not uniform; values shown are for mid-elevation locations, i.e., about half way from Shark Slough to upper edge of landscape.
***Water depths along downstream axis of Perrine Marl Marsh may not have been uniform; values shown may apply only near mid-elevation locations.

Inflows to the Everglades

The principal inflows into the Everglades were rainfall and outflows from Lake Okeechobee. Directional landscape patterns, early maps and the few available narrative accounts suggest that water also entered the pre-drainage Everglades from the Big Cypress, possibly in substantial volumes. Inflows from groundwater are mentioned by several observers, and may have been significant but are not easily quantifiable from historical sources. Additional water may have flowed into the Everglades from the Eastern and Western Flatwoods, but landscape patterns suggest the volumes were small. Water in the Loxahatchee Slough flowed at different times both in and out of the Everglades, so at times would have contributed water.

Inflows (to the Everglades) from Lake Okeechobee

Examination of the pre-drainage vegetation bordering the southern half of Lake Okeechobee suggests that water from Lake Okeechobee flowed continuously into the Everglades during much of each year. The portion of the lakeshore that overflowed—70 miles along the southern shore, from Fisheating Creek on the west to Pelican Bay on the east — was formed by the accumulation of organic, wetland soils. These soils, as much as 10 or 12 feet thick prior to drainage (Kraemer 1892; Wright 1911), provided the "plug" or dam that allowed the waters of Lake Okeechobee to accumulate. Two different Everglades landscapes contributed to the formation of the soil: the Sawgrass Plains bordering the southwestern shoreline and the Custard Apple Swamp bordering the southern and southeastern shoreline (**Plate 13**).

Sawgrass extended directly to thee dge of Lake Okeechobee which suggests that water depths along this shoreline must have typically varied within the range that sustains sawgrass and the absence of an elevated rim between the lake and the Sawgrass Plains. As might then be expected, the water surface within the sawgrass marsh was simply an extension of the water surface of the lake:

> "The men waded the swamp [south of Lake Hicpochee] and continued the [survey] line in the direction of Lake Okeechobee until a point was reached where

> there was no slope in the surface of the water for several miles. This condition extended to the open water of Lake Okeechobee." (Wright 1911, p. 153).

A rimless border, water levels continuous with the lake, a sawgrass shoreline, and deep, continuous profiles of sawgrass peat (Dachnowski-Stokes 1930) can provide a quantitative measure of typical pre-drainage lake levels. The annual rise and fall of the lake apparently stayed mostly within a range that would produce shoreline depths favorable to sawgrass. Along the western and southwestern shoreline, lake levels would have typically risen to a maximum of about 1.5 feet above the peat surface by the end of the wet season, and dropped annually to about 0.5 feet below peat surface by the end of the dry season. During the 9 to 10 months of the year that lake levels typically were above the peat surface, water would then have flowed from the lake into the Everglades:

> "The overflow from Lake Okeechobee floods the Everglades except in the dry season of the year." (Wright 1911, p. 159).

This analysis does not provide a measure of the velocity of outflow, but it does provide an estimate of the outflow cross-section (height times width). For the southwestern, Sawgrass Plains portion of the shoreline, the cross-section would have ranged between zero toward the end of the typical dry season, to a wet season maximum of roughly 20 miles long by 1.5 feet high, or 160,000 ft^2 (15,000 m^2).

A similar calculation can be made for the Custard Apple Swamp portion of the shoreline. Chapter 4 suggested that it is very unlikely that the Custard Apple Swamp formed an elevated rim under pre-drainage conditions, and that the descriptions of a rim which began appearing in post-drainage accounts probably are the result of differential, post-drainage soil subsidence. It was also noted that custard apple generally grows under deeper water conditions than sawgrass. To estimate the timing and cross-sectional area of outflows through the southern shoreline, the narrow strip of Custard Apple Swamp can therefore be considered simply as a shallow extension of the lake, such that outflows would be controlled by the Sawgrass Plains just south of the swamp. Outflows would occur when lake and Custard Apple Swamp water elevations exceeded the ground elevation in the Sawgrass Plains. We assume that elevations in this portion of the Sawgrass Plains were equal or very nearly equal to the elevation of the more westerly portion of the Sawgrass Plains analyzed above, so the same calculations of outflow cross-section can be made. (The assumption of similar elevation is based on assuming that peat accumulation in both areas was controlled by lake water levels. It is also consistent with historical observations (e.g., Wright 1911) that the whole southern shoreline overflowed at the same time.)

As a first approximation for estimating the outflow cross-section of the Custard Apple portion of the shoreline, one can therefore simply use the previously mentioned sawgrass dimensions, yielding a minimum of zero and a wet season maximum of 50 miles long by 1.5 feet high, or 400,000 ft^2 (37,000 m^2). Adding this to the previous estimate for the southwestern (sawgrass) shoreline yields a total of 560,000 ft^2 (52,000 m^2) for the cross-sectional area flowing at the end of the typical wet season.

If this analysis is correct, and pre-drainage narratives, vegetation and soils all appear to suggest that it is, this was a remarkable geomorphological phenomenon: 70 miles (110 km) of extremely flat lake shoreline, parallel to the equilibrium water surface, and all contributing to outflow with a typical annual maximum depth of about 1.5 feet. Compared to the vast majority of lakes, this would have been an exceptional shoreline. For most lakes, the shoreline is composed of mineral sediments whose elevation is formed, and varies, independently of the lake's water surface. Typically only a narrow area of low elevation is available and as a result, the width of the outflowing river is very small in comparison to the diameter of the lake.

In the Everglades, the opposite was the case: the width of the outflowing area was actually *wider* than the diameter of the lake, leading to radial outflow. The explanation for this atypical morphology would appear to lie in the organic sediments that formed the southern shoreline: the wetland peat deposits that accumulated, and also decomposed, in equilibrium with the long term average water surface. The (typically) annual period of aerobic decomposition that occurred when the lake water surface descended below the shoreline was likely an important process contributing to leveling of the organic shoreline relative to the water surface.

Several observations regarding the estimated rectangular cross-section of the lake-to-Everglades interface are appropriate here. First, to our knowledge, no pre-drainage measurements were made of the velocity of the water flowing from Lake Okeechobee into the Everglades. Estimation of this velocity would have to consider the likely high hydraulic resistance of the dense sawgrass stand formed by the Sawgrass Plains. Estimation would also have to consider that, at least near the shoreline, the hydraulic gradient might have been even less than the gradient of about three inches per mile that was representative of the Everglades as a whole. Close to the lake, the slope of the Everglades water surface would likely have been reduced by the lake influence, and the ground surface slope might also have been reduced.

Second, it is illustrative to compare the width of the flowing cross-section—70 miles of southern lake shoreline—with the typical width of the Sawgrass Plains further south from the lake—about 40 miles (**Plate 13**). As the similar vegetation suggests that water depths both at the shoreline and downstream in the interior of the Sawgrass Plains would also have been similar, the wider flow width, 70 vs. 40 miles, suggests that the velocity near the lake would likely have been lower than further downstream. This would also be consistent with radial flow directions at the shoreline vs. the parallel flow directions found further downstream.

Thirdly, it is appropriate to consider variability in the geometry of the flow cross-section at the lake shore. We assumed a rectangular cross-section based on the assumption of the peat surface being parallel to the water surface. The latter assumption was in turn based theoretically on the processes of peat accumulation and decomposition, but also empirically on the reports of the whole southern shoreline overflowing at much the same time. (The short "dead" rivers might have been an exception to this, but they dissipated quickly within the Sawgrass Plains, so we assume that their contribution to outflow volume was negligible.) Nevertheless, it is likely that at various scales there was some variation in the ground surface elevations. Tussocks or hollows in the peat, if present, might have locally raised or lowered the ground elevation as much as 0.5 feet over areas generally less than a foot in diameter. The effect of this or other sources of local variation on the overall estimate of the flow cross-section is probably, but not necessarily, small.

In summary, the estimate of a typical end-of-wet-season cross-sectional area of inflow to the Everglades from Lake Okeechobee of roughly 560,000 ft^2 (52,000 m^2) appears to be logical and consistent with the available information, but further research might yield a measure of the uncertainty associated with the estimate. No estimates of the pre-drainage velocities present in this area are available, but they would almost certainly have been lower than pre-drainage velocities in the sloughs of the Ridge and Slough landscape.

Lake Okeechobee's very long fetch as well as historical accounts suggest that in addition to typical outflow conditions, lake seiches occasionally would have contributed significant pulses of water into the Everglades. Pre-drainage and pre-dike accounts record high water marks of five feet (Wintringham 1964 [1883]; Williams *et al.* 1911) and even six or seven feet above ground surface (Hancock 1907) near the lake shore. These were presumably exceptional events, most likely associated with hurricanes. Estimates based on stage measurements taken during recent hurricane-induced seiches suggest several points: (1) probably not the full 70 miles of southern shoreline would have been affected—40 miles might be more typical; (2) durations would likely be 6 to 18 hours; and (3) seiche elevations could be as much as 6 feet.

The hypothesis suggested by the shoreline vegetation, that typical (non-hurricane) lake outflows lasted as much as three quarters of the year is further supported by the distribution of water depths within the pre-drainage Everglades. The uniformity of vegetation along the downstream axis of the Sawgrass Plains and Ridge and Slough landscapes suggests that water depths were also very close to uniform along the downslope axis. This suggests the presence of an upstream inflow counterbalancing the downstream outflow. It seems likely that inflows from Lake Okeechobee (along with local rainfall) contributed to this balance.

Pre-drainage descriptions made by early drainage engineers also support the hypothesis that Lake Okeechobee outflows continued throughout the majority of the year during most years. George Hills, who "literally crawled on … hands and knees" for many miles of the pre-construction survey for the West Palm Beach Canal, states:

> "Under those natural conditions the normal elevation of Lake Okeechobee was approximately that of the surface of the muck lands along its shores. Any increase in height of the lake resulting from floods in its tributaries resulted in the discharge of such flood waters upon the muck lands of the Everglades ... Under such conditions it is apparent that the muck lands of the Everglades were continuously saturated and constantly subject to inundation by waters of outside origin." (Hills 1931, p. 3).

Ben Herr was chief drainage engineer for the Okeechobee Flood Control District:

> "The excess of water from rainfall and inflow over evaporation spilled over the low southern shore into the Everglades. This water together with the rainfall kept the Everglades flooded most of the year." (Herr 1943, p.12-13).

Both the long duration of annual inflows and the occasional pulses from seiches help explain the early drainage engineers' strong emphasis on lowering Lake Okeechobee levels as a first step in draining the Everglades:

> "This [5 foot water mark] shows conclusively that the Glades can not be drained to prevent overflow until the lake is lowered and converted into a reservoir. … The intention of the drainage operations is to lower the level of this lake 6 feet…" (Williams et al. 1911, p. 197-198).

The importance to the Everglades of Lake Okeechobee outflows along the whole 70 mile shoreline helps explain the appearance of changes in the Everglades as early as the 1890's, when for a period, Disston and Kraemer's drainage efforts succeeded in lowering Lake Okeechobee levels. Kersey attributes the decline of the Indian trade in alligator and otter hides to this early drainage: "The second reason for Brown's [sale of his store in Feb 1908] was that he had foreseen the beginning of the end of the truly profitable trade in pelts, plumes, and hides as a result of the drainage of the South Florida wetlands which was just getting under way." (Kersey 1975, p. 70). While this is Kersey's *post facto* interpretation, a contemporary (1910) quote from a medical missionary at Everglades Cross Mission, Dr. W. J. Godden, suggests that Kersey's interpretation is correct: "[they make their living] now by hunting the alligator and otter and selling their hides, but soon the hunting season will be a thing of the past, as a means of livelihood" (quoted in Kersey 1975, p. 71). Significantly, the declines in Everglades water depths implied by these observations are necessarily associated with Lake drainage, because the Everglades drainage canals had not yet been completed.

Altogether, despite the absence of pre-drainage measurements of outflow velocities, multiple lines of evidence, including shoreline vegetation, Everglades vegetation, early hydrologic descriptions, and early post-drainage changes confirm that Lake Okeechobee outflows were a critical source of water for the pre-drainage Everglades.

Inflows from the Eastern and Western Flatwoods and Big Cypress

Surface water flow from the Pine Flatwoods east and west of the Everglades does not appear to have been large. Directional vegetation patterns that might suggest significant flows from the adjacent flatwoods communities into the Everglades are not visible on aerial photographs (USDA-SCS 1940) or on historical maps. However, the higher wet season water levels probably allowed water to occasionally flow from the Everglades to the adjacent pine and cypress landscapes. Ives (1856) reported a well-traversed trail through the Eastern Flatwoods, passable by canoe during high water, and leading to "the swamp bordering the Everglades."

Along much of the boundary between the Eastern Flatwoods and the Everglades in Palm Beach County (present day boundaries), cypress strands were present; usually these were oriented north-south, but occasionally east-to-west. East of the cypress border, the transition to Flatwoods appears fairly sharp on aerial photographs (USDA-SCS 1940). The presence of numerous isolated and circular cypress domes within the flatwoods suggests the absence of a continuous surface water connection to the Everglades, but that high water tables were present during the wet season.

Along the western boundary, tree island orientation, landscape directionality visible on 1940s aerial photographs and directionality visible on recent satellite imaging (**Plate 30**) suggest that surface water flowed from the Mullet Slough portion of Big Cypress into the Everglades. Watershed boundaries estimated for pre-drainage conditions in Big Cypress also suggest that flows were directed through Mullet Slough toward the Everglades during wet conditions (Duever *et al*. 1979).

Inflows from Groundwater

A number of early and apparently credible accounts discuss the presence of seemingly large groundwater discharges into the Everglades. This is puzzling, as such discharges are not observed at present, nor does there seem to be evidence of downstream plumes that would be expected from the discharge of calcareous groundwater onto softwater peatlands. (One could speculate however that King's 1917 soil profiles of intermixed marl and peat along the future route of Tamiami Trail might be related groundwater discharge.) We include the following observations for the reader's consideration.

In the early part of the 1800's, J. L. Williams, a life-long student of Florida geography, wrote that he gave credence to,

> "a statement made by a respectable gentleman who resides near the border of the Glades, and who has often visited them. He states that not far from the center of the Everglades there is an immense spring rising from the earth, covering an extent of several acres, and throwing up a large quantity of water with great force, and supplying the Everglades with all the water flowing through them." (Williams, unpublished manuscript in Senate Doc 89, 1911).

MacGonigle, in a detailed National Geographic article, felt that water balance argued for an important contribution from "subterranean streams or springs:"

> "The evident elevation of the area above the east, west, and south coasts precludes the idea of drainage from surrounding areas, and we must look elsewhere for the sources of the water. These, I think, are found in part in precipitation, and, in part, in subterranean streams or springs. The rainfall over this vast area of three million acres must be very great. But when we remember that all the creeks and rivers lead out of and not into the glades, the rainfall, which possibly approximates an average of ten inches per month during the months of June, July, and August, is not sufficient. From what we know as to the subterranean relations between the lakes in the lake region, from the well-known conditions of Silver, Blue, and De Leon springs, as well as from data acquired by drilling for artesian water, it is reasonable to infer that the volume of water due to precipitation is materially increased by an underground supply." (MacGonigle 1896, p. 388).

Willoughby, writing after his trip across the Everglades, also felt that groundwater played a significant role in Everglades hydrology. His firsthand observations, while not quantitative, make it hard to reject the possibility that groundwater contributed significantly to the pre-drainage water budget:

> "Sometimes pools would be crossed eight or ten feet wide and five feet deep. ... Occasionally, in the centre of these pools, a dark hole a few inches in diameter could be seen; down one of these I could push my pole to a long distance, and the water was coming out from it with quite a little head. They are to be found all over the Everglades, and are, I believe, one of its greatest water-supplies.
>
> All this moving water cannot be accounted for by the rain alone, and the water is too hard for rain-water, so that in all probability more comes from below than above." (Willoughby, 1898).

King, engineer and naturalist, while exploring part of the Ochopee Marl Marsh during the dry season, described a surface-to-groundwater connection. His descriptions refer to surface water entering, rather than leaving the ground, but Willoughby's observations suggest this would have been reversed in the lower, non marl marsh majority of the Everglades:

> "This area of the Everglades [SE corner of the Hopkins tract; i.e., Ochopee Marl Marsh] is similar in character to other sections of the Everglades and covered with a growth of sawgrass and a round water grass, separated and divided by a number of Myrtle Hammock[s], very narrow and much elongated, following in parallel lines with the main Coastal Hammock and ranging approximately 200 yards apart. From the ends of these long projecting Myrtle Ridges extends rocky reefs connecting with the preceding hammock. These rocky reefs project upwardly in sharply pointed finger-like masses, level with or above the surface of the ground. The sloughs that in periods of high water spread over this ground, were at this time mostly dry, owing to the effect, among other causes, of a long period of drought, gather at irregular intervals into rivulets which usually lead to sink holes at the ends of some Myrtle Ridges and disappear beneath the surface of the ground. …
>
> Underlying the entire area of this A. W. Hopkins tract is a bed of hard blue limestone known as the Lossmans River Limestone, lying very near the surface, and in instances projecting through in the form of an outcrop…
>
> This limestone in its natural formation, is a carbonate of calcium and is of a hard, blue, homogeneous structure, much 'water worn' on the surface. It is unquestionably of considerable porosity and cavernous, as indicated by the number and extent of the sink holes found within this area. On the surface fragments of this rock show a high state of silicazation, wherein the more soluble Calcium Carbonates have been replaced by a precipitation of soluble silicas, creating an extremely hard, flinty structure.
>
> It is evident that a system of subterranean drainage exists throughout this entire area, from the dryness of the soil, the formation of streams, and the disappearance of same in sink holes of large or smaller extent. (King 1917, p. 413-416).

In summary, some type and some degree of groundwater-surface water interaction certainly was present in the pre-drainage Everglades, but it is not possible to use historical observations to quantify the role of groundwater. It may have been a more important component of the Everglades water budget under pre-drainage conditions when water levels in the surrounding areas—Lake Okeechobee, the Eastern and Western Flatwoods, and even the Kissimmee Valley—were all higher than at present.

Outflows from the Everglades

Surface water left the Everglades through five principal outflows. In clockwise direction (**Plate 13**), these were: (1) The East-West Cypress Strands (Townships 48, 49, and 50), oriented from west to east; (2) The Peat Transverse Glades and associated coastal rivers (Townships 51, 52, and 53); (3) The Marl Transverse Glades (Townships 54, 55, and 56); (4) Taylor Slough (Townships 59 and 60); and (5) Shark Slough (Townships 59 and 60). These outflows are known from historical accounts and are visible on older maps, soil maps, and aerial photographs. Additionally, the relation of these outflows to flow patterns within the Everglades can generally be seen in maps of surface flow directions, such as Parker *et al.* (1955), reproduced here as **Figure A.1-4**.

These outflows can be classified into two types: (1) "spillways" in which discharge occurred only when a threshold elevation was exceeded; or (2) "flowways" which lacked a threshold, and in which discharge varied as a function of water depth, resistance of the vegetation and overall slope of the watercourse. Flowways flowed throughout the year, as long as there was surface water on the landscape; spillways only when water levels exceeded the threshold elevation. Flow rates within flowways were controlled primarily by the internal resistance of the landscape itself.

Flowways sloped continuously downward. In contrast, ground surface in spillways increased near the threshold, after which the ground surface sloped downward towards the ocean. In the post-drainage Everglades, soil subsidence appears to have converted some outflows from flowways into spillways, as upstream subsidence led to the formation of an artificial ledge or threshold. This occurred in the Peat Transverse Glades, to some extent in the East-West Cypress Strands, and in the headwaters of the more southerly coastal rivers (especially Little River and Miami River), in all three cases due to post-drainage peat subsidence in the Ridge and Slough landscape west of the coastal ridge.

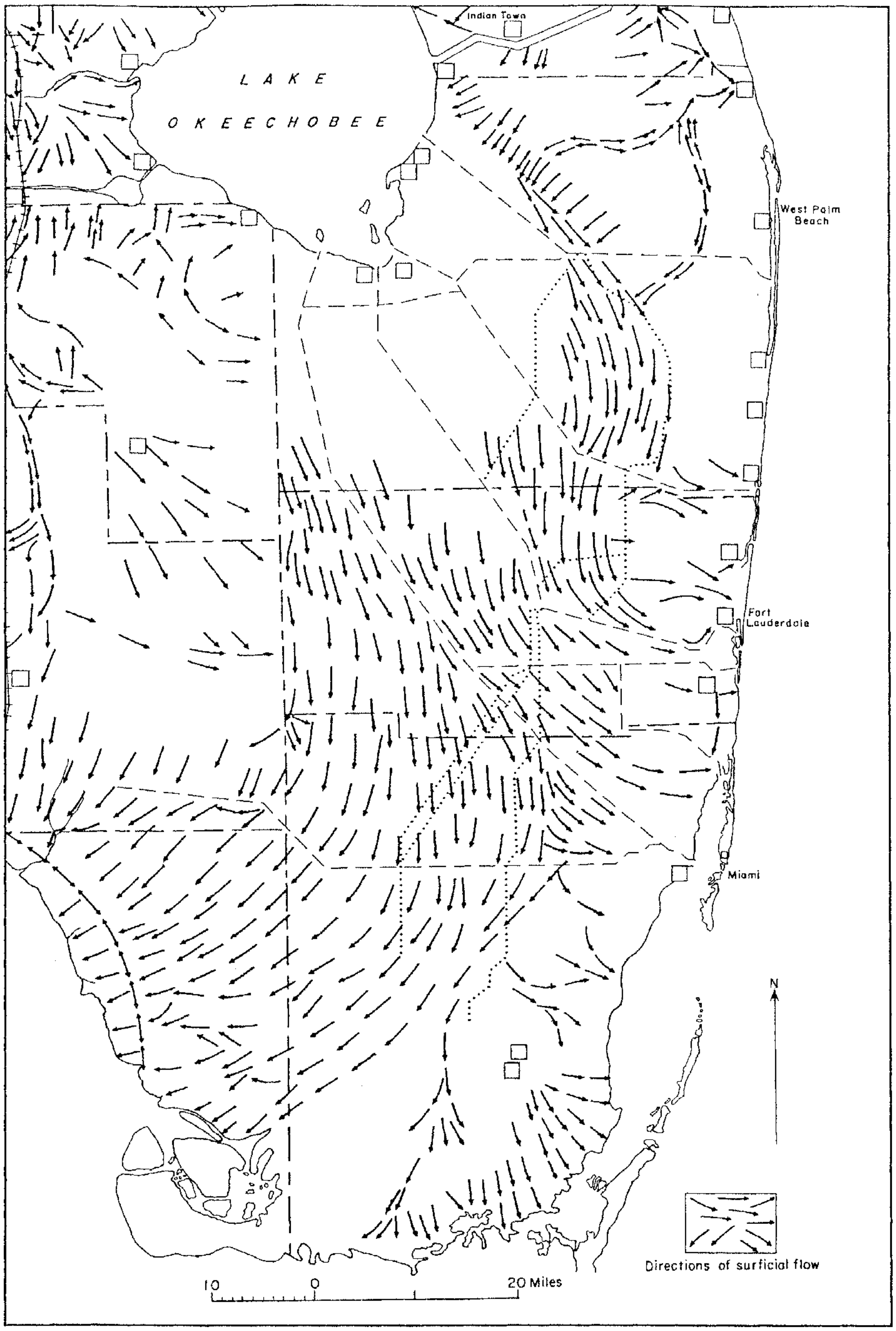


Figure A.1-4. “Map of southeastern Florida, showing directions of surficial drainage.” Flow directions estimated by G. G. Parker. Likely represent pre-canal drainage conditions. From Parker et al. (1955) and Parker (1974). Major pre-1950s canals (dashed lines) and 1990s canals or levees (dotted lines) included for location.

Under pre-drainage conditions, the Marl Transverse Glades were natural spillways. The East-West Cypress Strands, Shark Slough, Lostman’s Slough and the Peat Transverse Glades were natural flowways. The fifth outflow, Taylor Slough, was unique. Surface water inflows into Taylor Slough occurred over a shallow spillway, controlled by rising water levels in the Rockland Marl Marsh. Internally, flows through Taylor Slough resembled a flowway controlled, like Shark Slough, by the internal resistance of the sawgrass and slough vegetation.

Outflows through the Cypress Strands

The principal East-West cypress strands were present in the southern portion of the Eastern Flatwoods (see Chapter 4) in present-day Broward County, north of Ft. Lauderdale (Townships 49 and 50 on **Plate 13**), and to a much lesser extent, in Palm Beach County. These strands formed funnel-shaped areas—the wider side facing the Everglades, the narrower end oriented eastward and terminating in coastal rivers (**Plate 36**). Flow directions in the Ridge and Slough landscape adjacent to the cypress strands appear to turn southeastward in Township 49 (Figs. 5.7 and 5.8), less likely so in the next Township north (T 48). The southeast turn may reflect some influence of the eastward flows through the cypress strands. Such a relation between Everglades, cypress swamp and coastal rivers was described in 1823 by Charles Vignoles:

> "New river and all the branches [i.e., the North and South Forks of the Middle River, and part of Cypress Creek] discharging though its bar originate in the Great Glade, running through pine lands and heading in cypress swamps; which have previously been inundated from the Glade..." (Vignoles 1823, p. 49).
>
> Cypress swamps are mostly near the head of rivers, and in a continued state of inundation; little or no underbrush, but only crowds of the cypress shoots or knees, which point up like small pyramids." (Vignoles 1823, p. 90).

The ground surface of the cypress strands was slightly elevated above the Everglades peat surface immediately to the west, providing some resistance to outflow, but most of the resistance was probably due to the long, shallow slope through the cypress area, and to vegetation within the cypress strands, which included a mixture of deeper areas of open water and shallow areas with dense vegetation. The combination of these resistances apparently prevented the cypress strands from becoming a major outflow from the Everglades. At the same time, Vignoles (1823, p. 91) and others suggest that very little peat accumulated in the cypress strands :

> "The land in the cypress swamps here appears to be neither rich nor deep, being apparently but pure silex [silica] with an admixture of [organic] sediment." (Mallory, 1847, in Senate Doc. 89, 1911, p. 63).

Possible explanations for the limited pre-drainage accumulation of peat within the cypress strands compared to in the Everglades include lower primary productivity, faster decomposition of organic materials, flushing during occasional high-flow events, and scarcity of graminoid root mats which might otherwise have stabilized peat in the shady understory. Of these, scarcity of root mats and occasional flushing seem the most likely explanations for the predominantly sandy, peat-free substrate.

Outflows from the cypress strands terminated in Cypress Creek, the North and South Forks of the Middle River, the North Fork of the New River and possibly one of the southern forks of the Hillsboro River.

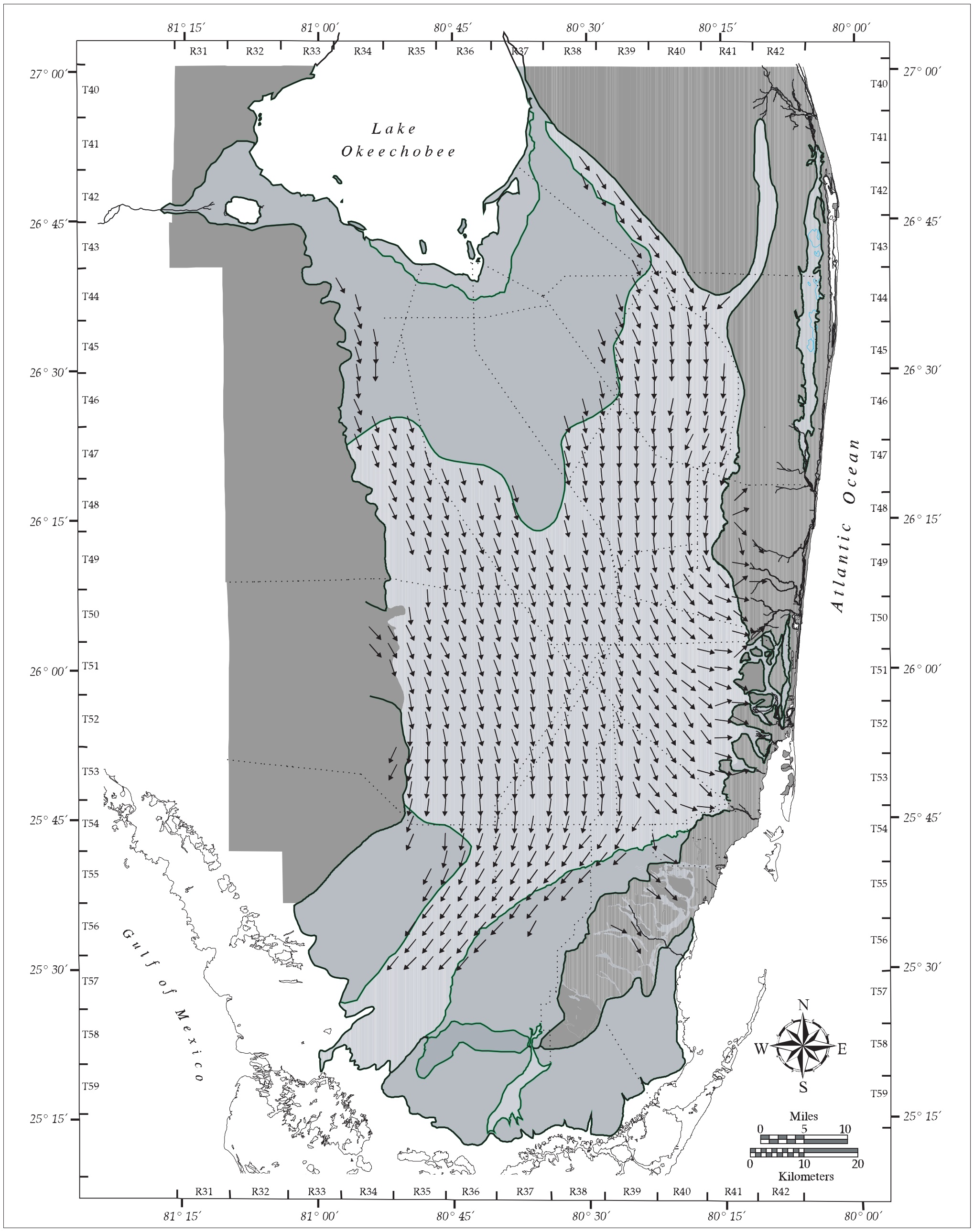


Figure A.1-7 Landscape directionality determined by angular measurement of the “grain” formed by parallel sawgrass ridges and sloughs, based on 1940 aerial photographs (see text). Arrowheads point in downslope direction

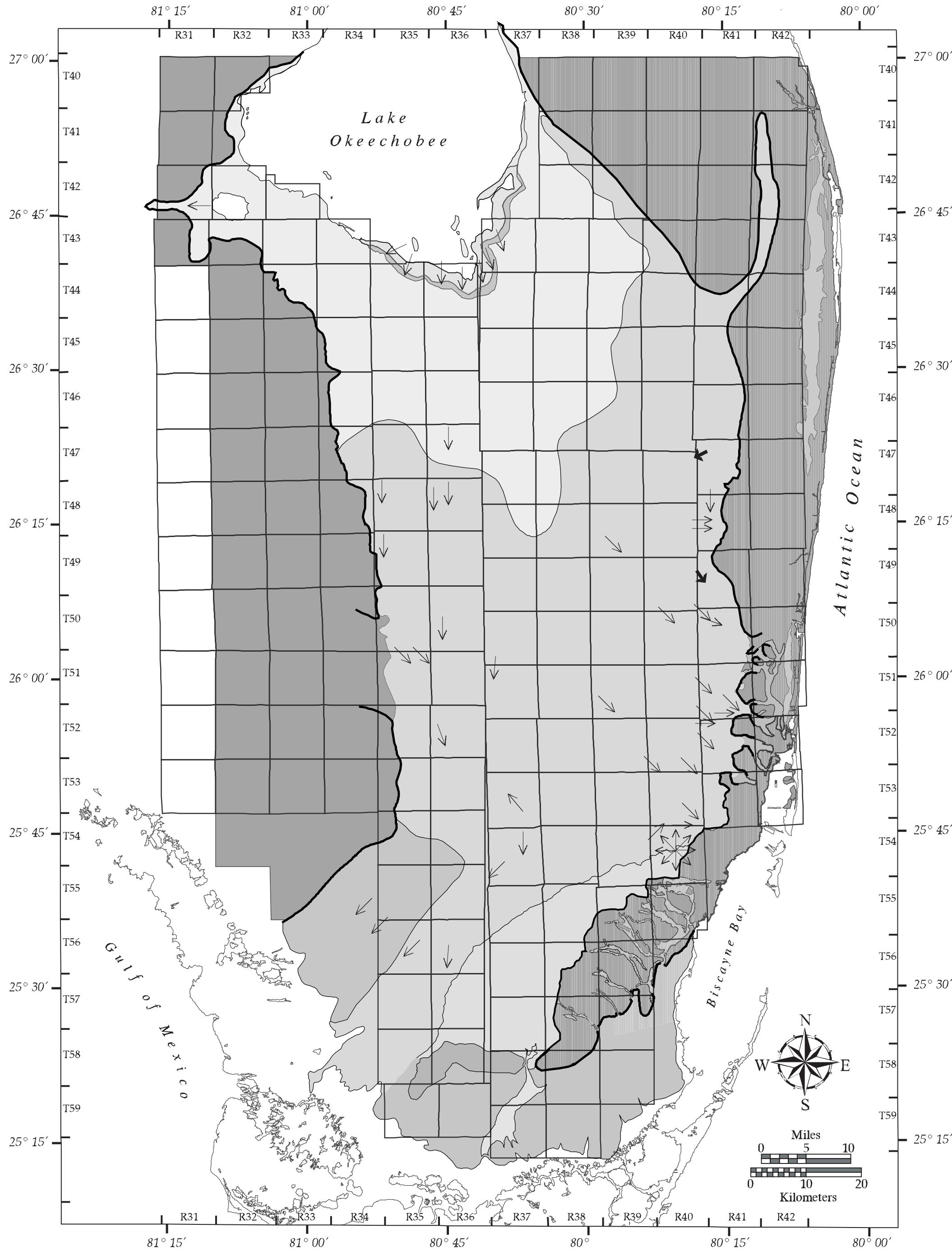


Figure A.1-8 Recorded observations of water flow directions, prior to 1913. Sources include township surveys, soils surveys, and cross-Everglades expeditions (Appendix O). Thicker arrows in townships 47 and 49 indicate that these are based on an average of 7-8 adjacent observations

Outflows through the Peat Transverse Glades and Coastal Rivers

The "coves and indentations" of the Everglades (Buckingham Smith 1848), here called the Peat Transverse Glades, were an important part of the pre-drainage hydrology of the eastern axis of the Everglades, transferring water to the coastal rivers, into Biscayne Bay, and ultimately into the Atlantic. Without gauging stations it might seem impossible to understand pre-drainage flows through these indentations, but in fact enough key details are known to narrow the possibilities considerably. Pre-drainage land surveys and the post-drainage soil map (Jones et al. 1948) accurately define the spatial aspects: width, length, location, and relation to the Everglades and to the often braided headwaters of the coastal rivers (**Plates 35, 37** and **38**). Knowledge of pre-drainage soil types and vegetation bracket the possible water depths and help clarify the original topographic relation to the Everglades. Narrative descriptions of rapids, of year-round water flow and of canoe travel provide further definition.

On the other side, several issues have understandably clouded understanding of pre-drainage Peat Transverse Glades hydrology. Townships 50 to 53 and west to about the middle of Range 39 were diked and drained very early, separating the area from the rest of the Everglades to allow both agricultural and urban development from Ft. Lauderdale south to Miami. With these successful drainage efforts, the Peat Transverse Glades soon dried out, the wetland vegetation disappeared and even the organic soils disappeared by oxidation, eventually down to the underlying sand. As these changes occurred, an area that had once resembled a series of islands separated by wetlands came to resemble a more continuous, dry ridge—the Atlantic Coastal Ridge. The impression of continuous ridge was further strengthened as westward the peat soils of the former Everglades oxidized, creating a two to four feet subsidence trough just west of the ridge of former islands.

The combination of trough and continuous ridge, even though post-drainage phenomena, could lead to the impression that surface water flowing southeast through the Everglades would impound behind such a ridge, filling the trough. And in fact at some post-drainage times it did impound, most dramatically during the flood of 1947, when Parker et al. (1955) observed "6 to 8 feet [of water] over vast areas of the central glades." Although the water *stages* observed (elevation above sea level of the water surface) at this time were likely similar to pre-drainage stages, the 6 to 8 ft water *depths* were much greater than pre-drainage depths. Such depths were only possible because peat subsidence had lowered the ground surface, and were definitely not an indication of pre-drainage impoundment patterns. It is important therefore to understand the pre-drainage topography that prevented such impoundment.

Prior to drainage and subsidence, the Ridge and Slough landscape west of the Peat Transverse Glades sloped southeastward toward the coast at a rate of about three inches to the mile (Newman, in Stewart 1907). Approaching the coast, the pinelands on the horizon formed a distinct line where they met the Everglades. Breaks in the horizon line served as landmarks, indicating places where the Everglades extended farther eastward, between the islands of higher, pine-covered ground. These extensions, or "coves and indentations" were sawgrass marshes growing on peat soil (Jones *et al.* 1948; pre-drainage land surveys). In addition to sawgrass, some of these Peat Transverse Glades also included a tree island (**Plates 39** and **40**) or variations that suggest a ridge and slough-like mosaic (**Plate 31**).

The transition from Everglades to Peat Transverse Glades would have occasioned almost no change in vegetation or in depth of water. Only the progressive narrowing of the vista by pinelands to the north or south would have indicated a departure from the open Everglades (**Plates 35** and **37**). As settlers explored the connection between Everglades and the coastal rivers (e.g., Pierce 1970), usually by canoe, the individual Peat Transverse Glades became known by the names of their respective rivers: “Undefined waters of Arch Creek,” “Glades,” “Valley of Snake Creek,” “Waters of Snake Creek” (**Plate 37**). The label on one branch of Snake Creek, “Principal Passage to the Everglades,” is indicative of the pre-drainage boat travel.

There was no noticeable ledge or increase in elevation between the Everglades and the Peat Transverse Glades (**Plate 40**). The land surface, formed by 1-3 feet of sawgrass peat on top of sand, extended the same slightly sloped plane of the Everglades. Two to four miles east of the open Everglades, the Peat Transverse Glades typically ended at or enclosed the headwaters of a coastal river. These headwaters included braided rivulets or rapids or both, and likely marked a breakpoint in the slope, with the river channel falling more steeply to the ocean than did the transverse glade.

Two different early observers, a drainage engineer and a landscape ecologist, note free and rapid flow through these rivers draining the Everglades. Similarly, a number of accounts refer to the substantial currents in the coastal rivers. J. O. Wright, formerly supervising drainage engineer at the U.S. Dept. of Agriculture and later Chief Drainage Engineer for the State of Florida, noted that:

> “there are numerous channels [on the east and west coast] through which the surface water flows quite freely from the Everglades, both into the Atlantic Ocean and the Gulf of Mexico. In many places these channels are worn down several feet, but do not extend far beyond the rim into the interior. The water is brought from the margin of the 'Glades in small rivulets to the heads of these streams, which increase in size as they approach their outlets. The difference in elevation between sea level and the source of these streams gives many of them sufficient fall to cut out large and deep channels. The streams on the east coast, beginning at Rockledge and going south, are as follows:
>
> Sebastion River, St. Lucie River, Loxahatchee River, Hillsboro River, Cypress Creek, Middle River, New River, Snake Creek, Arch Creek, Little River, Miami River and Snapper Creek. These streams are shorter, and have more fall per mile than those on the west coast." (Wright 1912, p. 24).

Harshberger (1914) noted the more rapid flow in the eastern rivers, likely because of the shorter, steeper slopes mentioned by Wright:

> “The [natural] drainage of the Everglades is by the short rivers previously mentioned that empty into the Atlantic Ocean. Part of the surplus water of the 'Glades finds its way into the Gulf of Mexico by several short rivers, such as the Harney, Rodgers, Lostmans, Shark and Chatham rivers, but the drainage in this direction must be much more sluggish than through the eastern streams that empty into the Atlantic Ocean. ... The short rivers that flow from the Everglades

> into the Atlantic Ocean are characterized by rapids where they flow from the 'Glades." (Harshberger 1914, p.54-55).

These accounts suggest, but do not conclusively demonstrate the absence of impounded waters upstream from the coastal rivers. Barriers or restrictions to flow that would cause impoundment could have been present either along the western edge of the coastal ridge (Range 41, **Plate 35**), or in the eastern portions of the Peat Transverse Glades at the junctions with the river headwaters. The vegetation, soils and narrative accounts provide the key information suggesting that neither form of impoundment was originally present.

A barrier to flow along the western edge of the ridge would have to have been either a topographic ridge or an area of increased hydraulic resistance, such as a strip of much denser vegetation. Either of these would have been an obvious obstacle to boat travel, yet no obstacle was ever mentioned in narrative accounts. A topographic ridge would have been associated with a soil difference, either sand or bedrock at the surface, yet no such feature was indicated on either the land survey plats or on the soil map.

A barrier to flow at the eastern end of each Peat Transverse Glade would have impounded water within the glade. Such barriers would likely have been noted in the narrative accounts, marked on the surveys or appeared as a feature on the soil map, but again these indications were all absent. Additionally, impoundment at the eastern ends of the Peat Transverse Glades would have raised water levels in each, creating linear reservoirs. The pre-drainage presence of sawgrass vegetation speaks strongly against presence of reservoirs, as sawgrass is not tolerant of long or deeper inundation (Andrews 1957).

Altogether, the available evidence suggests that the parallel, eastwardedly sloped planes of peat surface and water surface maintained essentially the same downward slope while passing eastward from the open Everglades into the Peat Transverse Glades. It seems likely that annually rising and falling water levels shaped the peat soil accumulation within the Peat Transverse Glades to conform to the plane in the open Everglades. This *downward* slope of the peat and water surface planes appears to have been independent, in fact opposite, of the *upward* rise of the land surface of the so-called coastal ridge. From the latitude of the New River (Ft. Lauderdale) south to the Miami River, under pre-drainage conditions this portion of the "ridge" was discontinuous and actually a series of pine islands, separated by the lower lying Peat Transverse Glades or by the short coastal rivers (**Plate 37**). The combined outlow capacity of the gaps between the islands of high ground was apparently sufficient to avoid impoundment of water on the Everglades side of the series of islands.

Outflows through the Marl Transverse Glades

In contrast to the unobstructed, rim-less and continuously flowing Peat Transverse Glades, the Marl Transverse Glades were raised "spillways," receiving water from the Everglades only during the wet season, and then only once water levels reached the upper edge of the Rockland Marl Marsh. The significance of the Marl Transverse Glades for understanding pre-drainage Everglades hydrology lies not in their volumes of outflow, but instead in their role as clear indicators that Everglades waters from Shark Slough and from the Rockland Marl Marsh typically rose high enough each year to flow out over the Marl Transverse Glades elevations. Assuming a level water surface, this provides a strong basis for estimating the typical annual maximum elevation of waters covering Shark Slough and the Rockland Marl Marsh.

Previous studies have not generally distinguished between the Marl and Peat Transverse Glades—perhaps because of their similar shapes and similar sawgrass vegetation. Historical observations, topography and the soils present all suggest that they functioned quite differently. While the Peat Transverse Glades typically remained inundated and maintained several feet of peat soil, the Marl Transverse Glades were only seasonally inundated and supported only marl soils. These differences in hydrology and soils are consistent with the differing slopes of the adjacent Everglades landscapes: The Ridge and Slough landscape sloped *down*, toward the Peat Transverse Glades, whereas the Rockland Marl Marsh slopes *upward* to the Marl Transverse Glades. The Marl Transverse Glades could only fill once water had risen to the upper (eastern) edge of the Rockland Marl Marsh.

Drainage has so drastically lowered water levels, both within the Marl Transverse Glades and within the Everglades, that it is now nearly impossible to imagine waters high enough to overflow through these former Transverse Glades. Name changes in this area help picture the original hydrology. By the 1940s, after years of drainage, the eastern rim of the Everglades basin south of Miami had become known as the "Miami Rock Ridge," suggesting a continuous, dry ridge forming the edge of the Everglades. The original name, “Everglades Keys” (Small 1929 [**ref 369**]; Beard 1938; Davis 1943) was much more evocative of the appearance of these areas during the pre-drainage wet season: a series of keys (islands), bounded both west and east by waters of the Everglades, and separated from each other by water in the elongated sections of the “Everglades in miniature” (Simmons and Ogden 1998), the Marl Transverse Glades.

Under post-drainage conditions, only the occasional high water event or “flood” comes close to reproducing pre-drainage water levels. For example, from a human perspective, the high waters of 1947 constituted a devastating flood, contributing to Congressional approval of the Central and Southern Florida Project for Flood Control and other Purposes. Yet if the boundaries of the flooded area are compared with the pre-drainage boundary of the Everglades (**Figure A.1-5**), they prove to be very similar, suggesting that the perceived “flood” simply returned water levels back to what they typically had been each year under pre-drainage conditions.

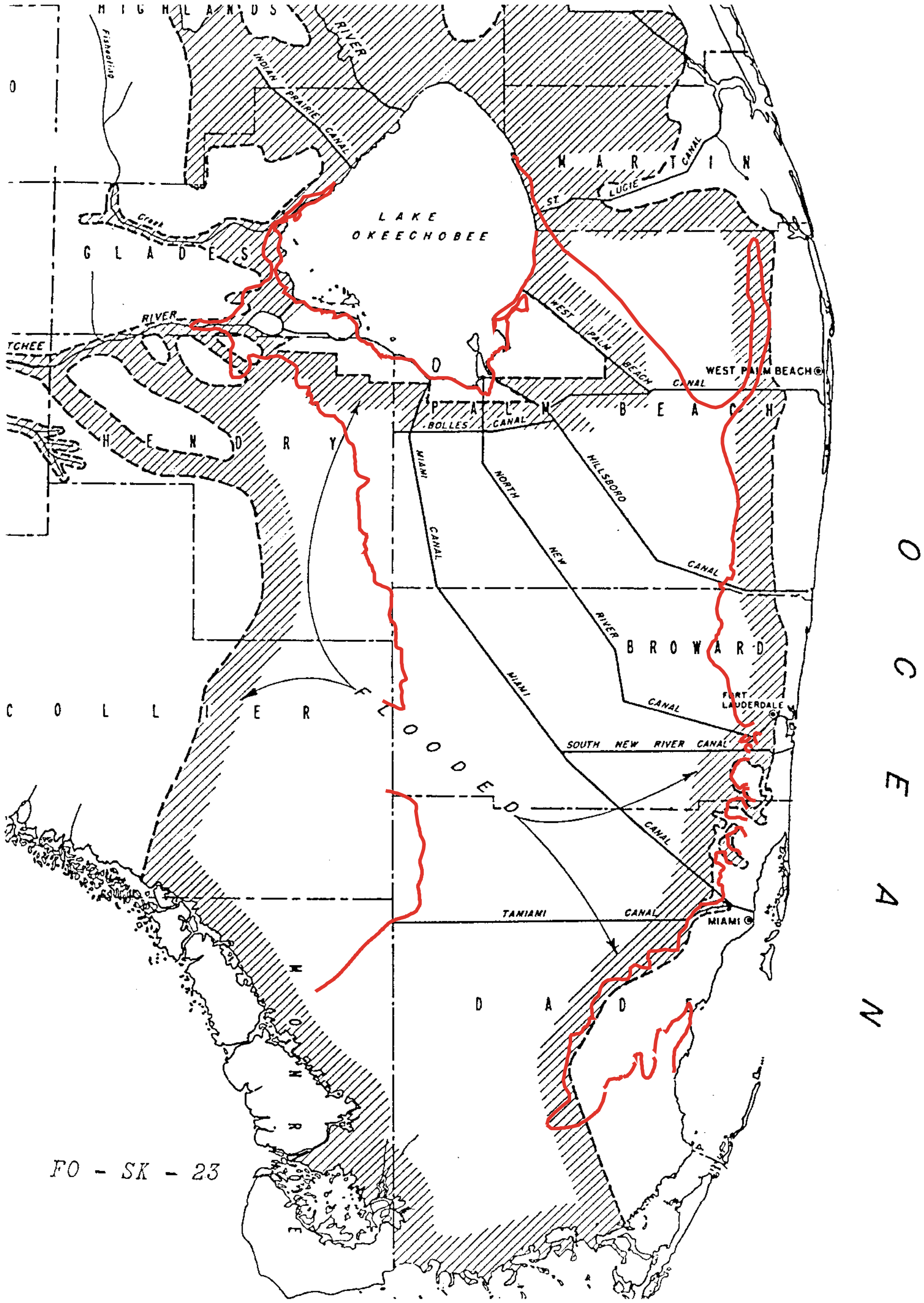


Figure A.1-5 Comparison of extent of the flood of 1947 (U.S. Army COE 1947) with extent of the pre-drainage Everglades (red line). After 70 years of drainage, water again filled the Everglades basin. Note coincidence of southeastern edge of the flood with the high ground of the Atlantic Coastal Ridge and the Everglades Keys.

Figure A.1-5 shows water fully covering the Rockland Marl Marsh, and once again extending up to the pines and pinnacle rock of the Everglades Keys/Miami Rock Ridge, just as described in 1896:

> "At the border of the Everglades the rough surface of the oölite becomes concealed for the most part beneath a mat of grass, and pines grow no further west... In the zone of oscillation of water the grasses change in character from a

> small wiry variety near the pines to saw-grass six feet or more tall, and flags and cane growing in water." (Griswold 1896, p.53)

Although probably too detailed to draw on the map of **Figure A.1-5**, water was most likely flowing eastward through the Marl Transverse Glades during the 1947 flood. Even as late as the early 1960s, and despite expanding drainage, they still flooded seasonally, at least in wet years (Bill Robertson, written pers. comm., 1997).

Like the map of the 1947 flood extent, a map of water table contours measured during a post-drainage "high stage" provides another possible window onto typical pre-drainage water levels in the Everglades Keys/Marl Transverse Glades area. There is no inherent reason that post-drainage high stage should be equivalent to pre-drainage typical stage, but several features of the September 23, 1941 contours suggest that they in fact are indicative of typical pre-drainage end-of-wet season conditions. These are: (1) the similarity of the water table contours to ground surface contours; (2) the strong dissimilarity to the lower "medium stage" contours, and (3) the 9.5 foot elevation of the water table in the Everglades Keys, high enough to be consistent with pre-drainage descriptions of a water table close to the surface (McKay 1847 in Senate Doc 89; Harper 1910 [608]) and in sink holes (Harshberger 1914; Harper 1910 [608]). In contrast, two other features suggest that the September 1941 contours may be a little lower than pre-drainage: the decline in elevation westward toward Shark Slough and the below, rather than above ground water table in the vicinity of the former rapids of the Miami River (elevation approx. 7 feet).

The September 23, 1941 "high stage" contours would appear to be similar to or below pre-drainage water levels. These contours therefore extend the information provided by the 1947 flood map, suggesting that water depths along the border between the Everglades Keys and the Rockland Marl Marsh were about one or two feet above ground surface. It would have been these depths that helped provide water to the Marl Transverse Glades. Depths of one or two feet would be consistent with the presence there of sawgrass, and with the basin topography. In addition to water from the Everglades, local rainfall and groundwater mounding may also have been contributed to the Marl Transverse Glades.

Plate 15 clarifies the relation of present to pre-drainage water depths. It shows two post-drainage cross-sections of water depths, measured at the end of the dry and wet seasons. The upper portion of the plate shows the extent of surface water at both times, relative to the extent of Shark Slough and the flanking Marl Marsh landscapes. At the end of the dry season, surface water was restricted to Shark Slough, with depths there less than one foot, somewhat drier than the pre-drainage Ridge and Slough depths estimated in this study. The greater difference from pre-drainage conditions, about 1.5 feet shallower, occurred at the end of the wet season. Not only was the Shark Slough water depth much reduced, but the width of inundation as well— surface water extended only slightly more than half way up the Rockland Marl Marsh. No water was present at the top of the Rockland Marl Marsh where it bordered the Everglades Keys, and accordingly no water would have been flowing into the Marl Transverse Glades.

At the end of the pre-drainage dry season, about one foot of water remained in the sloughs of Shark Slough, and the surface of most of the Rockland Marl Marsh would have been dry (water table at -0.5 feet at mid-slope). At the end of the pre-drainage wet season, the Rockland Marl Marsh would now be fully covered by surface water, +2 feet at mid-slope, with about one foot at the spillway into the Marl Transverse Glades. Sloughs would have been three feet deep; sawgrass ridges covered by 1.5 feet of water. **Plate 16** suggests that the ground elevation of the spillway into the transverse glades would have been around eight feet above sea level.

Outflows through Taylor Slough

Taylor Slough, while much smaller than Shark Slough, is easily recognizable on satellite imagery (e.g. **Plates 1** and **2**), topographic maps, vegetation maps (e.g. **Plate 4**), and aerial photography (**Plate 21**). It is a topographic low that was and still is distinct from the surrounding Perrine Marl Marsh. Soil studies (Olmsted and Loope 1984; Willard 199x) indicate peat or mixed peat and marl soils versus pre-dominantly marl outside of Taylor Slough. Aerial inspection and photographs confirm the presence of Ridge and Slough landscape patterning, as suggested by **Plate 21**. An 1850 map by surveyors of the northern coast of Florida Bay indicates a sizeable river connecting the interior area (“Everglades”) to Florida Bay. The river bisects the Perrine Marl Marsh into a western portion labeled “Prairies and Hammocks” and an eastern portion labeled “Rocky and Sandy Prairies mixed with Hammocks.” From the position and size, there is little doubt that this is the Taylor River, shown on the Bureau of Topographical Engineers (1856) map, and forming the termination of Taylor Slough.

Topography, landscape patterning visible on aerial photographs, and historical accounts suggest that much of the Rockland Marl Marsh was a collecting area for flows through Taylor Slough. The Everglades Keys to the east and Long Pine Key to the south may have helped direct water rising from Shark Slough toward the low spot between them: west of Camp Jackson and east of Royal Palm Hammock (Paradise Key). These latter two points were well-known, slightly elevated landmarks, separated by the waters of Taylor Slough. The levels and width of inundation appear to have varied considerably here, from as little as ten feet wide and only a foot deep, to four or five feet deep and a mile or more wide:

> “About a mile east of Long Key there is a shallow slough running north and south, which is one of the principal outlets for that end of the Everglades in the rainy season, and is a route frequented by hunters at times when there is not quite enough water for their boats elsewhere in the vicinity. This slough has given previous explorers by the overland route considerable trouble. One botanist whom I know was once wading across it a little ahead of his two companions, in water up to his armpits, when he stepped on a large alligator – or possibly a crocodile (for these ferocious beasts do inhabit the south coast of Florida) – which of course immediately raised a great commotion and almost scared him to death. Another (Dr. Small on his first trip to Long Key) found about six feet of water and mud, not to mention alligators and moccasins, in the same slough, and in order to cross it he had to go back nearly to Camp Jackson and get an old boat which had been abandoned there by the surveyors a year or two before. But where Mr. A. and I crossed it the first time the water was only about a foot deep

(and the channel perhaps ten feet wide), and on the way back we found a place a little farther south where it was practically dry." (Harper 1910, p. 149).

Harper indicates that water levels at the time of his trip (March 25-30, 1910) were very low, perhaps even lower than what would typically be expected late in the dry season.

Taylor Slough is somewhat difficult to classify as either a spillway or a flowway. Relative to Shark Slough, Taylor Slough would clearly be a spillway, since water levels in Shark Slough had to rise above the Rockland Marl Marsh before passing between Camp Jackson and Royal Palm Hammock to descend down Taylor Slough. Most water entering Taylor Slough probably followed this path. However, there is also some indication of a slight channel immediately west of the Everglades Keys, used by hunters for navigation when water levels were too low further west into the Rockland Marl Marsh (Williams 1874-T57 R39; Willoughby 1898; Harper 1910). Although most of the length of this area was close to level, it eventually sloped southward toward the gap between Camp Jackson and Royal Palm Hammock, apparently without raised ledge or obstruction, so this path would classify as a flowway.

Taylor Slough has sometimes been considered the southernmost of the Marl Transverse Glades. The location of the upper portion of Taylor Slough between the last of the Everglades Keys and Long Pine Key, as well as the slight spillway aspect of the Rockland Marl Marsh a little further north and west would reinforce this classification. At the same time, there were important differences which are made visible in the soils and landscape patterning of Taylor Slough. Where the Marl Transverse Glades formed marl soil and grew predominately sawgrass, Taylor Slough formed a mix of marl and peat soils and formed Ridge and Slough microtopography. The correspondingly deeper water depths and longer hydroperiod of Taylor Slough is likely a reflection of a stronger connection to the waters of Shark Slough, that is, of outflows from Shark Slough into Taylor Slough continuing for longer portions of the year. This in turn may be a reflection of a shallower ledge, about one foot between the two Sloughs compared to an approximately two foot ledge to initiate flows into the Marl Transverse Glades.

Outflows through Shark Slough

Shark [River] Slough was the largest single outflow from the Everglades. The land surface above and within Shark Slough sloped continuously downward, to within a few miles of the coast. Near the coast, the Buttonwood Embankment (Craighead 1971) may have formed a slight rise across some portions of Shark Slough, but it was not continuous, being interrupted by the many headwater channels of Harney and Shark Rivers. With a continuous downward slope and no continuous rim or threshold, Shark Slough was a flowway. Water levels and flow rates were therefore controlled by the internal resistance to flow of the vegetation, the slope of the land, and the supply of upstream water. The lack of a continuous dam or ledge at the bottom portion meant that Shark Slough could dry out if upstream flow stopped. Historical quotes indicate that Shark Slough did occasionally become dry:

> "Have known the Glades to be dry around the head of the river [Shark River]." (Roberts in Stewart 1907, p. 39).

However, such observations are rare in the historical record, compared to descriptions of ample surface water:

> "We have plenty of water at present, and go along with a great deal of ease." (Anonymous 1841 [1960]).

> "wad[ing] through mud and water three or four hundred yards, up to our waists..." (Anonymous 1841 [1960]).

The historical record suggests that prior to drainage, dry-downs of Shark Slough probably did not occur more frequently than once every twenty or thirty years. The frequency of such dry-downs would have been determined primarily by the storage capacity of the upstream portions of the Everglades, including perhaps Lake Okeechobee and the Kissimmee Valley; that is, by the capacity of the whole watershed to continue to supply water downstream during one or more dryer than normal years. Within the Everglades itself, this capacity would have been principally a function of the upstream water depths, and the annual range in water depths.

The landscape pattern visible on satellite images and aerial photographs of Shark Slough appears elongated relative to other parts of the Ridge and Slough landscape. Longer, thinner ridges, sloughs and tree islands give a somewhat more streamlined appearance and suggest that flow rates within Shark Slough may have been greater than farther north in this landscape. Faster, streamlined flow would be consistent with funneling of flow from a cross-sectional width of about 20 miles north of Township 54, down to 8-10 miles wide within Shark Slough. Mass balance requires either an increase in water depths or an increase in flow rate, or some combination of both. Direct, comparable measurements of depth are not available, but the apparently similar vegetation suggests that depths were not greatly deeper than elsewhere in the Ridge and Slough landscape, lending further support to the idea that flow rates were probably higher within Shark Slough.

Paired pre-drainage measurements of flow rates within and outside of Shark Slough do not exist. The few available qualitative descriptions of flow in Shark Slough do suggest it was fast flowing, perhaps but not necessarily faster than elsewhere in the Ridge and Slough landscape:

> "Has seen a good current 6 [typed characters unclear: 5?, 26?, 25?l miles north of the head of Shark River. At high water period saw same current throughout Glades." (Graham in Stewart 1907, p. 24).

> "Shark River has a rocky channel and a swift current at its head in the high water period. At low water the tide runs nearly to the head where the channel suddenly disappears into the Glades. At the high water period have traveled by boat 30 miles northeast of the head." (W. A. Roberts in Stewart 1907, p. 39).

Outflows through Lostman's Slough

Very little documentation was found for this area, but satellite imagery suggests that this may have been a minor, secondary outflow from the Ridge and Slough landscape, parallel to the main western outflow, Shark Slough (e.g., **Plates 1** and **2**). Some degree of landscape directionality aligned with the NE-SW axis of Lostman's Slough furthers the impression of secondary outflow (upper left corner of **Plate 15**). Overall reduction of post-drainage Everglades water levels and flows, and construction of Tamiami Trail have likely reduced flows through Lostman's Slough; in contrast, the significant westward compression of flow by the L-67 levees may have increased flows. Too little information is available to make a definitive pre-drainage to post-drainage comparison. If the Jones *et al.* (1948) soil mapping can be assumed representative of pre-drainage soils in this area, then the absence of peat and presence of marl only within Lostman's Slough would suggest that water depths and hence flow volumes were much less than in either Shark Slough or Taylor, both of which included peat and Ridge and Slough patterning.

Outflows as Groundwater

The existence of pre-drainage groundwater outflows from the Everglades seems well-established from numerous observations similar to the following:

> "... The rock [of the Everglades Keys] is usually wet, even in the driest times. In fact, under the limestone ridge there are channels of water running from the Everglades and bubbling out in the form of springs along the shore of Biscayne Bay." (Gifford 1911, p.17).

Many historical accounts refer to submarine springs along the shore of Biscayne Bay (e.g., Romans 1775 [1961]; Sunderman 1950; Griswold 1896; MacGonigle 1896; Willoughby 1898), as do post-drainage studies (e.g., Parker et al. 1955; Kohout 1966; Kohout and Kolipinski 1967; Kohout et al. 1973; and Gaby 1993):

> "Small springs, recognized by the birefringent mixing action of the waters, are reported by local residents to have existed as far as three-quarters of a mile seaward from the shoreline in the Cutler area. Near shore, freshwater springs welled up through the bottom of Biscayne Bay as large boils; one such potable spring just north of the study site is marked by the words 'fresh water' on Coast and Geodetic Survey Navigation Chart No. 166 , published in 1896. The early mariners and spongers customarily lowered kegs to the spring orifice to obtain fresh drinking water." (Kohout and Kolipinski 1967, p.488).

Several early observers (e.g., Mackay 1847; Shaler 1890; Griswold 1896; Dix and MacGonigle 1905) relate these springs to waters originating in the Everglades and passing through the porous rock of the Everglades Keys:

> "...and in the dry season I found that that the course of these currents was, owing to numerous rock basins, in many instances perforated with holes in the bottom like a colander, into which these currents poured and disappeared; and in the pine woods, between the Glades and the Bay of Biscayne [i.e., the ridge formed by the Everglades Keys, most likely in Township 54, Range 41 or 40], may often be heard the rippling sound of running water, and frequently, in the fissures of the rock, it may be seen at from 6 to 8 feet below the general surface of the ground..." (George MacKay, 1847, in Senate Doc. 89, 1911).

The endnotes for the Everglades Keys (Chapter 4) include additional observations suggesting an active groundwater connection between the pre-drainage Everglades and the Atlantic Coast.

As water levels within the Everglades were lowered by drainage, the springs largely disappeared (Ferguson et al. 1947):

> "Springs in Dade County, such as Mangrove Spring at Coconut Grove, Miami Springs, and various bayside springs which were reported to flow in earlier years, no longer flow owing to lowered water tables in the area. Mangrove Spring which supplied water for the United States Fleet at Havana in 1898, was reported to flow at a rate of 100 gallons per minute in 1903." (Kohout and Kolipinsky 1967, p.65).

As was the case for inflows from groundwater into the Everglades, the historical record does not provide enough information to quantify pre-drainage groundwater outflows. The record does clearly document their existence and their reduction or elimination after drainage began.

Internal Flows

The term "sheet flow"--widely used in discussions of Everglades hydrology--is typically applied to all landscapes of the Everglades. Depth to width ratios on the order of 1:100,000 (40 miles wide vs 2 feet deep) gives some idea of the extreme breadth and thinness of this flowing "sheet," as well as further credence to the term sheet flow. Nevertheless, we suggest here that differences in flow regimes between landscapes were originally strong and important enough to merit separate names. We suggest that "sheet flow" be reserved for the Sawgrass Plains and the Marl Marshes, and propose "slough flow" for the Ridge and Slough landscape.

To better understand the differences in flow regime it is helpful to distinguish between three different aspects of Everglades land surface conditions: slope, levelness and microtopography (**Table A.1-4**). Slope is defined here in the ordinary sense as relative change in elevation along the upstream-downstream axis. Levelness refers to the presence or absence of curvature in transverse direction, i.e., in the direction perpendicular to the downslope axis. The distinction between level and "flat" is one of scale; a landscape can be regionally level, but microtopographically uneven or bumpy. The conditions can occur in any combination. For example, using the definitions given in **Table A.1-4**, an Everglades landscape could be simultaneously "sloped," "level" and "uneven," or horizontal, convex and flat, despite the apparent inconsistencies.

Table A.1-4 Classification criteria for Everglades landscape surfaces.

Aspect	Possible Conditions			Axis	Scale
Slope	horizontal	vs.	sloped	Downstream	Regional
Levelness	Level	vs.	concave, convex, rolling, etc.	Transverse	Regional
Microtopography	present ("uneven")	vs.	absent ("flat")	--	Local

Table A.1-5 applies these criteria to the main landscapes, as well as noting whether the landscape was a patterned peatland (Wright et al. 1992), and whether the patterning was directional.

Table A.1-5 Classification of Everglades Landscapes.

Landscape	Slope	Levelness	Microtopo.	Substrate	Patterned Peatland	Directional Patterning
Custard Apple S.	Horiz.(?)	Level	Flat	Peat/Silt	No	No
Sawgrass Plains	Sloped	Convex to level	Flat	Peat	No	No
Ridge & Slough	Sloped	Slightly convex	Uneven	Peat	Yes	Yes
Marl Marshes	Sloped	Level	Uneven	Marl, Rock, Peat	No	No

Not surprisingly, all the landscapes but one were sloped; this is noted simply to clarify the distinction with levelness. In the transverse direction, the convexity introduced into the Sawgrass Plains by the approximately semi-circular shoreline of Lake Okeechobee appears to have dissipated (become close to level) with increasing distance from the lake. The slight convexity of the central portion of the Ridge and Slough landscape will be discussed further in the sections on Flow Directions and on Topography.

The key distinction recorded in **Table A.1-5** is that between the Sawgrass Plains and the Ridge and Slough landscape. Although both were formed on a peat substrate, the former was an unpatterned, nondirectional peatland, whereas the latter was a patterned and clearly directional peatland.

Sheet flow in the Sawgrass Plains

The Sawgrass Plains formed a remarkably uniform stand of dense, impenetrable sawgrass (Chapter 4). To the degree that other species were present, they appear to have been intermixed within the sawgrass stand, rather than forming distinct patches. The predominance of sawgrass suggests that water depths must have been relatively uniform across the landscape. If microtopography had been present, creating areas of different water depths, this would have been reflected in the vegetation: broad-leafed aquatics and emergents in the deeper areas; and shrubs in the shallower ones. A thin and apparently remarkably uniform layer of surface water flowed across the Sawgrass Plains – “sheet flow” is a highly appropriate description here.

Slough flow in the Ridge and Slough landscape

While sheet flow is an appropriate term for water movement in the Sawgrass Plains, it is much less so for water movement through the pre-drainage Ridge and Slough landscape. At the regional scale, it is true that similar water movement occurred in similar sloughs throughout the length and breadth of the Ridge and Slough landscape. At the local scale, however, flow characteristics associated with the three main landscape components--ridges, sloughs and tree islands--almost certainly differed.

Tree islands, especially the tails but occasionally also the heads were at times covered with water (e.g., explorers reporting no dry place to camp), but the combination of shallow depths and dense vegetation would have kept flow rates much lower than those present in pre-drainage sloughs. Similarly, the peat surface of sawgrass ridges was typically 1.5 feet (45 cm) higher than the bottoms of adjacent sloughs. As a result, part of the year surface water was simply absent from the ridges; obviously flow was absent as well. Even when water levels again rose to cover the ridges, the flow rates were likely much reduced from those in sloughs, due to the shallower depths and the density of sawgrass stems.

Use of the term "slough flow" is therefore proposed to emphasize that within the Ridge and Slough landscape, directional microtopography and the correspondingly directional pattern of plant growth (**Plates 28, 30** and **32**) meant that neither resistance to flow nor water depth were uniform over the landscape. Water flow most likely occurred preferentially through the generally continuous network of sloughs. Sloughs appear to have covered somewhat more than half of the Ridge and Slough landscape. Given the differences in resistance to flow, as a first approximation it is reasonable to assume that most of the water flow passed through sloughs, that is, through the larger half of the landscape cross-section (**Plate 14**).

Physically, chemically and biologically this creates a very different hydrologic environment from the much more uniform sheet flow of the Sawgrass Plains. An analogy can be drawn to water flow through structured clay soils or other bimodally porous media, such as a sponge with two distinct populations of pores, smaller ones and larger ones. In such cases, the water held within the larger pores, corresponding to sloughs, moves convectively through the sponge/porous media whereas the water of the fine pores (water on top of ridges) moves only very little by convection. Water in the larger more pores is considered mobile, in the smaller pores, immobile, and the two types exchange dissolved constituents only by the much slower process of diffusion. Within the Ridge and Slough landscape, the surface water on the ridges likely was not completely immobile, but almost certainly was slower moving, differentiating ridge from slough water and creating the potential for exchange processes between the two. Additionally, there was likely a differentiation of habitats and seasonal exchange of organisms between them. All these features reinforce the need for distinguishing uniform sheet flow from the bimodally differentiated slough flow.

Finally, a key distinction between the sheet flow of the Sawgrass Plains and the slough flow of the Ridge and Slough landscape is that resistance to flow in the Sawgrass Plains was isotropic; the resistance was the same in all directions. This was certainly not the case in the Ridge and Slough landscape, where the resistance to flow in the direction parallel to the ridges and sloughs was much less than the resistance in the transverse direction, i.e., the resistance was anisotropic. Under pre-drainage conditions, the direction of least resistance appears to have been aligned with the downslope direction, so the effects of anisotropic resistance to flow may have been primarily local (e.g., elongating the dissipation of a local storm-induced bulge in the hydraulic head). Later, as drainage and soil subsidence altered the landslope, newly arisen differences between the downslope direction and the microtopographic direction of least resistance may have become more important.

Flow Directions

A number of sources of information are available for estimating the pre-drainage directions of water flow in the Everglades. The sources used here are: (1) pre-drainage and early post-drainage point observations of flow direction and/or landscape directionality that could be georeferenced to within a radius small relative to the size of the landscape; (2) narrative descriptions of general flow directions that refer to areas rather than specific points; (3) other studies of flow patterns by informed observers; (4) directionality of the long, linear ridges and sloughs of the patterned Ridge and Slough peatland; and (5) directionality of the lenticular tree islands of the Ridge and Slough landscape.

Fortunately for this effort, the Ridge and Slough landscape was a patterned peatland, and the patterning was strongly directional. The patterning and directionality were apparently so obvious that even without the benefit of an aerial perspective, many early observers remarked upon it. Several also noted that the direction of flow, the orientation of the landscape elements and the downslope direction were all the same (e.g., Dix and MacGonigle 1905; Harshberger 1914; Baldwin and Hawker 1915; Parker et al. 1955):

> "The 'grain' of the Everglades, ... is believed to be developed entirely on fresh-water peat and muck and apparently does not reflect an underlying pattern of marine bars. It merely represents a drainage pattern produced on a very gentle sloping surface of organic deposits. The 'grain' is composed of tree islands and swales [sloughs] that trend parallel to the regional slope, just as one would expect in an area of consequent drainage." (Parker et al. 1955, p. 152).

From these observations we assume that pre-drainage landscape directionality is equivalent to flow directionality. We also assume that because regional slope appears to have been the principal driver of flow direction (or in other words, that the plane of the water surface was parallel to the ground surface), flow directions did not generally change over the course of the year, i.e., "consequent drainage." Regional flow models generally support this assumption.

Figure A.1-7 shows the results of mapping directionality of ridges and sloughs using a 2 mile by 2 mile grid overlain on index sheets of the earliest comprehensive set of aerial photos (USDA-SCS 1940). A ruler was visually aligned parallel to the ridge and slough grain visible within each cell, while trying to ignore orientations of the tree islands. The distinction was not absolute, but the 2 x 2 mile cell size included enough grain and few enough tree islands to achieve reasonable separation. The arrows in **Figure A.1-7** show a spatially consistent pattern with a strong spatial correlation between cells. Within the Everglades, there are few abrupt changes in directionality. Instead one has the impression of a field of gradually bending, parallel paths.

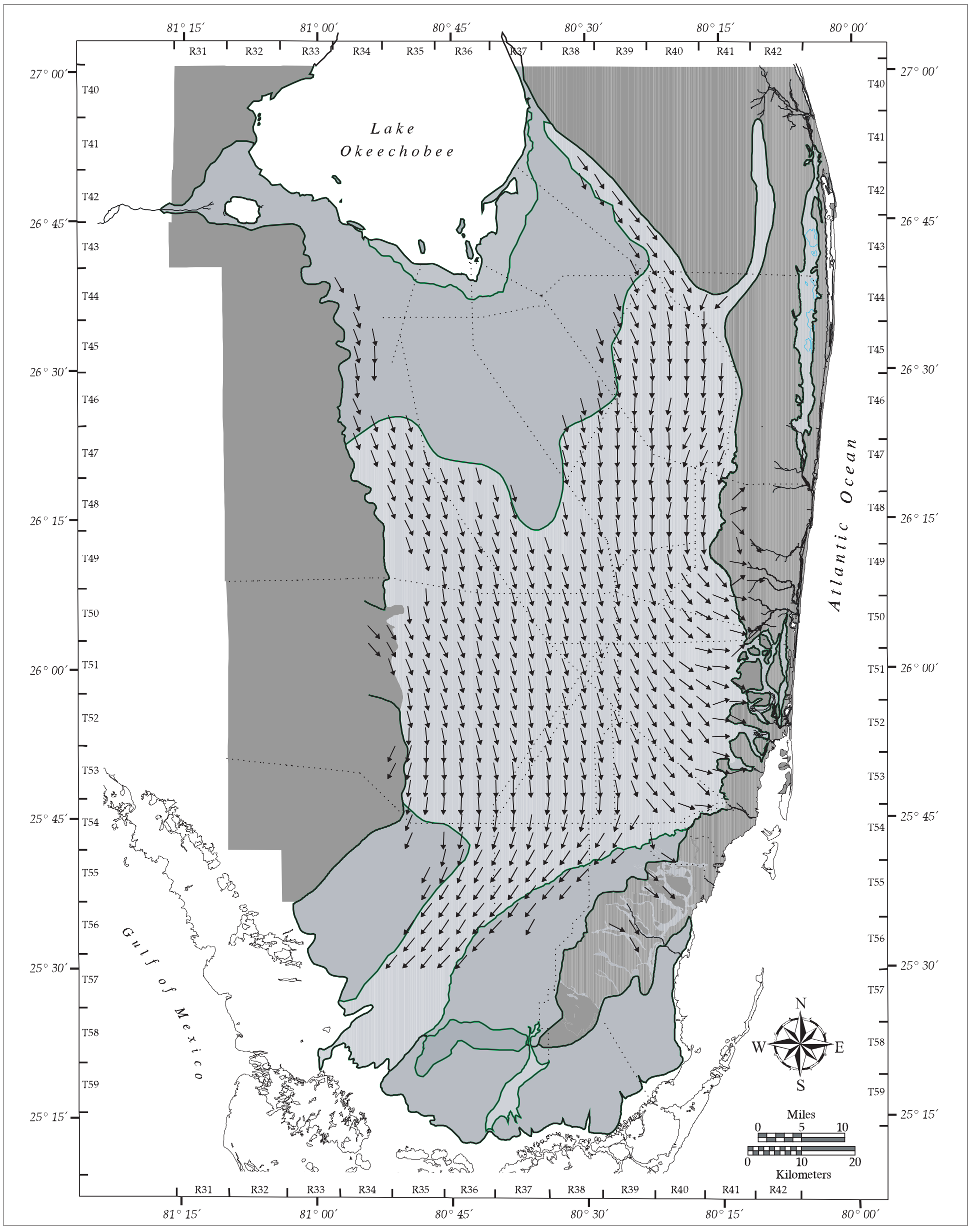


Figure A.1-**1** Landscape directionality determined by angular measurement of the "grain" formed by parallel sawgrass ridges and sloughs, based on 1940 aerial photographs (see text). Arrowheads point in downslope direction.

Figure A.1-8 maps individual observations of directions of water flow and landscape orientation made between 1827 and 1917, and tabulated in **Appendix O [not provided]**. The following representative quote, made during the dry season (March) of 1884, refers to what is now western Water Conservation Area 3A. The surveyor indicated that the flow direction was likely to be the same during the wet season as well, an expected constancy:

> "The ["12-18 inches" of] water running in the glades [sloughs] is pure, and tends toward S.E. There is every appearance that the water runs S.E. in the wet season." (Sollie 1884-T51 R35).

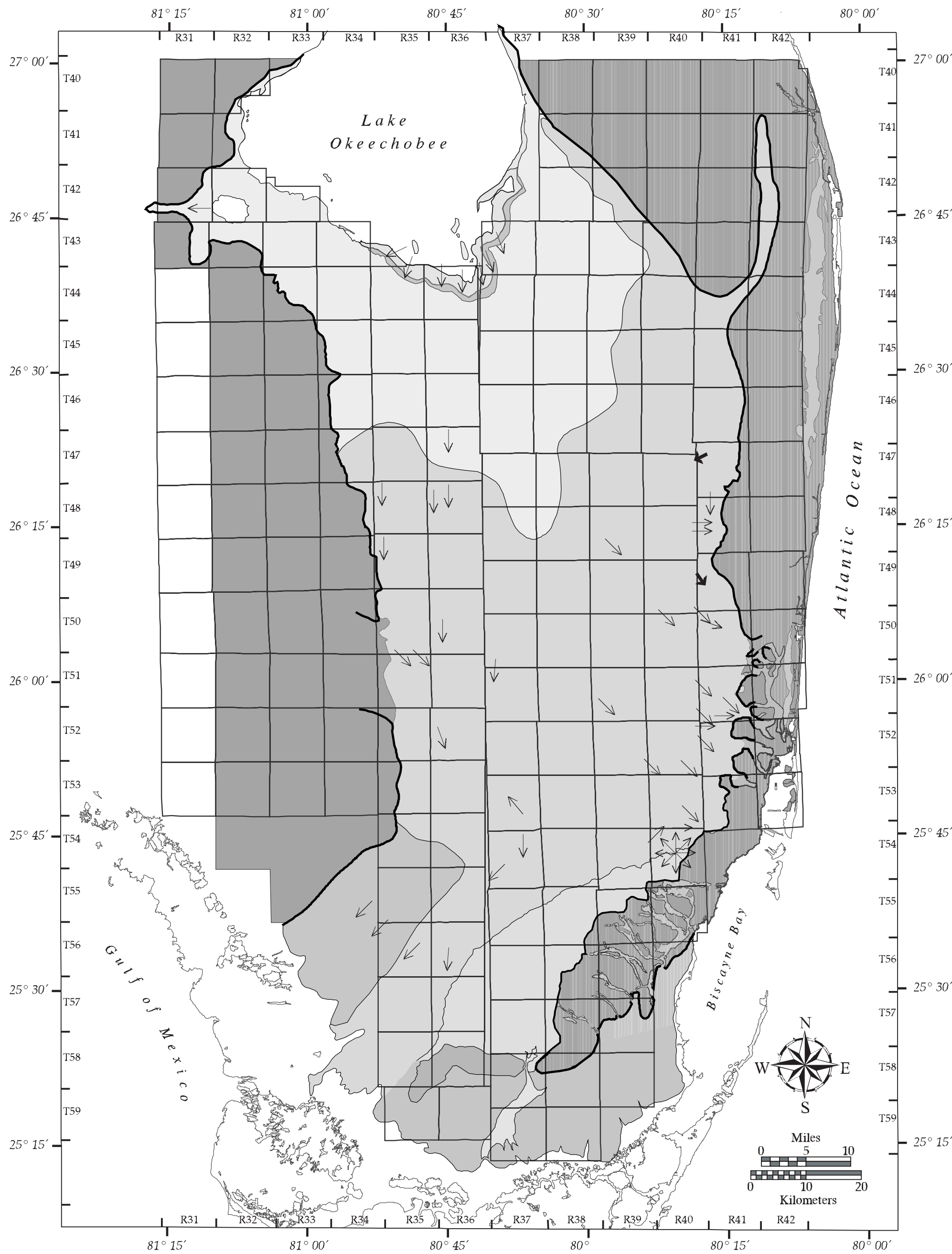


Figure A.1-8 shows directionality toward the southeast within the eastern half of the Everglades, as described qualitatively by many observers. Further west, the directionality appears generally southward, then mostly southwestward, also consistent with narrative accounts.

Figure A.1-4, drawn by Gerald Parker as part of an extensive, thorough study of the Everglades, is certainly attributable to an informed observer, but not to a pre-drainage one (Parker's studies began around 1940). There is therefore some question as to whether his "directions of surficial drainage" refer to observed post-drainage, or estimated pre-drainage conditions. The figure also includes arrows in areas already drained by the 1940's, further suggesting that it was an estimate of pre-drainage conditions. We note that the directionality shown on **Figure A.1-4** resembles that noted by historical observers, as shown in **Figure A.1-8**

Figures A.1-4, **A.1-7** and **A.1-8**, as well as the tree island directionality visible in **Plates 17** and **18** all show very similar patterns. The strong spatial correlation and the gradually bending directions suggest a vast, nearly level surface with gentle turns arising from slight convexity or concavity. This is consistent with formation of the Everglades from accumulation of peat soil, leveled by influence of the water surface.

A Conceptual Model of Pre-drainage Everglades Hydrology

This conceptual model attempts to capture the hydrology of the Everglades as it was during the 1800's, prior to anthropogenic drainage. It might apply as well to the preceding century or two, but makes no attempt to describe the full 5,000 year period of peat accumulation.

The pre-drainage Everglades was an enormous pulsed wetland. An annual rise and fall in water levels occurred over an area of more than 1.2 million hectares (4,600 square miles), driven by the seasonal variation in three main inflows: direct rainfall, inflows from Lake Okeechobee, and inflows from Big Cypress. Outflows from Lake Okeechobee into the Everglades continued for 8 to 10 months of most years. The duration of inflows from Big Cypress are uncertain.

Not only did water levels pulse up and down over time, but within the Ridge and Slough landscape, the presence of microtopography meant that when traversing the landscape, rises and falls in the ground surface elevation would be encountered as well. Thus for this largest landscape of the Everglades, two sets of elevation means can be defined, a spatial one for ground surface and a temporal one for water surface. Additionally, typical ranges can be defined around these means. Comparison of the means and ranges helps understand the pre-drainage Everglades. The ranges were very similar, 2-3 feet for water levels and 2-4 feet for ground surface (2 feet from slough bottom to ridge top; roughly 3-4 feet to tree island surface). The difference between the means, 1-2 feet, was also of the same magnitude.

Together these numbers mean that water levels typically oscillated from a little above slough bottom to around tree island surface, creating over the course of the year large variations in the fraction of water-covered land. Although this might seem no more than a roundabout, numerical way to state that the Everglades was a wetland, we believe these numbers in fact capture much of what made the pre-drainage Everglades unusual.

Considering the implications of slight deviations from the numbers helps explain. With the same ranges, if the mean water stage had been four to six feet higher, the ridges, sloughs and tree islands would all have been covered; the Everglades would simply have been an enormous lake. The two foot annual rise and fall would then have been of little consequence: a five foot vs. a seven foot deep lake. In the opposite direction, if the mean water table had been six feet lower, all of the Everglades would have been permanently dry land, and not a wetland at all. Similarly, even if the pre-drainage mean water elevation had been the same, but the annual range had been greater, say three to four feet instead of the actual two, this would have eliminated both the year-round aquatic and the year-round terrestrial habitats, very likely resulting in a much harsher, less hospitable environment.

The uniqueness of the Everglades as a partly terrestrial, partly aquatic wetland was therefore created by the particular combination of factors that together kept water stages fluctuating right around the average ground surface elevation. The uniqueness is further accentuated by the fact that the Everglades was sloped, so that all these relations were dynamic; permanently in a state of non-equilibrium. The basin was continually draining out to the south and periodically re-filling from the north. Without the annual pulses of new water during each successive wet season, the Everglades would naturally have drained dry. The average depth of water was therefore determined by a critical balance of rates: rates of inflow, of outflow, and of overland flow down the landscape. Parameters determining inflows and the rise of water levels include the duration of the wet season, the annual rainfall rate, and the annual volume of outflows from Lake Okeechobee and Big Cypress. Parameters determining outflows and the fall of water levels include the slope of the land surface, the hydraulic resistance to flow due to vegetation and to surface microtopography, and the rate of evapotranspiration. It was the particular combination of all these rates together that sustained what we know as the Everglades.

It appears likely that both positive and negative feedback mechanisms were present, particularly among flow rates, depths of water, vegetation growth, and plant-based hydraulic resistance to flow. Similarly, it seems likely that there were feedbacks involving the formation and persistence of the peat microtopography.

The regular patterns of plant and soil distribution that characterize the Ridge and Slough landscape reinforce the impression that the soils, plants and hydrology mutually influenced each other. The strongly directional pattern and the regular dimensions of the ridges and sloughs suggest that the processes that controlled this landscape were not random. The parallel network of sloughs, repeated across the full width of the landscape, was likely the result of the unique combination of flows, slopes, and hydraulic resistances. Both lower energy, continuous flows and higher energy, infrequent flows likely played a role.

Inflows to the Everglades from Lake Okeechobee formed a critical part of the timing and levels of water in the system. We note that long stretches of the southern shore of Lake Okeechobee were bordered directly by the Sawgrass Plains and Custard Apple Swamp landscapes. Ground levels in both areas were apparently very similar such that the entire 70 miles of southern shoreline overflowed into the Everglades. Both vegetation types were formed on deep organic soils. These soils, in fact, formed a natural plug or dam that held water within Lake Okeechobee. The water surface of the lake extended smoothly into the adjacent Everglades, and water flowed southward as long as the lake level was above ground surface. Lake outflows appear to have persisted throughout much of the year, likely even after the end of the wet season, though at decreasing rates as the water level approached ground surface.

One way to consider pre-drainage Everglades topography is by following two imaginary flow paths, one beginning along the southeastern border of Lake Okeechobee, the other along the southwestern border. Both flow paths extended through the Sawgrass Plains, southeastward and in parallel. Further south, within the Ridge and Slough landscape, the two flow lines eventually diverged. The western one continued south and then southwest, finally ending at Whitewater Bay. The eastern flow path continued south and then southeast, finally dividing into the multiple Peat Transverse Glades and short rivers that breached the coastal ridge. Both flow paths passed through two large peat landscapes, first traversing unbroken sawgrass and then, further south, a mixture of sloughs, sawgrass ridges and tree islands. Due probably to the gradual slope, and the impedance to flow provided by the vegetation, water depths within a given landscape were approximately the same along that portion of the flow path. The landscapes were very uniform, so that water depths across the peat-based landscapes in the transverse (cross flow) direction were similar throughout. Canal surveys from 1913 (FEEC 1914) suggest that there were no obvious breaks in the slope of the land surface along either flow path. These canal surveys, the peat patterning and the pre-drainage vegetation together suggest that along each flow path, the pre-drainage water surface formed a sloped plane parallel to the sloped ground surface. This parallel configuration appears to have been largely preserved despite the annual rise and fall in water levels. The maintenance of a parallel configuration would imply that flow directions would be the same as the downslope land surface directions, and also that flow directions would not vary much during the course of the seasonal rise and fall. The concept of parallel water and ground surface planes applies in the downstream direction of the two flow lines. Laterally, in the latitude of Township 54, where the two flow paths diverged, the plane would actually have been slightly convex, mirroring the slight convexity of the land surface.

An exception to the parallel planes of water and ground surface may have been present in the lower reaches of Shark Slough. Here aerial observations made in the 1960's and 1970's suggest that then, and presumably also under pre-drainage conditions, there may have been some degree of natural impoundment that held water back slightly, creating a wedge of water.

A curious and unexplained geomorphological aspect of the Everglades is the simultaneous presence of two different peat-based landscapes – the unbroken Sawgrass Plains and the microtopographically varied Ridge and Slough landscape – with no apparent reason for the differentiation. No obvious break in soil type, soil thickness or slope is associated with the border between the two landscapes. One possible explanation for the differentiation might be that the water surface and ground surface planes were in fact not perfectly parallel, instead very slightly wedged with the downstream water deeper. If present, a wedge configuration could differentiate the upstream from downstream landscapes by the timing and spatial pattern of soil drying. A wedge-shaped relation between ground and water planes would suggest that during the dry season, after outflows from Lake Okeechobee ceased, a “drying front” would progress southward through the Sawgrass Plains. Southward movement would be rapidly reversed at the onset of the wet season. Under such a scenario, the interface between Sawgrass Plains and the Ridge and Slough landscape might correspond to the average southerly reach of the drying front. However, this and any other hypotheses would need to be reconciled with the contradictory observation that sawgrass ridges in the Ridge and Slough landscape dried to a similar extent, and presumably at a similar time, as did the Sawgrass Plains, and that within sawgrass areas, water depths were similar in both landscapes.

Considering the pre-drainage Everglades in this way suggests that the slow annual “pulsing” can be thought of as the rising and falling of a water surface parallel to the slightly sloped plane of the Everglades land surface. This impression appears to be consistent with other pre-drainage information, for instance with the observed uniformity of vegetation and similarity of water depths across the landscape at a given time of year.

The rise and fall of the water surface plane raises several additional questions. How often did the water surface decline to, or fall below, the land surface? How did the sloughs relate to the water and land surfaces? The bottoms of the sloughs were approximately 1.5 feet (45 cm) lower than the ridge surfaces. On average, the water surface appears to have descended to an annual minimum of about 0.5 feet (15 cm) below the surface of the sawgrass. At that point, the water surface was still about one foot (30 cm) above the bottom of the sloughs. This situation would be consistent with early descriptions of the Everglades as half land and half lake at the end of the dry season. The soil of the sawgrass ridges would have been exposed (“land”), while the sloughs would still have contained a foot of water (“lake”).

Deviations from long term average weather conditions during any given year would naturally cause corresponding deviations from the long term average water depths. The pre-drainage occurrence of periods when the sloughs dried completely would be related to the return frequency of drought conditions sufficiently extreme to remove an additional one foot of water from the normal, end of dry season depth of one foot. The absence, so far, of evidence of either widespread ash layers within sloughs, or of multiple ash layers within soil cores, suggests that complete drying over large areas, with consequent widespread muck fires, were very rare events. After man-made drainage lowered water levels, such muck (peat) fires definitely did occur, destroying as much several feet of soil over large areas.

Ecologically, there was an important difference between the Sawgrass Plains and the Ridge and Slough landscapes. The almost flat surface of the Sawgrass Plains appears to have provided very few aquatic refugia, since most of this landscape became dry during the annual descent of the water level below ground surface. In contrast, the sloughs, which were 1.5 feet lower than the ridges, still contained substantial water at the end of the typical dry season. This relationship between land elevations and water levels also had hydrologic implications. Surface outflows from the Sawgrass Plains obviously ceased for several months each year as water levels dropped below the surface. (Some southward seepage of pore water from the peats of the Sawgrass Plains and the sawgrass ridges may have continued after surface flows had ceased, helping sustain water levels in the sloughs.)

In contrast to the Sawgrass Plains, surface outflows from the Ridge and Slough landscape very likely continued year-round (during typical years), as surface water was still present within sloughs, even during the dry part of the year. This is consistent with early observations that the Atlantic Coastal rivers, fed by the Ridge and Slough landscape, flowed year-round.

The concept of parallel planes of surface water and ground surface is proposed to explain the formation and maintenance of peat-based landscapes in the Everglades, where the ground surface has likely evolved in equilibrium with water levels. The concept of parallel land and water surfaces clearly did not apply in the same way to the Marl Marsh landscapes. In these flanking areas, the ground surface was much more strongly influenced by bedrock slopes, and land surfaces that sloped upward with distance away from Shark Slough. As a result, annual inundation and drying of the Ochopee and Rockland Marl Marshes very likely occurred as lateral fronts of water that expanded out from Shark Slough during wet periods and later contracted back into the slough as water levels declined. This general expanding and contracting cycle would have been partially masked by the effects of direct rainfall.

The important distinction between the Peat Transverse Glades and the Marl Transverse Glades relates to the differing geometry of the contributing landscapes. The Marl Transverse Glades were connected to the upslope edge of the Rockland Marl Marsh. Outflows through the Marl Transverse Glades therefore occurred only when water levels rose sufficiently during the wet season to cover the Rockland Marl Marsh. While it is clear that water from the Everglades flowed through the Marl Transverse Glades regularly, it is also clear that these glades were often dry during a substantial portion of each year.

Taylor Slough appears to have behaved somewhat similarly, but had a lower threshold elevation and therefore was connected to waters of Shark Slough and the Rockland Marl Marsh for a longer part of each year. The mixed presence of peat and marl soils, and the pattern of ridges and sloughs indicate that Taylor Slough was much wetter than the Marl Transverse Glades. The topography of the Taylor Slough area likely contributed to its development as a separate portion of the Ridge and Slough landscape.

In contrast to the Marl Transverse Glades, the Peat Transverse Glades appear to have been simply a downslope extension of the Ridge and Slough landscape. The soils, vegetation, observations of pre-drainage water levels, and accounts of military road building, all suggest that the Peat Transverse Glades typically contained surface water throughout most years. This would be consistent with the observation that the contributing Ridge and Slough landscape also contained surface water throughout most years, as well as with the observation that year-round discharges occurred from the Atlantic Coastal rivers that were fed by, or bordered, the Peat Transverse Glades.

Summary

The pre-drainage Everglades was hydrologically unique due to its particular combination of geometry and climate. The basin topography allowed the accumulation of an enormous body of peat soil, which in turn allowed the formation of a vast and exceedingly flat ground surface. The slight slope of the basin kept the accumulating peat surface slightly tipped from horizontal; three inches to the mile (5 cm/km). This was just enough to create wetlands based on flowing, rather than static water conditions. Some combination of forces and phenomena, likely including the balance between the energy of the flows and the structural coherence of the peat, prevented formation of either a central drainage channel or a dendritic drainage pattern.

These flows however, were sufficient to create and/or maintain systematic microtopographic relief, making a large portion of the Everglades a patterned peatland, and creating a multicomponent landscape with sustained elevation differences. The apparently stable elevation differences between sloughs, sawgrass ridges and tree islands were sufficient to create thousands of semi-terrestrial areas surrounded by persistent wetlands. The absence of a central or dendritic drainage pattern meant that water flow was distributed, apparently very evenly, among hundreds of similarly-sized sloughs, spreading the flow field across the full 40 mile (60 km) width of the landscape. The resulting pattern bears considerable resemblance to the anabranching rivers of Australia, although there the flow energies appear to be considerably greater, the ridges are formed of mineral sediments, and the width of the sytem, whether measured in number of repeated slough/ridge pairs or in absolute distance, is much smaller.

The slope and flow meant that the Everglades was never in hydrologic equilibrium, but instead continually draining. The strongly seasonal rainfall distribution made the Everglades a pulsed system, with rainfall exceeding drainage during the wet season, each year reversing the declining water depths of the dry season. As a sloped system, it would have been possible that natural runoff had completely removed all surface water for months of each year, resulting in an ecologically very different environment. Instead, the balance between rates of inflow and rates of outflow was such that each year's rainy season typically arrived just before the system had completely dried out. Thus water depths within sloughs throughout the Ridge and Slough landscape typically rose and fell each year from a low of about one foot (30 cm) to a high of about three feet (90 cm); an environment that could support long-lived aquatic organisms. Sawgrass ridges were just enough higher to have been semi-aquatic—i.e., without surface water during part of each (typical) year. The annual cycle of wetting and drying on ridges may have been chemically and biologically important, releasing a nutrient pulse as the soil reflooded during the wet season, and concentrating populations of small aquatic organisms into sloughs during the dry season. Tree island peat surfaces were high enough to permit woody vegetation, and low enough to derive dry season water from surrounding sloughs.

In contrast to the peat-based majority of the Everglades, the flanking Marl Marshes apparently typically dried below ground surface each year, leading to a more diverse flora. Survival of longer-lived fauna appears to have been supported by aquatic refugia within the extremely irregular and porous limestone bedrock, and by recolonization during annual rise and lateral expansion of waters from Shark Slough.

Altogether, the particular combination of climate, geometry, peat and vegetation of the Everglades created a “region of mystery” (Dix 1905) that in the words of Buckingham Smith (1848) was “in some respects the most remarkable on this continent,” where the water was “pure and limpid and almost imperceptibly moves, not in partial currents, but, as it seems, in a mass, silently and slowly to the southward,” and where it annually rose and fell to create a “region that [was] not exactly land, and… not exactly water” (Dix 1905).

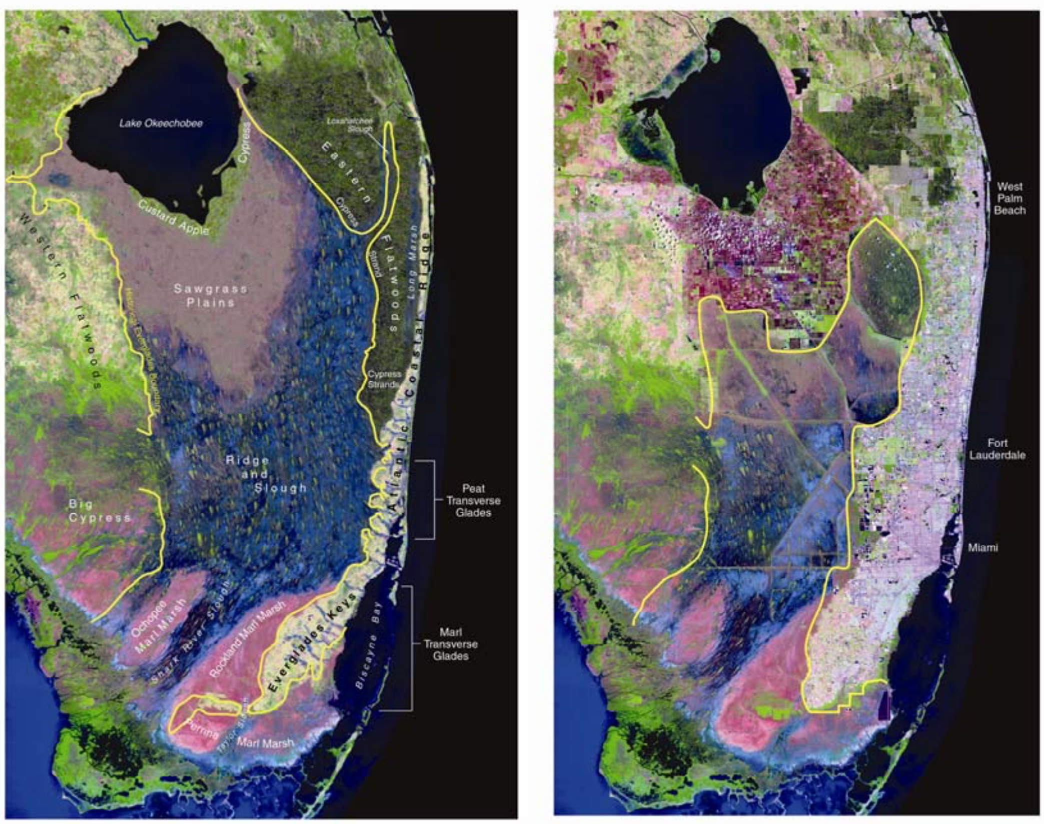


Plate 1. Reconstructed (left, circa 1850) and current (right, 1994) satellite images of the Everglades. Yellow line is border of the pre-canal drainage Everglades (left) and of the remaining Everglades (right).

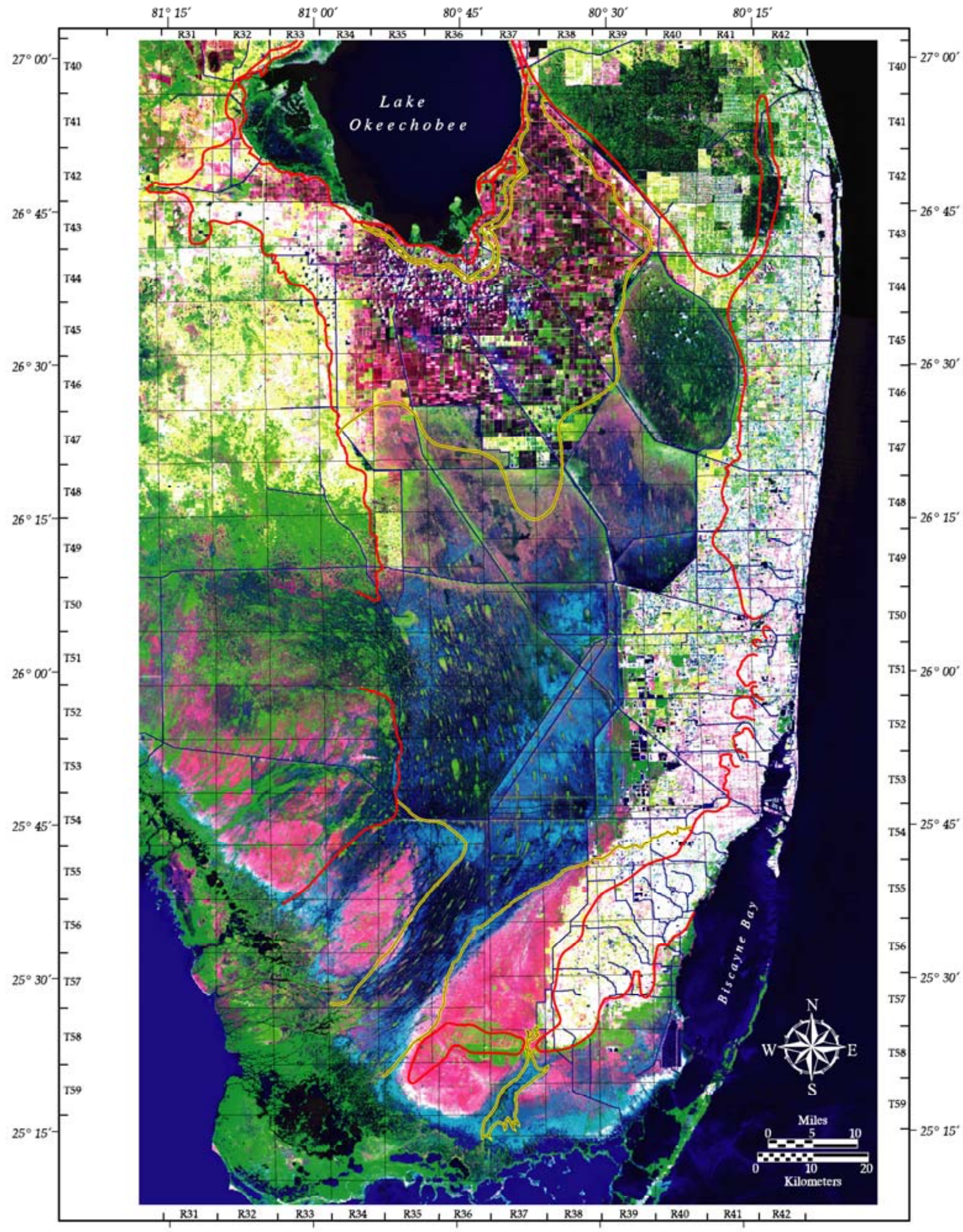


Plate 2. Satellite image of south Florida, 1 April, 1994. Overlays: outside border (red), and interior landscapes (yellow) of the pre-canal drainage Everglades; Township Range grid, and 1990s canals. (See also Fig. 1.1).

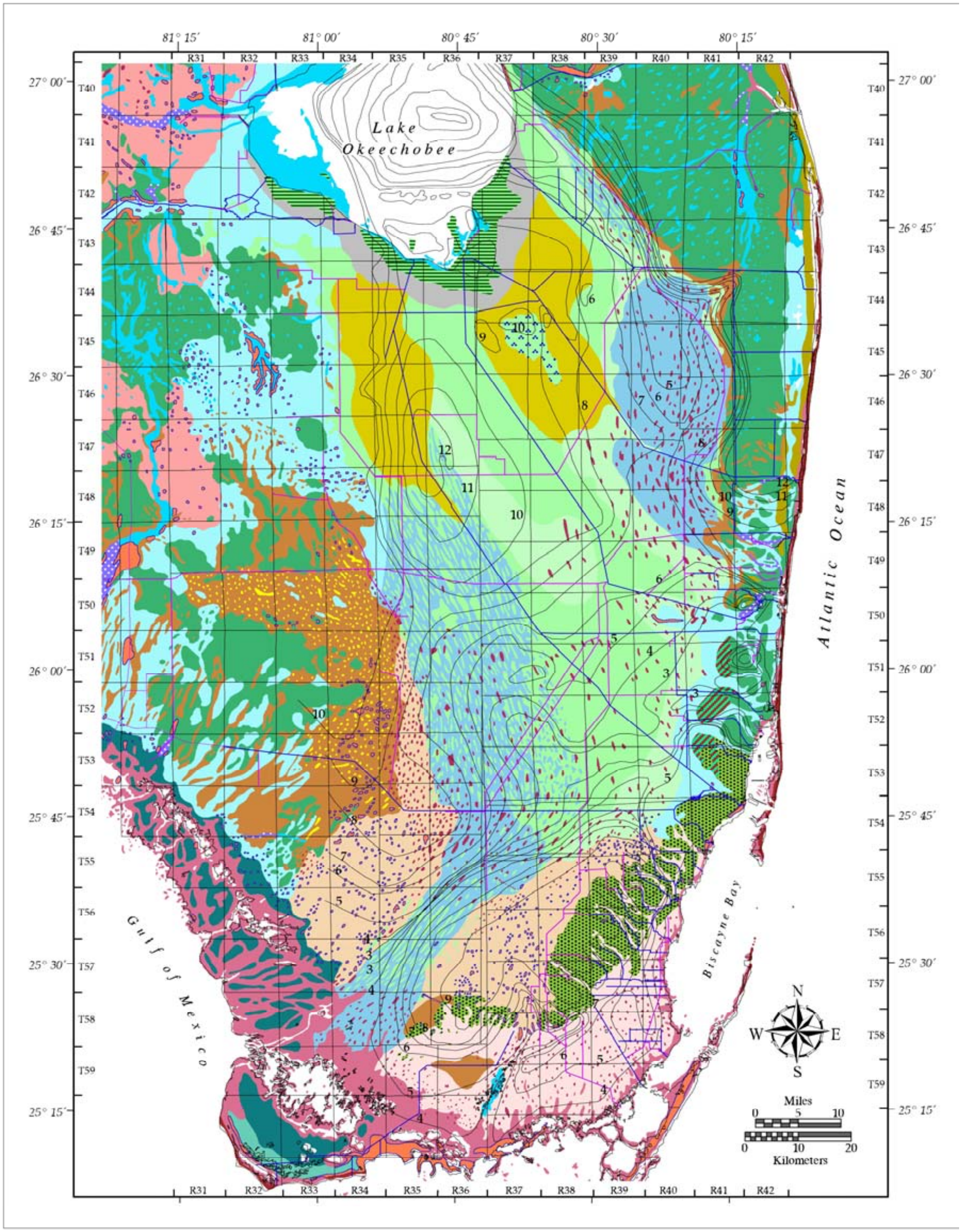

Lake Okeechobee
Gulf of Mexico
Atlantic Ocean
Biscayne Bay
Miles
Kilometers

Plate 4

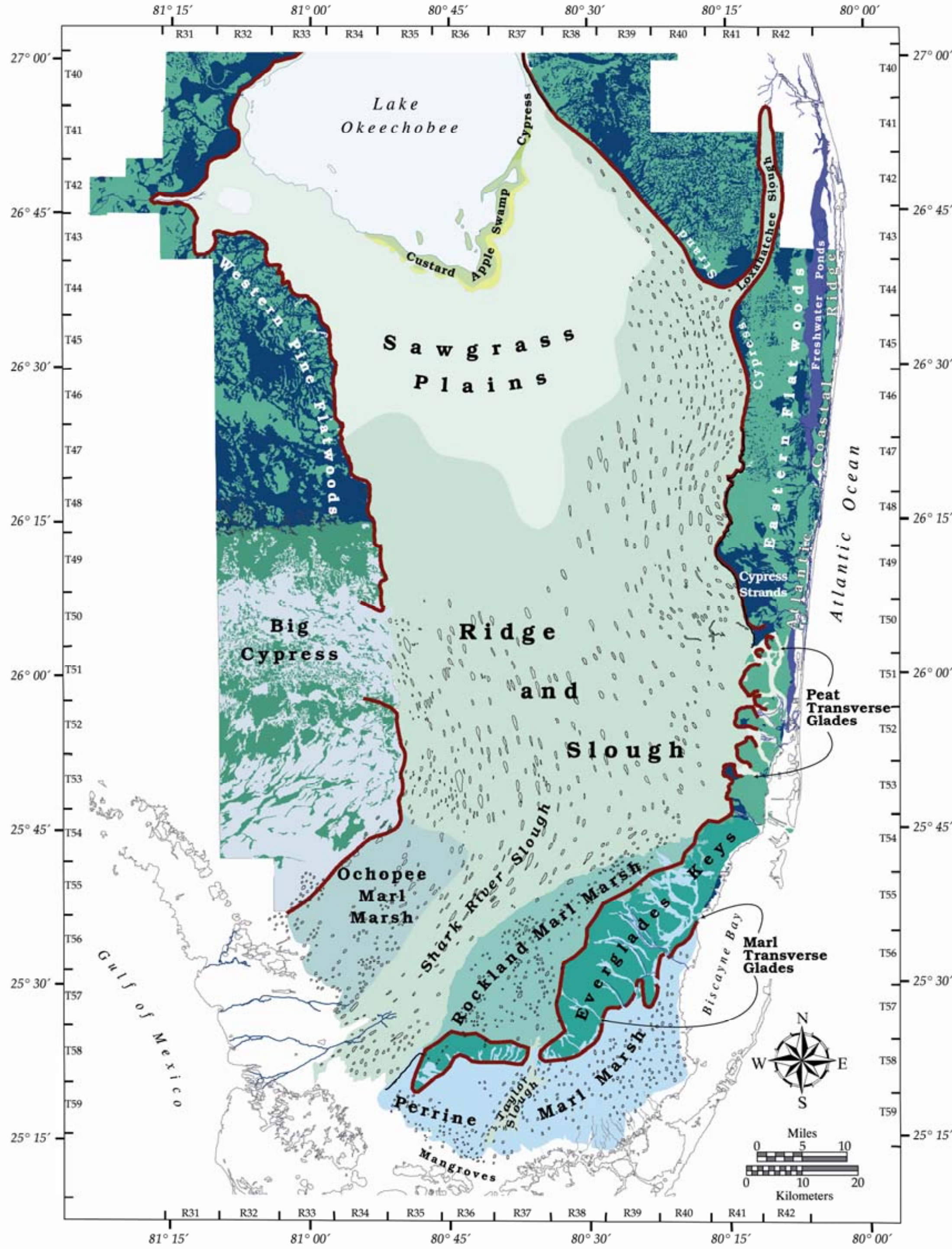


Plate 13. Landscapes of the pre-drainage Everglades and bordering areas, circa 1850.

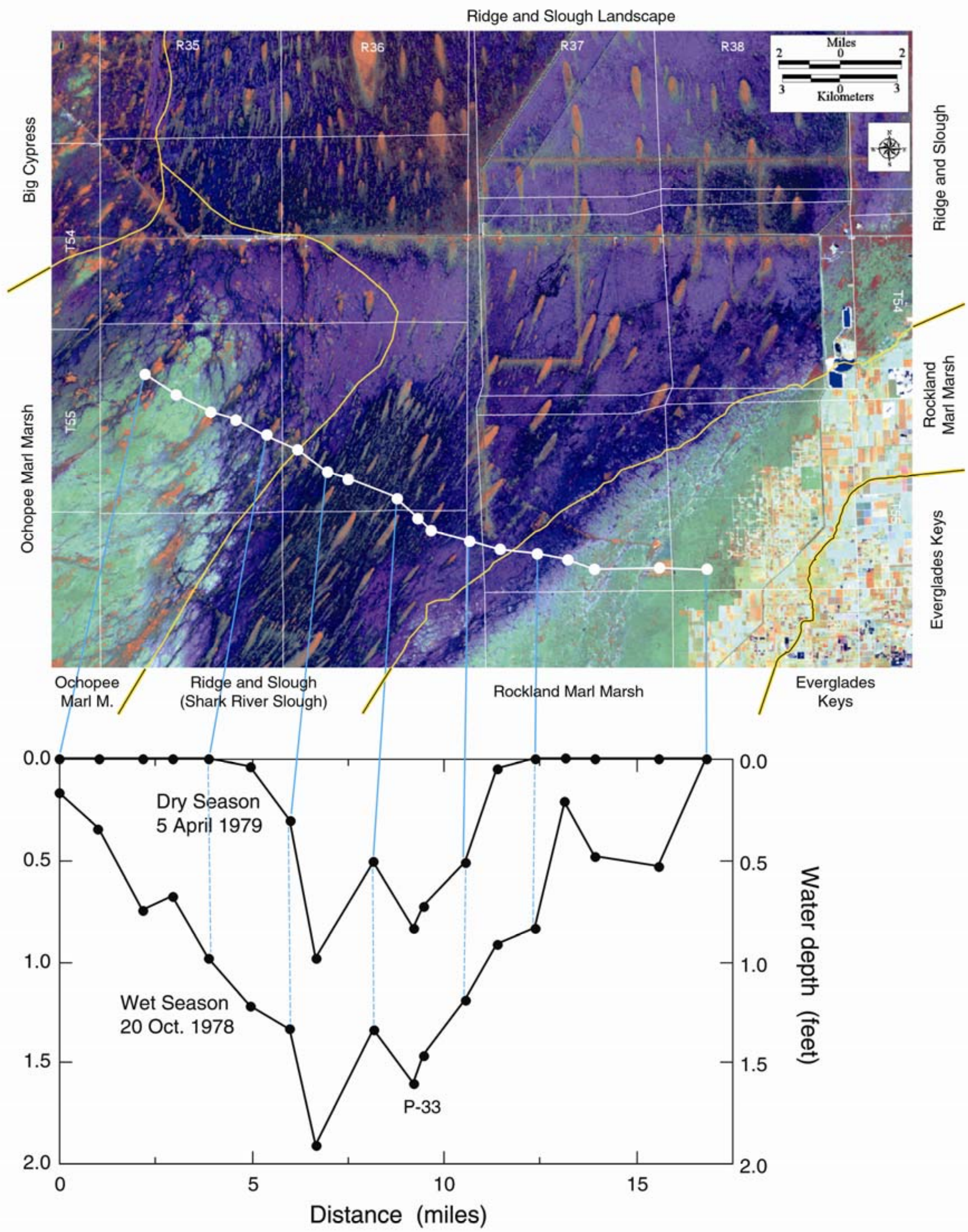


Plate 15. Water depths along transect across Shark River Slough and the bordering marl marshes. Concave pattern reflects ground and bedrock surface topography. Compare with Figure 4.2. Measured depths and locations from Rosendahl and Rose (1981). Image processing: BTR Labs, Palm Beach, FL, from April 1994 Landsat. TM data.

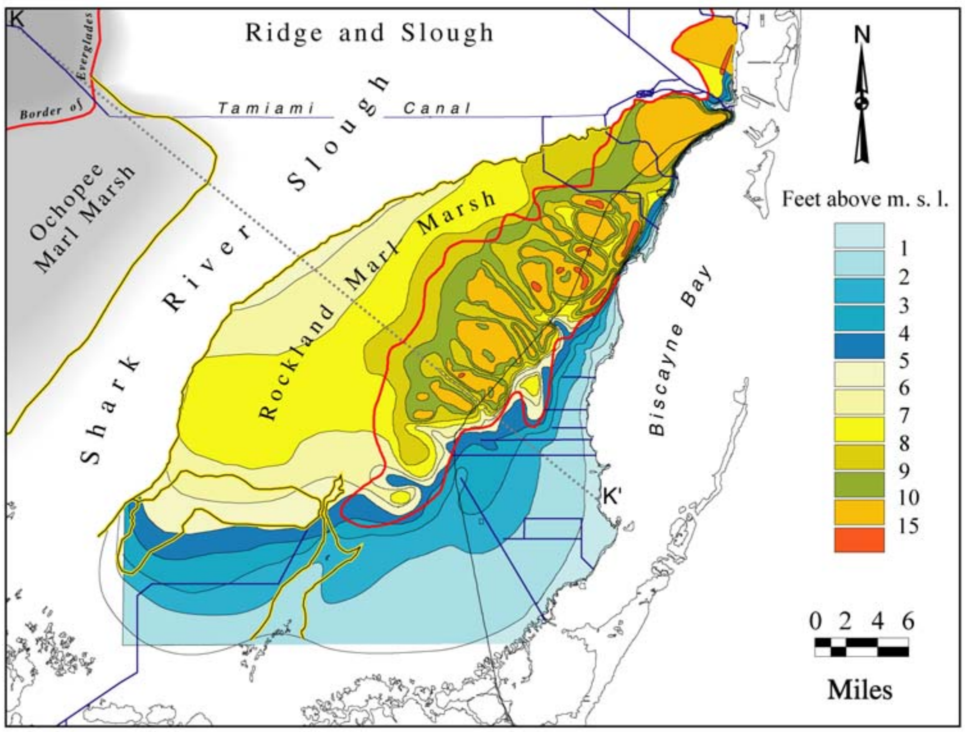


Plate 16. Contour map of the Everglades Keys (> 10 feet elev.; orange) and the Marl Transverse Glades (8-9 feet elev.; olive green). Note ledge at 9-10 feet elevation (dark green) along western edge of Keys, one foot higher than most of the Marl Transverse Glades. C.f. photographs of Keys (Figure 4.31) and transverse glades (Figure 4.30), and pre-drainage maps from 1847 (Figure 2.1) and 1856 (Figure 2.6). Figure 4.3 shows cross-section along K-K' transect. Elevation data from Jones *et al.* (1948).

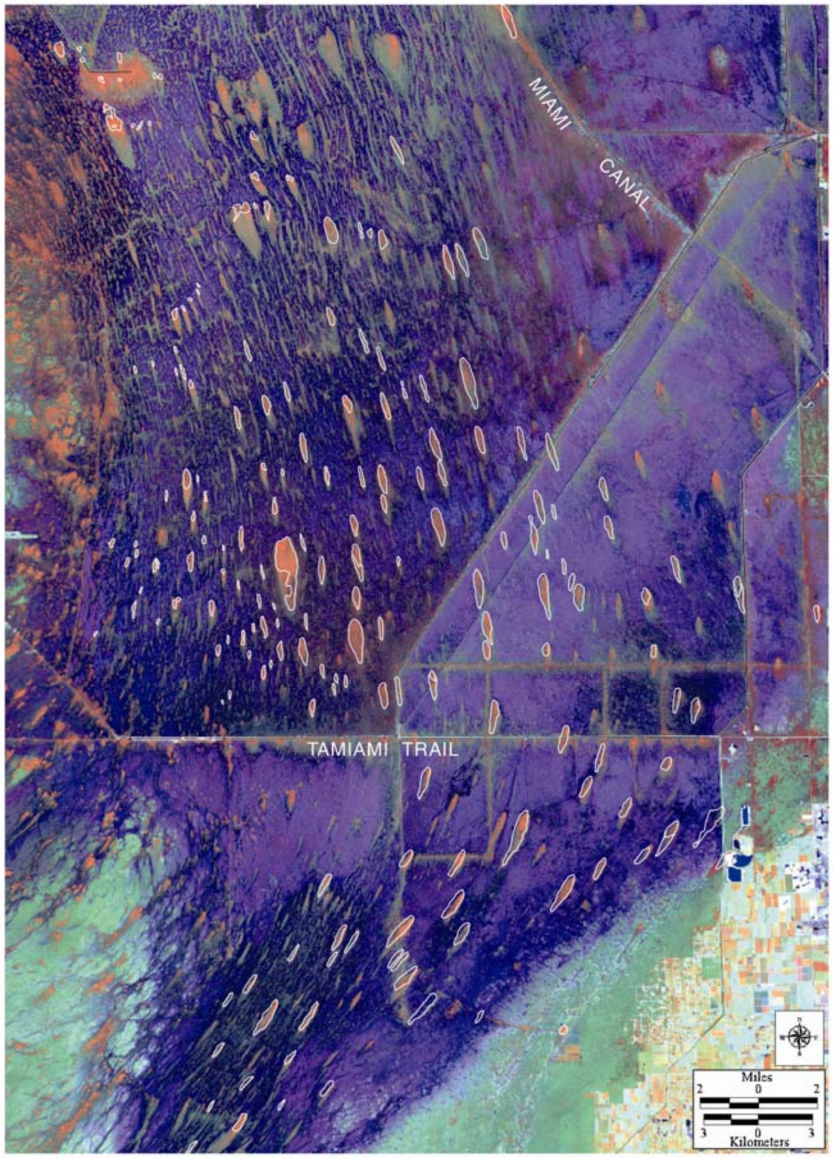
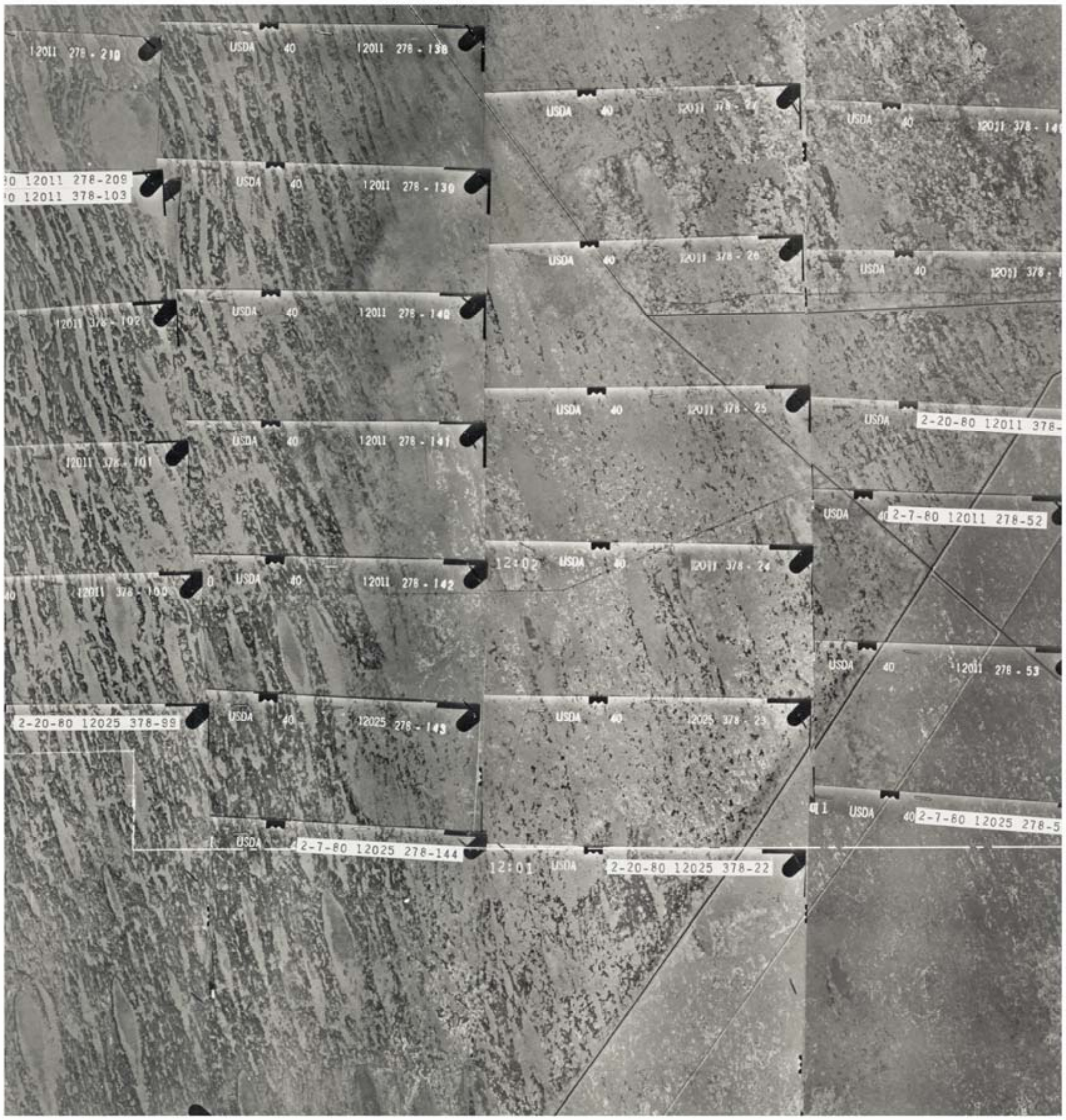


Plate 17. Strand tree island position and orientation in southcentral Ridge and Slough landscape, 1940 to 1994. Base map is Landsat TM imagery, bands 3, 4, and 5 (April 1994). White polygons overlain from 1940 soil map (Jones *et al.* 1948) indicating areas mapped as "Gandy peat" soil or as "myrtle and bay" land cover.

Plate 21. Aerial photomosaic of Taylor Slough, a separate portion of the Ridge and Slough landscape (1964). Wettest and widest portion is in lower left quadrant of image. Compare pattern there of linearly aligned, ovate patches of higher ground with other aerial images of Ridge and Slough landscape, and also with Little River Peat Transverse Glade, 1925 photo **Plate 31**.

Miami Canal



L-67A Canal
and Levee

Plate 28. Aerial photomosaic of Ridge and Slough landscape, Jan.-Feb. 1980. Central Water Conservation Area 3A (middle right of **Plate 30**). Light gray indicates sawgrass ridges or tree islands; black indicates deeper water of sloughs (or wet prairies). In left third of image, note clear, linear pattern of distinct, elongated sawgrass ridges, tree islands, and sloughs. Sawgrass ridges cover less than 50% of landscape. In right two thirds of image, note similar directionality, but much less distinct pattern, and apparent expansion of sawgrass coverage. Fine scale pattern suggests that the sawgrass has expanded laterally from original sawgrass ridges, displacing sloughs or wet prairies. Note also that although the directionality appears approximately constant across whole image, the spatial pattern differs between the compartments formed by canals and/or levees.

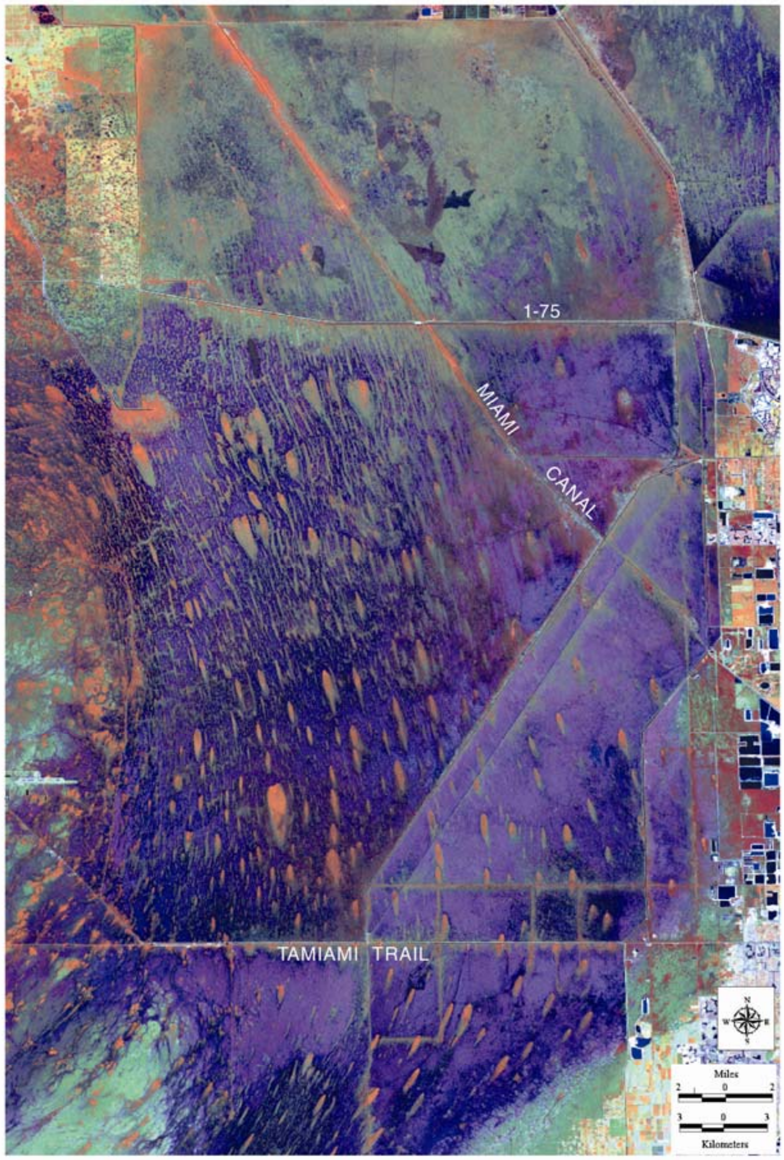


Plate 30. Satellite image of Water Conservation Area 3A, 3B, and northern Everglades National Park (Landsat TM imagery, bands 3, 4, and 5, April 1994). Aligned reddish ovals are strand tree islands; green generally indicates sawgrass; and dark blue or purple are generally sloughs or wet prairies. Note alignment of sawgrass ridges parallel to tree island alignment south of 1-75 and west of the Miami Canal. Image processing (SFWMD and BTR Labs).

Plate 31. Aerial photomosaic (1925) of the Little River Peat Transverse Glades. Note directional, aquatic texture of the transverse glade. Development (street grids) is confined to the higher coastal ridge. In 1845, there was sufficient outflow to operate a coontie mill on the Little River draining the transverse glade.

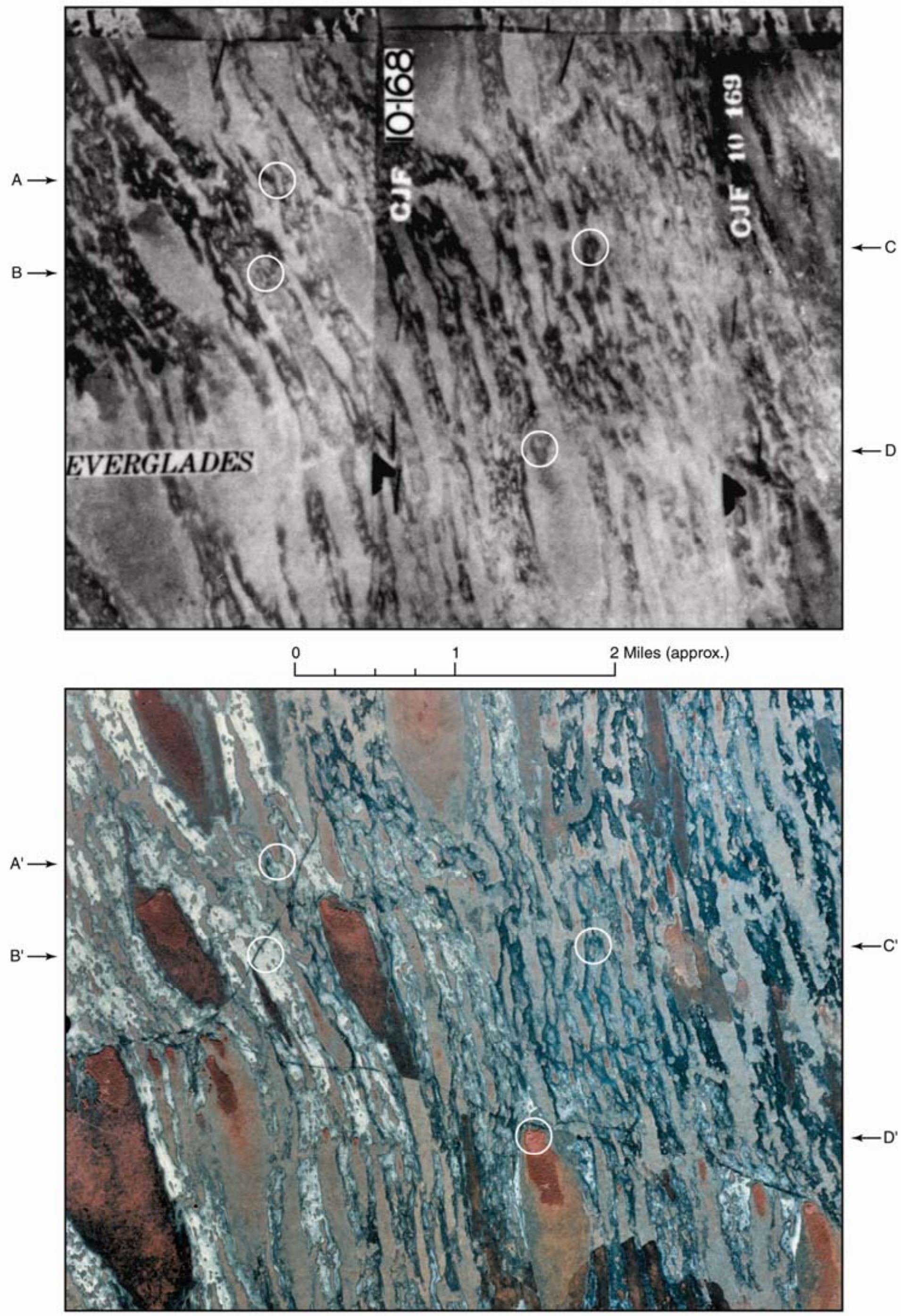


Plate 32. Aerial photographs of Ridge and Slough landscape: 1940 (top) and 1990 (bottom). Water Conservation Area 3A west side, 7 miles south of I-75. Gray indicates sawgrass ridges (A' marks southern tip of a ridge); white (B') or darker blue (C') indicate sloughs; and red indicates woody vegetation (D') of tree islands. Note remarkable similarity in landscape pattern, including fine detail. (bottom)

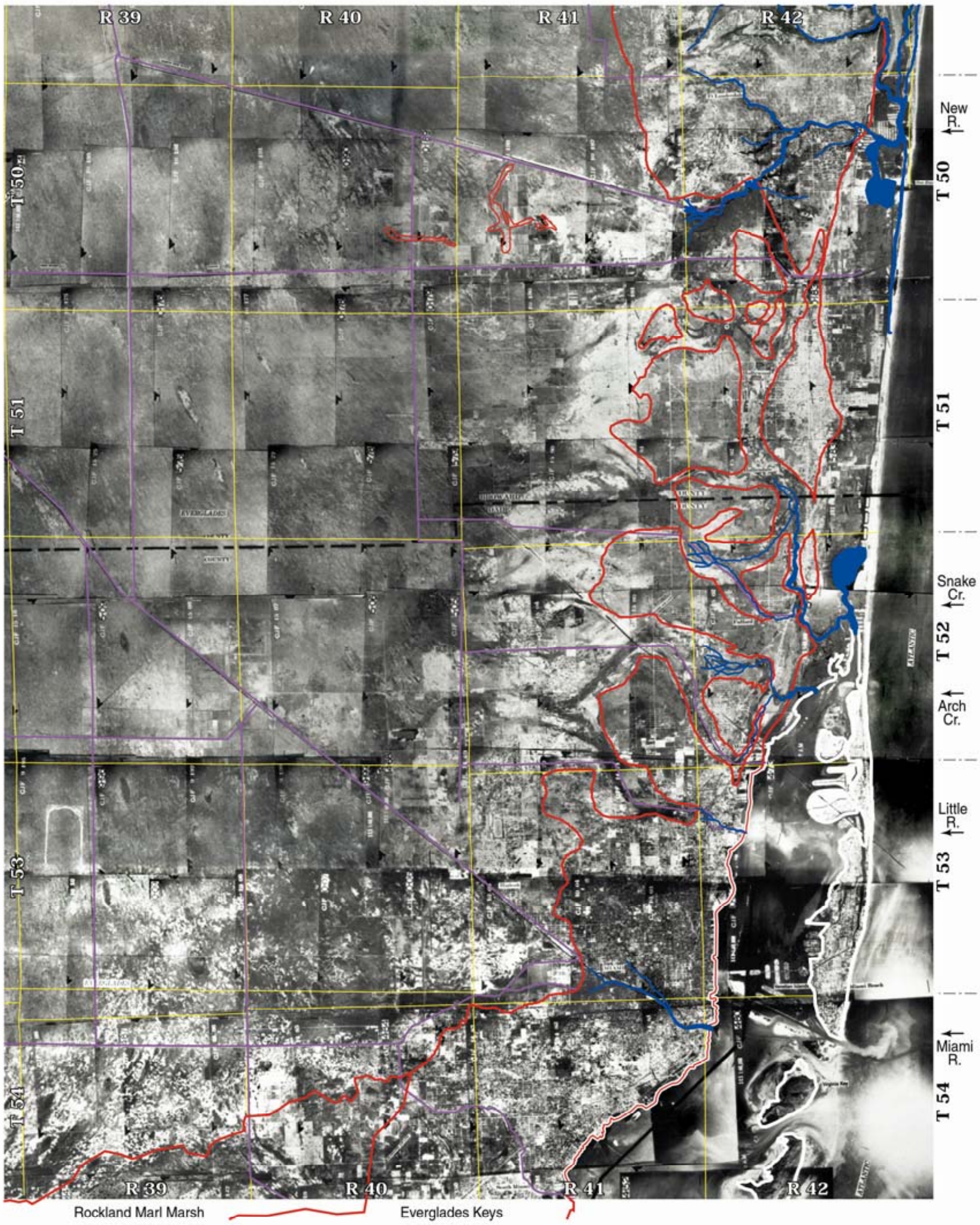


Plate 35. Aerial photomosaic (1940) of eastern Everglades and Atlantic Coastal Ridge. New River (Ft. Lauderdale) to Miami River region. Red polygons from Jones *et al.* (1948) soil map are islands of high ground, forming a discontinuous coastal ridge. Peat Transverse Glades and coastal rivers are visible between the islands. Whitish area, 1-2 miles wide immediately west of islands (R41) is most likely sand subsoil, exposed when overlying peats oxidized (**Figure 3.16**). Compare with pre-drainage map of same area (**Plates 37 and 38**).

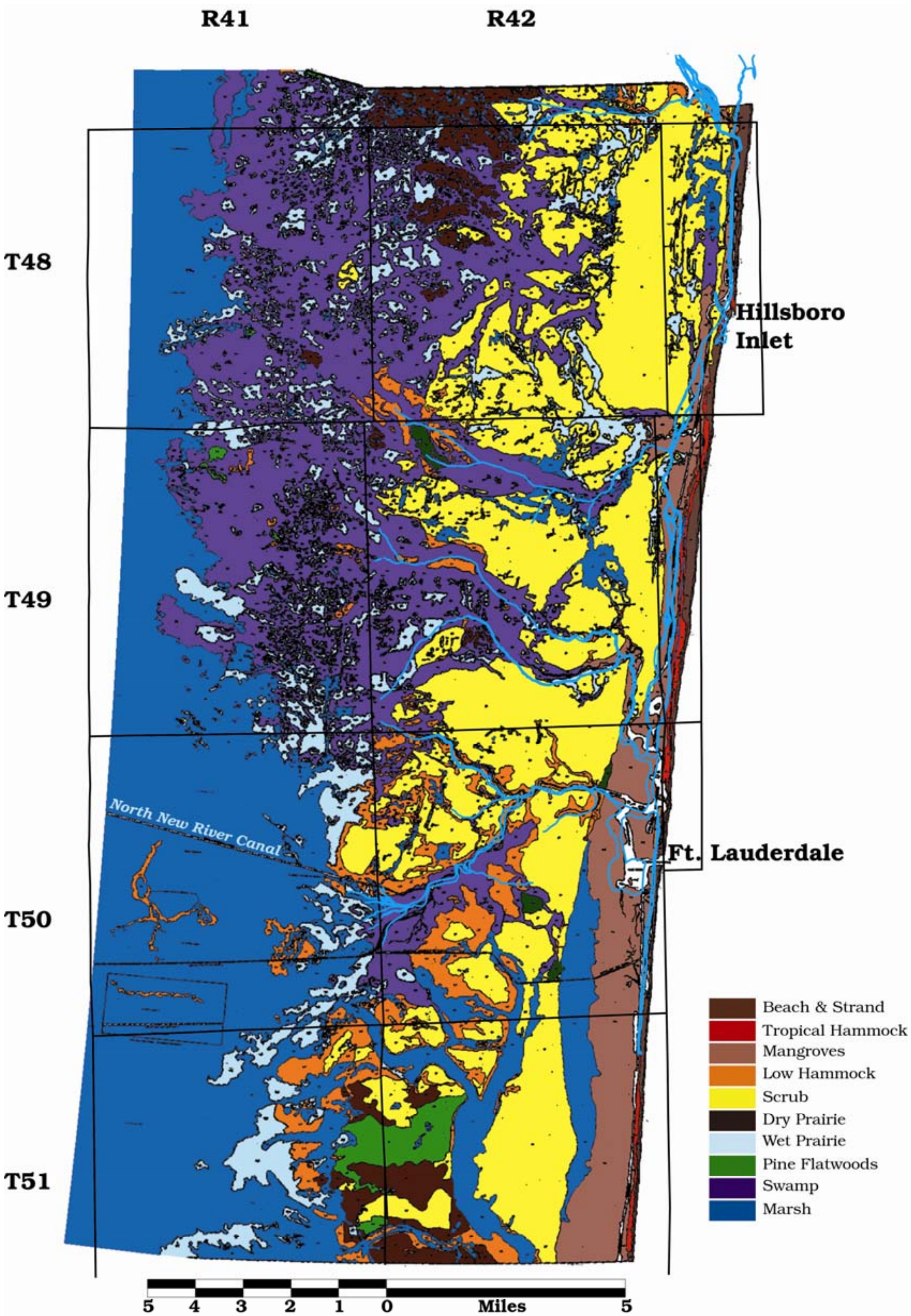


Plate 36. Estimated natural vegetation of Broward County, 1940. Mapped by Steinberg (1980). Additional overlays: Township boundaries (black) and pre-drainage rivers (blue). Geo-referencing approximate. Note extensive areas of cypress swamp draining from the Everglades eastward to the coastal rivers: Hillsboro Creek, Cypress Creek, No. and So. Forks of Middle River, and New River. See also **Plates 35** and **37**.

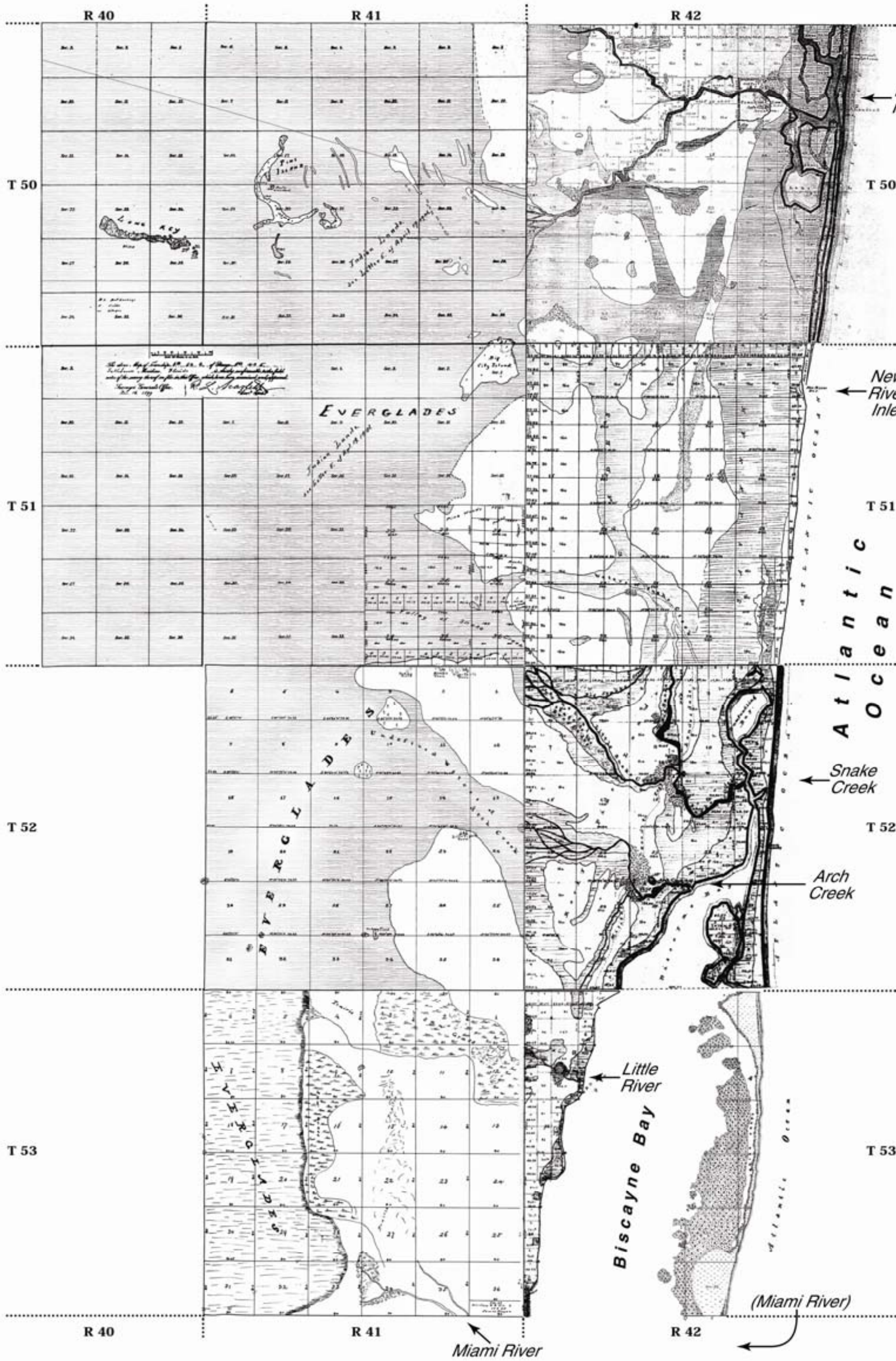


Plate 37. Pre-drainage landscape map of eastern Everglades and Atlantic Coastal Ridge. New River (Ft. Lauderdale) to Miami River region. White areas are islands of high ground (pine and palmetto), forming a discontinuous coastal ridge. Shaded areas between islands are Peat Transverse Glades. Everglades (shading in Ranges 40 and 41) directly border the ridge of islands and merge continuously with the transverse glades. (Mosaic of ten township plat maps, surveyed 1845-1898).

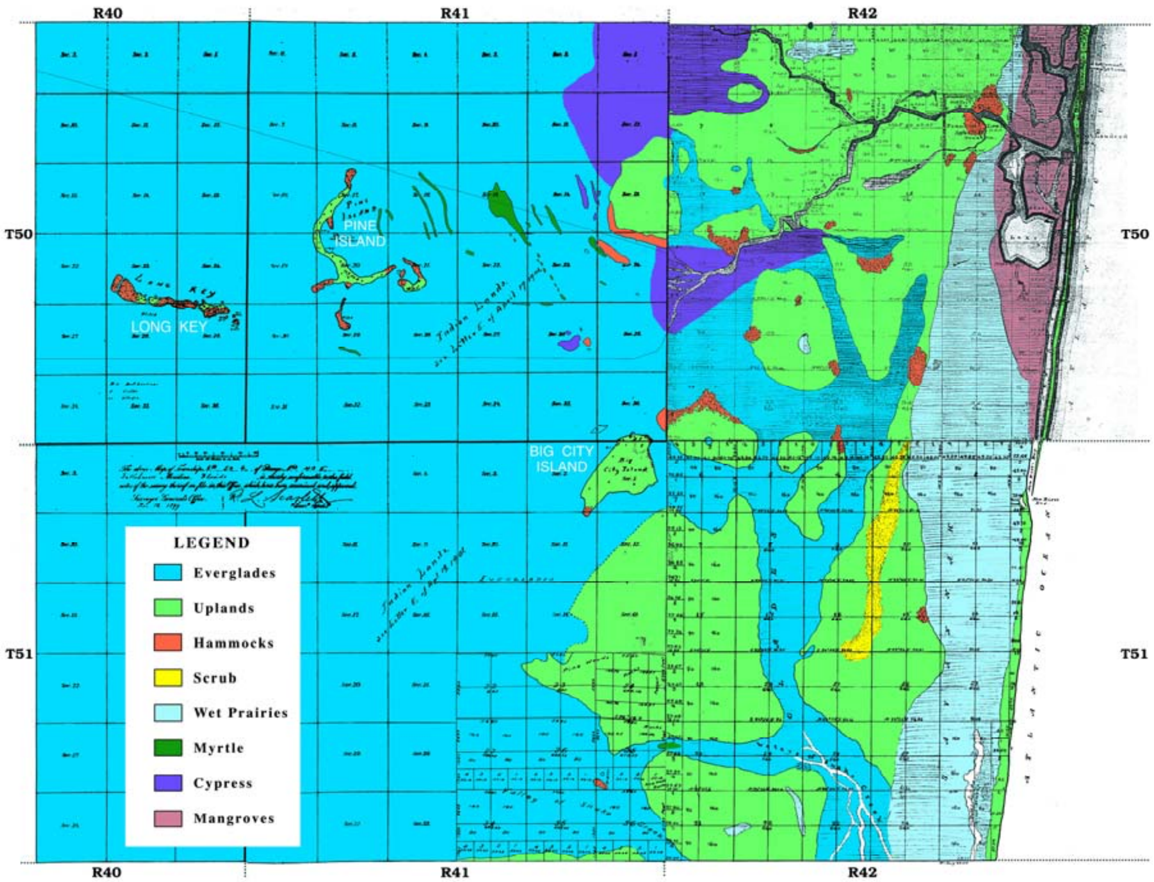


Plate 38. Pine Island, Big City Island, and Sam Jones Seven Islands (Long Key) in the pre-drainage Everglades near Fort Lauderdale, ca. 1898. Eastward, the Everglades extended into the Atlantic Coa Ridge as the Peat Transverse Glades. Survey plats: Fries (1898)-T50 R40, Fries (1898)-T50 R41, Newman (1908)-T50 R41, Williams (1870)-T50 R42, Fries (1898)-T51 R42, Newman (1908)-T51 Williams (1870)-T51 R42.

Plate 39. Aerial photo (1994) and survey map (1908) of edge of the Everglades and two Peat Transverse Glades in the Snake Creek area. Compare with **Plate 40**. In 1994 photo, northern portion of line of oak trees is still visible, as are oak trees of eastern half of former tree island and scattered oaks from western half (c.f. 1955 and 1947 photos). For regional context see **Plate 35**.

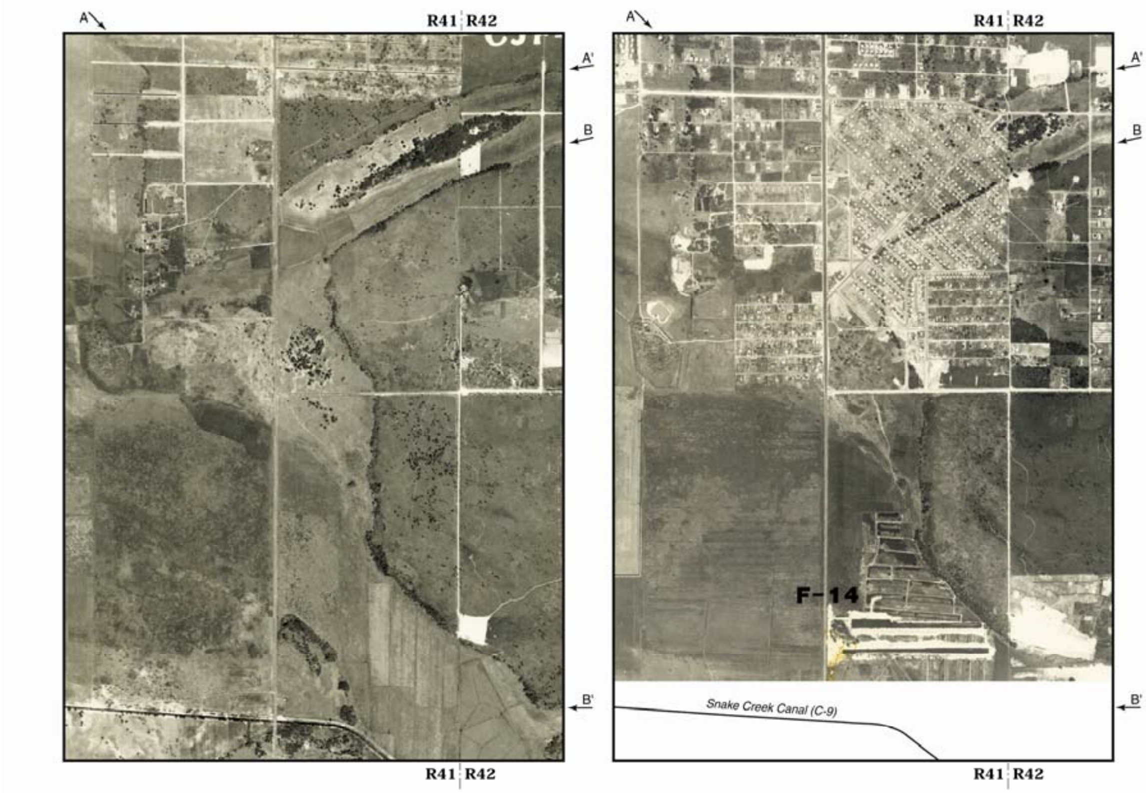


Plate 40. Aerial photos (1947 and 1955) of edge of the Everglades and two Peat Transverse Glades. Snake Creek area, (Township 51, Ranges 41 & 42). Upper Peat Trans. Glade (A' and B) includes tree island (1947). West half of tree island removed for development by 1955, but scattered oak trees left standing. Lower Peat Trans. Glade (B' and Snake Creek Canal) exits SE. Sharp border between Everglades and pineland in upper right half of images is marked by two distinctive lines of oak trees (A-A' and B-B') on aerial photos. Compare location with edge of pinelands surveyed in 1908 (Plate 36[DJ]).

A2: ST. LUCIE WATERSHED

Predrainage Landscape Ecology and Hydrology of the St. Lucie Watershed Estimated from Historical Sources by Christopher McVoy, SFWMD.

Introduction

This report was researched and written in response to a request for information from Dan Haunert, Upper East Coast Division, South Florida Water Management District. Objective of this time-limited study was to develop a sense of predrainage hydrology of the St. Lucie River watershed, based on understanding of the area's predrainage landscape ecology. Source materials included satellite imagery (**Figure A.2-1**), U.S. Government Land Office (GLO) township surveys from the 1850s, field notes from the same township surveys, knowledge of drainage history, maps of the present drainage system, USGS topographical maps, maps from the 1940s of vegetation and soils, and knowledge of remaining "natural" areas. Contour maps of elevation at 1 foot resolution would have been very useful, but were not available. The approach is deductive, using multiple sources of landscape information to piece together a predrainage picture consistent with all available information.

The following questions were to be addressed:

- What spatial patterns were present within the watershed?
- What directions might water have drained under natural conditions?
- What were the relative contributions of the North and South Forks of the St. Lucie River?

Ideally, these questions would be answered from direct observations of predrainage hydrology, e.g., water depths during the course of the year, durations of above ground water, observed flow directions, etc. As it was recognized that such direct observations were unlikely to be available, at least in sufficient numbers to cover the whole watershed, indirect approaches based on landscape ecological knowledge were encouraged. Predrainage vegetation and soils, when known, can be useful indicators of predrainage hydrology, particularly if additional topographical information is available to position the vegetation types and soils within the landscape.

It is important to recognize from that outset that, by all indications, the St. Lucie watershed has been extensively and intensively influenced by drainage. Almost every square mile is traversed by numerous drainage canals and ditches (**Figure A.2-2**). It is also important to recognize that historical information (e.g., Randolph & Co. *et al.* 1919), as well as the accessibility of the landscape suggest that significant drainage was in place well before the 1940s. Substantial and significant landscape change almost certainly accompanied this drainage. Peat soils in this area originally accumulated in low

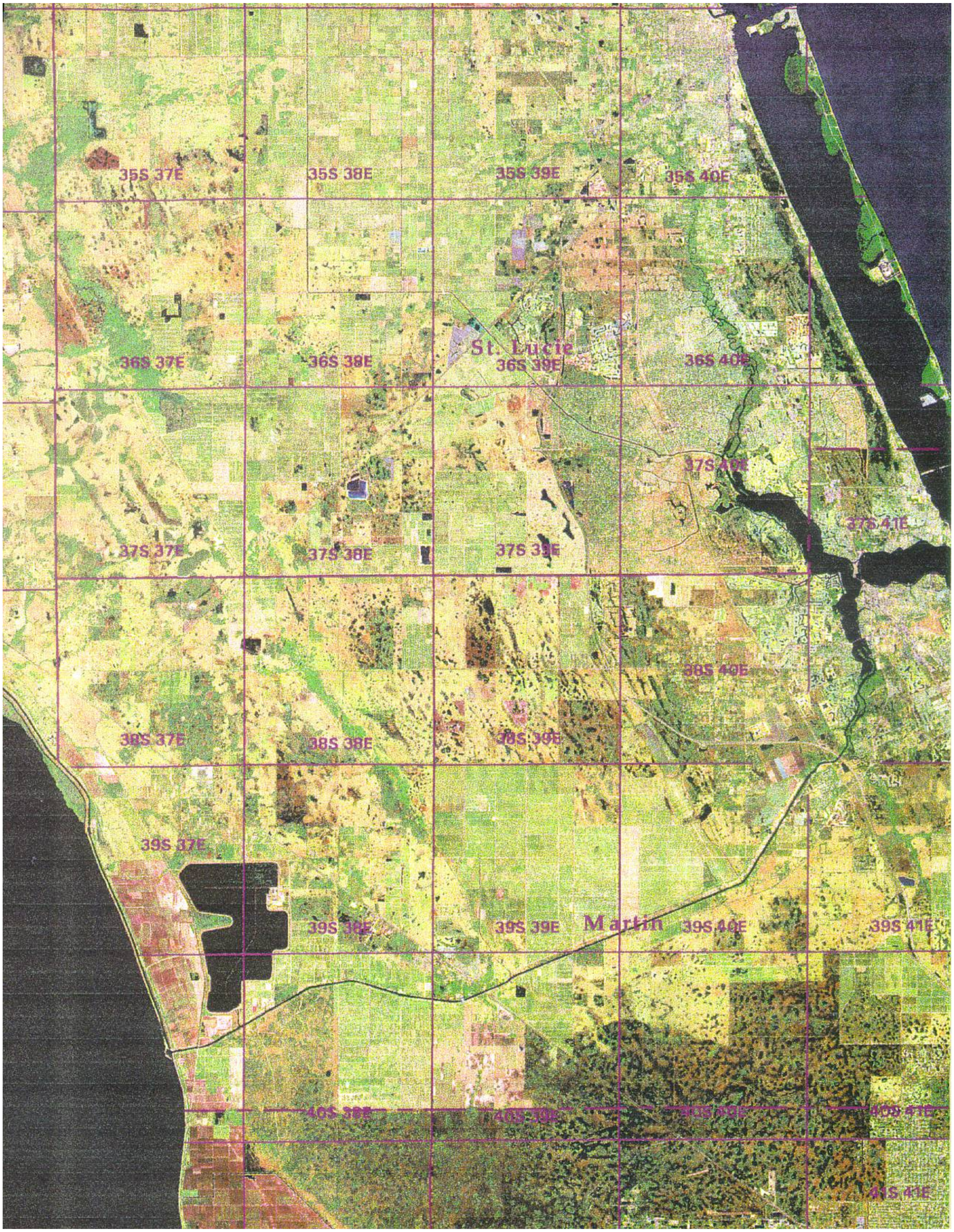


Figure **A.2-**1. Satellite Image of Majority of the St. Lucie River watershed, Overlain with Township Range Grid. Note relation of land use to T R grid.

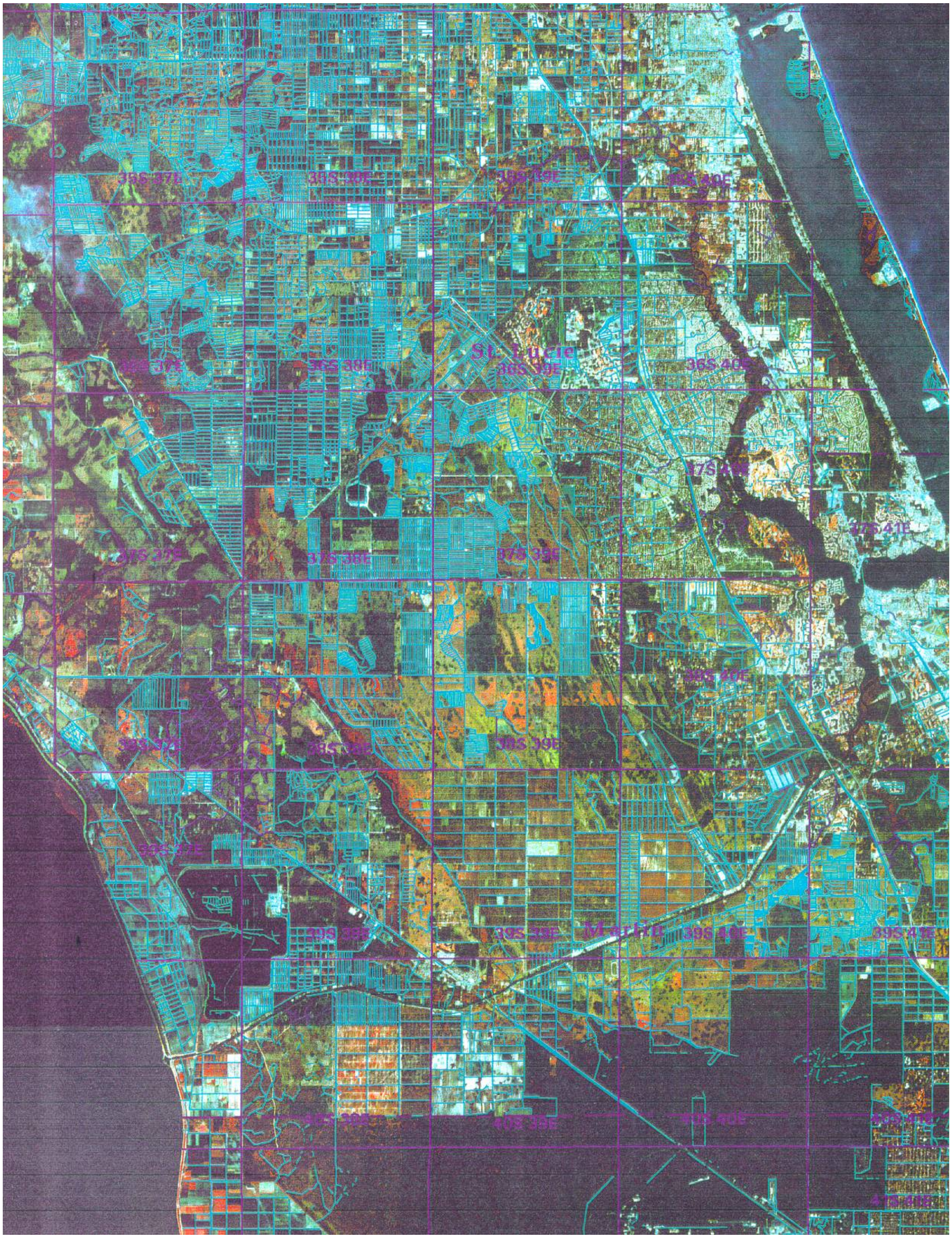


Figure A.2-2. Satellite Image of Majority of the St. Lucie River Watershed, Overlain with Current Canal System and Township Range Grid.

spots in the underlying sand, due to prevention of oxidation by standing water present during much of the year. Once drainage had lowered water tables below the land surface, complete loss of the peat could easily have occurred within a few decades (Stephens and Johnson 1951), as these soils were generally not more than a few feet deep.

The ephemeral nature of shallow peat soils in South Florida, once drainage is initiated, has important implications for understanding predrainage landscape ecology and hydrology. The flatness of the area, combined with the quantities and timing of rainfall that originally kept the water table close to ground surface, means that variations of only a few feet create the difference between upland pine or oak-cabbage hammock areas on a sand or loamy sand substrate and wetland swamps or sawgrass ponds on a peat substrate. If drainage causes the low-lying peat soils to completely oxidize away, the newly exposed underlying sand can come to resemble the sandy substrate of the original (predrainage) upland areas. Wetland and upland areas, once easily distinguishable, can blur, with upland vegetation starting to appear throughout. This is not surprising; in a sense it is the intended objective of drainage – to transform "swampland" into habitable or cultivatable "uplands."

The significance of the ephemeral nature of organic (peat) soils after drainage for correctly understanding predrainage ecology and hydrology is that it means that soil mapping carried out after drainage has begun cannot be assumed to reliably indicate the presence of predrainage wetlands. At best, post-drainage maps will underestimate the area of wetlands; at worst they can misleadingly indicate complete absence of wetlands if all peat has been lost.

As a result of the above, vegetation maps from the 1940s (e.g. Davis 1943), soil maps from the 1940s (Jones et al. 1948), present day soil maps, and present day satellite images all are inherently unreliable indicators of the predrainage landscape patterns within the St. Lucie watershed. These sources can provide very useful leads and suggestions of predrainage conditions, but the information must be carefully interpreted, using predrainage information that includes spatial detail.

Cursory inspection of a number of GLO township survey maps (**Figure A.2-3**) from within the watershed indicated that most of the area originally formed a mosaic, with multiple elements present within a square mile. Current topographic maps (**Figure A.2-4**), satellite imagery and the Davis (1943) vegetation map (**Figure A.2-5**) tended to confirm presence of a mosaic. In light of this, the original questions were necessarily modified as follows:

- What were the main two or three elements composing the predrainage mosaic?
- Was the mosaic random in orientation, or did elements form an organized pattern?
- Was the mosaic different in different parts of the watershed?

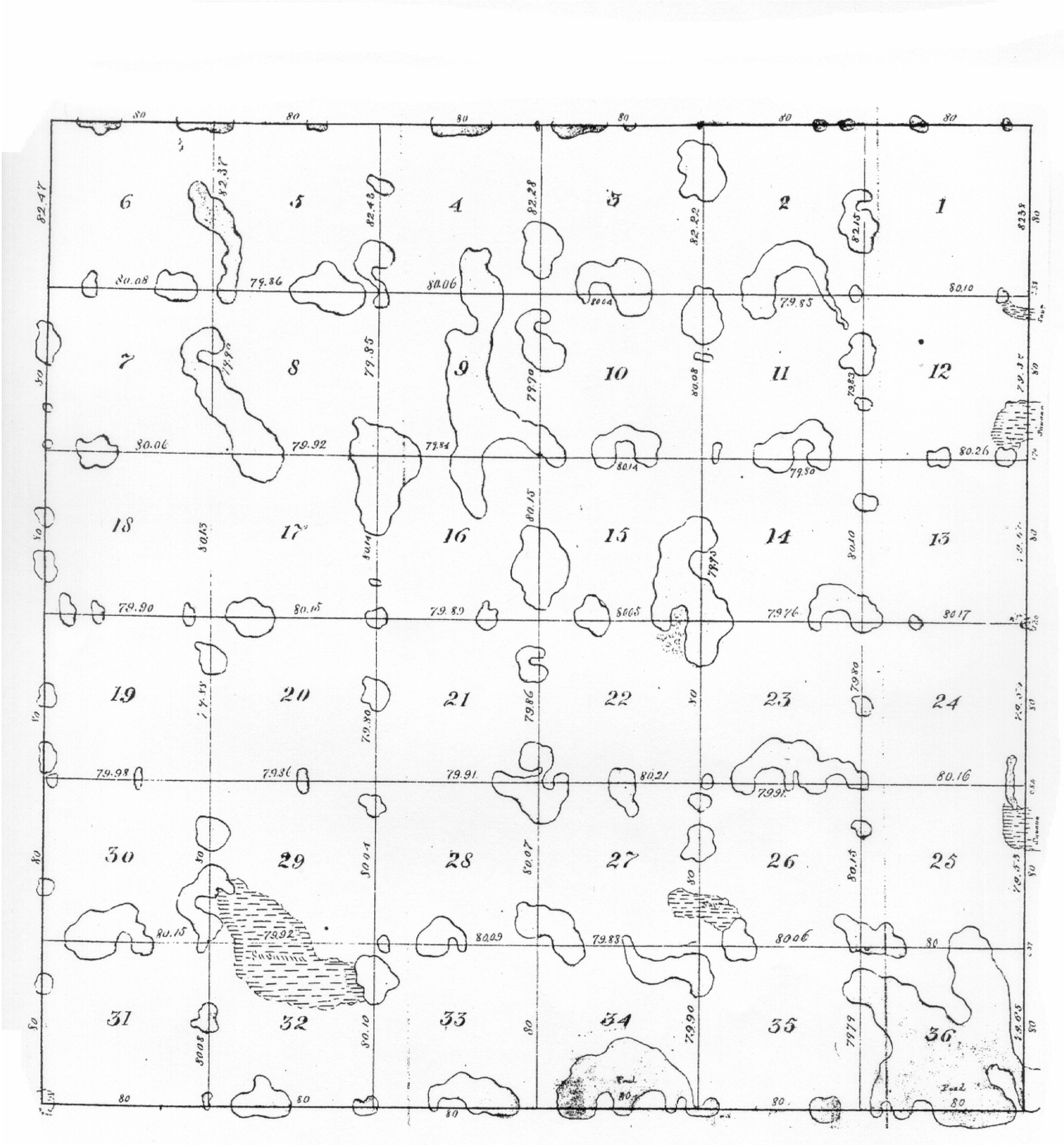


Figure A.2-3. Sample Township Plat Map of Township **38** S., Range **39** E., Surveyed by M. A. Williams in May & June of 1853. Open polygons are "Ponds," probably open water ponds, in a few cases labelled in the field notes as "Saw Grass Ponds."

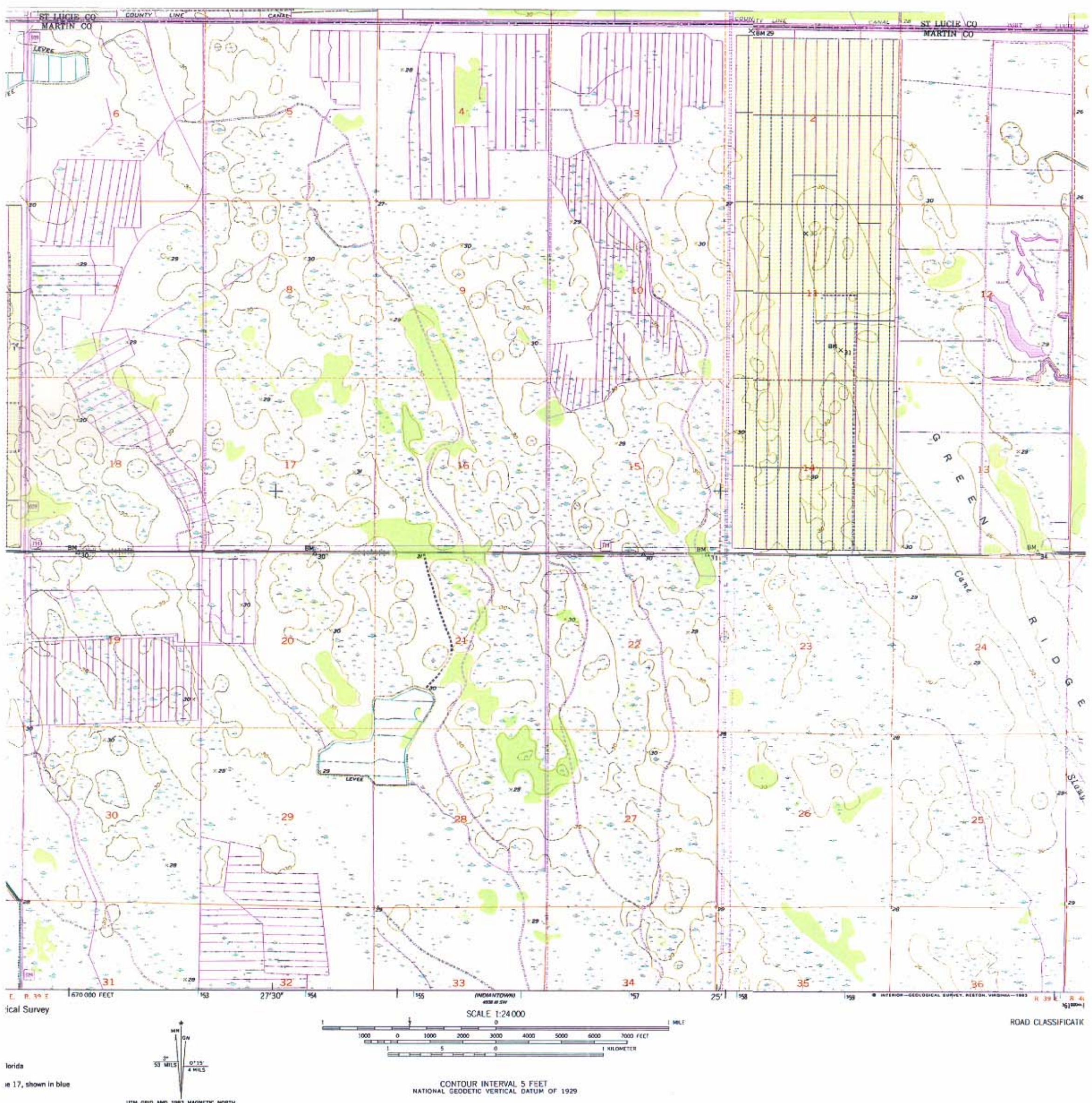


Figure A.2-4. U.S. Geological Survey Topographical Map of Township **38** S., Range **39** E, Photorevised in 1983. Presence of wetlands matches those drawn 130 years earlier on township plat (**Figure A.2-3**) along the surveyed Section lines. However, topographical map shows additional wetland extent within Section interiors, as well as wetland orientation, NW-SE. Note coincidence of drainage ditch network in Sections 29 and 32 with area marked “Savanna” on Township plat (**Figure A.2-3**).

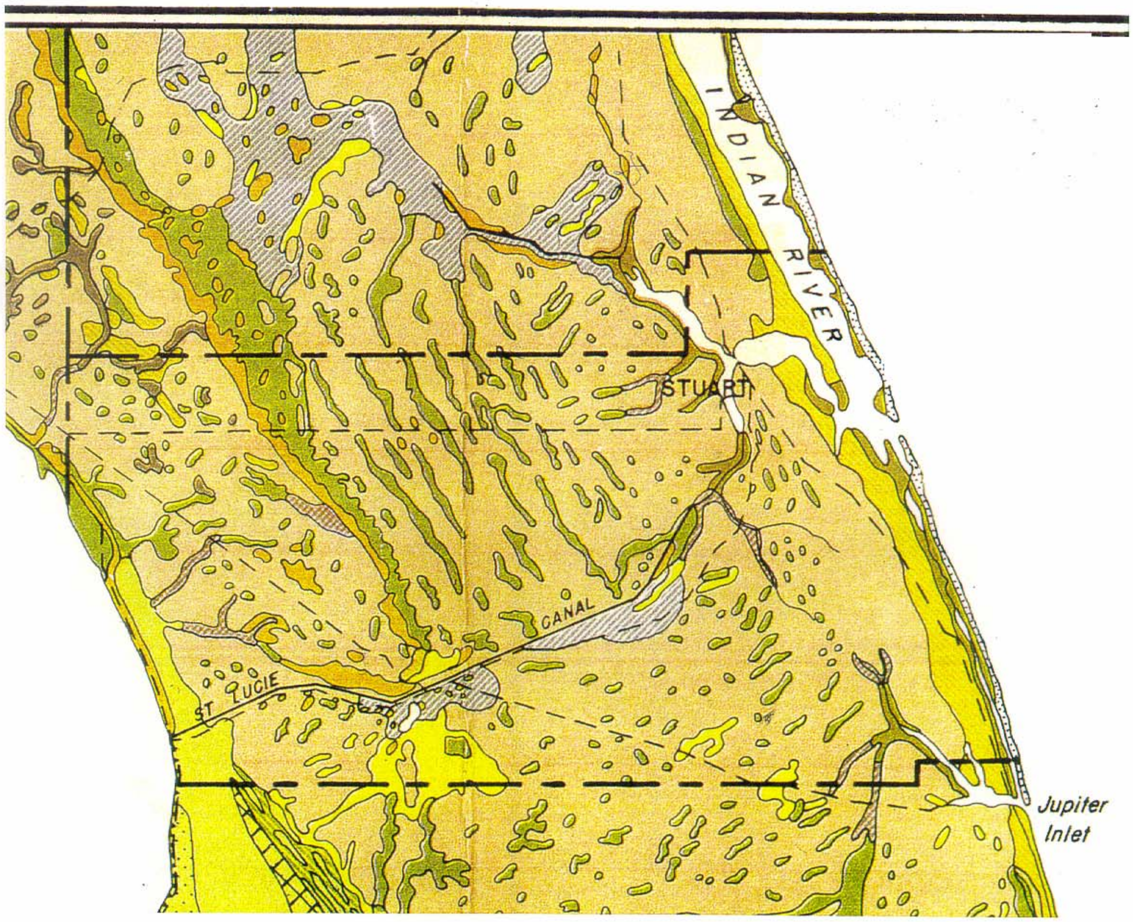


Figure A.2-5. St. Lucie Watershed Portion of "Vegetation Map of Southern Florida" (Davis 1943).

Methods

This brief reconnaissance study was initiated by examination of a satellite image overlain with a township range grid (**Figure A.2-1**). By inspection, four townships ranging from north to south within the watershed were selected, based on the remaining presence of original mosaic pattern (townships outlined in red on **Figure A.2-1**). The four townships were also selected for their alignment with the prevailing NW-SE pattern, possibly related to relict sand dunes. It was necessary to include an additional southern township (Township 40 Range 38), as field notes were not available on site for T 40 R40.

Each of these five townships (36 square miles each) was "sectioned," that is, walked along the boundaries of each square mile, with vegetation and presence of water bodies measured and described, between 1853 and 1855. Three different Deputy Surveyors were involved, all under the same State Surveyor General, John Westcott. I examined each of the five plat maps (scale 2 inches = 1 mile), and used the section boundaries to compare them with current USGS topographical quadrangle maps (scale 2 5/8 inches = 1 mile) (Compare for example **Figures F-3** and **F-4)**.

The field notes available for four of the five townships were then read (84 linear miles for each township) and compared with the plats to develop a sense of the mosaic elements present within each township. Three aspects associated with mile were examined: (1) the transitions between different elements (e.g., “33.00 [chains] exit Pine, enter Saw Grass Pond”), (2) the species of witness trees noted to locate the section and quarter section marker posts, and (3) the overall description included at the end of each mile (e.g., “3rd Rate Pine[, Saw] Palm[etto] & Ponds”). Given the time limitation, the examinations of the field notes were necessarily qualitative, rather than quantitative.

A separate second effort examined township plats located in the “Allapattah Flats” area along the eastern foot of the NW-SE ridge forming the western boundary of the watershed. This area was originally called “Halpatta Swamp” (Williams 1853) and “Alpatiokee Swamp” (Fla. S.G.O. 1853). Comparison of township maps with satellite imagery (**Figure A.2-1**) and with the Davis (1943) vegetation map (**Figure A.2-5**) suggested that much of the original extent and character of the Halpatta Swamp area had already been lost or altered prior to 1943, leading to an underestimate of this area.

A third effort compared township plat maps in the headwater areas for the North and South Forks of the St. Lucie River.

Written records of the area presently known to the author were examined; considerably more narrative material is almost certainly available, but was not researched within the present timeframe.

Results

General

A rough map (Fla. S.G.O. 1853) compiled by the Surveyor General’s Office in St. Augustine shows both the South and North Fork of the St Lucie River draining from an approximately 400 square mile area labelled the “Alpatiokee Swamp” (**Figure A.2-6**). Plat maps and field notes for several of the townships mention a “Halpatta Swamp” and an “Alpatiokee Swamp.” Further research would be needed to determine if these were alternate names for the same natural feature, or two separate features. As has often been the case in post–drainage South Florida, place names have changed as the landscape becomes drier under drainage. The current label “Allapattah Flats” is a post-drainage name certainly derived from Halpatta or Alpatiokee Swamp, but the area is no longer wet enough to be referred to as a “swamp” (much of it is now cultivated as citrus groves).

A map compiled in 1913 by the Florida Geological Survey on a base map by the U.S. Geological Survey (Matson *et al.* 1913) labels the South Fork of the St Lucie River as "Halpatiokee R.," suggesting a link with a Halpatta or Alpatiokee Swamp(s).

In a letter to Dr. V. M. Conway, Surveyor General of Florida, George MacKay, a U.S. Deputy Surveyor of many townships in southern Florida, wrote the following regarding what appears to be the St. Lucie River watershed:

> The country is generally poor land. Immediately on the Indian River Lagoon, it is low oak scrub & on my west line, it is open pine prairie, and saw grass savanna. Small pine scrubs. The savannas are the best land, tho' in the rainy season of the year they are covered with water. The --?-- --?-- entirely dry, and present a pleasing view. (MacKay 1846).

Mackay mentions the "sawgrass savannas" as the "best land" probably to contrast them from the common "3rd Rate Pine Lands" of Florida, found on sand with little native fertility. "Best" very likely refers to the presence of a top layer of organic peat soil, accumulated from wetland sawgrass growth. If this is the case, it would indicate that hydroperiods were probably 8-10 months of the year, such that the rate of organic matter accumulation slightly exceeded the rate of oxidative loss during the few months when standing water was absent. These also appear to be the optimal conditions for sawgrass; presence of peat soil, and water throughout most, but not all of the year.

In 1882, the Trustees of the Internal Improvement Fund, State of Florida, employed Silas L. Niblack as Agent to examine,

> The lands granted to the State of Florida as Swamp [and Overflowed] lands under the Act of September 28th, 1850" … [such examination being] "for the purpose of ascertaining the general character of the Swamp lands … with respect to their ability to overflow … and what proportion of said lands are already high and dry enough for cultivation… (Anonymous 1882).

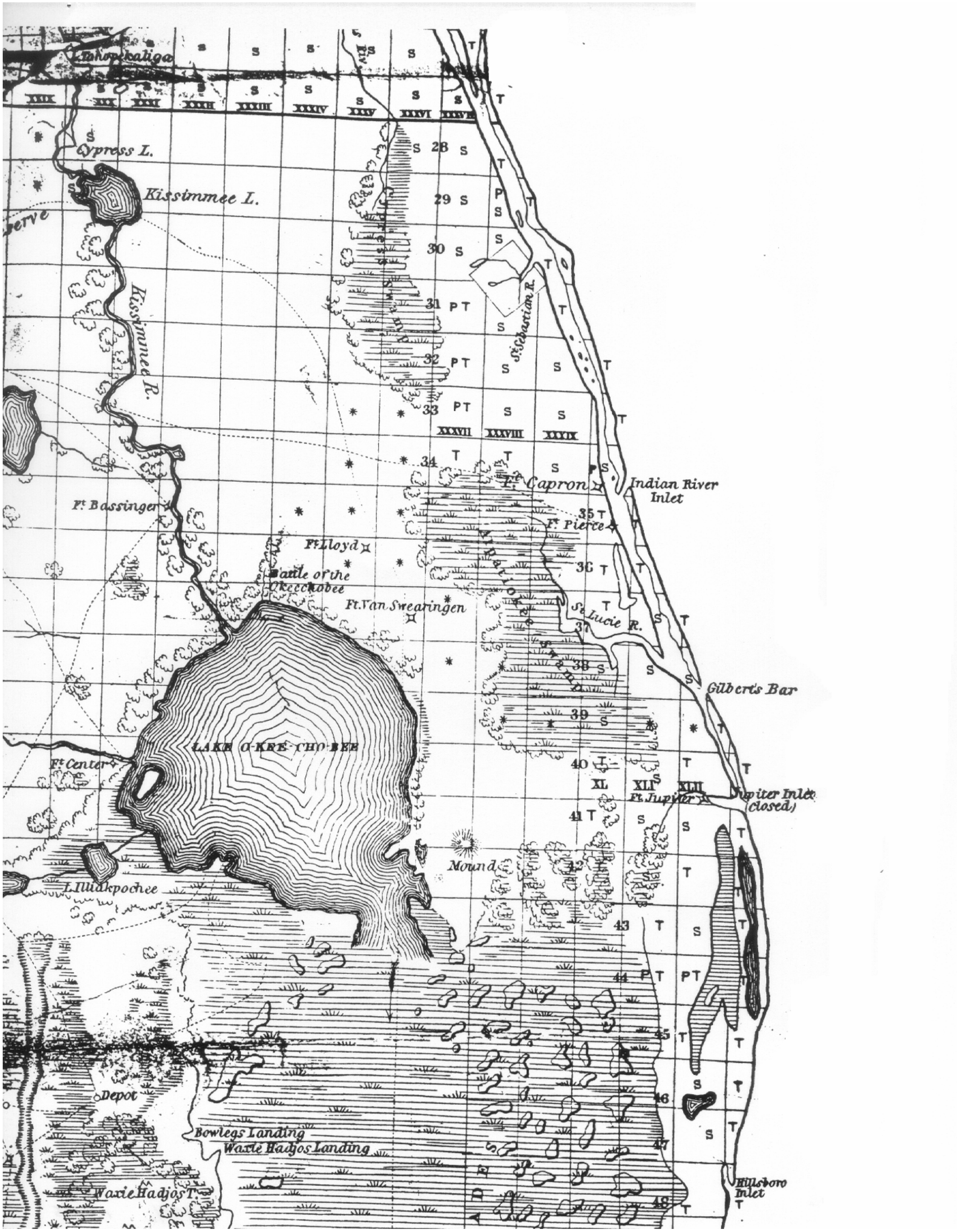


Figure A.2-6. U.S. Bureau of Topographical Engineers Map of Southern Florida, 1853, Showing "Alpatiokee Swamp" as Headwaters of North and South Forks of St. Lucie River.

Niblack's report of June 1882 states that "the balance of the land in Dade County would come within the terms of your drainage contract." (Niblack 1882). Niblack is stating that the whole St. Lucie watershed was in fact subject to overflow; Dade Co. at that time extended much farther north than at present. "Balance" refers to all of Dade County except the high ground near the New and Miami Rivers.

Even in adjoining, higher elevation pine lands, dry ground was the exception to the rule:

> Within this limit there is in the neighborhood of Fort Drum [T 34 R 35] a pine ridge about five miles in length and 1/2 to 3/4 mile in width, that might be, with light drainage cultivated; there is also near Taylor Creek a small ridge of Pine land that during a dry season might be cultivated, but subject to overflow in a wet season (Niblack 1882).

Niblack concluded by writing,

> I give it as my opinion and views resulting from examination and information received, [that] it is not advisable to have a … survey made of the State lands within said limits and a list prepared designating those not subject to overflow… [because] … I am satisfied the quantity of land not now subject to overflow, would be so small it would not pay the State the expense of examination and survey (italics added; Niblack 1882).

In 1919, two engineering firms, Isham Randolph & Co, Consulting Engineers, and Cunningham and Hallowes, Chief Engineers, issued a report and Plan of Reclamation for the North St. Lucie River Drainage District (Randolph *et al.* 1919). This drainage district (Townships 35 and 36, Ranges 38, 39, and 40) lies in the NE portion of the St. Lucie watershed (**Figure A.2-1**). We quote extensively from their report, as it gives a good sense of the landscape and landscape elements mapped by the township surveyors. Note however, that inspection of township maps from throughout the St. Lucie watershed indicate that the North St. Lucie Drainage District portion included a higher proportion of "Prairie" landscape than the rest of the watershed:

> The lands within the District may generally be described as flat, although elevations vary from fourteen to twenty-four feet above sea level. The highest lands are the pine woods which lie principally in the eastern half of the District. The prairie lands which are located mainly in the western portion of the district are flat, but there is a general slope from all portions of the District to Ten Mile Creek and Five Mile Creek and to the North Fork of the St. Lucie River, which is formed by the confluence of the first two named streams. These streams together afford the existing natural drainage outlets for the lands within the District as well as for a large body of prairie land lying further west. (Randolph *et al.* 1919).

The pine woods referred to on high ground in the eastern portion were probably associated with the Atlantic Coastal Ridge. This is in contrast to much of the rest of the St. Lucie watershed, where pines formed part of a mosaic landscape of "3rd Rate Pine and Ponds." The statement that Ten and Five Mile Creeks are the natural drainage outlets for the North district and even for the prairie lands further west is no doubt true. However, further research would be required to determine whether water reached the creeks primarily as surface water or as (shallow?) ground water flow. Three points suggest an important contribution of groundwater: (1) A later statement by Randolph *et al.* (1919) concerning the "lack of natural drainage" in the prairies; (2) apparent absence, at least in some areas, of a clear pattern of directionally connected surface wetlands; and (3) the presence of a soil layer of lower hydraulic conductivity several feet below the upper, more conductive sand horizon:

> SOIL AND VEGETATION: ... The soil of the District consists of Hammock, Muck, Prairie and Pine lands. Approximately ninety percent of the lands are underlaid with a marl or clay subsoil, at a depth of from one to four feet. Probably three percent of the lands are underlaid with hardpan, and the balance has a subsoil of sand. (Randolph *et al.* 1919).

Modern soil surveys should be consulted to confirm the widespread presence of a marl or clay subsoil. If present, such subsoil would provide high water holding capacity as well as a restriction to rapid downward drainage of water, tending to create consistent baseflow from the watershed, rather than the more transient, "spikier" groundwater discharges associated with a completely sandy profile.

> PRAIRIE: The District includes 40,418 [out of 75,000] acres of prairie land. These are lands, usually very level, which through lack of natural drainage in the past have been so wet as to prevent the growth of trees. The existing vegetation is confined to native grasses, which make a luxuriant growth where water does not stand for too long a period. These lands have a general top soil of heavy sandy loam, underlaid with clay or marl. They respond readily to drainage, and private operations on limited tracts have indicated them as well adapted for groves or general crop production. The fact that no clearing [of trees] is required in developing these lands is a consideration in determining their present and future value. (Randolph *et al.* 1919).

As sawgrass is not specifically mentioned, it is not clear to what extent this corresponds to the "saw grass savannas" mentioned by MacKay (1846), or to more of a wet prairie environment of some combination of spike rush (*Eleocharis*), beak rush (*Rhynchospora*), Maiden cane (*Panicum hemitomon*). "Luxuriant growth" is suggestive (but not conclusive) of saw grass. Reference to absence of vegetation where water "stands for too long a period" probably refers to the open water ponds depicted on all township plat maps I examined within the St. Lucie watershed.

In some parts of the prairie landscape, depressions were apparently deep enough to allow accumulation of significant peat soil deposits:

> In isolated tracts where local depressions in the prairie lands have brought about conditions favorable to a rank growth of [water] lilies, Maiden cane and other water grasses, a cover of well rotted muck varying from a few inches to six feet in depth is found. As at least the upper portion of the muck is ordinarily dry for a considerable part of each year, oxidation and decomposition of the vegetable matter has proceeded to an advanced degree, and the result is a soil which may be made highly producive by proper handling. (Randolph *et al.* 1919).

The description of open ponds (10% of the North St. Lucie River Drainage District) suggests sand-bottomed areas with sparse vegetation, perhaps 8-10 months of standing water, and maximum depths of 1-2 feet of water:

> OPEN PONDS: 7,270 [out of 75,000] acres of land in the District consists of open ponds. These lands similar in general nature to the prairie lands, but which are of such elevation as to be covered with a shallow depth of water for the greater portion of the year. For this reason the growth of vegetation in the past has been light and the top soil is of correspondingly poorer nature. These ponds are all of such elevation as to permit complete drainage under the Proposed Plan of Recommendation. (Randolph *et al.* 1919).

Absence of ponds on satellite imagery in areas where they had originally been shown on township maps suggests that Randolph *et al.* (1919) predicted correctly; sufficient man-made drainage was achieved to lower the water table below even the bottom of the pond elevations. Water tables were apparently lowered enough that both higher ground and former ponds could be farmed equally. (Note: there is little doubt that most predrainage ponds have disappeared, but land leveling, not just drainage alone, may have been partially responsible for this; pers. comm. K. Konyha, 21 Nov., 2000)

Township Maps

The following section focusses on detailed examination of a series of five townships extending NW to SE through the St. Lucie watershed. All township plats examined showed evidence of the mosaic nature of this region, mostly “ponds” within a matrix of less wet vegetation. Some plat maps also showed regional features, such as the Halpatta Swamp (Allapattah Flats), consisting of “impracticable” sawgrass and bordering “Bay Galls,” “Swamp,” or “Savanna”). Interestingly, the ponds were usually drawn as features about 1/8th to 1/4 of a mile across, and curiously lined up in north-south and east-west rows. Probability aside, the satellite imagery and the topographic maps clearly indicate that these neat rows do not accurately depict the original landscape. Detailed comparison of individual square mile sections between the township plats and the topo quads shows that the township surveyors tended to draw disconnected, circular ponds centered on the section lines (**Figure A.2-3**; see for example Sections 7 and 8), whereas in actuality the ponds had more complex shapes (**Figure A.2-4**). Actual ponds often extend, and presumably extended, NW to SE, and crossed two or more section lines. As the surveyors only walked the borders of the mile square sections, and did not have the benefit of aerial views of the landscape, they often incorrectly drew larger, rambling ponds as a series of circular, independent ponds, not realizing that they were in fact connected. From this I conclude that the township plats are not a reliable way to estimate the fraction of the mosaic occupied by ponds.

Evaluation of the landscape fraction occupied, prior to drainage, by ponds is best done using the topographical maps and/or the satellite imagery. (Note however that comparison of two different satellite images, taken at different times, suggested that the size of these ponds can change significantly as water levels rise and fall.)

No water depths or mentions of duration of standing water (hydroperiod) were found in the field notes for these townships. One mention of stream flow direction was found. An important limitation of this analysis of the watershed and these township survey results is the author's lack of having explored the area on foot.

Although streams were generally drawn on township maps, only one was found connecting between ponds within the St. Lucie watershed. (However, many streams connecting ponds are shown on township plats from within the high ridge area to the west of the watershed.) Shape of the ponds, when examined jointly on topographical maps as well as the township plats, generally did not suggest strong inter-pond connections, although this varied somewhat between townships. Overall, the impression was one of a landscape drained more by slow groundwater flow than by surface runoff. Ten Mile Creek, contary to expectations, was found not to extend much further on the plat maps than it currently does on topographic maps.

Township 36 Range 37

The southwestern corner of this township bordered the western ridge, and included what appeared to be a northern portion of the Halpatta Swamp (Allapattah Flats) area. This portion of the Hallapata Swamp included three separate areas of "Hammock" in a NW-SE line, as well as some "Swamp," "Bay Swamp," and "Low Prairie" area. Interestingly, this same western area now appears to have become wetter (used as a local detention basin??); the topographical maps currently show it as cypress swamp, rather than as hammocks. The majority of the Twp was labelled "Prairie." It is not exactly clear what "Prairie" refers to, but it appears to have included some pine, saw palmetto, and Cabbage Palm. Pits and mounds were used to mark some Section corners, apparently because no witness trees were available. Sawgrass ponds were scattered throughout the Prairie area. The Jones Hammock and North of Bluefield (Okeechobee 1 SE) USGS topo quads show a considerable number of isolated wetlands (former sawgrass ponds??), as well as a number of networks of drainage ditches. Elevations in the township ranged from 25 to 30 feet above sea level. Landscape categories reported in the GLO field notes for Township 36 Range 37 are presented in **Table A.2-1**.

Table A.2-1. Landscape Categories Reported in the GLO Field Notes for Township 36 Range 37. Surveyed by C. F. Hopkins in July 1853.

Surveyor's Name	Witness Trees	Comments
"3rd Rate Prairie", "3rd Rate Pine & Palm[etto] Prairie"	Pits, Cabbage [Palm], Pine	Matrix over most of Twp. Includes: Sawgrass Ponds, Pine Islands
"Saw Grass Ponds"	--	More scattered wetlands (ponds?) shown on USGS topo than on twp plat – significant?
"Pine Islands," "Pine Lands"	Pine	Considered as distinct inclusions within "Prairie"; Match well w/ forested areas on topo
"1st Rate Hammock"	Oaks, Cabbage Palms, Ash (1)	Occurred as northern extension of Hallapata Swamp, NW-SE; Probably rich soils
"Swamp"	Cypress	Two smaller areas; W side of Twp
"Bay Swamp," "Bay Gall"	Bay	Small; W side; w/ Low Prairie, Swamp
"Saw Grass Marsh"	-	One small area only

Township 37 Range 38

Western half of Twp was all “Saw Grass” and “Savanna” – part of the Hallapata Swamp feature. Eastern half was matrix of “3rd Rate Pine” with inclusions of numerous “Ponds.” As one pond was specifically labelled “Saw Grass Pond,” I assume that the numerous others labelled only “Pond” were either too deep for sawgrass or too shallow to accumulate enough peat for sawgrass. Appears to be more Pine than in T 36 R 37, and fewer Cabbage Palms. Less developed parts of Twp show wetlands throughout on USGS topographical quads Bluefield (Okeechobee 4 NE) and North of Bluefield (Okeechobee 1 SE); topo quads give wetter impression than the survey notes. The large Sawgrass area in Secs 31, 32, 30, 29, 19 (Hallapata Swamp/Allapattah Flats) is visible on topo quad; includes some forested area. Elevations in eastern half of Township (Pine Land) were 25 to 28 feet above sea level, mostly around 26 feet. Three “Flowing Wells” marked in eastern half. Landscape categories reported in the GLO field notes for Township 37 Range 38 are presented in **Table A.2-2**.

Table A.2-2. Landscape Categories Reported in the GLO Field Notes for Township 37 Range 38. Surveyed by M. A. Williams in June 1853.

Surveyor’s Name	Witness Trees	Comments
“3rd Rate Pine & Ponds”, “3rd Rate Pine & Rough Palm[etto]” (1)	Many Pines, A few Cabbage Palms	Matrix over East 1/2 of Twp. Includes: Ponds
“Ponds” “Saw Grass Pond” (1 only)	--	Vegetation unclear but either too deep for sawgrass; or too little peat for sawgrass
“Saw Grass”	--	17 sq miles; Hallapata Swamp
“1st Rate Hammock”	--	A few small hammocks within Sawgrass
“Savanna,” “Wet Savanna”	A few Pines, 1 Cabbage Palm, 1 Myrtle	Along E side of Sawgrass; Intermediate between Sawgrass and Pineland??
“Bay Swamp,” “Bay Gall”	Bay	Small; W side; w/ Low Prairie, Swamp

Township 38 Range 39

With the exception of one or two Twps on the southern border of the watershed, T 38 R 39 appears to be the least developed (**Figure A.2-1**), lending itself to comparisons between present day topo maps and the 130 year older township plat map. Regional drainage almost certainly affects the Twp, but local ditch systems seem to be less developed here than elsewhere in the watershed (**Figure A.2-2**). The survey notes are repetitively consistent, all “3rd Rate Pine & Ponds” with Pines as witness trees. Comparison of the Twp plat map (**Figure A.2-3**) with the USGS Indiantown NW topo quad (**Figure A.2-4**) suggests a close match in wetland delineation. The hammock found on the Section 15-22 border appears to still be present (benchmark elevation there of 31 feet above sea level). Elevations seem to indicate a very flat landscape, ranging from 29 to 31 feet, with the 30 foot contour line often being the coincident with the edge of the wetlands. The topo map also suggests that many of the wetlands are elongated and interconnected in the NW-SE direction. Green Ridge, reaching 35 feet, runs with the same NW-SE orientation through Sections 11, 13, and 24. A single note in the township survey, “18.00 [chains] to Pond Running Water E S E” (N boundary Sec 11 Course W), suggests that drainage from this location east of Green Ridge might proceed toward the South Fork of the St. Lucie River. Elongated, interconnected wetlands oriented NW-SE could be consistent with this, but no other flow information is available from the 1853 notes. Landscape categories reported in the GLO field notes for Township 38 Range 39 are presented in **Table A.2-3.**

Table A.2-3. Landscape Categories Reported in the GLO Field Notes for Township 38 Range 39. Surveyed by M. A. Williams in May & June 1853.

Surveyor's Name	Witness Trees	Comments
All "3rd Rate Pine & Ponds"	All Pines	Matrix. Includes: Ponds
"Ponds" "Saw Grass Pond" (1 only)	1 Bay, probably on edge	Vegetation unclear but probably deeper than Sawgrass; or too little peat for sawgrass
"Hammock"	--	One small hammock
"Savanna"	1 Pine, might have been outside	A few small areas

Township 40 Range 40

This Twp was chosen as approximately two-thirds of the Twp is undrained natural area, and therefore might provide a model for the predrainage condition of the more developed townships further north in the St. Lucie watershed. The West of Rood (West Palm Beach 2 NE) orthophotomap suggests that there might be an important difference from townships further north in the watershed as the wetlands in T 40 R 40 generally appear more circular, less directional and the regional pattern less oriented than was the case in T 38 R 39.

Although field notes were not available for this Twp (should be obtainable from Tallahassee), comparison of the plat map with the USGS orthophotomap confirmed that the plat map underestimates the large quantity of wetlands (which appear to be ponds with areas of cypress), showing only those crossed by the section lines. Comparison of Section 35 suggests a good match for those shown. Elevations range from 20 to 25 feet above sea level, with lower elevations to the NE.

Township 40 Range 38

This Twp was examined as a proxy for T 40 R 40, due to the local unavailability of field notes for latter. Information from two different surveyors is available for this Township; M. A. Williams surveyed the north boundary in August & Sept. of 1853 and W. J. Reyes surveyed the whole Twp in February 1855. Elevations 24 to 26 feet above sea level, with one isolated spot in NE corner of 30 feet. As for other townships, the topo maps (Port Mayaca and Barley Barber Swamp (Okeechobee 4 SE)), indicated many more wetlands than those shown on the Twp plat. The field notes indicate numerous wetlands, generally either "ponds" or "cypress swamps." This could be an underestimate, as this Twp appears to have been significantly affected by drainage. Landscape categories reported in the GLO field notes for Township 40 Range 38 are presented in **Tables A.2-4** and **A.2-5**.

Table A.2-4. Landscape Categories Reported in the GLO Field Notes for Township 40 Range 38 (North boundary only). Surveyed by M. A. Williams in Aug. & Sept. 1853.

Surveyor's Name	Witness Trees	Comments
"3rd Rate Pine", "3rd Rate Pine & Ponds"	Pines	Includes Ponds
"2nd Rate Hammock"	Cabbage Palm	"Cabbage Hammock"
2nd Rate Pine & Cabbage & Hammocks & Sawgrass Ponds"	Pine, Cabbage	Includes: Sawgrass Ponds, Hammocks; Cabbage appears to be mixed with pine
"1st Rate Hammock"	--	
"Savanna"	Cabbage Palms, Pines	

Table A.2-5. Landscape categories reported in the GLO field notes for Township 40 Range 38. Surveyed by W. J. Reyes in Feb. 1855.

Surveyor's Name	Witness Trees	Comments
"3rd Rate Cypress (Swamp), Pine & Palmetto		Inclusions: "Cypress Swamp", "Pine [Land]", "Ponds" (many; several per mile), "Sawgrass & Cypress (Pond)"
"Cypress Swamp"	Cypress, Pine, Cabbage, Bay, Myrtle	Many; probably as frequent as "Ponds"
"Pine [Land]"	Pine, Cabbage	
"3rd Rate (flat) Pine & Palmetto (land)", "3rd Rate Sawgrass Pine & Palmetto"	Pines, Cabbage	Inclusions: "Ponds" (many; several per mile), "Shallow Pond" (1), "Sawgrass"
"2nd Rate Pine & Cabbage"	Pines	Inclusions: "Ponds" (many; several per mile), "Willow Swamp" (1)
"Prairie"	Myrtle, Maple, Cabbage	Not much, but distinguished from "Sawgrass"
"Hammock"		Not many

Cross-Township Landscape Features

Figure A.2-7 shows a portion of the Halpatta Swamp (Allapattah Flats) that extended NW-SE across five townships. This area of "impracticably" dense and boggy sawgrass would originally have included peat soils and may have in part drained overland, along the NW-SE axis.

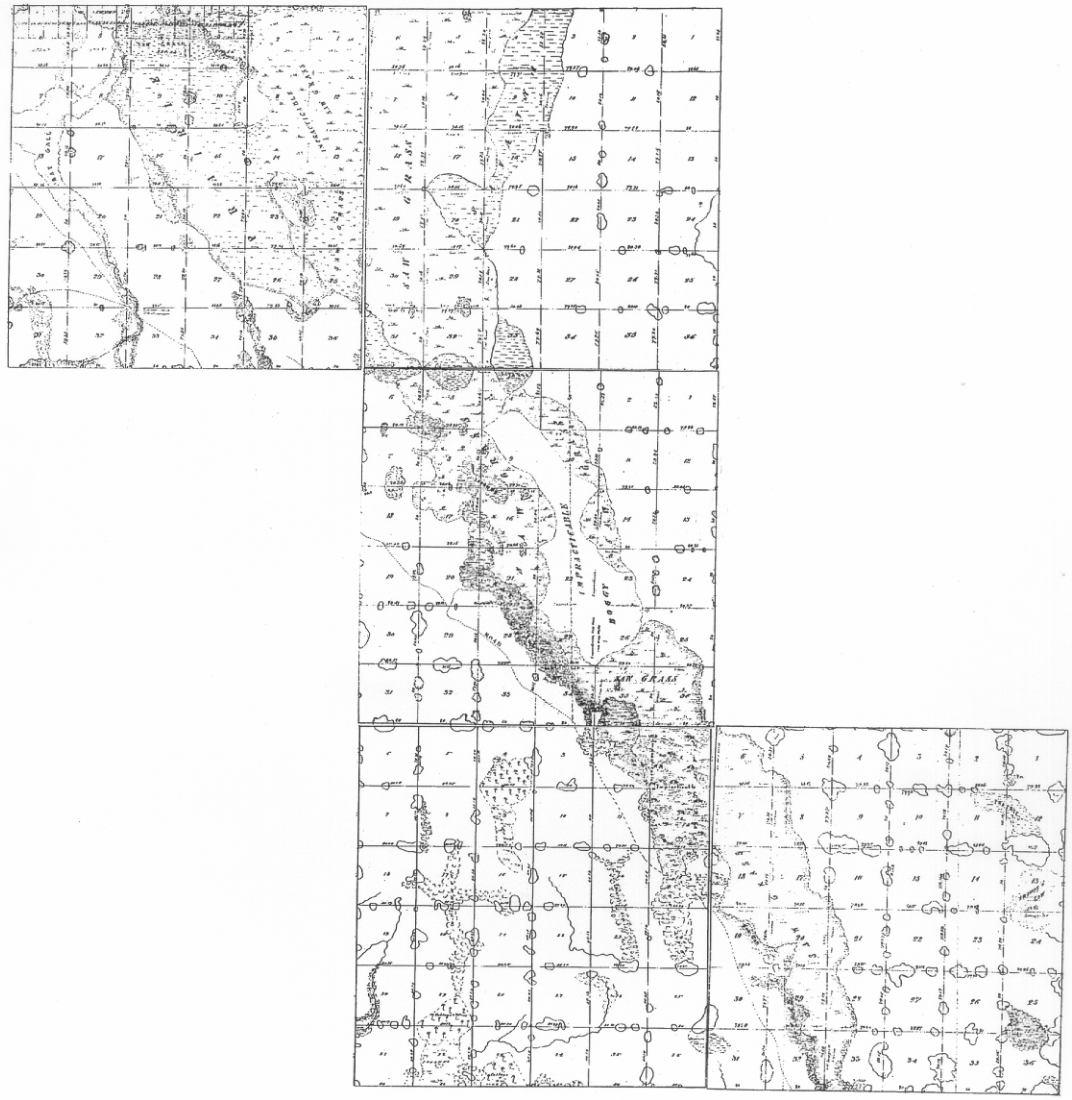


Figure A.2-7. Mosaic of Five Township Plats from Townships 37 to 39 S., Ranges 37 to 39 E., Showing Extensive Sawgrass Marsh, Too Dense and Wet, Hence “Impractible” to Survey. Surrounding swamp, and perhaps sawgrass area as well, referred to as “Halpatta Swamp,” Later Called the “Allapattah Flats.” Much of original extent has disappeared under drainage and cultivation.

Headwaters of the St. Lucie River

Figure A.2-8 is a township plat map that includes the South Fork of the headwaters of the St. Lucie River. It appears similar to the township plats mapping the North Fork (not shown; Townships 35 and 36, Ranges 39 and 40). It is tempting to assume that all of the "Prairie and Ponds" physiographic region present within the northern part od the watershed contributed surface run off to the North Fork of the St. Lucie River, and that the therefore flow through the North Fork was much greater than through the South Fork. While the North Fork likely passed more water than the South Fork, it is important to note that no actual evidence was found within the township survey plats or field notes documenting surface runoff. The difference between the two forks may be less than expected. There is some indication that the Halpatta Swamp / Allapattah Flats area may have been connected to the South Fork, but this certainly bears additional investigation.

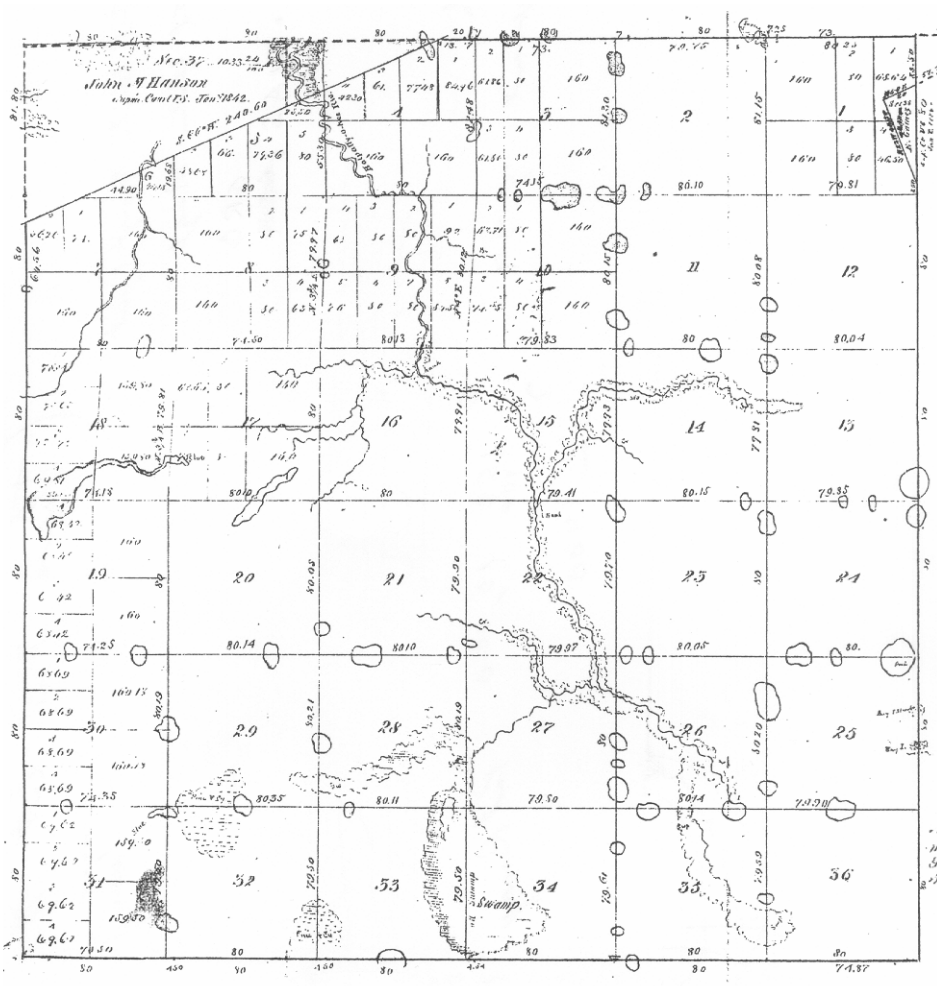


Figure A.2-8. Township **39** S., Range **41** E., Showing Several Branches of the South Fork of the St. Lucie River. Surveyed by M. A. Williams in June 1853.

Conclusions

The conclusions presented here are based on examination of field notes and plat maps, as described above, for five of approximately 30 townships making up the watershed. Plat maps for a number of additional townships were examined briefly. The author has not had the opportunity to explore the watershed in person.

Three main physiographic regions appear to have been present in the predrainage watershed: an area of Pine & Ponds mosaic, an area of Prairie & Ponds mosaic, and an area referred to as the Halpatta Swamp, later as the "Allapattah Flats." Ponds, whether of sawgrass, open water or "grassy species," appear to have been very common throughout the Pine and the Prairie areas. The difference in the non-pond "matrix" found in the Prairie compared to that found in the Pine areas is not completely clear, but the Prairie matrix appears to have been covered by standing water for longer periods each year, with as result a reduced density (in some places, complete absence) of pine trees.

All three physiographic regions appear to have been very flat, with the elevation difference between pineland and pond probably often as little as two feet. It is likely that the depths of the depressions varied, with the shallower depressions forming either open water or wet prairie-type ponds, and the deeper depressions accumulating peat deposits and supporting sawgrass vegetation. Once the deeper depressions had accumulated peat, the elevation difference between peat surface and surrounding pine land surface may have been similar to the elevation difference between pine land and the bottom elevation of the open-water, sand-based ponds.

The Prairie mosaic was described primarily in the northern portion of the St. Lucie watershed. The sawgrass marshes and bordering forested wetlands (Bay Galls and Cypress Swamps) that formed the Halpatta Swamp were present along the western edge of the watershed, along the eastern foot of the high NW-SE trending ridge. Cypress occurring in pond-like patches seems to have been confined to the southernmost townships of the watershed.

Although there appears to have been variation in spatial pattern and apparent interconnection between the ponds present in the watershed, generally there does not appear a strong suggestion of extensive connection nor of extensive surface runoff. The most important contribution of the watershed to St. Lucie River may have been more through groundwater contribution to baseflow than through surface runoff. The long duration of standing water in ponds and even longer duration in the sawgrass marshes may be of assistance in estimating duration of the baseflow recession during each year's dry season.

The presence of extensive surface water throughout the watershed, the probably limited degree of surface runoff, and examination of townships surrounding the headwaters of the North and South Forks of the St. Lucie River tentatively suggest that the difference in discharge between the two forks may be smaller than might at first appear.

References

Davis, J. H., Jr. 1943. The natural features of southern Florida. Geol. Bull. 25. Fla. Geol. Surv., Tallahassee. 311 pp.

Florida. Surveyor General's Office. 1853. A plat exhibiting the state of the surveys in the State of Florida with references. "Approved John Wescott Surv. Genl.". 18 miles to 1 inch (1:1,140,000). Surveyor General's Office, St. Augustine. 22 x 25 inches.

Hopkins, C. F. 1853. Field notes and plat map for U.S. Survey of Township 36 South, Range 37 East. Surveyed July, 1853. Florida. Surveyor General's Office, St. Augustine, Fla.

Jones, L. A., R. V. Allison, G. D. Ruehle, et al. 1948. Soils, geology and water control in the Everglades Region. Agric. Exp. Stat., Bull. 442. University of Florida Agricultural Experiment Station, Gainesville. 168 pp + 4 map; 3 + 38 sheets pp.

MacKay, G. 1846. Letter from G. MacKay to The Surveyor General of Florida. p. 475. In: Letters and Reports to Surveyor General, 1825-1847, ed. Transcribed by Dr. J. Knetsch, 1993. Florida. Dept. of Environ. Protection. Bur. Survey and Mapping, Tallahassee, Florida.

Matson, G. C., and S. Sanford. 1913. Geology and ground waters of Florida. Water Supply Paper 319. U.S. Geol. Survey, Washington, D.C. 445 pp.

Niblack, S. L. 1882. [Report on the boundary of the Okeechobee Drainage District. Lake City, Fla., June 27, 1882]. p. 191-195. In: Minutes of the Trustees, Dec. 18, 1882 Meeting. . Vol. III (1904). Trustees of the Internal Improvement Fund, Tallahassee, Fla. 524 pp.

Randolph, I., Cunningham, and Hallowes. 1919. [Report of surveys and studies of the North St. Lucie River Drainage District]. May 21, 1919. Isham Randolph and Co., and Cunningham and Hallowes [Eng. Co.], Jacksonville, Fla. 13 pp.

Reyes, W. J. 1855. Field notes and plat map for U.S. Survey of Township 40 South, Range 38 East. Surveyed Jan. & Feb., 1855. Florida. Surveyor General's Office, St. Augustine, Fla.

Reyes, W. J. 1855. Plat map for U.S. Survey of Township 40 South, Range 38 East. Surveyed Jan., 1855. Florida. Surveyor General's Office, St. Augustine, Fla.

Stephens, J. C., and L. Johnson. 1951. Subsidence of organic soils in the Upper Everglades region of Florida. Soil Sci. Soc. Fla. Proc. 11: 191-237.

Williams, M. A. 1853. Field notes and plat map for U.S. Survey of Township 37 South, Range 38 East. Surveyed June, 1853. Florida. Surveyor General's Office, St. Augustine, Fla.

Williams, M. A. 1853. Field notes and plat map for U.S. Survey of Township 38 South, Range 39 East. Surveyed May & June, 1853. Florida. Surveyor General's Office, St. Augustine, Fla.

A.3: KISSIMMEE RIVER BASIN

Reference Conditions for the pre-Channelized Kissimmee River excerpted from

Volume II- Kissimmee River Restoration Studies DEFINING SUCCESS: EXPECTATIONS FOR RESTORATION OF THE KISSIMMEE RIVER

Edited by David H. Anderson, Stephen G. Bousquin,
Gary E. Williams, and David J. Colangelo

Technical Publication ERA #433
November 2005

The Kissimmee River Restoration Study (SFWMD 2006) defines a reference condition as "representative of the pre-channelization condition, or the best attainable estimate of the pre-channelization condition." Reference conditions for the Kissimmee River are described in the following pages.

CONTINUOUS RIVER CHANNEL FLOW

Reference Condition

Pre-channelization reference conditions were based on mean daily discharge at S-65 (Water Years 1935–1962) and for S-65E (Water Years 1930–1962). At S-65, the number of days of zero discharge was 0 d in every water year except one (Figure 1-1, not provided, see web site). At S-65E, the number of days with zero discharge was 0 d for each reference period. During October 1956, six days of reverse flow into Lake Kissimmee followed 16 in. of rainfall in two days. Severe drought conditions existed prior to this storm, and constructed levees along the river reduced the floodplain width to 400 ft in some downstream areas. The heavy rainfall and constricted floodplain caused reverse flow from the river to Lake Kissimmee. Low flows typically occurred during April and May (Toth et al. 1995; 1997). Headwater inflows contributed approximately 60% of the flows through the Kissimmee River, while tributary contributions represented about 40% of historical discharges.

Table 1-1. Mean number of days that zero discharge occurred at S-65 during 1971 to 1998.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
8	4	5	2	2	13	14	10	9	14	15	12

MEAN FLOWS

Reference Condition

Reference conditions were derived from daily discharge data at historic river channel gages at the outlet of Lake Kissimmee (near existing location of S-65) and near Lake Okeechobee (near existing location of S-65E) from 1933 to 1960. Historic mean monthly flows (Figure A.3-1(A)) were highest during September through November and lower from January through June. Interannual variation of historic monthly flows (Figure A.3-1(B)) indicates minimal differences between months, with the largest variation occurring in June at the downstream gage near Lake Okeechobee. Figures A.3-1(A)) and A.3-1(B)) include estimated historic data at the existing location of S-65C [S-65C (est.)], which represents reference conditions for the lower portion of the first phase of restoration. These data were estimated using historic daily discharge at the outlet of the Kissimmee River basin (S-65E) and the ratio of drainage basin areas associated with these locations.

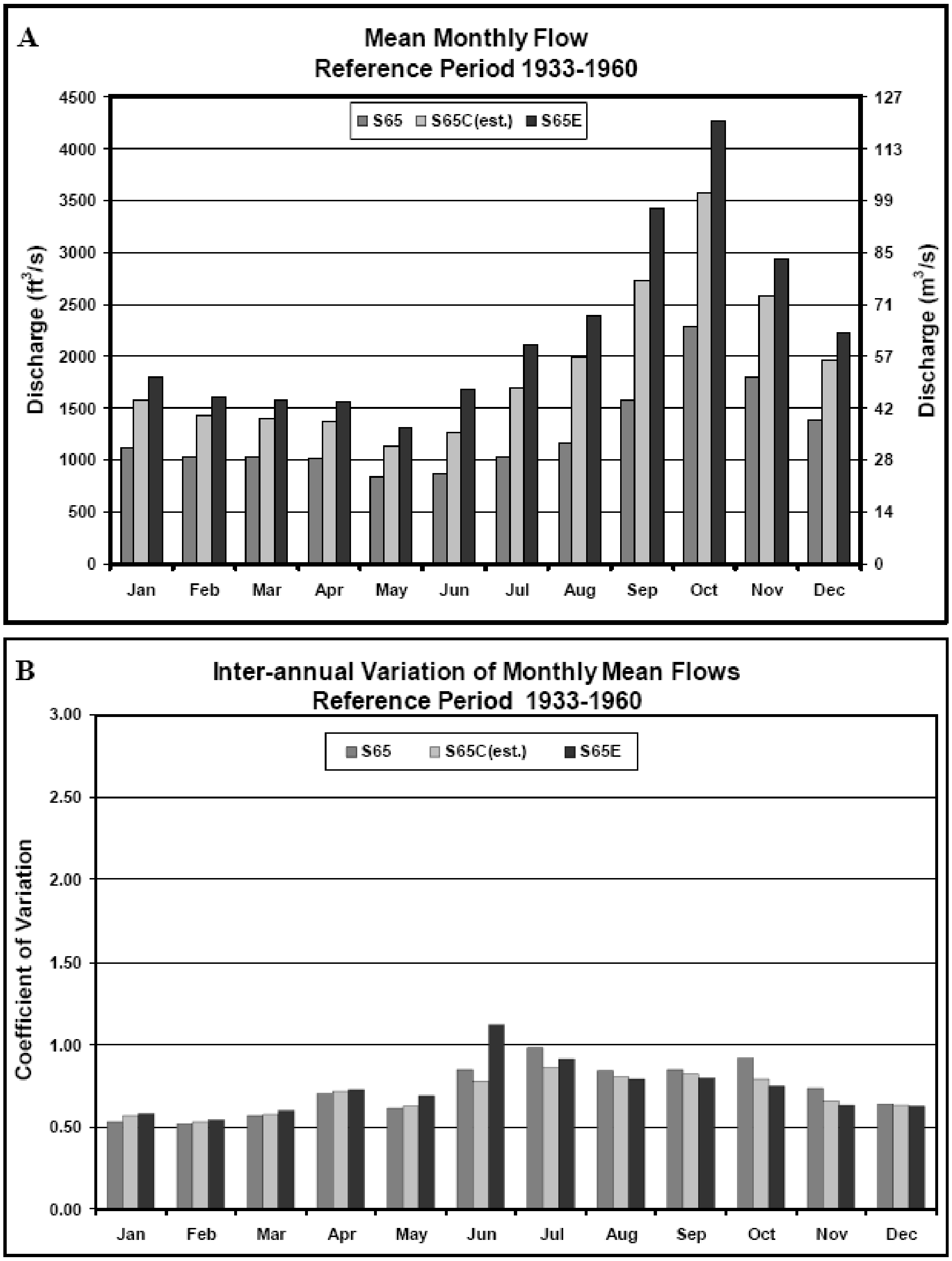


Figure A.3-1. (A) Historic mean monthly flows along the Kissimmee River. (B) Historic year-to-year variation of monthly mean flows along the Kissimmee River.
S-65 represents flows at the outlet of Lake Kissimmee. S-65E represents flows near Lake Okeechobee. S-65C (est.) represents estimated flow conditions for the lower portion of the first phase of restoration.

RIVER CHANNEL VELOCITIES

Reference Conditions

Reference conditions were derived from the U. S. Geological Survey (USGS) historic stream gauging data at the Kissimmee River below Lake Kissimmee (USGS site 2269000) and at the Kissimmee River near

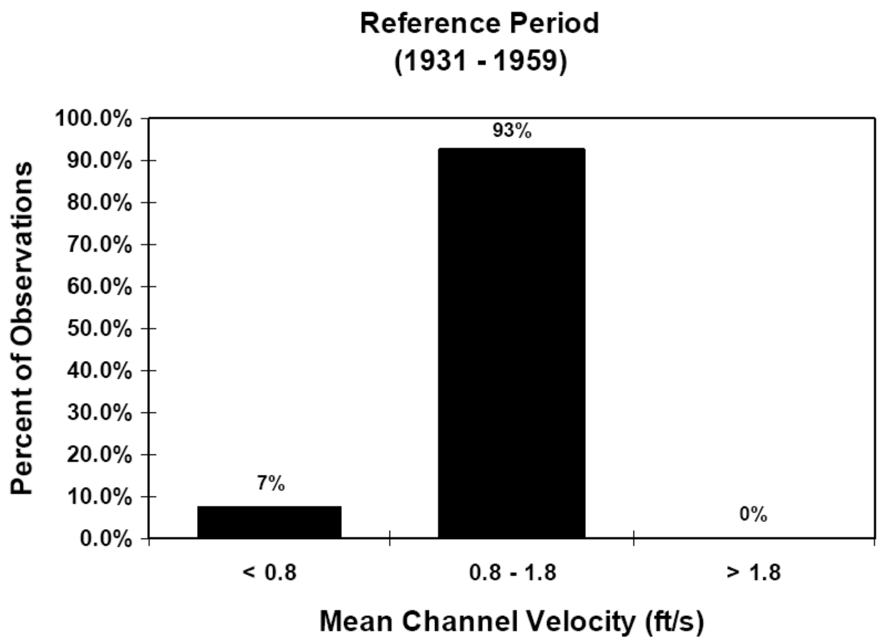


Figure A.3-2. Frequency distribution of mean channel velocities near Fort Bassinger (n=24) and downstream of Lake Kissimmee (n=155).
Data were collected during stream gauging events and are not from continuous monitoring.

Cornwell/Bassinger (USGS site 2272500). A total of 342 measurements were collected between 1931 and 1959 (309 below Lake Kissimmee and 33 near Cornwell/Bassinger). Of these measurements, 179 were rated fair to excellent by the USGS and were used to derive mean velocities in the main river channel, which ranged between 0.8 to 1.8 ft/s (0.2 to 0.6 m/s) during 93% of these sampling events (Figure A.3-2). Main channel discharges associated with velocities between 0.8 to 1.8 ft/s (0.2 to 0.6 m/s) ranged from approximately 100 to 2100 ft^3/s (3 to 59 m^3/s), with flows exceeding 500 ft^3/s (15 m^3/s) during 88% of the sampling events.

STAGE HYDROGRAPH

Reference Conditions

Reference conditions were based on mean daily stage at Fort Kissimmee (Water Year 1943 – 1962), Fort Basinger (Water Year 1933–1959), and S-65E (Water Year 1931–1962). During the reference period, boxplots for the inundation metric overlapped broadly for Fort Kissimmee, Fort Basinger, and S-65E (Figure A.3-3). This overlap suggested that a threshold could be established for any station. For inundation, the 25th percentile was at least 180 d, so a reasonable expectation would be for inundation to be 180 d in most years. Boxplots for the change in stage metric for the reference period also broadly overlapped, which suggested that a threshold could be established for a desirable minimum fluctuation in stage for most years. The 25th percentile for change in stage during the reference period was 3.75 feet, so that a fluctuation in stage of 3.75 feet might be expected in most years.

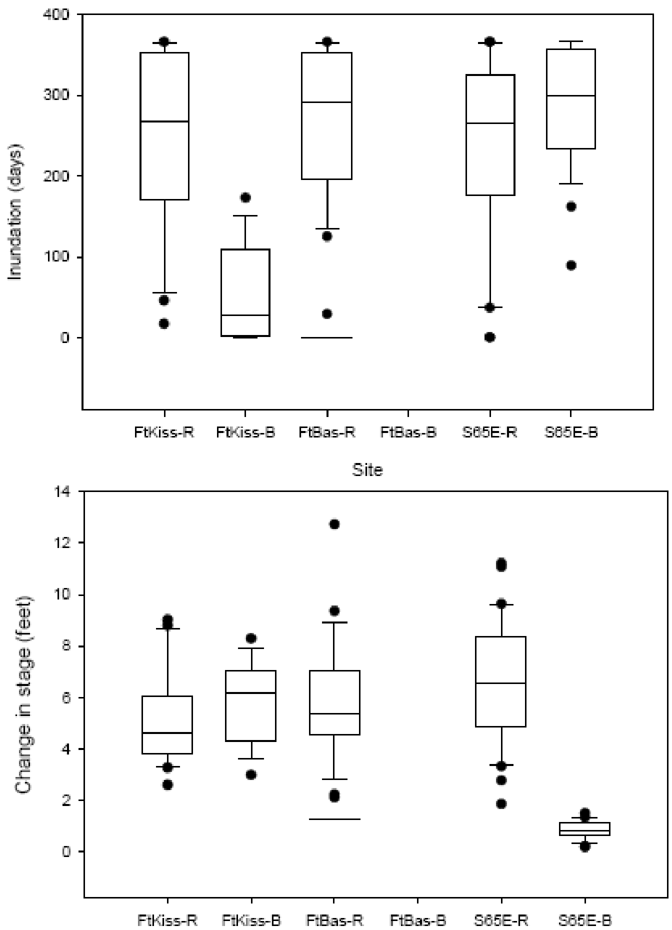


Figure A.3-3. Box plots for inundation (number of days that stage exceeds the average ground elevation in a water year) and the change in stage per water year.
Sites were Fort Kissimmee during the reference period (FtKiss-R) and baseline (FtKiss-B) periods, Fort Basinger during reference (FtBas-R) and baseline (FtBas-B) periods, and S-65E during reference (S65E-R) and baseline (S65E-B) periods. A box plot was not constructed for Fort Basinger during the baseline period because the single water year of data during the baseline period was insufficient.

STAGE RECESSION RATES

Reference Conditions

Reference conditions were derived from daily stage data at Fort Kissimmee (Figure A.3-4(b)) and Fort Basinger (Figure A.3-4(c)) from 1942 to 1959. Based on these data, peak stages typically occurred in September or ctober and slowly receded until May or June. Slow stage recession rates provided connectivity between the river and floodplain, which contributed to habitat diversity and functionality, and allowed for the transfer of food resources. Thirty-day recession rates were calculated by the difference in maximum and minimum stages for each recession event divided by the total number of days water levels receded, and multiplied by 30 days (Tables 4-1 and 4-2). Small increases in stage were ignored during prolonged recession events. However, if stage increased >1.5 ft (45 cm), the recession event ended and another event began.

The duration of recession events at Fort Kissimmee (Table 4-1) ranged from 66 to 359 days and averaged 218 days. Stage recession rates ranged from 0.26 to 1.39 ft (8 to 42 cm) per 30 days. Only 1 of the 17 recession events exceeded 1.0 ft (30 cm) per 30 days. In April 1951, a dry season rainfall event caused stages to rise briefly before receding to a seasonal low in June. This recession event lasted 66 days, with water levels receding at a rate of 1.39 ft (42 cm) per 30 days.

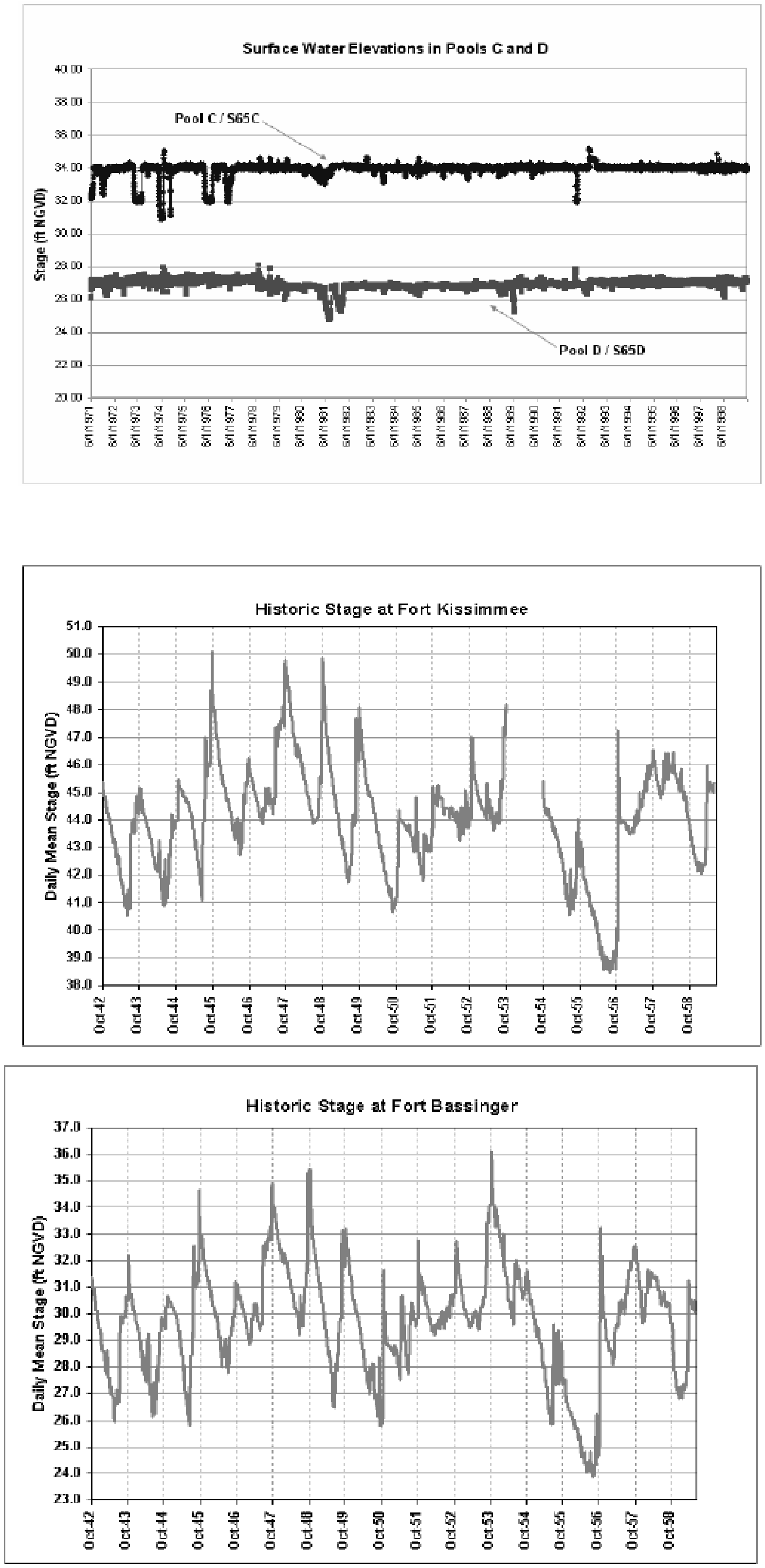


Figure A.3-4. (a) Daily surface water levels at S-65C and S-65D along C-38. (b) Historic daily surface water levels at Fort Kissimmee. (c) Historic daily surface water levels at Fort Basinger.

The duration of recession events at Fort Basinger (Table 4-2) ranged from 16 to 355 days and averaged 173 days. Stages receded at a rate that ranged from 0.27 to 1.93 ft (8 to 59 cm) per 30 days. Rates of 7 of the 22 recession events exceeded 1.0 ft (30 cm) per 30 days and were associated with unusual weather conditions. Three events (April 1944, April 1951 and October 1957) resulted from aberrant dry season rainfall, which caused stages to rise briefly before receding to a seasonal low in June. During the recession event of 1948–1949, stage decreased by 8.9 ft (271 cm) and followed two extremely wet years that were due to hurricanes in the Kissimmee valley. In 1955–1956, two of three recession events had short durations (<20 days) and occurred early in the wet season prior to the normal seasonal stage recession period from September to May. The October 1956 to February 1957 event lasted 121 days and occurred during a severe drought, which was followed by rainfall that caused stages to increase until October 1957.

RIVER CHANNEL BED DEPOSITS

Reference Condition

Prior to channelization, the river bed substrate was composed primarily of deposits of fine and medium-grained sands intermixed with shells, silt, and clay that were laid down during the late Miocene/Pleistocene epochs (Warne et al. 2000). In baseline core samples from Control and Impact areas, the substrate beneath the accumulated organic/marls deposits was primarily sand (Anderson et al. 2005).

Because pre-channelization data were not available, data collected during the Kissimmee River Demonstration Project (1985–1988) (Toth 1991; 1993) were used as the reference condition for expected changes in substrateoverlying deposits. During the Demonstration Project, weirs were used to divert up to 60% of the flow through the C-38 canal to each of three remnant river channels (R1, R2, and R3) in Pool B (Toth 1993). Between April 1985 and December 1988, each remnant channel had flow >26 m^3/s, which approaches bankfull discharge, for 233–307 days (Toth 1991). River channel sediments were characterized by collecting core samples using similar methods to those used for the baseline study on 24 transects across these remnant river channels. Transects were sampled one time before reestablishing flow, and up to six times after flow was reestablished, which allowed the tracking of changes in the three metrics used for the baseline study. Mean thickness of the substrate-overlying deposits declined from 15 cm to 5 cm, a 67% reduction (Figure 6-1 not provided, see web site). Percent of samples without substrateoverlying deposits increased from an average of 21% to 56%, an increase of 167%. The thickness of substrateoverlying deposits at the thalweg decreased by 70% from an average of 30 cm to 9 cm. These reference values are likely to be conservative estimates of the condition of the river bed substrate before channelization because these metrics continued to change (Figure 6-1 not provided, see web site) and because the magnitude and duration of flow was less than what was observed prior to channelization. Achieving these values within three years of reestablishing flow indicates the eestablishment of processes that determine river bed substrate characteristics. These processes will likely continue until the channel adjusts to the restored flow conditions.

AREAL COVERAGE OF FLOODPLAIN WETLANDS

Reference Conditions

Pre-channelization aerial photography (1952–1954) data (adjusted from Pierce et al. 1982) indicate that, prior to channelization, wetland plant communities covered approximately 81% of the floodplain in the restoration and control areas of Pools A–D, 83% of Pool C alone, and 80% of the area slated for restoration in construction Phases I– IV (Table A.3-1). The restoration-area pre-channelization data were used to predict the expected minimum of 80% wetland coverage following restoration of flow and inundation.

AREAL COVERAGE OF BROADLEAF MARSH

Reference Conditions

Pre-channelization (1952–1954) data (adjusted from Pierce et al. 1982) indicate that BLM covered approximately 49% of the area that will be affected by all phases of the restoration project (Table 13-1 not provided, see web site). The pre-channelization restoration-area data, adjusted as described below, were used as reference conditions to obtain the value of 50% BLM coverage predicted by this expectation.

Table A.3-1. Areal coverage of wetlands and other general vegetation categories by restoration phase. The 1952 pre-channelization data (Pierce et al. 1982) were used to predict the expected effect of restoration on wetland area. The 1974 data (Milleson et al. 1980) were used for whole-system channelized-condition (baseine) estimates).

		Area (ha)		Percent of restoration area	
Phase	Status	1952	1974	1952	1974
Phase I	Aquatic	61	36	0.6	0.3
	Non-vegetated	210	561	2.0	5.4
	Unknown	20	0	0.2	0.0
	Upland	402	2414	3.8	23.1
	Wetland	3154	836	30.1	8.0
Phase II/III	Aquatic	115	68	1.1	0.7
	Non-vegetated	461	961	4.4	9.2
	Unknown	17	1	0.2	0.0
	Upland	389	2019	3.7	19.3
	Wetland	3405	1337	32.5	12.8
Phase IV	Aquatic	25	50	0.2	0.5
	Non-vegetated	120	219	1.1	2.1
	Unknown	6	0	0.1	0.0
	Upland	186	661	1.8	6.3
	Wetland	1354	761	12.9	7.3
Phase IVA	Aquatic	8	12	0.1	0.1
	Non-vegetated	65	122	0.6	1.2
	Unknown	2	0	0.0	0.0
	Upland	33	185	0.3	1.8
	Wetland	439	228	4.2	2.2
Grand Total		10472	10472	100	100

AREAL COVERAGE OF WET PRAIRIE

Reference Conditions

Pre-channelization data based on mapping of 1952 to 1954 aerial photography (adjusted from Pierce et al. 1982), indicate that Wet Prairie communities comprised approximately 22% of the areas of Pools B–D slated for restoration in construction Phases I–IV (Table 14-1 not provided, see web site). These pre-channelization restoration-area data, adjusted as described below, were used as reference conditions for predicting post-restoration recovery of Wet Prairie to 17% of the restored system.