Chapter 2: Hydrologic Needs – Effects of Hydrology on the Everglades

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SUMMARY

This year's report on hydrology focuses on Water Year 2000 hydrologic patterns in relation to water management, biological processes and ecological restoration of the greater Everglades system. Previous reports reviewed antecedent conditions and suggested numerous hydrologic relationships with plants, soils, salinities and wildlife. The importance of these relationships continues to be explored experimentally in greenhouses, rhizotrons and mesocosms, synoptically along transects in Water Conservation Areas and Florida Bay, and analytically with ecological models, such as the Everglades Landscape Model.

This year's hydrology was dominated by Hurricane Irene (Oct. 15, 1999) and by a general lack of rain the rest of the year. Total rainfall for the Water Year 2000 was on average, 3 to 5 inches below normal. Hurricane Irene created high water during the wet season that persisted well into the dry season. In fact, without Hurricane Irene, the dry season might have produced severe muck burns, habitat destruction and loss of wildlife throughout much of WCA-3. Instead, the lack of rain was seen as an opportunity to draw down Lake Okeechobee (to increase water clarity and increase the growth and recruitment of submerged aquatic vegetation).

This year was also one of emergency operations (ISOP) associated with preventing the high water of Irene from entering the Park and disrupting the nesting success of the Cape Sable Seaside Sparrow. The Biological Opinion, rendered on February 1999 by the Fish & Wildlife Service, required the Corps of Engineers to take certain operational adjustments to maximize the potential for sparrow breeding. In particular, the western-most population, Subpopulation A, required that water levels remain below 6.0 feet at the NP-205 water level gage for 60 consecutive days between March 1 and July 15, 2000. This was not accomplished due to two distinct rainfall events that temporarily increased water levels and disrupted the dryout period short of the goal.

Despite the sparrow's nesting problems, there was a 42 percent increase in the number of wading bird nests throughout the interior Everglades compared to last year. It

was once thought that such nesting success would only occur after several very dry years. However, the increased nesting this year followed several very wet years. While things look better for wading birds, there are still problems and information gaps. Nesting in coastal regions has not improved, the number of nests in the Park is still extremely low, numeric nesting targets for all wading birds (except Great Egrets) have not been met, and Roseate Spoonbills have shifted their large colony location from the Northeast part of Florida Bay to the Northwest region for unknown reasons.

This year marked the beginning of a tree island research program and the conclusion of a detailed analysis of cattail and sawgrass growth patterns in relation to hydrology and nutrients. Dendrometer bands, designed to measure changes in tree diameter at breast height (dbh) and estimate tree growth rates were attached to 342 individual trees on 18 different tree islands. Growth responses, litterfall, soil chemistry, photosynthesis, plant and animal community structure, groundwater interactions, and peat accumulation rates are all new tree island parameters designed to understand tree island importance, sustainability, and restoration. Meanwhile, under very exacting, controlled environments, it was shown that cattail can survive and likely displace sawgrass under high water conditions because cattail can pump air down to its roots to compensate for low oxygen concentrations. Sawgrass has only a passive diffusion mechanism for moving air to its roots. However, it was also discovered that this greater flooding tolerance of cattail comes at an energetic cost and this cost requires additional phosphorus. This could be why the N:P ratio of cattail plant tissue increased at low phosphorus concentrations.

Ground elevation in the marl prairies of the Southern Everglades, formed primarily by bedrock, is nearly constant over time. Water depths in these prairies are, therefore, determined simply by regional water elevations. In the peat-based ridge and slough landscape, that is, WCAs 1, 2, and 3, and Shark Slough, the situation is very different. Peat microtopography is pervasive, affecting relative water depths, vegetation, aquatic versus emergent ecological niches, and hydraulic resistance to water flow. Many of the studies included in this report illustrate the importance of peat-based elevation differences. Unlike the stable substrate of the marl prairies, peat microtopography is inherently unstable. A carbon balance model (SFWMD, 2000) suggests that persistence of the adjacent niches created by differing ridge and slough elevations appears to require not only particular hydropatterns, but also downstream transport of carbon. If flocculent matter proves to be a significant component of the downstream transport, then any impedances, especially to transient, high velocity flows, will affect persistence of peat microtopography and the associated ecology it supported. Structures such as bridges, culverts or weirs may not greatly restrict low velocity water flows. However, such structures may significantly reduce particulate transport and high velocity flows.

Progress toward understanding submersed aquatic vegetation in Florida Bay has also been made. It was previously thought that as Everglades restoration progressed, increased freshwater flow to the Bay might stress *Thalassia* seagrass beds by lowering salinity. However, healthy populations of *Thalassia* (turtlegrass) have been measured in areas of maximum Everglades freshwater inflows, despite periodically low salinities and dark, tannin-colored waters. *Thalassia* primary production does not appear to be light limited by Everglades waters, which contain few light-absorbing particulates. However, light limitation has been observed in *Thalassia*, caused by a combination of carbonate particulates from marine waters and, in certain central Bay areas, phytoplankton blooms. The source of blooms in Central Florida Bay remains uncertain.

Finally, models for environmental management and hydrologic restoration have become more formalized and used. The Everglades Landscape Model was successfully calibrated for systemwide water quality and is now being used to evaluate alternatives associated with Modified Water Deliveries to Everglades National Park. Conceptual models for eight regions in the Everglades have been incorporated into the Comprehensive Everglades Restoration Plan (CERP). These have been used to develop ecological performance measures, monitoring goals, research plans and restoration targets.

INTRODUCTION

The 1999 Everglades Interim Report focused on the state of the Districts' ecological, biological and geological knowledge of the Everglades in relation to historic drainage and current hydrology. This year's report on hydrology focuses on Water Year 2000 hydrologic patterns in relation to water management, biological processes and ecological restoration of the greater Everglades system.

This chapter is divided into three sections: (1) hydrologic trends; (2) ecological trends; and (3) tools for hydrologic management. The hydrology section examines rainfall, flows, stage, Hurricane Irene, and the ISOP for the last year, and discusses pre-drainage hydrology of the Everglades basin. The second section, the impacts of altered hydrology, will examine current accounts of ecological impacts of altered hydrology in the Everglades gleaned from experiments and ongoing research programs. The third section, tools for management, will focus on the state of the Everglades Landscape Model (ELM) and the process of using regional conceptual models for the development of restoration performance measures.

HYDROLOGIC TRENDS

Historic hydrologic trends, detailed in previous consolidated reports, explained how drainage of the Everglades was able to reduce water tables up to nine feet, reverse the direction of surface water flows, alter vegetation, create abnormal fire patterns, and induce high rates of subsidence. These changes were initiated by lowering of Lake Okeechobee levels beginning in 1883 and exacerbated by construction between 1910 and 1920 of four major canals (Miami, North New River, Hillsboro and West Palm Beach). Other significant hydrologic alterations included the levee around Lake Okeechobee and construction of the Tamiami Trail. The initiation of the C&SF Project for Flood Control in 1947 created a system of levees and borrow canals, essentially complete by 1963, that created a highly compartmentalized landscape. This allowed water levels to be raised, reducing peat oxidation and fires within what are now the Water Conservation Areas (WCAs), but eliminating uninterrupted overland sheet- and slough-flow through the Everglades. In addition to eliminating virtually all but the structure-related flows, compartmentalization has induced ponding in the southern regions of each WCA, increased the frequency and intensity of peat/muck fires in northern regions of WCAs, and created a hydrologic environment dominated by flows along levee edges, in borrow canals, and through water control structures.

Despite these extensive alterations, the District attempts to sustain a more natural hydroperiod throughout the Everglades by maintaining distinct wet and dry seasons and by increasing water deliveries to Everglades National Park. The recent hydrologic trends, summarized below, compare the 2000 Water Year (WY) with the 30-year average. A Water Year is defined as beginning 1 July (the start of the wet season) and ending 30 June (the end of the dry season). This definition differs from the May 1, 1999 to April 30, 2000 Water Year used in other chapters of this Report.

PRECIPITATION

Total annual rainfall for most of the Everglades Preserve Area was slightly below average in 2000 (**Table 2-1**). The average rainfall in WCA-1 was 5 inches below average. The average rainfall in WCA-3 was 2 inches below average. The Park rainfall was some 7 inches below the annual average. The north-south gradient to the rainfall pattern in South Florida, discussed in previous reports and reflected by the long-term averages, was not apparent in the 2000 data. The big difference for 2000 was the relatively high rainfall in WCA-2. WCA-2 was the only region with above-average precipitation.

Table 2-1. Total rainfall (inches) for Water Year 2000 in comparison to the average rainfall. SFWMD rain gauge stations for each region are shown in parentheses. Gauge locations are shown in **Figure 2-1.**

	WCA-1 (S5A_R)	***WCA-2 (S7_R)***	***WCA-3 (3A-S_R)***	***ENP (FLAMIN)***
Average (1997–1999)	55.94	47.77	50.76	45.12
2000	50.63	54.98	48.45	37.68

The annual trends indicate a consistent rainfall pattern (**Figure 2-2**). All regions experienced higher than average rain in 1995 and 1996, but it was WCA-3 that saw over 100 inches of rain. Curiously, WCA-3 is also the region that often receives the least amount of rain. In 1979, less than 30 inches fell at the 3A-S_R gauge in WCA-3. Current temporal patterns clearly show a downward trend throughout the Everglades since Water Year 1995. Despite an overall temporal consistency, a closer examination of the interannual rainfall variations indicates that any one region can be significantly different from all the others. For example, in Water Year 1986, all the WCAs received above average rainfall, while the Park received 20 inches below normal.

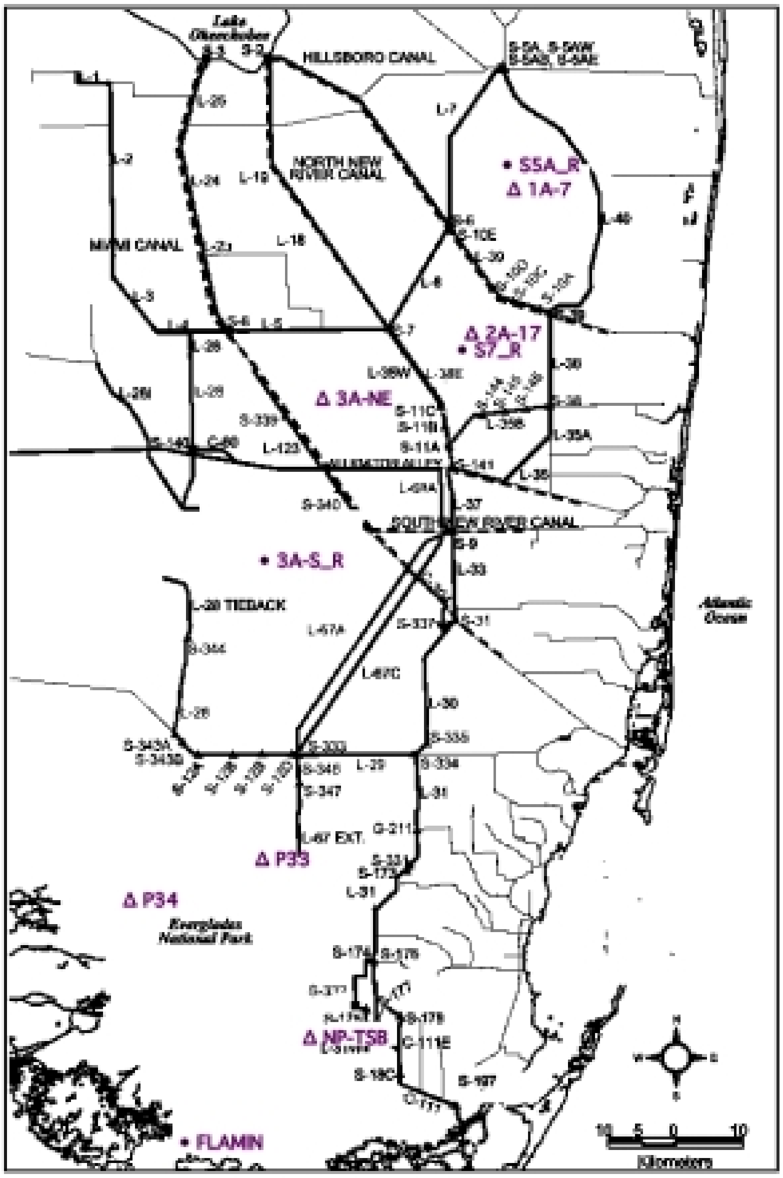


Figure 2-1. Map of the Everglades Protection Area showing the location of the major water control structures (S-#) and levees (L-#), as well as the four rain gauge sites (filled circles) and 6 stage recorders (open triangles) used in this analysis.

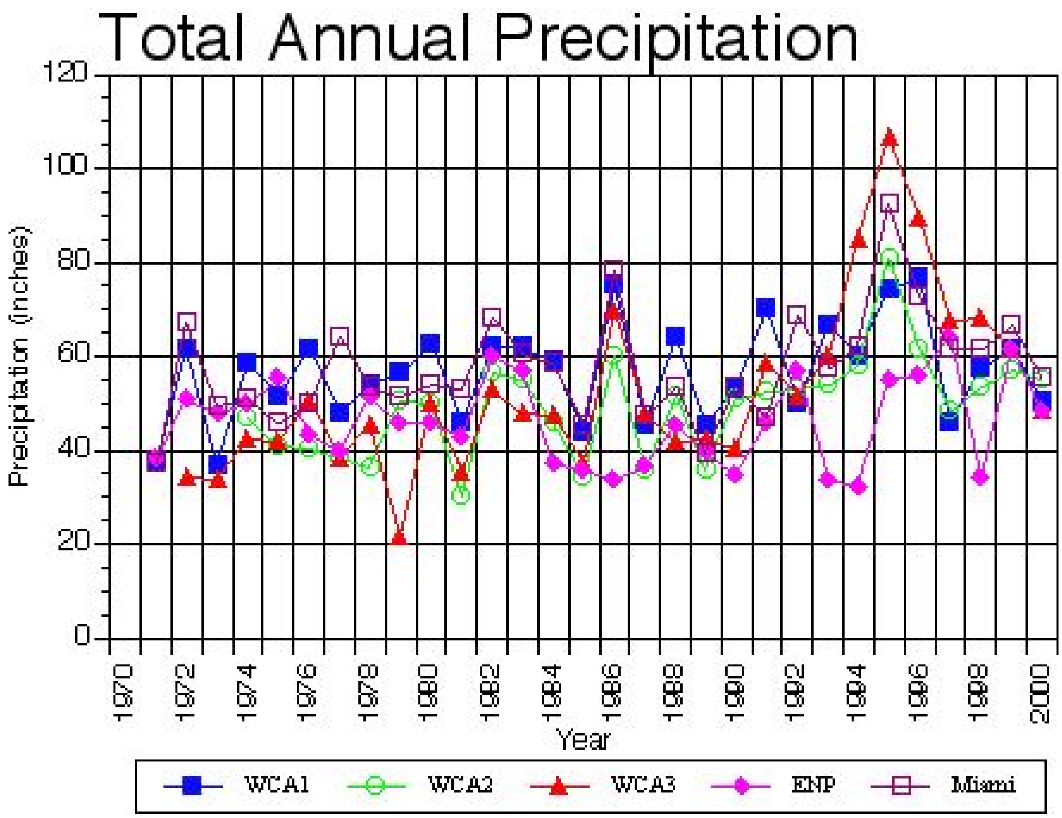


Figure 2-2. Total annual rainfall in the Everglades (refer to **Table 2-1** for gauge station names).

Of course, total annual rainfall is not the whole picture especially when restoration is concerned with managing for slow and steady draw-downs of water levels during the dry season and the reduction of very high water levels and ponding during the wet season. On average, the Everglades receives 1-2 inches of precipitation every week during the wet season, and 0.5-1 inch every week during the dry season. However, for 2000, the wet season rainfall pattern was event related (**Figure 2-3**). There were long periods of no rain, followed by short periods of high precipitation. The entire Everglades Protection Area experienced one very large October event (Hurricane Irene). In the Park, rain was sparse during the wet season, except for two very distinct periods. In Conservation Area-3, rain came as three pulses during the wet season and a pulse in the dry season. This dry season April pulse was a large-scale event and was responsible for reversing draw-down trends. This interfered with maintenance of water levels for Cape Sable Seaside Sparrow nesting as well as wading bird foraging.

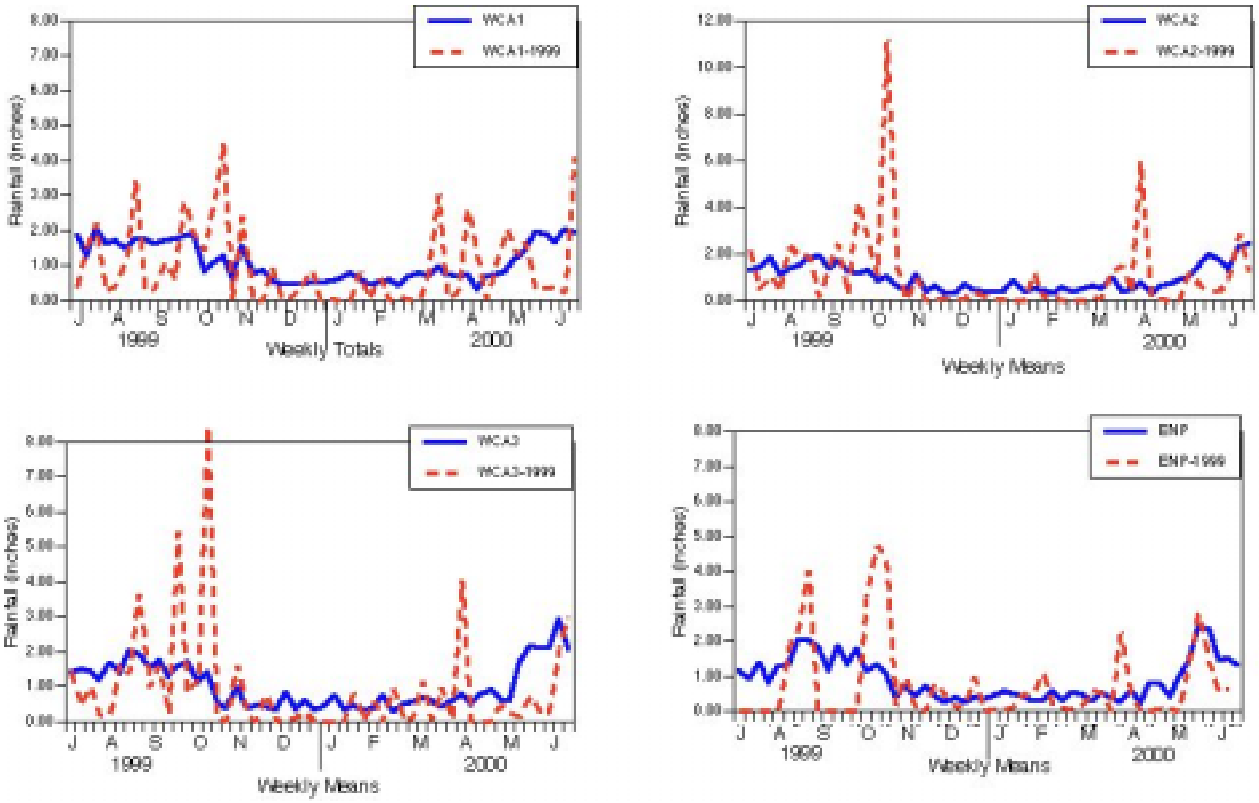


Figure 2-3. The Water Year 2000 rainfall pattern in comparison to the 30-year average in each region of the Everglades.

DISCHARGE

Total cumulative inflows from water management structures into each of the WCAs and the Park were above average in Water Year 2000 (**Table 2-2**). The most significant difference was in the Park. The 2000 structure inflows to the Park were 120 percent greater (1,066,801 ac-ft) than the 30-year average. The percent increases, relative to the average for WCA-1, WCA-2 and WCA-3, were 27, 11 and 27 percent, respectively. These increases appear to represent the combined effects of Hurricane Irene, a management strategy to increase water deliveries to Everglades National Park, and, to a small degree, a Lake Okeechobee recession to improve the lake's submersed aquatic vegetation (SAV). This recession was designed to increase light to the SAVs by reducing the lake's high water levels. This was accomplished in May by moving water to the estuaries and through the Everglades (WCA-1 and WCA-2).

The seasonal distribution of structure inflows in 2000 (**Figure 2-4**) reflected a management response to rainfall associated with Hurricane Irene. The District responded by pumping more water into each WCA, especially WCA-2. These structure inflows were almost twice the maximum reported in last year's consolidated report. This appears to have created a downstream cascade of water to the Park, albeit somewhat moderated by the time the water reached the Park. Water flows to the Park were not as pulsed as they were to the WCAs. However, the October weekly average of 8,000 CFS to the Park was almost three times the October 1998 average of 2,800 CFS. If the high discharge rates of October are removed from the seasonal trends for 2000, then one notices below average structure inflows in WCA-2 and WCA-3, average inflows for WCA-1, and higher than average inflows to the Park.

Table 2-2. Total inputs of freshwater (acre-ft) via water control structures in water-yr 2000 in comparison to the average structure inflows. Based on weekly average inflows (CFS), multiplied by seconds in a week (604,800) and divided by cubic feet in an acre-ft (43,560).

	WCA-1 [1]	***WCA-2*** [2]	***WCA-3*** [3]	***ENP*** [4]
Average (1970–1999)	623,898	550,403	1,115,220	826,194
2000	790,381	613,165	1,414,445	1,892,995

1 Stations = S5A, S5AS, S6,ACME1, ACME2, G251

2 Stations = S7, NSPRNG_C2A, S10E, S10D, S10C, S10A

3 Stations = S11A, S11B, S11C, G155, S140, S190, S9, S8, G204, G205, G206, S150

4 Stations = S332, S18C, S12A, S12B, S12C, S12D, S333, S175

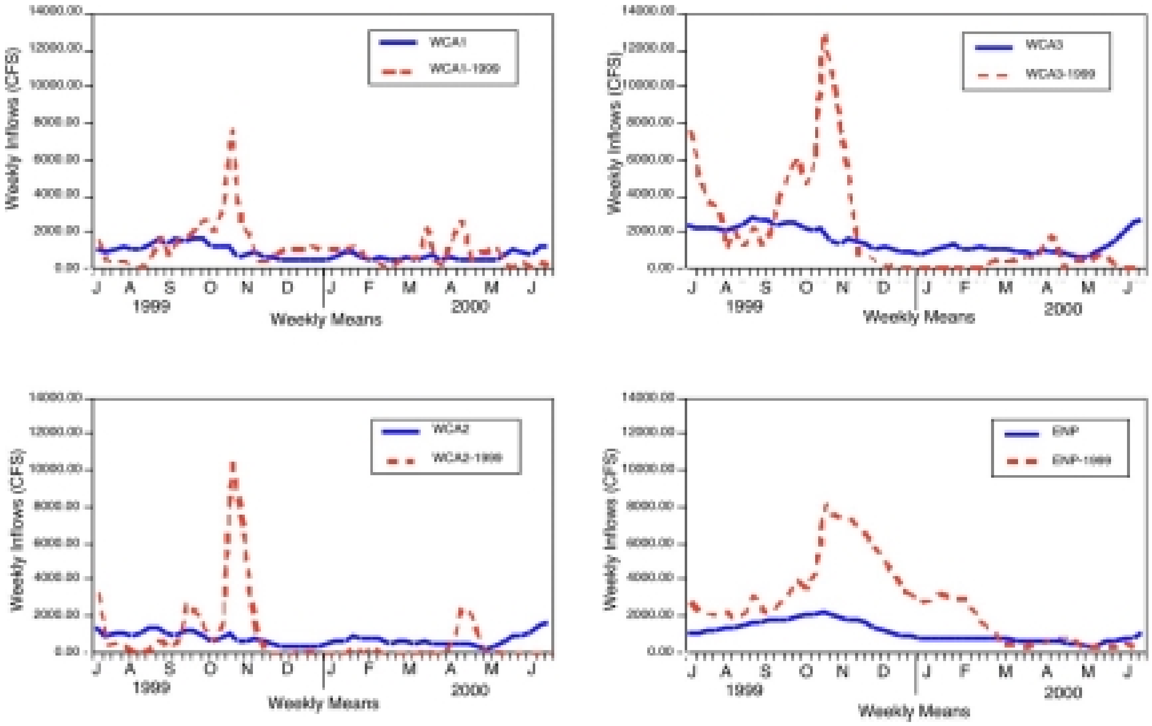


Figure 2-4. The Water Year 2000 structure inflow pattern in comparison to the 30-year average in each region of the Everglades.

STAGE (WATER LEVELS)

Average water depths in each of the WCAs were above average in WY 2000 (**Table 2-3**). It was interesting to see this trend because rainfall was generally below average (**Table 2-1**). These high water depth averages reflect the combined effects of Hurricane Irene, high structure inflows (**Table 2-2**), and management for slow recession rates in WCA-2 and WCA-3. WCA-1 water depth in WY 2000 was again (as it was last year) almost double the 30-year average due to relatively deeper regulation schedules for WCA-1 then were applied historically. Water depths in WCA-3 were significantly higher than the 30-year average because water management has changed. The 30-year average is more indicative of an era of fast drainage to prevent residential flooding and meet water supply needs. Data from the Park, showed a similar turnaround in the quantity of water and the same trend, especially at the Taylor Slough Bridge (NP-TSB). In the 1999 Everglades Interim Report, NP-TSB was identified as very hydrologically modified due to subsidence and a lack of overland flow. The District's Natural Systems Model v4.5 indicated that during the last 30 years, Park stations were significantly deprived of water due to water management. The Water Year 2000 depths were approximately one foot greater than the long-term average for most of the Park.

Table 2-3. Average water depths (ft) for WY 2000 in comparison to 30-yr average water depths. Based on 52 weekly means. Gauge locations are shown in **Figure 2-1.**

Area	*Gauge Station*	*Station Elevation (ft NGVD)*	*Average (1970 – 1999)*	*Average 2000*
WCA-1	1A-7	15.4	0.7	1.3
WCA-2	2A-17	11.1	1.4	1.7
WCA-3	3A-NE	10.2	0.1	1.2
Shark Slough	P33	5.1	1.0	1.8
Wet Prairie	P34	2.1	0.1	1.2
Taylor Slough	NP-TSB	3.5	-0.6	0.5

The weekly water depths, in comparison to the 1970-1999 weekly averages (**Figure 2-5**), indicated that the 2000 seasonal hydrologic pattern was substantially deeper during the wet season and significantly pulsed with higher than average depths during the dry season. The extreme high water during the wet season from Hurricane Irene altered the typically slow dry down trends from November until May. In WCA-1, the October extreme was quickly reduced to almost average depths in a matter of months due to releases of water to WCA-2. In WCA-2, the October extreme of 2.5 feet above average was the highest in the region. Discharges to WCA-3, the Park, and to tide reduced this extreme to 0.5 feet below average by March. If it weren't for the April storms, the WCA-2 region would have experienced a typically dry-down by June.

In WCA-3, the October extreme receded very slowly, and until April looked like a very “natural” Everglades hydropattern. However, the April storms followed by very dry conditions converted this trend in WCA-3 into something of a “pulsed” event. Similar things can be said about the Park hydropattern. The Park sites start off with similar WCA trends; however, at the Taylor Slough Bridge, water levels stay relatively high until March when, in a short period of time, water levels drop to zero.

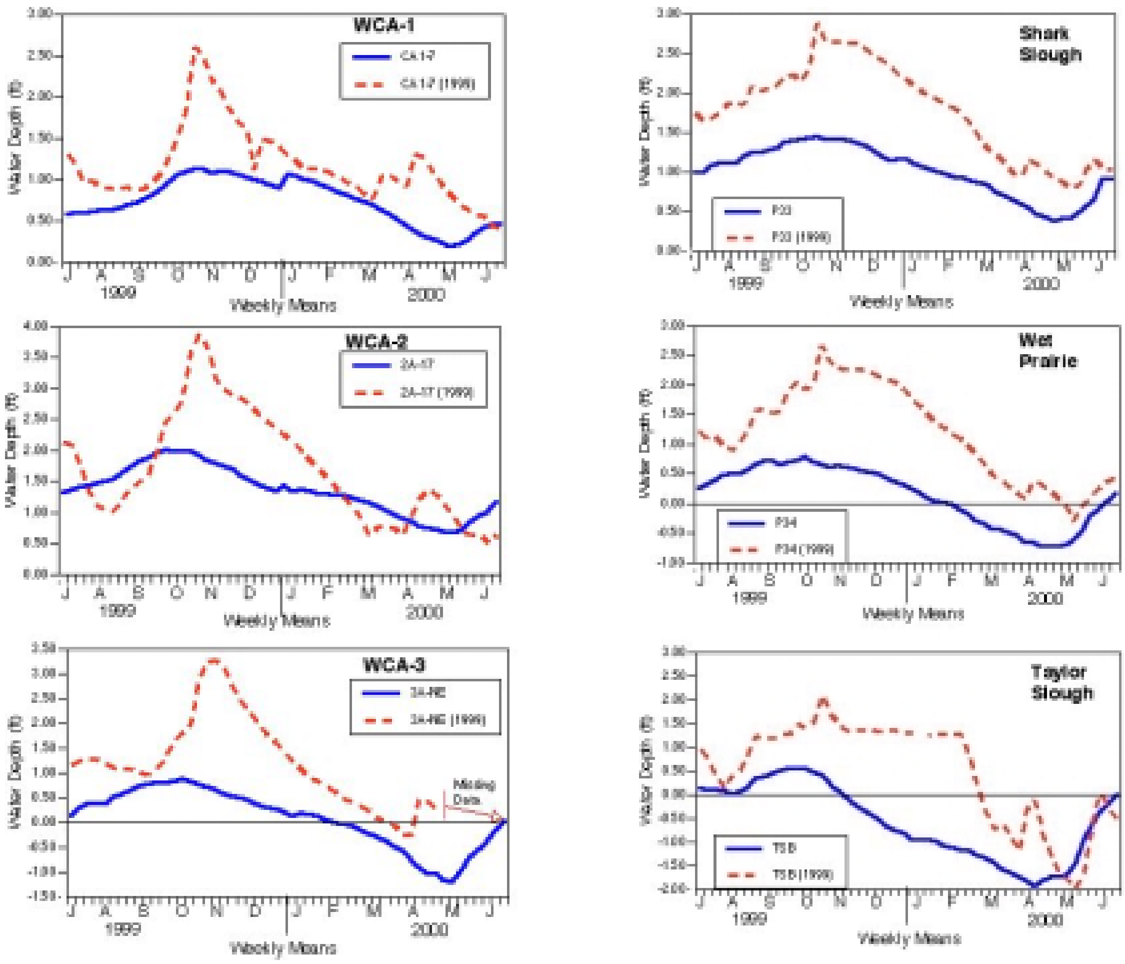


Figure 2-5. The WY 2000 depth pattern in comparison to the 30-year average in each region of the Everglades.

HURRICANE IRENE

On October 15, 1999, Hurricane Irene dropped over nine inches of rain, on average, over Palm Beach, Broward and Miami-Dade Counties. The three-day totals at specific measuring sites ranged between 11 and 17.5 inches. The path of the hurricane took it on a southwest to northeast track through the Everglades. **Figure 2-6** shows radar estimates of the accumulated rain as the hurricane passed over Southeast Florida. Some areas of Miami-Dade County show daily accumulation of rain of up to 6 inches. Above-average antecedent conditions contributed to the severity of Irene's impact. The antecedent conditions compounded by rainfall from Irene made the 1999 wet season the third wettest since 1960. An evaluation of the frequency of the rainfall associated with this event has not been done.

The rainfall associated with Irene resulted in an extreme rise of water levels in the Everglades. **Figure 2-7, left,** shows the hydrograph for Everglades National Park gage NP-205, located on what was originally the Ochopee Marl Prairie, west of Shark River Slough, and approximately 10 miles south-southwest of the S-12A structure on Tamiami Trail. **Figure 2-7, right**, shows the hydrograph for gage NTS1, located at the eastern edge of Everglades National Park, near the L-31W canal and two miles north of where S-332 discharges flood waters directly into Everglades National Park. The water level rise at both gages is similar, 0.8 and 0.9 ft, apparently independent of the proximity to water control facilities, and similar in magnitude to the rainfall. However, the recession limb is noticeably steeper for the eastern gage (NTS1). This is the expected drainage effect of the canal system along the eastern edge of the Everglades National Park.

The operational objectives of the Central and Southern Flood Control Project in place before, during, and after Irene are established in the Water Control Manuals. In particular, the Environmental Assessment for the *Experimental Program for Water Deliveries to Everglades National Park, Test Iteration 7,* lays out the operating rules for the South Dade Conveyance System. For South Miami-Dade County, the test objectives were to evaluate methods to restore a more natural hydroperiod to ecosystems within ENP, including northeast Shark River Slough (NESRS) and Taylor Slough, enhance flow to Florida Bay via Taylor Slough, and reduce large freshwater discharges through S-197 into Manatee Bay and Barnes Sound "to the degree possible without compromising flood control."

Inflows to Everglades National Park. Rain from Hurricane Irene produced canal water levels that triggered flood control releases into Everglades National Park. Water releases into the Park were made through the S-12s, S-332D via L-31W overflow, S-332, S-175, and S-18C via lower C-111. Undesired but necessary releases were made from S-197 to Barnes Sound. Maximum discharges, as allowed under the operating rules, were made to the Park and Barnes Sound through these structures, as detailed in **Table 2-4**.

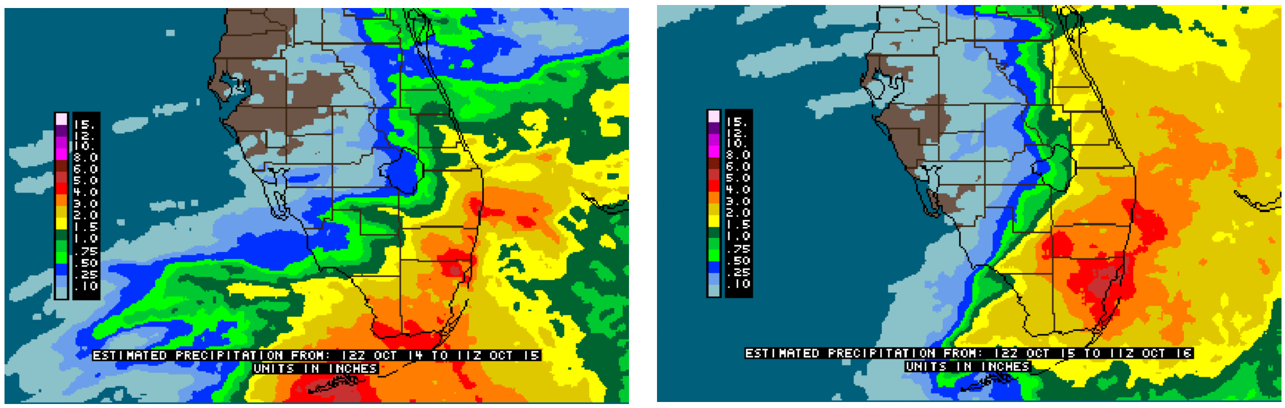


Figure 2-6. Estimated accumulated rain for (a) 24-hour period starting October 14 at 8 a.m., and (b) 24-hr period starting October 15 at 8 a.m.

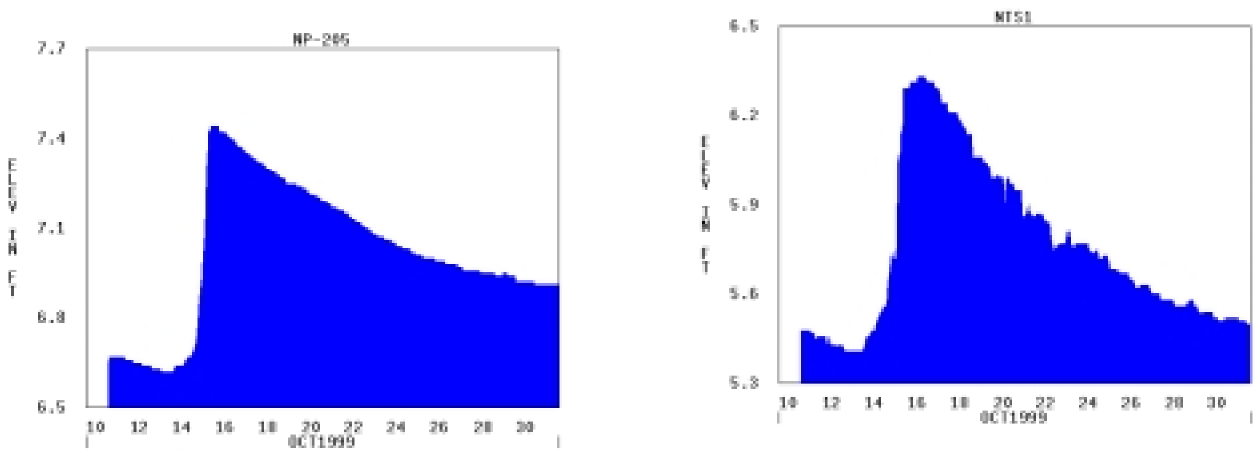


Figure 2-7. Hydrographs for Hurricane Irene at NP-205 (left, elev. 5.86), 10 miles distant from nearest management structure, and at NTS1 (right, elev. 5.04), close to managed canal. Note similar rise but differing recession. Water level initially above ground surface at both gages. See text for locations.

Table 2-4. Hurricane Irene Peak Flows and Volumes

	Irene Peak Flow cfs	*Volume October 13-31* acre-ft
S-12s	5,850	195,624
S-332D	445	12,515
S-332	539	20,175
S-175	550	16,377
S-18C	2,070	43,760
S-197	2,942	37,344

INTERIM STRUCTURAL AND OPERATIONAL PLAN (ISOP)

Summary of Operations: Up until December 1999, the Corps of Engineers operated the structures near Everglades National Park according to the Test 7 Phase 1 operating rules. Due to the operational and structural requirements in a February 1999 U.S. Fish and Wildlife Service Biological Opinion on the Cape Sable Seaside Sparrow (CSSS), the Corps of Engineers deviated from Test 7 and implemented the "Interim Structural and Operating Plan," valid through the end of the wet season 2000. To summarize:

- The upper regulation limit for WCA-2A was raised, allowing WCA-2A water to be held back from WCA-3A (closure of S-11s).
- Early closure of S-343s, S-344, S-12A, and S-12B.
- Obtained emergency permit to operate S-332D up to 500 cfs, cutting back to 165 cfs during sparrow breeding.
- S-332B, a 575 cfs pump, was built in April 2000 to discharge to a retention area near CSSS Subpopulation F. It is intended to increase water levels in Subpopulation F.
- The 7.5-foot ceiling in L-29 was relaxed for discharges of S-333 into NESRS via L-29 culverts.

These operations were designed to route water from WCA-3A east and south toward the South Dade Conveyance System. The objective was to move water away from CSSS Subpopulation A in Western Everglades National Park, while not adversely impacting private property. Specific operations included early closure of the S-11s on Nov. 12 to keep WCA-2A water from discharging into WCA-3A; early closures of S-12A on Dec. 16 and S-12B on Dec. 29, and S-12s C and D on Feb 15 to reduce outflow from WCA-3A into habitat of the sparrow's western subpopulation. The S-11s and the S-12s remained closed throughout the dry season.

Sparrow Subpopulation A. The February 1999 Biological Opinion required the Corps of Engineers to make certain operational adjustments to maximize the potential for sparrow breeding. In particular, for the western-most population, Subpopulation A, water levels were to remain below 6.0 feet at the NP-205 water level gage for 60 consecutive days between March 1 and July 15, 2000. Despite elimination of inflows from WCA-3A by prior closures of the S-12 structures (see above), the 60 consecutive day goal was not achieved due to two rainfall events that interrupted the dryout period (**Figure 2-8**). Less than four inches of rainfall, within 48 hours, was enough to raise the water table in this area from two feet below ground to above the soil surface (April 13-14).

Eastern Sparrow Subpopulation. The Biological Opinion required that water levels similar to those that would be attained under Test 7 Phase 2 be achieved, but no specific water level and duration criteria at any individual monitoring water level gage were established. However, once the 2000 breeding season started, the U.S. Fish & Wildlife Service coordinated with the Corps of Engineers to maximize nesting opportunities in the eastern subpopulations. Subpopulations C, D and F had the opportunity for a successful nesting season, as indicated by 80 days or more of consecutive dryout for a significant portion of each habitat.

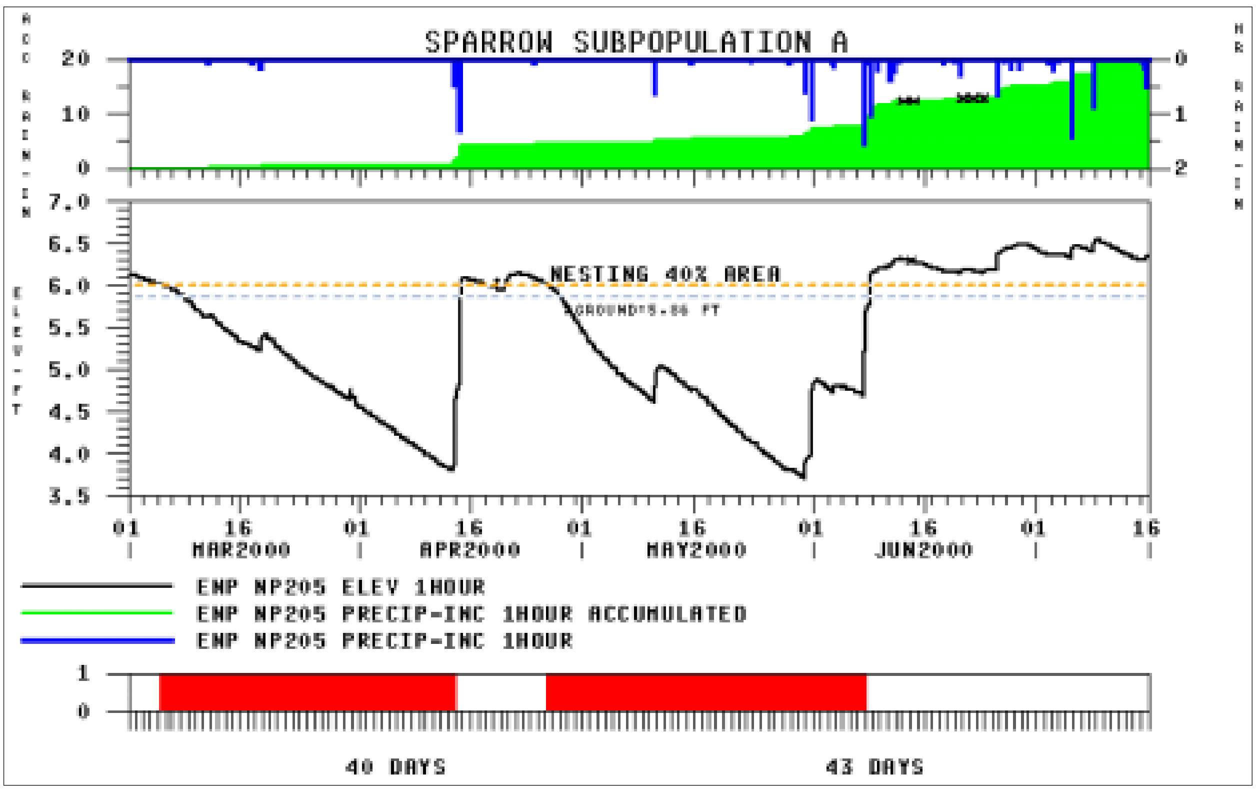


Figure 2-8. March to July 2000 water level at gage NP 205, within the Ochopee Marl Prairie. Area is habitat of the Cape Sable Seaside Sparrow, Subpopulation A.

Water Conservation Area 2A. The S-11s are normally open whenever stages in WCA-2A are above the regulation schedule. The effect of the November closure on water levels and recession rates can be evaluated by comparison with pre-drainage conditions and with previous managed conditions. Under pre-drainage conditions, water would not generally have flowed from what is now WCA-2A into WCA-3A (**Figure 2-9**). Pre-drainage outflow from WCA-2A and 2B normally went south and south-southeast, but sheetflow in this direction is now blocked. Closure of the S-11s therefore: (1) essentially reproduced the pre-drainage separation of WCA-2A from WCA-3A; and (2) closed the primary present-day outflow from WCA-2A, likely slowing the recession within WCA-2A.

Whether such slowing actual occurred is unclear from the data. An apparent inflection point in the 2A-17 gage hydrograph (**Figure 2-5**) visible in November may reflect slowing of the recession due to S-11 closures on November 12. On the other hand, the hydrograph shows a faster, steeper recession than the 30-year average under managed conditions. The three feet decline from 1999 wet season peak (3.75 ft deep) to the dry season minimum (0.75 ft deep) may be greater than the typical pre-drainage range. However, it might not be an atypical pre-drainage response to end-of-wet-season hurricane rainfall of almost 1 to 1.5 feet. This is supported by the observation that the recession crossed the average by mid-February, suggesting that any effect of the early S-11 closures on water levels had disappeared by that time, and suggesting that the March through May portion of the dry season was normal. A more detailed comparison with pre-drainage conditions would need to consider the inflows to WCA-2A.

Water Conservation Area 3A. The S-12s are not normally closed on specific dates, instead operated to make regulatory discharges depending on WCA-3A water levels. Evaluation of the early S-12 closures in comparison with either pre-drainage or present-day conditions is complicated by the drastic alterations to flow paths created by the L-67A, C, and Ext. levees. Prior to drainage, the majority of WCA-3A water would have flowed south-southeast through WCA-3B, then turned south and southwest to flow through the pre-drainage Shark Slough, the present-day “NE Shark Slough” (**Figure 2-9**). Flow through 3A, 3B, and Shark Slough would have been all through ridge and slough landscape (Fernald and Purdum, 1998; **Figure 2-9**). At present, WCA-3A water is impounded against the L-67A levee, forced westward to exit primarily through the S-12 structures. These discharge not onto ridge and slough landscape, but instead onto a more elevated area flanking the original Shark Slough: the Ochopee Marl Prairie (Fernald and Purdum, 1998) and habitat of Subpopulation A of the Cape Sable Seaside Sparrow.

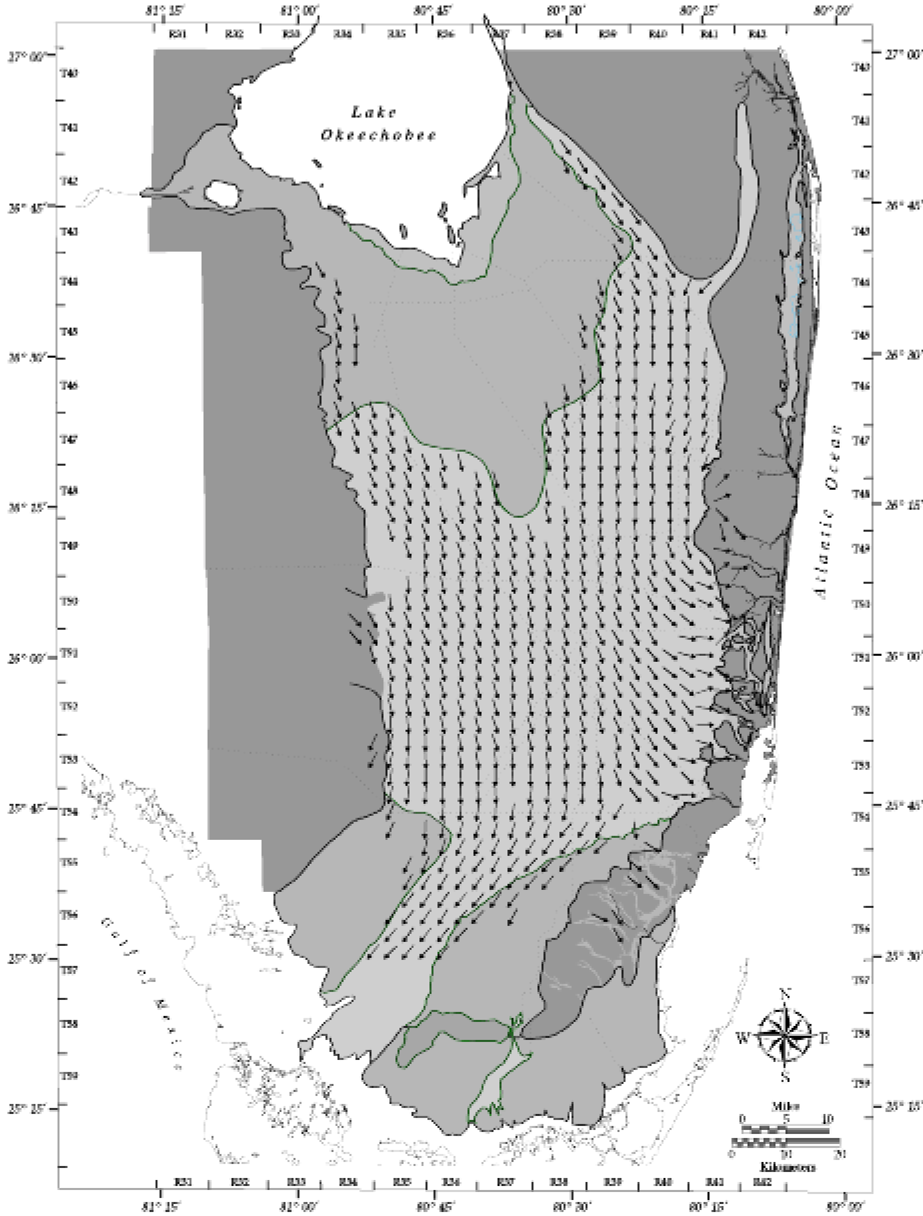


Figure 2-9. Estimated directions of pre-drainage water flow in the Ridge and Slough landscape. Angles measured from landscape "grain" formed by parallel sawgrass ridges and slough visible on 1940 aerial photographs (USDA-SCS 1940). No arrows shown for other landscapes (Sawgrass Plains and Marl Prairies) as no grain visible.

Closure of the S-12s, although apparently drastic, probably more closely reproduced the pre-drainage relation between the Ochopee Marl Prairie and WCA-3A than if they had been left open. Water levels within WCA-3A receded more slowly with the S-12s closed, but the actual recession may have been similar to a pre-drainage response to similar antecedent and end-of-wet-season rainfall conditions. The hurricane-induced peak depth had already receded to a pre-hurricane water depth of about 1.5 ft before the first of the S-12 closures on Dec. 16 (**Figure 2-5**). If closure of the S-11s eliminated the same volume of inflow as would have flowed out of open S-12s, then the S-12 closures would have had little effect on the WCA-3A recession. Additionally, S-333 outflow to the east contributed to WCA-3A recession. The absence of an inflection point in the WCA-3A hydrograph (**Figure 2-5**) supports the hypothesis that the combination of S-11s closures, S-12s closures and S-333 operations did not strongly alter WCA-3A recession. An additional comparison with a more southern WCA-3A gauge and a model simulation using actual rainfall might be helpful.

Tree Islands. The raised water levels due to Hurricane Irene and the water management changes associated with ISOP might be expected to have affected two key aspects of the ridge and slough landscape (i.e., the WCAs, NE Shark River Slough): (1) tree island vegetation and (2) peat microtopography associated with sawgrass ridges and aquatic sloughs (see below, Pre-drainage Hydrology section).

District studies of tree islands (see section below) suggest that many islands consist of three concentric vegetation zones, each with quite different water tolerances (**Figure 2-9**). Comparison of two islands thought to be "wet" and "dry" revealed that only the very small "head" portions differed in inundation frequency and tree health. The shrubby and small tree vegetation of the much larger "near-tail" areas appeared stable on both islands, despite the presence of nearly continuous (1991-1999) above ground water on the near-tail areas of both "wet" and "dry" islands. The tree island studies reported below suggest that Hurricane Irene and ISOP effects may have been small on near-tail and tail portions of islands, but that certain island "heads" which are, or have become, low relative to the surrounding marsh, should be monitored. It is also important, though difficult, to distinguish natural rises in water level from any that may have arisen specifically from water management.

Peat Microtopography of the Ridge and Slough Landscape. As described below, pre-drainage maintenance of elevation differences between sawgrass ridges and aquatic sloughs may depend, in part, on the cumulative effect of incremental downstream transport of particulate carbon. Such transport events are more likely to occur during transient high flow events, such as Hurricane Irene. As discussed in regard to WCA-3A, the presence of levees and even of the bridges and culverts found under Highway I-75 and Tamiami Trail strongly alter present-day flow paths from pre-drainage ones (**Figure 2-9**). It is, therefore, unlikely that Hurricane Irene-induced flows contributed to carbon transport and landscape maintenance, as they would have under pre-drainage conditions.

PRE-DRAINAGE HYDROLOGY

Research (Willard, 1997; Cohen et al., 1999) supports the impression that the ridge and slough landscape of the Everglades has persisted for hundreds of years and a conceptual model for the maintenance of the microtopography in this peat-based ridge and slough landscape (SFWMD, 2000), offers a mechanistic explanation for their persistence.

Current research regarding the regional organization of pre-drainage Everglades inflows and outflows, combined with the microtopography model, suggest an improved hydrology with the removal of all anthropogenic impedances to water and particulate carbon flow. Impedances that may not create significant resistance to water flow under average (low velocity) conditions, such as roads with occasional bridges or culverts, may turn out to be very significant impedances to transport of particulate carbon and nutrients under transient high velocity conditions. Such man-made impedances may affect landscape patterns (structure) within the freshwater Everglades as well as downstream nutrient cycling in the mangrove zones (function). These hypotheses will be addressed by the District next year, as part of a new ridge and slough research program.

Lake Okeechobee Outflows. Outflows from this lake into the Everglades have typically been described as overflows, occurring only when lake levels rose above the elevation of a custard-apple swamp rim (Parker et al., 1955; Parker, 1974; Davis et al., 1994). This overflow concept has been reinforced by the impression that all lake outflow into the Everglades passed first through the custard apple swamp. This impression, in turn, derives from incorrect mapping of the pre-drainage custard apple swamp as a 4-5 mile wide, 30 mile long band, encompassing the whole southern shore of the lake (e.g., Davis 1943; Davis et al., 1994). Such mapping appears to have arisen from post-drainage expansion of woody vegetation (Baldwin and Hawker, 1915; Dachnowski-Stokes, 1930). Early observers (e.g., Kreamer, 1892; Harshberger, 1914; Baldwin and Hawker, 1915; Clayton, 1936) report a width of one-half to two and one-half miles, encompassing an area of approximately 20,000 acres.

While the custard-apple area was likely somewhat elevated relative to the sawgrass plains to the south, the concept of a bordering “rim” may also be, in part, a post-drainage artifact, arising from differential subsidence rates. The presence of eight very short, southward flowing streams that passed through the custard apple swamp (Wintringham, 1963; Stewart, 1907) may have supplemented Lake Okeechobee outflow, whether or not a pre-drainage rim was present.

Of greatest hydrological significance is evidence that the custard apple zone extended only along the eastern portion of the southern lake shore, while the western portion of the south lake shore bordered directly on sawgrass marsh (Canova, 1885; Meigs, 1879; Kraemer, 1892) (**Figure 2-10**). This marsh formed on as much as seven feet of peat (Kraemer, 1892; Menge in Stewart, 1907), and extended as a level surface continuously to the lake (Wintringham, 1963). Water levels in this extensive sawgrass marsh bordering the lake were level with the water surface in the lake throughout much of the year, reaching two feet deep in the wet season (Meigs, 1879; Wintringham ,1963).

This more detailed picture of the interface between Lake Okeechobee and the Everglades is hydrologically and ecologically important in suggesting that (1) outflow occurred throughout much of the typical year, not just as an exceptional wet season overflow; and (2) that more Lake Okeechobee outflow than previously thought may have passed through the western portion of the southern shoreline.

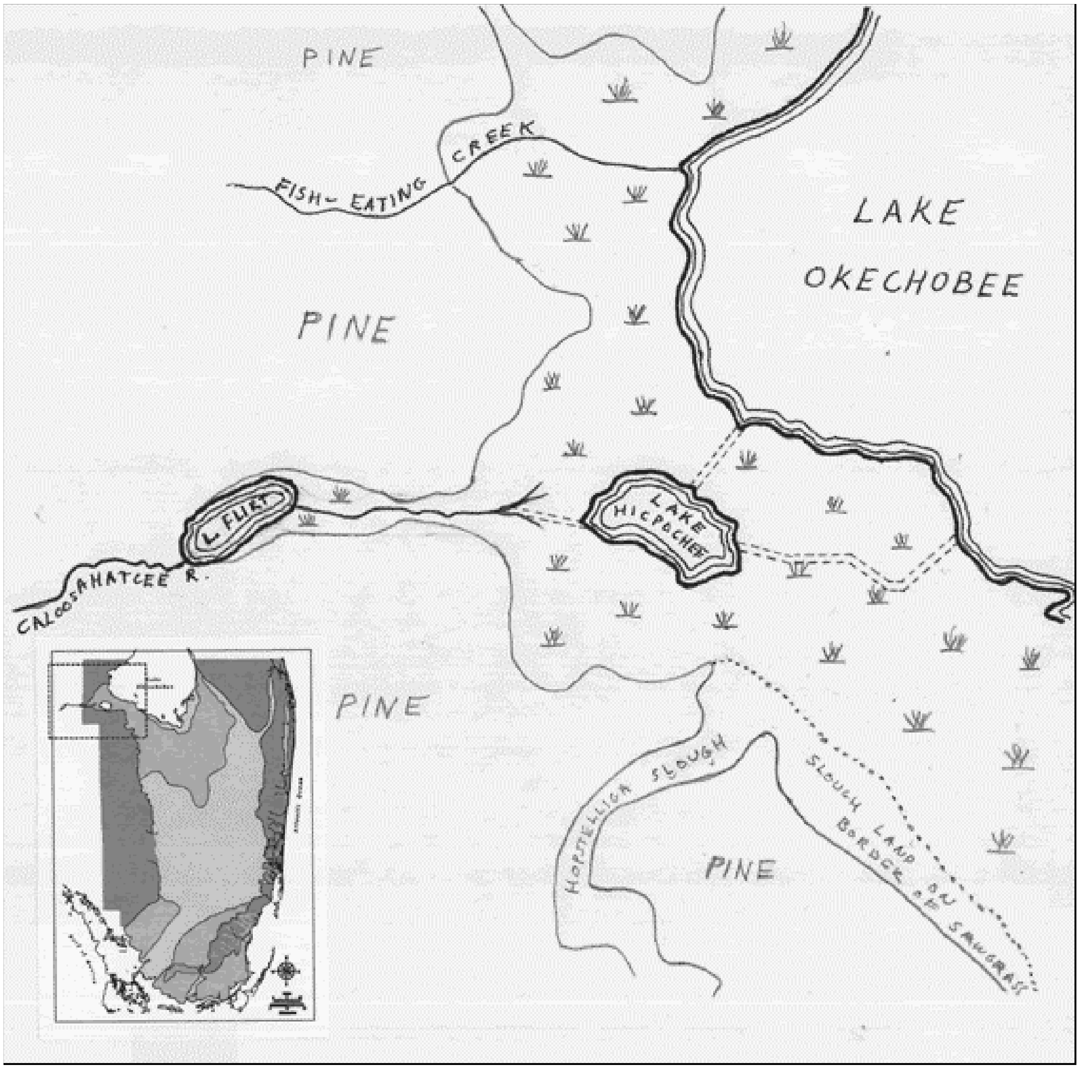


Figure 2-10. Pre-drainage map of southwest shore of Lake Okeechobee, showing extensive sawgrass area directly bordering lake. Synthesized from maps by Tannehill (1871-T42 R30); Tannehill (1871-T42 R31); Meigs (1879); Kraemer (1892); Corps of Eng. (1929).

Distinction between the Peat Transverse Glades and the Marl Transverse Glades. Water flowed eastward out of the Everglades through two geographically and hydrologically separate sets of "transverse glades." The presence of these elongations of the Everglades eastward across/through the areas of coastal high ground was recognized early (Smith, 1848; Griswold, 1896; Harper, 1910). They were noted along 55 miles of the eastern border of the Everglades, from the New River (Ft. Lauderdale) south to what is now Homestead. Military records from the 1850s report the necessity of building bridges across the ones between the New and Miami Rivers (Knetsch, 1999).

Parker et al. (1955) distinguished a northern and southern group of transverse glades (north and south of the Miami River), but did not elaborate on their differences, probably because the northern group had by then already been drained and disconnected from the Everglades for several decades. The differences between the northern, peat glades and the southern, marl glades are hydrologically significant. Both types were covered by sawgrass. The differences center on the soils, the slope of the adjoining Everglades, and the hydrology of the transverse glades. According to Williams (1870a, b) and Jones et al. (1948), the Peat Transverse Glades supported several feet of sawgrass peat soil, indicating that they were covered with water for most or all of the year. Available water depths (2-2.5 feet, occasionally 3 feet) appear deeper than for other areas of sawgrass and sawgrass peat. Eastward toward the coast, each of the Peat Transverse Glades narrowed into coastal rivers (Williams, 1870b). The presence of year-round water flow in these rivers (Jones, 1847 in Senate Doc, 1911; MacKay, 1847 in Senate Doc, 1911; Harshberger, 1914) is consistent with year-round inundation of the Peat Transverse Glades. Several early observers report that the peat surface of the Everglades sloped southeastward, <u>downward</u> toward the Peat Transverse Glades (Rose, 1898; Newman in Stewart, 1907; Ashworth, 1919). The peat elevation within the Peat Transverse Glades appears to have simply extended the downward slope from the main Glades further to the east, eventually merging into the headwaters of the coastal rivers (Corps of Engineers, 1960).

The Marl Transverse Glades present from the Miami River to Homestead were connected to the main Everglades in a very different configuration. Instead of downward as in the Peat Transverse Glades, land surface adjacent to the marl glades sloped <u>upward</u> from Shark Slough through the Rockland Marl Marsh landscape to the elevations of the Marl Transverse Glades. (Rosendahl and Rose, 1981) Outward flow through the Marl Transverse Glades was perpendicular to the primary southwestward flow direction in Shark Slough. In contrast to the peat glades, outflow through the marl glades occurred only when water levels in Shark Slough rose sufficiently to inundate the Rockland Marl Marsh, and thus occurred only toward the end of the wet season (Tropical Bioindustries, 1990). The seasonal flooding could not support peat accumulation, but did form marl soil. These lateral, seasonal outflows were secondary to flows through Shark Slough. The Marl Transverse Glades contribute significantly to our understanding of the pre-drainage Everglades. The mineral soils of the marl glades are not subjected to subsidence, so their pre-drainage elevations are known (Jones et al., 1948). Based on the level pool assumption, elevations of these known outflows provide a quantitative estimate of typical annual maximum water stages in Shark Slough under pre-drainage conditions.

Pre-drainage Flow Directions. Patterns of water flow in the pre-drainage, peat-based ridge and slough landscape were estimated by mapping the directionality of landscape features on the earliest aerial photographs of the Everglades (USDA-SCS, 1940;

USDA-SCS, 1938). The mapped 1940 directionality was assumed to accurately reflect pre-drainage flow paths because:

- Pre-drainage narrative accounts described water flow as following the same orientation as the ridge and sloughs (Sollie, 1884; Baldwin and Hawker, 1915);
- Mapped 1940s directionality matched available pre-drainage observations;
- No evidence of altered directionality was found in aerial photographs spanning 1940 to 1994
- Drier post-drainage conditions would have lacked the water flows required to overwrite the original pattern in new, post-drainage directions.

While canal drainage prior to 1940 did partially obscure the original pattern of microtopography (SFWMD, 1999; SFWMD, 2000), it was concluded that Everglades drainage patterns could be reliably inferred from the 1940 photography.

Figure 2-9 was created by laying a regular 2 x 2 mile grid over the 1940 aerial photo-index sheets, scale ca. 1:63,000, then drawing a line through the cell's centerpoint, parallel to the ridge and slough grain visible within each cell. Emphasis was placed on aligning specifically to the ridge and slough grain. The directional pattern, shown in **Figure 2-9**, is essentially identical to that published in Parker et al. (1955) and Parker (1974) and is also consistent with the pattern of existing tree islands and known information on former islands in now urbanized areas (Davis, 1943; Jones et al., 1948).

Estimated flow directions in **Figure 2-9** were strongly spatially correlated. Large areas follow very similar orientations, and where changes in direction occur, they are gradual. The pattern resembles magnetic or electric fields, and appears consistent with many pre-drainage descriptions of the Everglades as remarkably flat. Parker et al. (1955) interpreted this by observing that the ridge and slough grain, "trend[s] parallel to the regional slope, just as one would expect in an area of consequent drainage."

Figure 2-9 also suggests that the eastern portion, or basin, of the Everglades drained eastward through the Peat Transverse Glades and into Biscayne Bay and the Atlantic Ocean. The western basin, corresponding closely to the combination of Water Conservation Areas 3A, 3B, and Everglades National Park, drained south-southeastward from Lake Okeechobee turning southwestward in the vicinity of the present Tamiami Trail to drain through Shark Slough into the Gulf of Mexico. Annual wet season water levels in Shark Slough were typically high enough to inundate the full cross-section of the Shark Slough basin, covering the lateral Rockland and Ochopee marl marshes, and extending to the western edge of the Everglades Keys (Miami Rock Ridge). While the volumes of outflow were probably not large, water levels in the Shark Slough basin typically rose high enough to cause lateral outflow through the Marl Transverse Glades (Rosendahl and Rose, 1981; Simmons and Ogden, 1998). Flow through Taylor Slough was also a lateral outflow, with the peat soils present there suggesting a longer period, and greater volumes, of outflow than that typical for the other Marl Transverse Glades.

Synthesis. Taken together, the combination of (a) the pattern of Lake Okeechobee outflows, (b) the outflow patterns of Peat and Marl Transverse Glades, and (c) the map of directions of pre-drainage Everglades water flow suggest a long, continuous, peat-based wetland landscape, sustained by the continuous downstream movement of water. The post-drainage presence of man-made impedances within this formerly continuous landscape may in part explain the on-going disappearance of ridge and slough microtopography, and of the ecologically critical slough component of this landscape.

It has been suggested by McVoy (SFWMD, 2000) that a carbon export mechanism is necessary to explain the long-term persistence of the network of aquatic sloughs and the fact that they did not fill in with peat. Landscape patterns, in turn, suggest a downstream transport of dissolved and flocculent organic matter through the sloughs. Transport of dissolved organic carbon would have occurred at even the slowest water velocities, but may not have been sufficient to balance *in situ* carbon accumulation in the sloughs. Downstream transport of flocculent organic carbon would most likely only have occurred when a velocity threshold was exceeded, suggesting that flocculent transport would have been a discontinuous process. McVoy hypothesizes that flocculent transport may have been the cumulative result of multiple, discontinuous displacements, each driven by transient peak velocities resulting from local thunderstorms and/or intense regional events (e.g., hurricanes). More research is needed.

An important implication of this hypothesis is that preservation of the ridge and slough landscape would depend on unimpeded water and organic matter flow through the full length of the ridge and slough landscape. This would require that: (1) water flows in the present day system occur in the same direction as the pre-drainage ridge and slough grain; and (2) any manmade structure (road, canal, levee, etc.) present only the same impedance to flow as the (pre-drainage) landscape itself, especially during transient high velocities. Elimination of present-day impedances to flow would appear particularly critical in the formerly continuous ridge and slough area consisting of Water Conservation Areas 3A, 3B, and Everglades National Park.

Implications. This examination of the pre-drainage landscape by the District, combined with an understanding of ecological trends (see next section) were used to evaluate a proposal for Nutrient Management by Ray and Gherini (Appendix 1) to create artificially P-enriched regions in the Everglades. A detailed response to this proposal is provided in Appendix 1 to this report. It has been suggested that creation of manmade, nutrient-enriched zones would "develop some of the [lost] ecological niches" and "lead to a restoration that comes closer to providing the heterogeneity of habitats that was vital to the historical Everglades." It has been proposed that not creating a nutrient-enriched zone will lead to a sterile environment of homogeneous sawgrass and that such a man-made enriched zone would remain stable, rather than expanding southward as a continually "moving front."

This proposal was found to be flawed because causal mechanisms for habitat heterogeneity, spatial gradients, wading bird abundance, biodiversity, and peat accumulation in the Everglades were incorrectly inferred from pre-drainage spatial patterns. This inference fails at two levels by: (1) assuming that correlation of spatial gradients implies causation; and (2) inaccurately identifying the spatial patterns themselves. The central postulate of this proposal is that a transition zone associated with relatively high soil phosphorus is responsible for creating "natural" downstream gradients in vegetation, birds and peat. Although pre-drainage downstream gradients did exist south of Lake Okeechobee, careful examination of the spatial gradients indicates that the patterns do not reflect monotonic declines with distance from the Lake. Reexamination of the sources for this proposal, and comparison of the spatial patterns suggests more plausible, non-phosphorus-based causal mechanisms.

It is well known that pre-drainage peat thickness decreased from Lake Okeechobee southward through the Everglades. However, there is not any evidence in the Everglades that greater peat thickness is due to elevated phosphorus levels. Dachnowski-Stokes (1930) analyzed numerous soil cores within the present Everglades Agricultural Area, measuring both the core contents and the elevation of the core above sea level. In essentially all cores, he found a uniform layer of more decomposed peat at about elevation 14 feet, which he ascribed to a period of altered climate. This strongly suggests a pattern of spatially uniform rate of accumulation of sawgrass peat.

Soil phosphorus gradients and fronts exist today and are a source of concern for restoration because all available evidence indicates that these fronts continue to expand (Chapter 3, DeBusk, et al., In Review). However, they didn't always exist. Hammar (1929) said about the custard apple soils directly adjacent to the lake, and the sawgrass soils further south: "*The content of phosphorus does not vary to any marked degree from one type to another*."

The idea that greater wildlife abundance and diversity was supported by elevated nutrient levels is also flawed. The diversity of wading birds in the custard apple swamp adjacent to Lake Okeechobee and the lack of wildlife in the Sawgrass Plains south of the custard apple swamp can be explained by more plusable hydrologic processes. The persistence of a low nutrient ridge and slough landscape results in an <u>increase</u> in wildlife downstream from Lake Okeechobee rather than a decrease. The low abundance in the Sawgrass Plains likely was related to the uniformity of this landscape: a vast, almost perfectly flat area with neither elevated nor deeper spots. The relative abundance of wildlife in the Custard Apple Swamp and in the ridge and slough landscape is most likely related to the proximity, in both landscapes, of elevated areas with trees (roosts) next to open water areas, the latter containing both prey as well as accessible water depths (during part of year).

ECOLOGICAL TRENDS

The success of restoration and protection of the Everglades depends on several different types of scientific research: (1) identification of the original, pre-drainage state; (2) development of mechanistic understanding of the processes that maintained the original state, and (3) mechanistic understanding of the processes that control the present state of the system. By "state of the system" scientists mean all aspects, including types of vegetation, topography, soils, birds, wildlife, water quality, hydrology, and types of fires.

Part of the true uniqueness of the Everglades is that all of these aspects are here closely inter-related. For example, in most other environments, topography and variations in topography are largely unchanging over human time scales, being fixed by the mineral soil surface and the rock substrate. In contrast, in much of the Everglades the ground surface is peat. Elevation of the ground surface is highly changeable, rising or falling as changes in plant growth, hydrology and fire patterns alter the balance of accumulation or loss of organic peat soil. In the Everglades, the tendency is toward circular, complex interactions where hydrology controls the accumulation of peat, which determines the land slope (topography), which affects the hydrology (drainage). The hydrology affects vegetation (species and density), which affects hydrology (resistance to sheet flow) again.

Protection and restoration depend on the accurate understanding of these processes and their interactions. Such understanding arises from many different types of research: laboratory and greenhouse studies to identify specific cause-and-effect relations; field studies to observe known as well as unexpected patterns; remote sensing and mapping of large-scale pattern and change; and simulation modeling to integrate and test our understanding of the mechanisms.

BIOGEOCHEMICAL RESPONSES TO HYDROLOGY

Vegetation fires, that is, burning of sawgrass leaves, appear to have been a natural and frequent component of the pre-drainage Everglades (Robertson 1953; Gunderson and Snyder 1994). As long as water levels were either above ground or the soil wet enough to protect sawgrass culms from burning, sawgrass plants recover quickly and may in fact benefit from fire (Forthman, 1973; Hofstetter, 1984). Below ground peat fires are a different phenomenon. Peat fires occurred frequently in the 1920s through 1940s after the onset of uncontrolled canal drainage (Kelly, 1931; Loveless, 1959; SFWMD, 1999). Estimated pre-drainage water levels would have kept peat soils too wet to permit peat fires to start (SFWMD, 1999, 2000). Although it is technically difficult in soil cores to unequivocally distinguish vegetative fire ash from peat fire ash (Cohen et al., 1999), so far there appears to be no unambiguous evidence for peat fires of any significant spatial extent (Cohen, 1984). The dark layers observed in the field during canal digging (Davis, 1943; Parker, 1974) appear more likely to have been synoptic layers of a decomposed, black peat (Dachnowski-Stokes, 1930), than layers of ash.

Secondary evidence therefore becomes important in trying to determine whether pre-drainage fires occurred. The following two studies from an over-drained area report on muck (peat) fire effects on the soil and vegetation. The fact that both studies find a tendency for cattails to increase after muck fires but not after vegetation fires, combined with absence of cattail in the pre-drainage soil core record, suggests that muck fires are a post-drainage phenomenon, originating with lowered water levels. This information should be helpful in identifying appropriate minimum flows and levels for the Everglades.

The effects of above-ground (vegetation) and below-ground (muck) fires on a number of soil constituents were examined within a hydrologically-altered marsh in the northern Florida Everglades (**Figure 2-11**). Muck fire resulted in losses of total carbon, nitrogen, and organic forms of phosphorus while inorganic phosphorus was elevated. In addition, muck fires resulted in increased vertical heterogeneity in concentrations of most constituents between upper and lower sediment layers. Surface fires had a limited impact on the measured constituents. The effect of physical versus chemical processes during burning were assessed using ratios of constituent:total calcium concentrations. In this context, increases in the levels of inorganic P fractions in muck-burned areas were due to the physical reduction of soil, while decreases in N and C were the result of volatilization. In an ecological context, the observed soil transformations may encourage the growth of opportunistic plant species such as *Typha domingensis* (cattail).

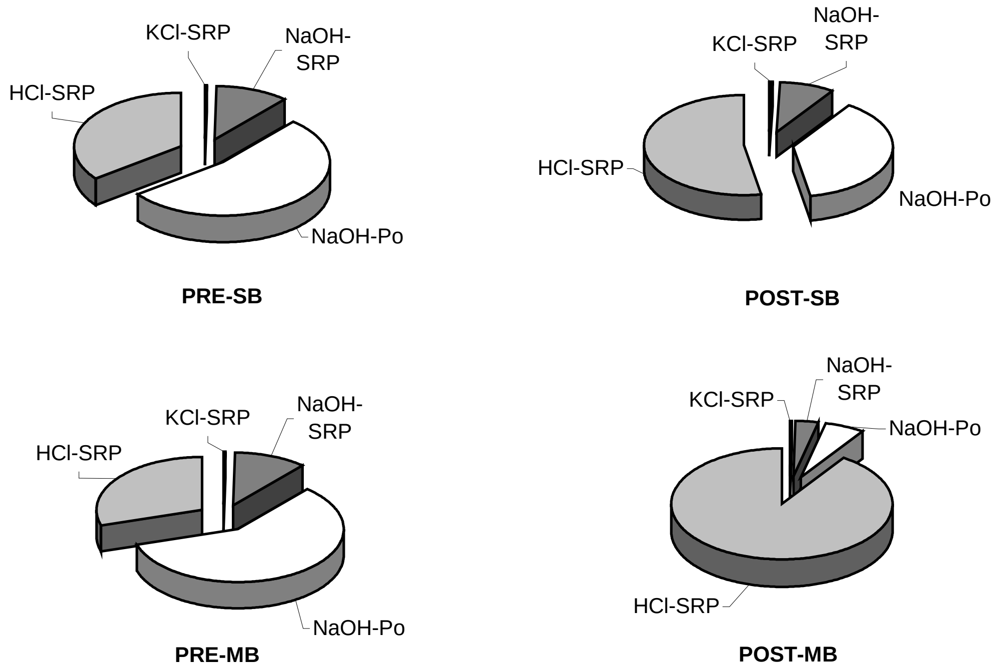


Figure 2-11. Proportions of inorganic (X-SRP) and organic (Po) P fractions in the 0-2 cm layer of soils from the Rotenberger Wildlife Management Area. Bold labels represent samples from muck-burned (-MB) and surface (vegetation)-burned (-SB) areas before (PRE-) and after (POST-) a May 1999 fire.

VEGETATION RESPONSES TO HYDROLOGY

Marsh Plant Response to Fire

Seedlings of the southern cattail (*Typha domingensis*) were used to assay Everglades soils that had recently experienced fire disturbance. After two months, growth patterns were sufficiently different to distinguish soils that came from areas that had been muck-burned (MB), surface-burned (SB), or non-burned (NB). Percent height gain, number of leaves, culm diameter, number of rhizomes, length of rhizomes, live leaf biomass and root biomass were all highest in the MB treatment. In addition, root architecture and biomass allocation was influenced by burn type. Seedlings from NB and SB treatments developed more root hairs and allocated more biomass to the root system - characteristics indicative of a search strategy under conditions of lower nutrient availability. In contrast, seedlings grown in muck-burned soils developed large rhizomes in addition to thicker, hairless roots but allocated a higher percentage of total biomass to leaves. Tissue nutrient analyses showed that both assayed and field-harvested plants from MB soils assimilated more phosphorus than those from SB or NB soils. The results suggest that muck fire-related increases in the bioavailability of P may encourage cattail establishment and expansion in the Everglades (**Figure 2-12**). Chapter 7 provides a discussion of the role of fire in Everglades mercury levels.

Figure 2-12. Cattail seedlings after 2 months of growth in muck-burned (left), surface-burned (middle), and non-burned (right) soils from the Rotenberger Wildlife Management Area.

Cattail and Sawgrass Response to Hydrology and Nutrient-Hydrology Interaction

The spread of invasive cattail (*Typha domingensis*) within portions of the remaining Everglades ridge and slough landscape (e.g., WCA-2A, northern WCA-3A, perimeter of WCA-1) is well-known (e.g., Rutchey and Vilchek, 1999). Studies in the past year by District staff and by collaborating scientists from the University of Louisiana (Project C-6642) have focused on ecophysiology of both cattail and sawgrass (*Cladium jamaicense*). Advances have been made in quantifying key aspects of cattail and sawgrass life cycles (seed persistence, germination, and seedling, young, and mature plant growth) that are controlled by water depths, or by the combined influence of phosphorus enrichment and water depth. Additionally, controlled plant growth chamber studies have quantified aspects of root oxygenation, growth and phosphorus uptake in the two species. Important implications of the results are: (1) cattail and sawgrass tolerances to environmental stressors vary during the course of their life cycles; (2) the timing of ecophysiological aspects of the life cycles interacts significantly with the timing of annual Everglades cycles (e.g., hydrology, temperature); (3) phosphorus levels can alter the timing of the life cycles; and (4) differences between the two species may help identify methods to control cattail invasion. **Figure 2-13** illustrates the relation of selected sawgrass and cattail life cycle timing aspects to hydrologic cycles typical for the Everglades.

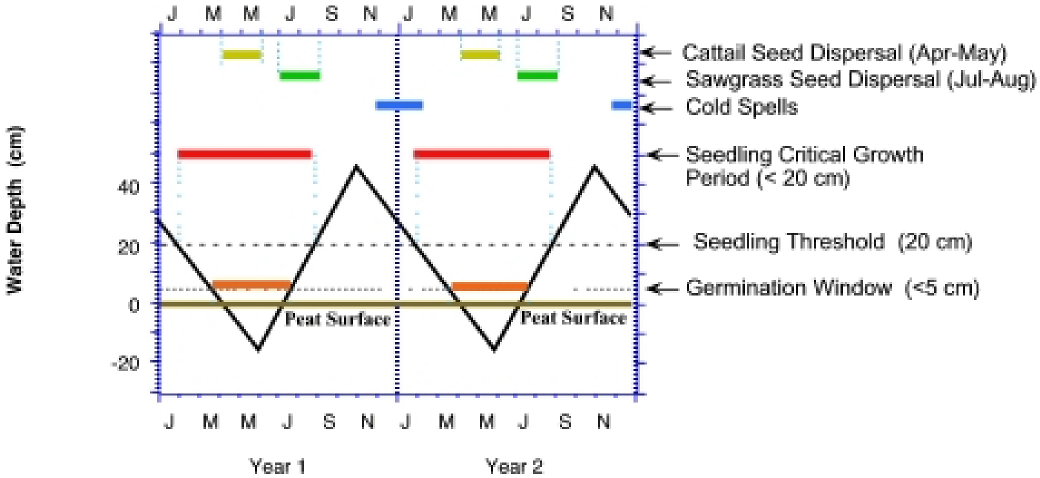


Figure 2-13. Relations of sawgrass and cattail life cycles to typical seasonailty of the Everglades. Hydrograph shown is estimated pre-drainage one for a sawgrass ridge.

A quantitative understanding of the mechanisms influencing the life cycles and geographic spread of cattail and of sawgrass is needed to address both present and future landscape concerns. In addition, knowledge of these life cycles should eventually become sufficiently complete to understand the mechanisms that, under pre-drainage conditions allows: (1) sawgrass ridges to persist; (2) sloughs to remain free of sawgrass for centuries at a time (Cohen et al., 1999; Willard, 1997); and (3) cattails to be rare and limited to specific sites such as alligator holes. Present concerns focus on accurate understanding of the reasons for cattail invasion and on management possibilities for restraining invasion. Future concerns include: (1) the search for practical methods of restoring cattail-invaded areas back to a landscape of sawgrass ridges and aquatic sloughs; and (2) genetic concerns. The large size of the areas already invaded, (and the likelihood of future increase due to continued P inputs, stored soil P, etc.), makes it likely that only mechanisms based on detailed knowledge of the life cycle will be useful in guiding cattail to sawgrass restoration, emphasizing the importance of this understanding.

The genetic aspect of future cattail expansion derives from the combination of cattail's extreme fecundity (typically 0.25 million seeds per inflorescence) with the possibility that the cattail population may presently be subjected to strong selection pressure. Together, these two aspects may constitute an inadvertent, large-scale plant breeding experiment, possibly leading to strains better adapted to present Everglades conditions, and hence more aggressive. It is not known whether the presently expanding cattail population derives from the very small native pre-drainage Everglades population, or whether it originated outside the Everglades. In either case, the post-drainage changes in Everglades hydrology and water quality mean that the presently expanding population are subjected to a new (changed) environment. The hypothesis of the population being subject to strong selection pressure arises from the life cycle studies. Several steps (e.g., germination and seed survival) were measured to have very low, but non-zero survival rates. For example, measured cattail seed germination was 0.5 percent germination in 5 cm of water. This water depth eliminated 99.5 percent of the 0.25 million seeds produced by an inflorescence. However, the remaining thousand germinating seeds would be unusual genotypes tolerant of 5 cm water. Any that survived to maturity would presumably pass on this tolerance. The situation may be analogous to anthropogenic origins of antibiotic-resistant bacteria, or pesticide-resistant weed species in agriculture. Rapid evolution in those cases appears to be traceable to application of a strong, but non-lethal, application of the stressor (antibiotic or pesticide), allowing a small but resistant fraction of the original population to reproduce.

A preliminary study of seed germination and seedling growth, in relation to water depth, showed the importance of timing of marsh flooding or drawdown in sawgrass restoration and cattail exclusion/elimination. Cattail invasion depends on the coincidence of seed dispersal with favorable water levels and nutrient conditions. Maintenance of higher water depths during cattail seed dispersal may inhibit cattail colonization in the Everglades. Conversely, drawdown of marsh water levels during cattail seed dispersal (April to June) would probably enhance cattail invasion.

The cattail seedbank within the Everglades is known to be small (van der Valk and Rosburg, 1997, Miao et al., 2000a). Non-vegetative reproduction therefore depends almost solely on seeds produced in the current year. District and University of Louisiana studies have shown that cattail seed survival, seed germination rates, seedling survival, and seedling growth rates all are strongly influenced by water depths (Stewart et al., 1997, Miao et al., 2000a, Lorenzen et al., 2000, McKee et al., In internal review). As water depths in the Everglades cycle up and down annually--whether under pre-drainage, current, or restored conditions—the timing of seed dispersal relative to the annual rise and fall is a key aspect. The wet season typically extends from the annual minimum water depth through to the annual maximum (June-Nov.); the dry season from the maximum to subsequent minimum (Nov.-May). Cattail seed dispersal in the Everglades presently occurs in April-May, coincident with the end of the dry season (Miao and Sklar, 1998). Sawgrass seed dispersal occurs in July-August, during the early wet season (Maio and Sklar, 1998). The interactions of ground surface, water depths, seed dispersal, and seedling survival are shown in **Figure 2-13.**

Seed germination of both sawgrass and cattail is highest on moist peat substrate, with little or no standing water (Miao et al., 2000a). For both species, germination dropped to less than 0.5 percent at water depths greater than 5 cm of water.

Seed viability over time also differs between both species. Percent germination of cattail seed decreases rapidly over time; about 50 percent within 2-3 months of dispersal (Miao, unpublished data). This, combined with the timing of dispersal in April-May, and the onset of wet season water level rise, creates two windows for germination: (1) immediately after seed dispersal, but before water levels have risen sufficiently to eliminate germination; and (2) toward the end of the following dry season, when water levels have come down again. These two windows may select, respectively, for (1) very quick germination; or (2) for long (11-12 month) seed viability. In contrast, seed germination of sawgrass actually increased greatly over time; about 30 percent increase within three months of dispersal (Miao, unpublished data). This increasing viability likely allows sawgrass seed released in July-August, when increasing water levels restrict seedling survival, to persist to germinate in the following dry season.

Cattail seeds cannot germinate when covered (Miao, unpublished data) possibly because germination requires light activation. Covering or burial by sediments, detritus, or periphyton algal mats appears to inhibit cattail seed germination (Lorenzen et al., 2000). In areas not enriched by phosphorus (which inhibits periphyton growth), drydowns may cause periphyton mats to cover previously deposited cattails seeds, effectively preventing germination. Under pre-drainage conditions, a layer of flocculent organic material present in sloughs may have contributed, along with water depths, to the absence of sawgrass or cattail establishment in sloughs. Phosphorus enrichment inhibits periphyton mats, creating an opportunity for cattail seed germination.

Sawgrass and cattail showed different strategies with regard to seed production, germination, seedling survivorship and growth rate. While sawgrass produces fewer seeds, and has lower seed germination compared with cattail, it has greater survivorship. Cattail seedling mortality, even under optimal conditions of less than 5 cm of water, is high. Approximately 80-95 percent of cattail seedlings died within three months of germination (Miao et al., 2000a). In contrast, under the same water conditions (<5 cm), sawgrass seedlings showed no mortality. However, seedlings greater than 20 cm tall of both species show different responses to water depth. When completely inundated under 20 cm of water, none of the sawgrass seedlings survived, but 100 percent of cattail did (Miao, unpublished data).

Growth rates of cattail seedlings are affected by water depth, but also by P enrichment. Experiments have found that in soils enriched with approx. 1600 mg P kg-1 (typical for northern WCA-2A), cattail seedlings grew more in 6 months than seedlings in soil with background level P (400 mg P kg-1) grew in 2 years (Miao et al., 2000b). Increased growth rates also tend to increase survivorship of seedlings.

As part of Project C-6642, the District completed its investigation of the nutrient uptake kinetics and flood tolerance mechanisms of cattail and sawgrass. A controlled phytotron was used to conduct studies of whole plant ecophysiological responses to specific environmental conditions. A phytotron is a large plant incubation chamber where light and temperature are precisely controlled. However, it also is capable of tracking and compensating for any changes in oxygen and nutrients in the growth medium. This research showed that sawgrass and cattail have developed different mechanisms of flooding tolerance.

Other significant findings from this project include the following:

- Pressurized gas flow through the shoot and down to the roots to enhance root and soil oxygen concentration was discovered in *cattail* but not in *sawgrass* (Chabbi et al., 2000).
- *Cattail* responded more than *sawgrass* to flooding by increasing air space development in the root apex (**Figure 2-14**). Concurrently, root alcohol dehydrogenase activity (ADH) and ethanol concentration, indicators of alcoholic fermentation, were greater in *sawgrass* than *cattail*, although both species showed increases. These results strongly suggest that *sawgrass* is more subject to root oxygen deficiencies than *cattail*.
- Both species increase oxygen release to the sediments in response to flooding stress. However, oxygen release to the sediments from *cattail* roots greatly exceeded that from *sawgrass* roots (**Figure 2-15**).

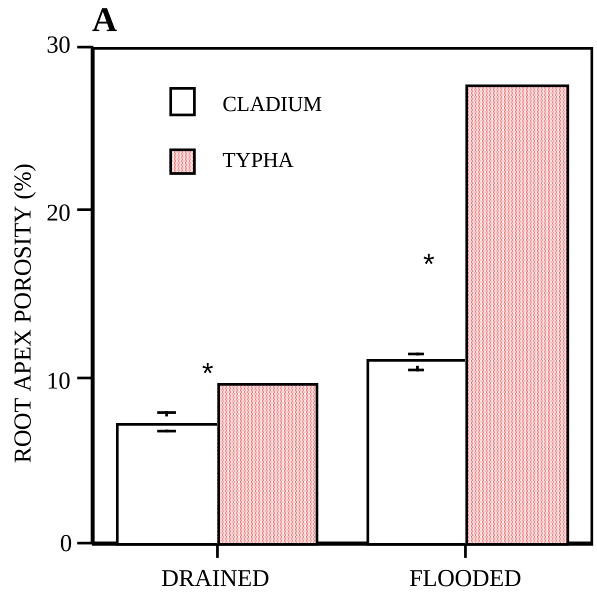


Figure 2-14. Porosity of apical region of *Typha* and *Cladium* roots grown under different treatments. Values are the mean ±SE (n=3) (note that some SE bars are too small to be visible). Significant differences between species (within treatment) are indicated by * (P≤0.01).

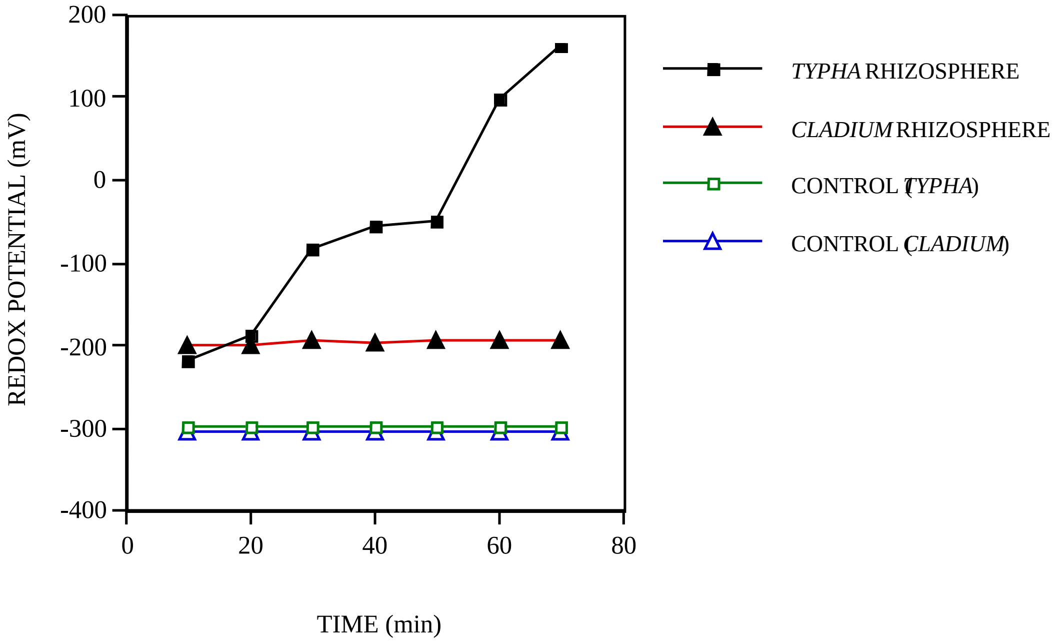


Figure 2-15. Time course changes in rhizosphere (root zone) redox potential (Eh) --- a measure of soil oxygenation --- when root systems were placed in reduced methylene blue-agar solutions. Platinum electrodes were inserted close to the root tip or several cm away from a root, outside the zone of halo formation (control). Values are the means ± SE (n=3-4) (note that the SE bars are smaller than the symbols). Root lengths were similar for Typha (24 cm) and Cladium (25 cm).

- Cattail produced an extensive and deep, fibrous root system within one month of transplantation (**Figure 2-16**). In contrast, sawgrass produced only two primary roots. Individual root elongation rates by Cattail (0.71 cm d-1) are significantly faster than sawgrass (0.47 cm d-1) (P<0.0001). Cattail produces longer, finer lateral roots than sawgrass, which increases the surface area per unit root mass for P absorption.
- *Cattail* produces many more primary roots per plant than *sawgrass* (24 versus 4 roots, respectively) (P<0.0001). The maximum root length of *Cattail* (21-41 cm) is also greater than *sawgrass* (3-18 cm) (P<0.0001). The soil volume exploited by *cattail* is several times greater than that of *sawgrass*.
- Under flooded conditions, the total number of primary roots produced by *Cattail* increased relative to the drained treatment (from 19 to 28 roots), but *sawgrass* root numbers did not change (4 roots) (P=0.0563).

A **B**

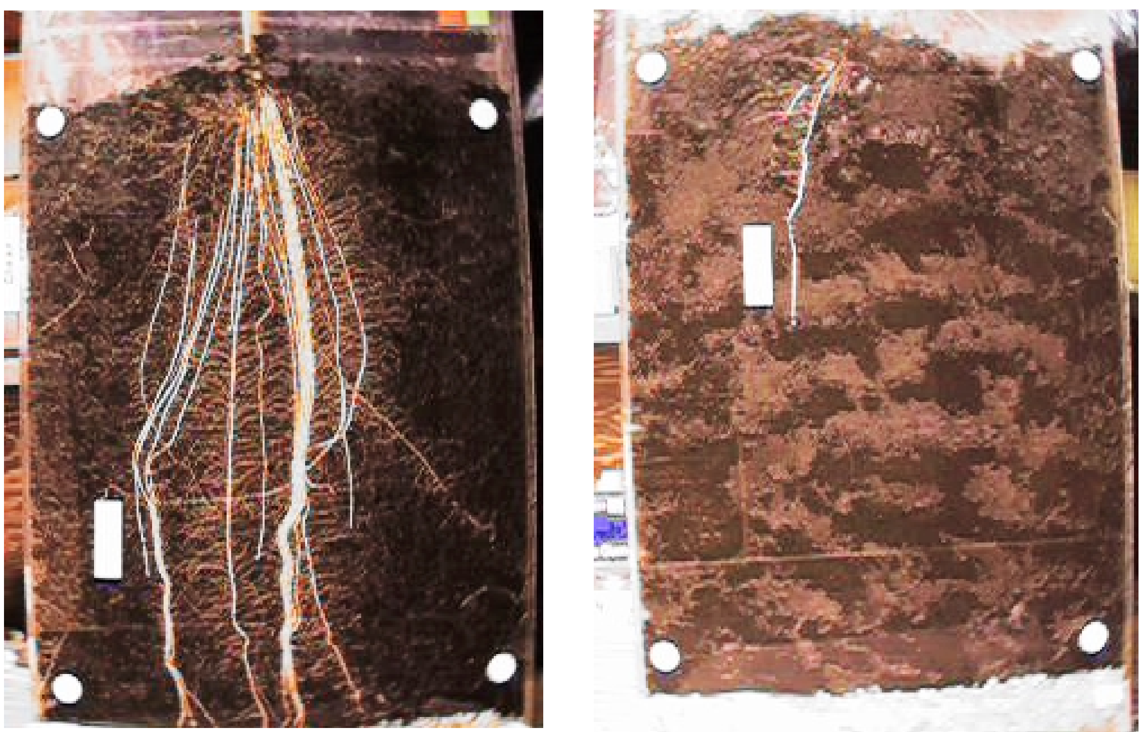


Figure 2-16. Root systems of *Typha* (A) and *Cladium* (B) grown in rhizotrons for 1 mo in flooded Everglades peat at high phosphorus loading. The white bar is 5 cm long.

The phyton was also used to run experiments to answer questions of nutrient uptake in relation to physiology and growth. The experimental treatments included four P concentrations (10, 40, 80 and 500 µg P l^{-1}) and two oxygen levels (aerated and <0.5 mg O_2 l^{-1}) in the culture solutions. These incubation experiments produced several important findings. First, cattail and sawgrass exhibited significantly different growth rates and responded differently to P availability. The growth rate of cattail (48-89 mg g^{-1} d^{-1}) was more than twice as high as that of sawgrass (19-37 mg g^{-1} d^{-1}) at all P concentrations. For sawgrass, no clear relationship existed between growth rates and P concentrations. However, cattail growth rates significantly increased with increasing P availability. Second, cattail exhibited a greater nutrient uptake capacity than sawgrass. Third, cattail exhibited a deficiency in nutrient uptake at a P concentration of 40 µg P l^{-1}, indicated by atomic N/P ratios. However, this deficiency did not reduce the competitive capacity of cattail, since the growth rate of cattail was twice that of sawgrass at 10 µg P l^{-1}. The results of this experiment, together with our other studies, indicate that sawgrass have characteristics typical for plants from nutrient-poor habitats, which include slow growth rates and low capacity for P uptake. In contrast, cattail have characteristics typical for plants from nutrient-rich habitats, which include high growth rates, a high degree of flexibility in growth, and a high capacity for nutrient accumulation relative to nutrient availability.

Tree Islands

As the highest elevation components of the Everglades, tree islands have been suggested as indicators of the health of the present day Everglades, particularly within the Water Conservation Areas (ridge and slough landscape). This suggestion reflects considerable concern regarding the loss, “drowning” or “death” of tree islands during the last few decades. The District has initiated a multi-disciplinary research program in WCA-3 to examine ecological processes controlled by hydroperiods and water depths. These processes include rates of tree growth, litter production, nutrient cycling, and accretion/loss of organic soil (peat). The preliminary results presented here for two tree islands suggest that tree island vegetation is not sensitive to <u>absolute</u> water elevations (distance above sea level) as such, but instead are sensitive to the differential, that is, the vertical distance between tree island ground surface and surrounding water elevations, or water <u>depths</u>. The distinction is significant because it has been previously reported that tree island ground surface elevations decreased prior to the 1940s and 1950s due to peat oxidation and actual peat burns on many islands (Davis, 1943; Loveless, 1959; Craighead, 1971). Tree island health may therefore be as much an indicator of tree island subsidence as it is an indicator of appropriate water levels. This suggests that tree island health can provide only partial information regarding appropriate water levels for the ridge and slough landscape; supplemental indicators are needed.

Tree islands in Water Conservation Areas 3A and 3B are typically recognizable on aerial photographs as asymmetric ovoid areas, the upstream (northerly) end somewhat more rounded, the downstream end often tapering to an elongated point. Within this ovoid, three asymmetric concentric zones of differing elevation and vegetation can frequently be recognized (**Figures 2-17** and **2-18**, blue lines): an elevated, northern **head** usually covered with large upland and/or tropical trees; a lower elevation **near-tail** region of more water-tolerant, usually smaller trees, and a **tail** region dominated by sawgrass and scattered small shrubs. Shrubs and numerous herbaceous plants occur in the understory of both head and near-tail regions.

The overall ovoid tree island extent is usually recognized by a fairly sharp edge between the sawgrass of the outermost concentric region (i.e., the **tail**) and the deeper water surroundings of slough (or wet prairie). While the head area is almost always a quite small percentage of the total tree island extent, it is ecologically very important for its ability to support large trees and as the driest habitat found within the Everglades. The partitioning of the much larger, non-head portion of the tree island between primarily shrubby **near-tail** and primarily sawgrass **tail** varies between islands, and appears to vary over time as well (e.g., Johnson, 1958; McPherson, 1973; Alexander and Crook, 1974).

Examination of aerial photographs (SFWMD, 1990) and vegetation maps (Rutchey and Vilchek, 1999; Doren et al., 1999) from Water Conservation Area 3A suggests that the distinction between sawgrass ridges of the ridge and slough landscape and tree islands of the same landscape may be largely a matter of degree. The presence of intermediate forms supports this; for example, long elongated ridges with a minor concentration of shrubs at the northern end.

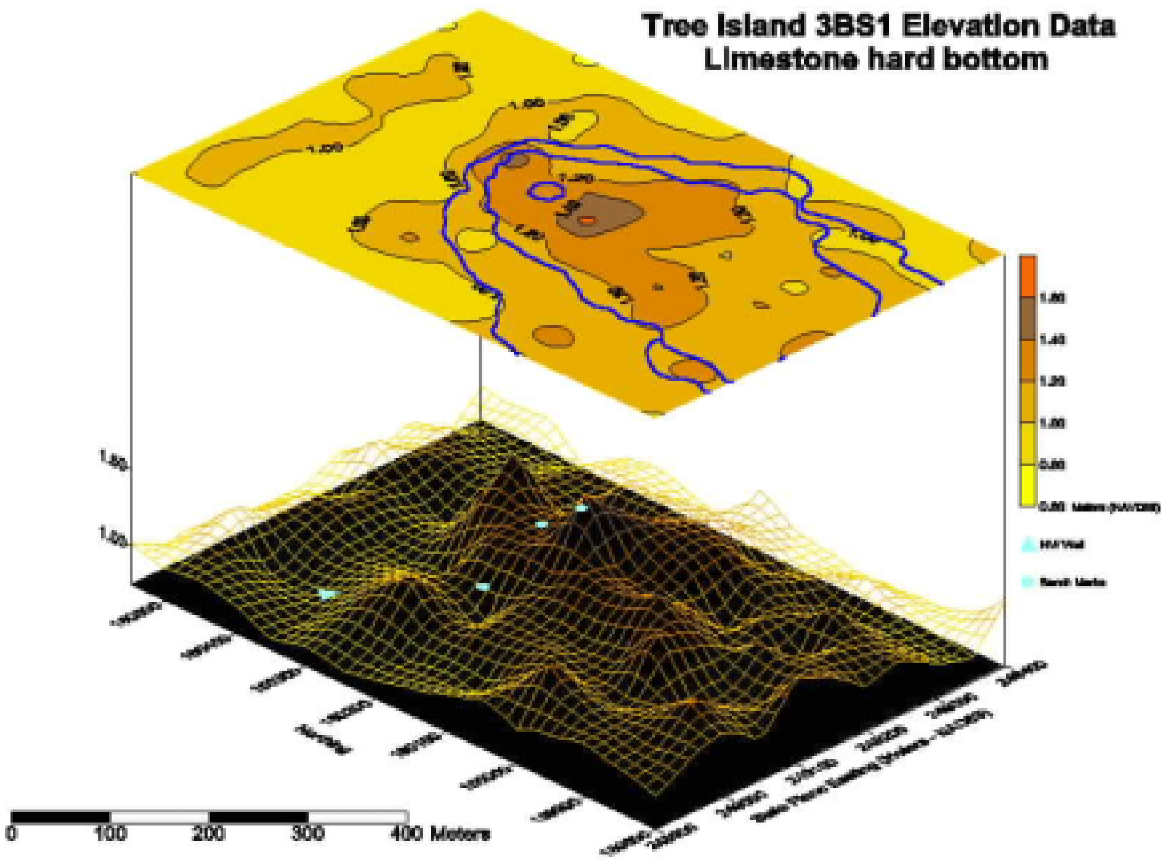


Figure 2-17. Elevation above sea level of the limestone bedrock underlying "dry" tree island 3BS1 in WCA-3B. Upper and lower surfaces show same information. Concentric blue lines on upper surface were separately mapped from vegetation, and show three concentric zones: **head** area (smallest inner circle) with tropical hardwood trees, **neartail** area (next zone, a large, incomplete ovoid) with water-tolerant shrubs and trees, and **tail** area (outermost zone, visible as narrow band) with mostly dense sawgrass. Head elevation may be related to the two pedestal-like structures in the bedrock surface.

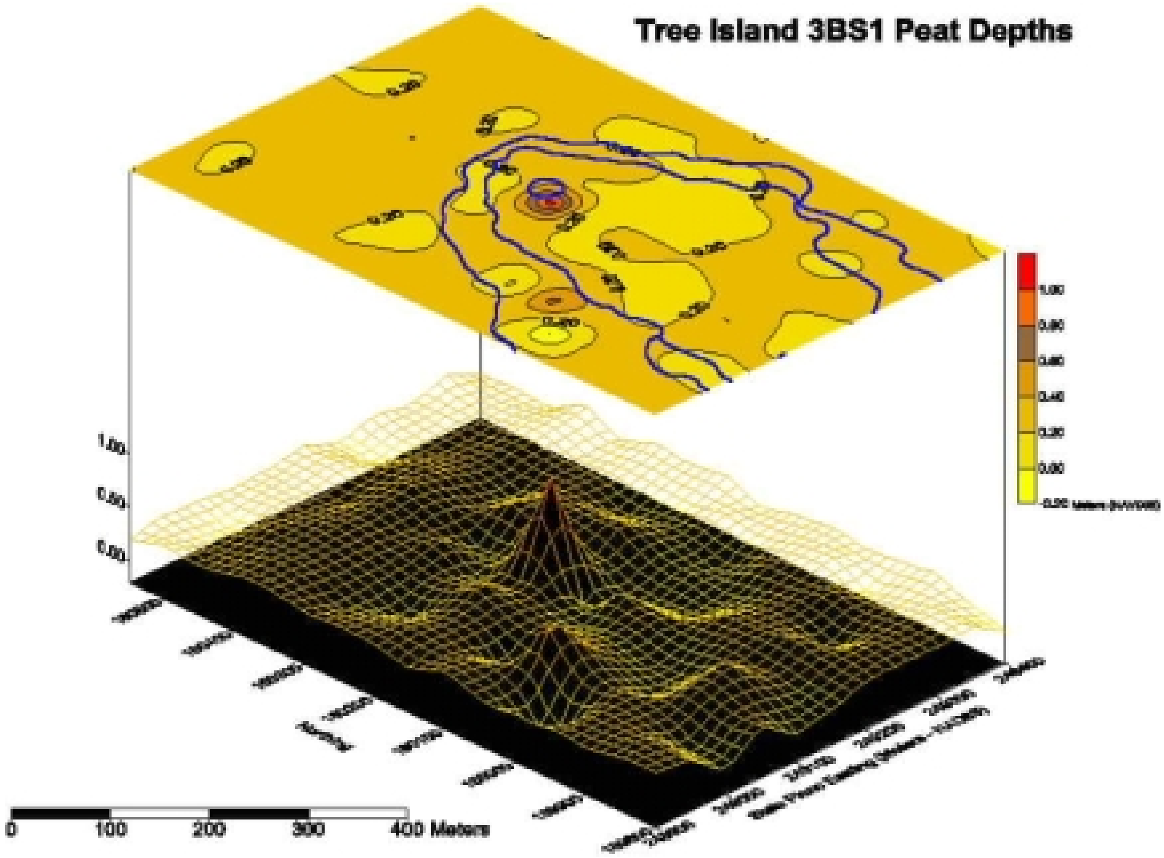


Figure 2-18. Thickness of peat soil underlying "dry" tree island 3BS1 in WCA-3B. Upper and lower surfaces show same information. Blue lines on upper surface show concentric vegetation zones: **head** of tropical hardwood trees, **neartail** of water-tolerant shrubs and trees, and **tail** of dense sawgrass. Note almost exact overlap of head area mapped from vegetation with the peak mapped from peat thickness. Survival of tropical hardwoods on this island has apparently been sustained by peat elevation.

The typical concentric structure described above, that is, a small, elevated head surrounded by more water-tolerant shrubs and an exterior band of sawgrass, is generally consistent with historical descriptions from the ridge and slough landscape, such as those reported in 1840 (Anonymous 1960) and 1897 (Willoughby 1898):

"...[the guide] halted at a low tuft of bushes, about half a mile in circumference, which seemed to us all to be entirely flooded with water, but after penetrating about 300 yards, we came to a magnificent little spot in its centre, about 150 yards in circumference, here we found an old Indian camp." (Anonymous 1960 [1841]).

"[To reach the island] we had to wade through mud and water three or four hundred yeareds [yards], up to our waists, before we gained dry land." (Anonymous 1960 [1841]).

"Nothing now presents itself to view except one boundless expanse of sawgrass and water, occasionally interspersed with little islands, all of which are overflowed, but the trees are in a green and flourisheing state." (Anonymous 1960 [1841]).

"But at last a little island hove in sight with large enough bushes on it to invite an investigation. … The island was surrounded with saw-grass, and we... found about the usual amount of wet ground, --- some twenty square yards. "It was hard on these small patches to find a place where the canoes could be turned bottom up to dry and examine. I have adopted a method of throwing them on top of the saw-grass, which is so strong that it keeps them a couple of feet out of the water."; "In my conceit as an old camper I had made an error in selecting my canoe for this journey. I expected always to find dry islands; such were conspicuous by their absence. The Seminole when travelling always sleeps in his boat, but not until many nights spent on wet ground did I realize why this was necessary." (Willoughby, 1898).

While it is true that the above historical descriptions appear similar to tree island conditions seen at present, it is also true that at least some of the trees present now do not appear to be "in a green and flourishing state." Goals of the District tree island program include quantitative measurement of tree status and, wherever possible, identification of the mechanisms responsible for changes.

Comparison of the ovoid outlines of tree islands in Water Conservation Areas 3A and 3B seen on 1994 satellite imagery with the same outlines drawn in 1940 as "Gandy peat" (i.e., tree island peat) on a soil map (Jones et al., 1948), indicates that these larger tree islands have been fixed in size, orientation, and position for over 50 years. The vegetation <u>within</u> the footprint may have in some cases changed, but the footprint itself appears to have remained quite constant. The same is true even in the more extreme circumstances of Water Conservation Area 2, where the shrubs and trees have almost all disappeared, leaving only sawgrass or emergent aquatics, yet the tree island outline remains and still matches the 1940 outlines.

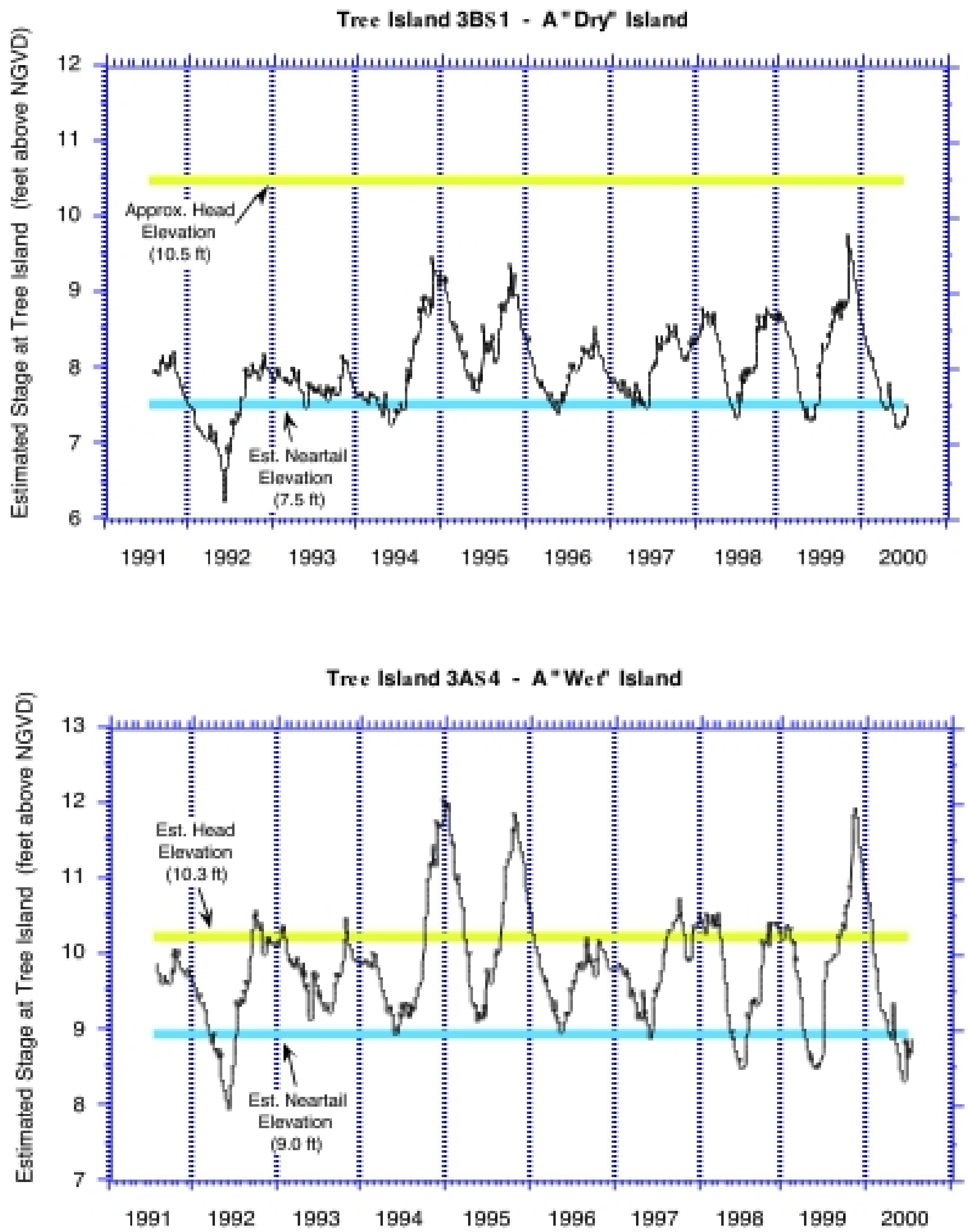
Detailed District research is focused on 20 tree islands in WCA-3, with nine studied intensively. Measurements include detailed topography (**Figures 2-17** and **2-18**), elevation change (Sedimentation and Erosion Table, SET, and feldspar marker horizons; see previous Consolidated Reports), tree growth (dendrometer bands), and tree litter production. In addition, hydrology and ground surface relations are monitored (**Figure 2-19**). Dendrometer bands and litter traps are sampled at approximately six-week intervals. At present, 342 individual trees are monitored. Encompassed in the 342 banded trees are 15 tree species: *Acer rubrum, Annona glabra, Bursera simaruba, Chrysoblanus icaco, Chrysophyllum oliviforme, Cocolobo diversifolia, Eugenia axillaris, Ficus aurea, Ilex cassine, Magnolia virginiana, Myrcianthes fragrans, Myrica cerifera, Persea barbonia, Salix caroliniana, and Schinus terebinthifolias.* neartail hydrology on both islands; but very different head hydrology.

As the research is ongoing, this report includes data from two tree islands, both at approximately the same latitude, approximately two miles north of Tamiami Trail, one in south-central Water Conservation Area 3A, the other in southeast WCA-3B. Large trees present on both suggest that at one time the heads of both islands provided good habitat for tropical hardwoods. The head of island 3BS1 is dominated by *Bursera simaruba* and *Ficus aurea*; the head of 3AS4 by *Bursera simaruba, Eugenia axillaris, Ficus aurea, Chrysoblanus icaco, Myrica cerifera, Salix caroliniana* and *Persea borbonia*. Neartail sections of both tree islands are lower than the heads, but generally 0.1-0.5 m higher in elevation than the surrounding sloughs. Neartail hydroperiods are correspondingly longer than those on the heads. Water-tolerant tree species such as *Magnolia virginiana, Persea barbonia, Ilex cassine, Chrysoblanus icaco, Annona glabra and Salix caroliniana* are usually found in this area. *Annona* and *Salix* are considered the most water tolerant.

Visual observation suggests important differences between the two islands, and between the head and neartail zones. The head of 3BS1 appears dry and the Gumbo Limbo (*Bursera*) trees healthy; the head of 3AS4 in contrast appears wet and the Gumbo Limbo trees in the process of dying, giving rise to the description of 3BS1 as a “dry” island, 3AS4 as “wet.” Curiously, the neartail regions of both islands appear much more similar, and the vegetation of shrubs and small trees much less stressed, if not healthy.

Regression equations developed to estimate past water levels on the two islands (**Figure 2-19**), suggest a possible explanation for the above observations. Comparison of the neartail elevations with the hydrographs indicate a similar relationship, with both neartail areas inundated most of the time. As might be expected, the fact that the neartail elevation, as well as the average hydrograph, is approximately 1.5 foot higher on 3AS4 than on 3BS1 (**Figure 2-19**), does not appear to be significant to the neartail vegetation.

The heads show a very different pattern. In absolute elevation the heads are almost identical, 10.5 and 10.3 feet above sea level. Relative to the average hydrograph, however, they are completely different. The head of 3BS1 has never been inundated between 1991 and 2000 (**Figure 2-19a**). The head of 3AS4 has frequently been inundated for significant periods: 1992 (77 days), 1993 (16 days), 1994 (187 days), 1995 (149 days), 1997 (198 days), 1998 (79 days) and 1999 (143 days) (**Figure 2-19b**).



(A)

(B)

Figure 2-19. Estimated recent hydrographs for a "dry" tree island in Water Conservation Area 3B (**A**), and for a "wet" tree island in WCA-3A (**B**). Horizontal lines indicate estimated elevations of the **head** and **neartail** portions of each island. Note similar neartail hydrology on both islands; but very different head hydrology.

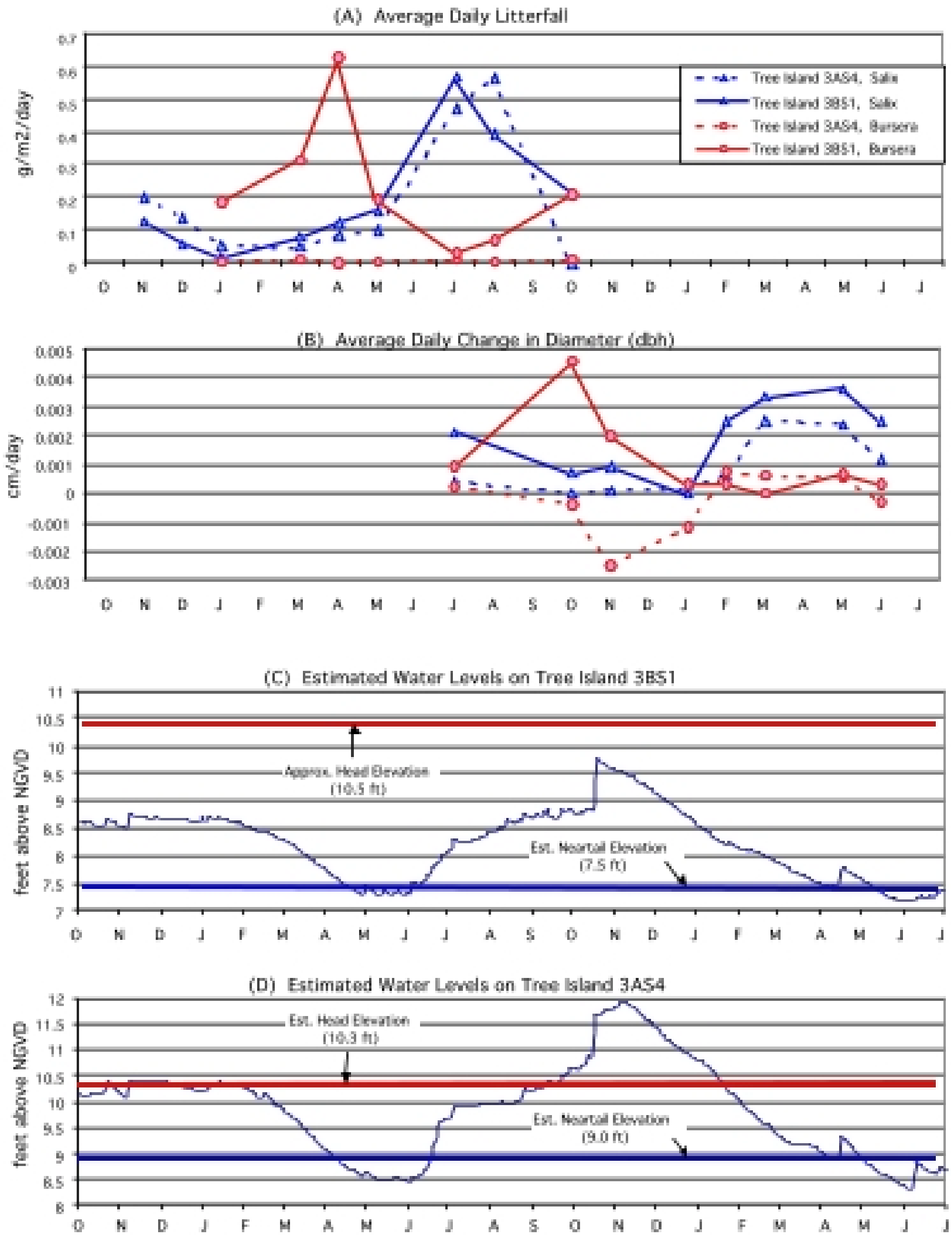


Figure 2-20. Average daily rates of litterfall (**A**) and change in trunk diameter (**B)** for a **head** area species, Gumbo Limbo (circles), and for a **neartail** species, Willow(triangles), on a "dry" tree island, 3BS1 (continuous lines) and on a "wet" tree island, 3AS4 (dashed lines). Lower two graphs relate elevations of head and neartail areas to estimated water elevations for "dry" (**C**) and "wet" (**D**) islands. Despite overall elevation differences, note similar hydrology on neartails, very different hydrology on heads.

Results from the litter traps and from the dendrometer bands (**Figure 2-20a** and **b**) appear to support both the visual observations of head and neartail zones of the two islands as well as the examination of relative elevation and hydrology. On the heads, Gumbo Limbo (*Bursera)* data are quite different, with no litter production at all on "wet" island 3AS4, but litter produced during the dry season on 3BS1 (**Figure 2-20a**). Growth data for *Bursera* were also different, with actual shrinkage during the wet season on 3AS4, but growth during that time on 3BS1. In contrast, the willow (*Salix*) data from the neartail zones showed very similar seasonal patterns of litterfall and growth between the two islands, as expected from the similar hydrology.

In summary, the relationship between vegetation and hydrology on tree islands is clearly a function of ground surface elevation relative to surrounding water elevations. These relations were found to be significantly different in different vegetation zones within tree islands (**Figure 2-20**). Elevation of a "dry" head in at least one case depends on accumulation of deep peat in a depression between two peaks in the bedrock surface **(Figures 2-17** and **2-18)**.

Florida Bay Water Quality and Submersed Aquatic Vegetation (SAV)

The amount and timing of Everglades freshwater input to northern Florida Bay strongly influences water column nutrient, light, and salinity regimes throughout much of the estuary. These properties, in turn, determine primary productivity and biomass of submersed aquatic vegetation (SAV), such as the important keystone species *Thalassia* (turtlegrass). Researchers are interested in how primary production is partitioned among phytoplankton, SAV, benthic algae and epiphytes within the community. For example, reduced water clarity can determine whether the plant community is dominated by bottom-rooted forms, such as seagrasses, or by free-floating plankton forms, which could possibly promote undesirable algal blooms. Freshwater effects on water quality and primary production are being examined through high-resolution mapping of water quality parameters and seasonal measurements of seagrass, phytoplankton and epiphyte productivity. The SFWMD is engaged in a multi-disciplinary program of monitoring and experimentation, aimed at discerning: (1) the time and space scales of Everglades hydrologic influence on northern Florida Bay, (2) nutrients, particulates and dissolved organic inputs to the Bay, and (3) the response of primary production to Everglades inflows.

Associated with this field and experimental research program, an ecological modeling program has been initiated to synthesize data from SFWMD and other research efforts on seagrasses, and to predict the effect of environmental factors on seagrass growth and survival. The objectives of the modeling program are the testing of hypotheses about the interaction of fresh and marine waters in the estuary, and enhancement of our understanding of management of freshwater inputs to optimize estuarine function.

Study Areas and Site Characteristics

District seagrass research efforts are focused on five study areas along a gradient from east to west (**Figure 2-21**) that lie within or near the transitional basins along the Everglades – Florida Bay boundary. The areas correspond to five hydrologic regimes, each resulting in different levels of hydrologic connection with the Everglades. At each site, *Thalassia testudinum* (turtlegrass) is the dominant seagrass, although at sites in Little Madeira, *Halodule* is mixed among the *Thalassia*. Trout Cove is the easternmost site, lying just bayward of Trout Creek, and in the path of the strongest fresh water inflow, in terms of volume, from the Everglades to the northeast Bay (USGS provisional data). The Trout Cove site is generally lower in salinity and more exposed to fresh water pulses than the other sites. *Thalassia* found here is thinner and sparser than all other sites (**Table 2-5**).

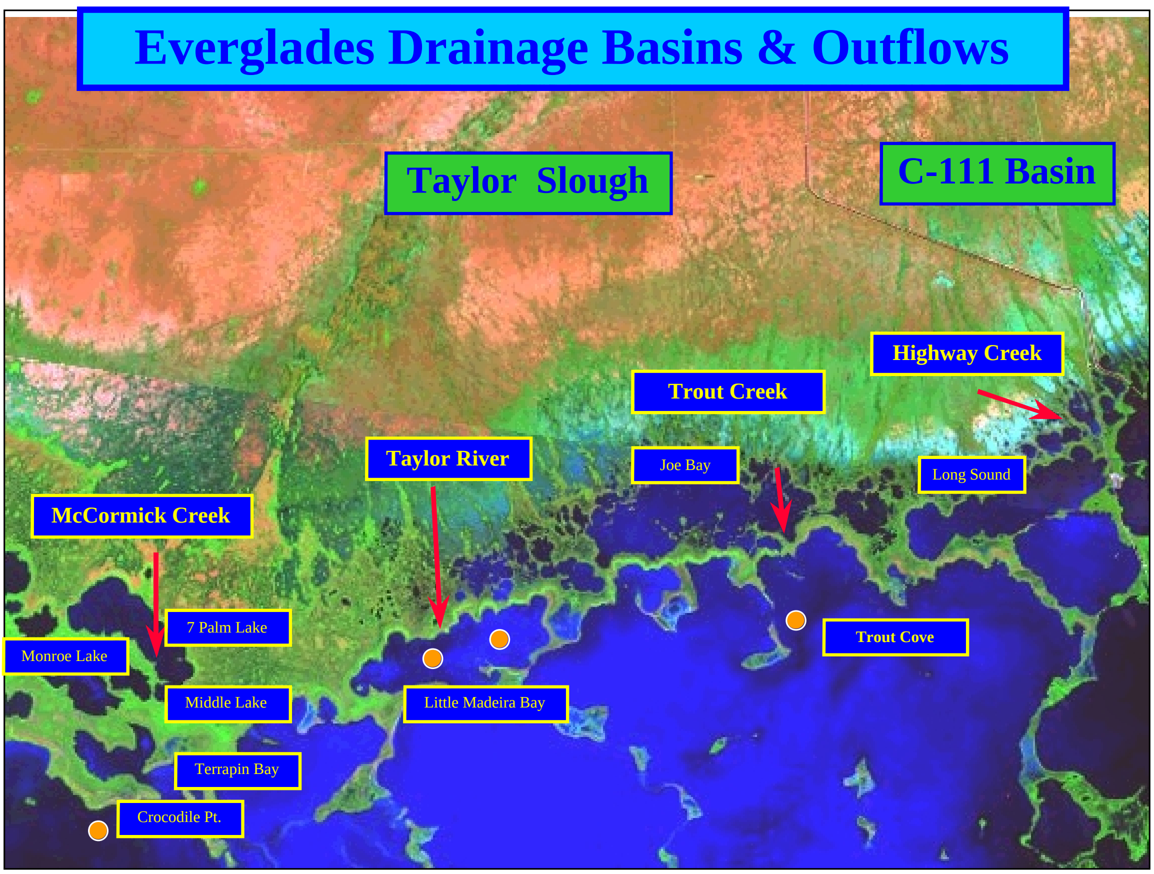


Figure 2-21. Study area map showing major Everglades inputs to northern Florida Bay, major water bodies, and four of the five seagrass study sites. East to west: Trout Cove, Little Madeira East, Little Madeira West, and Crocodile Point. Fifth site. Rankin Bay (not shown), is 10 km to west.

Table 2-5. Characteristics of *Thalassia* at study sites: average length of longest leaf, average width of all leaves, average short shoot density.

SITE	*Length (mm)*	*Width (mm)*	*Density (ss m^{-1})*
Trout	123	3.5	60
Lmad E	210	4	82
Lmad W	185	4	120
Croc Pt.	180	5	135
Rankin	105	7.5	77

Two sites in Little Madeira Bay lie 200 m east and west of the mouth of Taylor River. The sites were chosen because of the strong salinity differences due to a gradient established by prevailing currents at the mouth of Taylor River that push fresh water input to the west. The western of the two sites experiences lower salinities, and higher inputs of tannic Everglades-derived water, while the eastern site is more marine in character. *Thalassia* at both sites are of similar short shoot density and plant morphology.

A site adjacent to the mouth of Terrapin Bay at Crocodile Point is highly marine in character. It is periodically influenced by high ammonium levels, phytoplankton blooms and pulses of Everglades inputs flowing through McCormick Creek. This site is more exposed to wind and waves, but plants here are robust, dense and productive. Finally, a recently added site in Rankin Bay is mostly marine, farthest removed from direct Everglades inputs and typified by phytoplankton blooms. Seagrasses here are generally short, with thick cuticles, wide, short leaves, and short shoots occurring at low densities.

Scales of Interaction and their Measurement

Factors associated with fresh water inputs change on sub-daily, diel, seasonal and interannual timescales, and a high resolution mapping instrument has been designed to capture these variations synoptically from a moving boat. Chlorophyll-*a*, salinity, temperature, water clarity, dissolved oxygen, dissolved organic substances (DOM) and pH are routinely measured bi-weekly to bi-monthly in 2-D mapping transects with a continuous flow system. Water transparency is measured by in-line transmissometer, chlorophyll by in-line in vivo fluorescence using a 455 nm excitation source and DOM by in vivo fluorescence using 265 nm excitation.

Salinity changes occur on seasonal time scales, although sharp changes occur locally near creek mouths on scales of hours during strong rain events (**Figure 2-22**). During the dry season, Florida Bay is generally characterized by high salinities, low turbidity, and large phytoplankton patches. Although suspended particulate concentrations are similar across the Bay, levels of chlorophyll-*a* in central basins of Terrapin Bay and Crocodile Point are 40-1000 percent greater than in eastern basins **(Figure 2-23**). During the wet season, the estuary is characterized by reduced salinities in the transitional basins, although during periods of low rainfall, hypersaline conditions have occurred in Florida

Bay even during the wet season. Salinities as high as 50 parts per thousand (ppt) have been measured on several occasions in 1997 and 1998 in the central and western basins of Madeira, Terrapin and Crocodile Point. Strong differences in phytoplankton chlorophyll concentration and distribution routinely occurred in the northern transitional basins. High chlorophyll and increased phytoplankton productivity often occur at salinity discontinuities near inputs of fresh water.

Spatial gradients in water quality properties are, at least in part, related in the east-west direction to differences in the strength of Everglades hydrological inputs at specific locations. In a north-south direction, parameter variability is related to meteorological and hydrological forcing along the estuarine salinity gradient. The range and variability of water quality parameters in each transitional basin along the southern Everglades boundary respond differently to Everglades inputs, each with distinct chlorophyll, salinity and turbidity signatures that are largely dependent on the strength of hydrologic connectivity of the basin with the Everglades. Transitional basins maintain near-oceanic salinities until rains begin, usually in June, then quickly drop to mesohaline salinities.

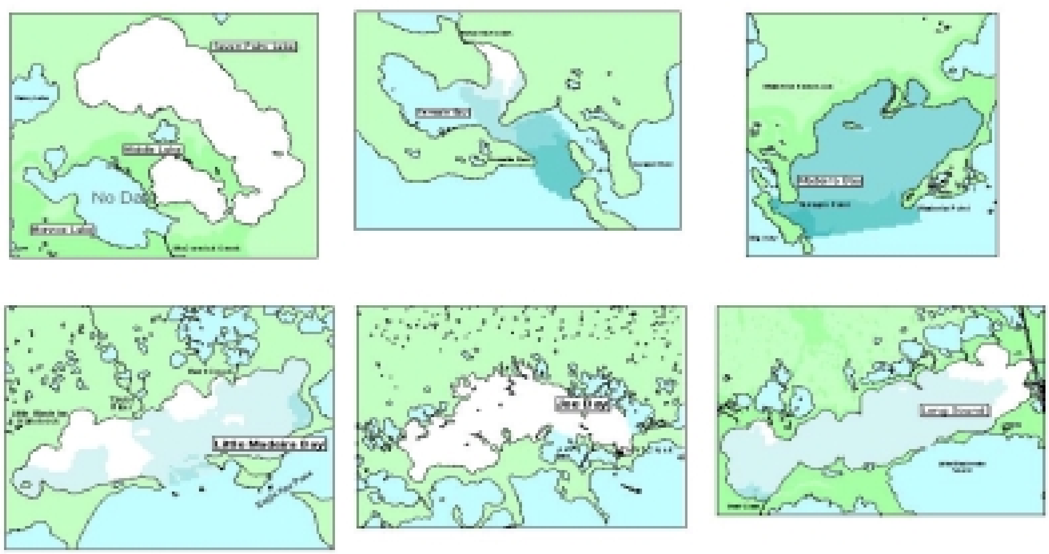


Figure 2-22. Synoptic salinity distributions in transition bays of Florida Bay. Lighter colors indicate fresher water. Note freshwater plumes in eastern Long Sound near Highway Creek, and in western Little Madeira Bay near Taylor River.

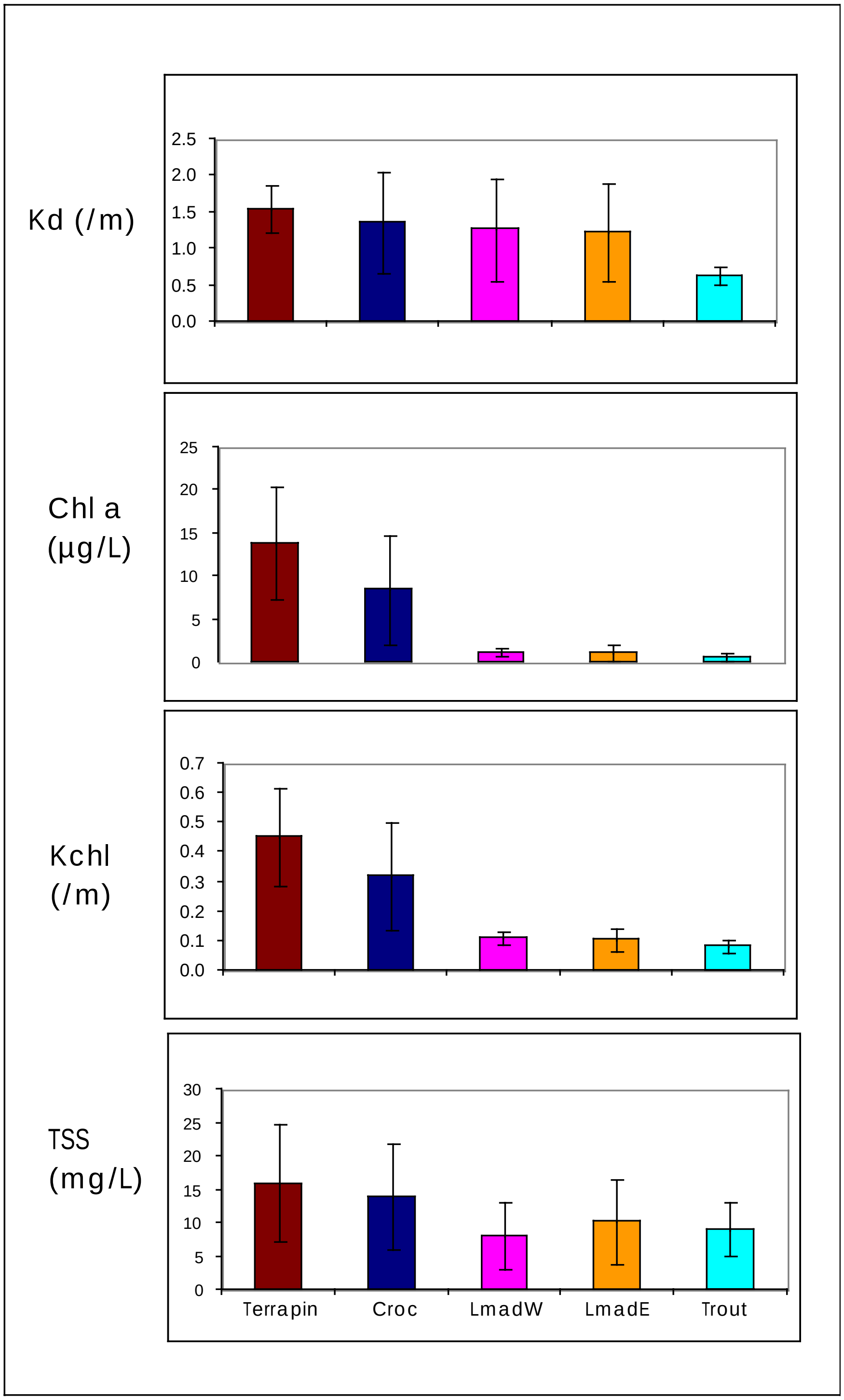


Figure 2-23. (Previous page). Average water column light parameters in Florida Bay, arranged right to left from west to east, Jun 1997-Jul 1999. Kd=water column attenuation coefficient; Chl a=chlorophyll *a*, Kchl=water column attenuation coefficient due to chlor. *a* alone; TSS=total suspended solid concentration.

Until 1997, the central basins apparently received the earliest and largest pulse of freshwater, proceeding from Taylor Slough through Taylor River and McCormick Creek. After levee removal and restoration of natural sheetflow in the C-111 Basin in October 1997, flows to eastern Florida Bay appear to be stronger, and occur earlier, than previously **(Figure 2-24**). In contrast to 1997, Long Sound and Joe Bay freshened markedly in May 1998, and salinities dropped to levels similar to those observed in the central transitional basin Little Madeira Bay, which is directly influenced by Taylor River. Madeira and Terrapin Bays had elevated salinities compared to Florida Bay background salinities and maintained higher salinities than the eastern bays. This is a preliminary conclusion, and natural interannual variability may play a role in the observed pattern, but the trend suggests an important increase in the delivery of fresh water to eastern Florida Bay as a result of restoration activities.

Effects of Everglades Inputs on Seagrasses

We can gain some idea of the effects of variations in fresh and salt water on the *Thalassia* community in northern Florida Bay by comparing community responses in regions of different salinity regimes. Photosynthesis versus irradiance (P-I) curves for *Thalassia* (not shown) measured at the Little Madeira-East, Little Madeira-West, and at Crocodile Point sites allow a comparison of light available in the water column for primary productivity. Crocodile Point is the most marine of the sites, and plants found there are dense and healthy. Little Madeira-West lies in the plume of tannic brackish water flowing from Taylor River. Little Madeira-East lies to the east of the Taylor mouth, in the marine-influenced region of Little Madeira Bay. The east site is influenced by generally high concentrations of suspended carbonate particulates, which tend to attenuate light penetration. According to the P-I curves, available light was saturating, that is, more than sufficient to power maximum production, at both the more marine, clear waters at Crocodile Point and at the Little Madeira-West site, fed by freshwater plumes of tannin-rich marsh waters. Light and productivity at Little Madeira-East, though more marine in salinity, was lowest at this site, apparently due to carbonate particulates in the water column.

The observation that tannin-rich Everglades freshwater is not limiting to *Thalassia* growth has some historical precedence as well. The geologist Alexander Agassiz, travelling in the Florida Keys and Biscayne Bay in 1896, before construction of canals through the southern Everglades, observed:

> "The bottom of Key Biscayne Bay near the northern extremity, about three miles from the entrance to the Miami River, is covered with *Thalassia*; the waters of the bay itself are of a dark brownish color, apparently saturated with vegetable matter. The dark color of the inland waters of the sounds back of the keys from Key Biscayne to Blackwater Sound is in marked contrast with the clear sea water which bathes the southern shores of the main line of keys." (Agassiz 1896, p. 42).

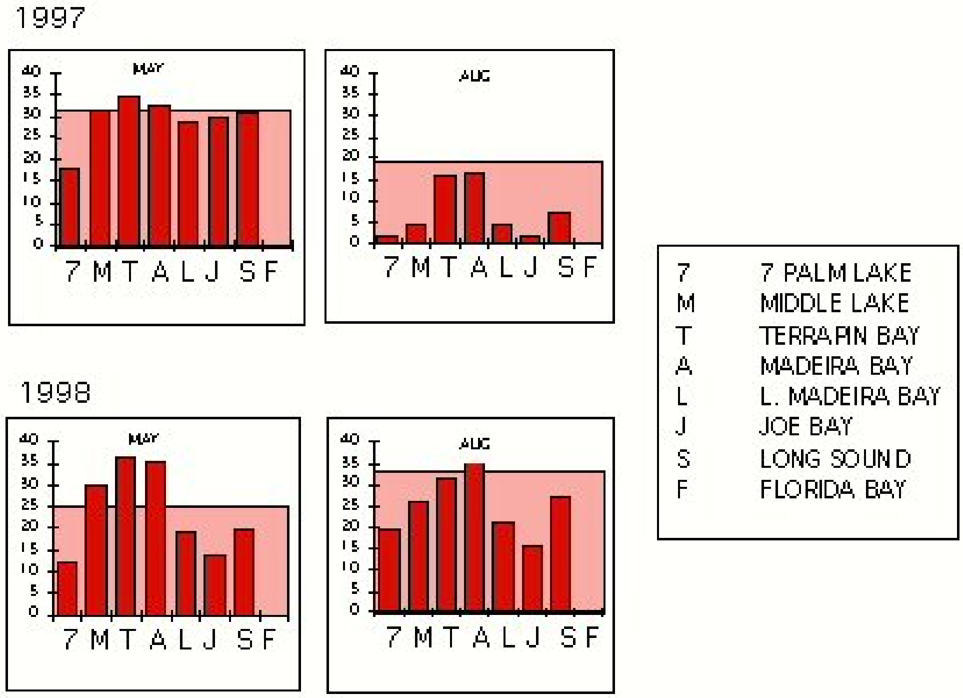


Figure 2-24. Synoptic salinity values for transition basins, arranged right to left from west to east, in May and August of 1997, prior to levee removal in the C-111 Basin, and in same months of 1998, after removal. Shaded background is Northern Florida Bay average salinity.

Although the transparency of the water column at Little Madeira-West is often greater than in Little Madeira-East, both the Little Madeira seagrass sites, and the Trout Cove seagrass site are clearer than the Crocodile and Terrapin sites to the west where phytoplankton blooms reduce available light. This is true of the eastern versus central and western Bay in general- light becomes more limiting moving westward. Measurements of mean per cent light reaching the seagrass canopy depth (**Figure 2-25**) repeatedly show that transparency is much greater in the eastern Bay, with 80-90 percent of light reaching the bottom, versus 50-80 percent in the west.

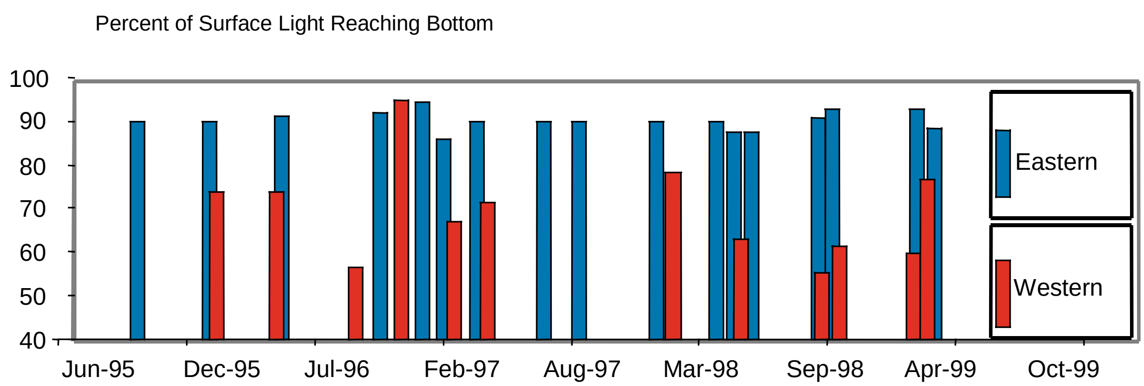


Figure 2-25. Percent of light at water surface reaching bottom for eastern and western sites in Northern Florida Bay. Throughout the year, water clarity is lower in the western than in the Eastern Bay.

Healthy populations of *Thalassia* living in the path of maximum Everglades freshwater flows, and periodically low salinities. Although calculations of light availability for primary production indicate frequent potential light limitation of photosynthesis, the primary factor in light limitation is not Everglades input. It is apparently a combination of carbonate particulates from marine waters and, in certain central Bay areas, phytoplankton blooms that are responsible for reductions in water column light. The source of the blooms in the central Bay remains ambiguous and is undergoing further study. But from east to west, primary productivity and biomass of all autotrophic components (seagrass, epiphytes and phytoplankton) increases, and an increasing fraction of primary production diverts to phytoplankton and epiphyte components. This shift follows a water column gradient in nutrients, particularly phosphorus (not directly related to freshwater inputs; Rudnick et al., 1999), whose source may be the western Bay and Gulf of Mexico.

WILDLIFE RESPONSES TO HYDROLOGY

Wading Birds

The information reported here represents a compilation of data collected by a variety of investigators monitoring wading bird nesting in South Florida (Gawlik, 1999). The time-period is for the nesting season that began January 1999 and ended during the summer of 1999. There are no data for the year 2000 nesting season because it has not yet ended. Preliminary reports for 2000 suggest that it will be one of the better nesting years for some parts of the Everglades and a poor year for other areas.

The estimated number of wading bird nests (excluding Cattle Egrets, which are not dependent on wetlands) in South Florida in 1999 was 27,105. That number is a 42 percent increase over 1998, which was similar to 1997 but down 17 percent from 1996. The number of nests in 1999 is similar to that of 1992, which was the best nesting year in the past 14. The large nesting effort in 1992 was consistent with the historic pattern of increased nesting following a multi-year drought. However, the increased nesting in 1999 followed several very wet years, suggesting that good nesting conditions can result from very different hydrologic regimes.

The increase in numbers of nests from 1998 was evident throughout the Everglades interior (note that despite an increase from 1998, the number of nests in ENP is still extremely low), but not so for the coastal regions (i.e., Florida Bay, Southwest coast, and Caloosahatchee Estuary). This is the second consecutive year in which an increase or decrease in the number of nests in the Everglades interior was the opposite of the trend in coastal areas. It was suggested in last year's report that nesting conditions in coastal regions may not have been impacted as severely as the interior marshes by the 1998 high water. Thus, coastal marshes may serve as a buffer to extreme hydrologic conditions. The 1999 pattern suggests that conversely, nesting conditions in coastal areas may not improve as much during good hydrologic conditions. If this pattern is apparent in subsequent years it will be a powerful example of a multi-year linkage between coastal and interior Everglades marshes for long-lived species.

This (1999) was the first year since 1992 that a survey designed to quantify Roseate Spoonbill nesting was conducted in Florida Bay. The number of nesting pairs was similar to that of 1992. More dramatic was a shift in the location of colonies from the NE part of the Bay to the NW region. The last large-scale change in colony site locations occurred in the 1960s, when they shifted from the SE to the NE part of the Bay.

Aerial wading bird distribution surveys in the WCAs indicate that peak bird abundance before and during the breeding season in 1999 was roughly 3 times that of 1998. In 1999, not only were there more birds in the WCAs in winter, there was no movement of birds out of the system just prior to the nesting season as there was in 1998. Although 1998 and 1999 in the WCAs were very different in terms of the numbers of birds that nested, they were similar in terms of the percentage of birds that nested (87 percent in 1998 versus 89 percent in 1999). This pattern supports the idea that the primary response by birds to unfavorable hydrologic conditions is to simply leave the system.

Despite the overall good nesting effort in 1999, the only species that met numeric nesting targets proposed by the South Florida Ecosystem Restoration Task Force was the Great Egret (**Table 2-6**). There was improvement in the timing of nesting for White Ibises and Great Egrets (nested 1 month earlier than in 1998) but not for Wood Storks.

Table 2-6. Numbers of wading bird nests in the Water Conservation Areas and Everglades National Park.

Species	***Base low/high***	***1994-1996***	***1995-1997***	***1996-1998***	***1997-1999***	***Target***
Great Egret	1,163/3,843	4,043	4,302	4,017	5,084	4,000
Snowy Egret/ Tricolored Heron	903/2,939	1,508	1,488	1,334	1,862	10,000-20,000
White Ibis	2,107/8,020	2,172	2,850	2,270	5,100	10,000-25,000
Wood Stork	130/294	343	283	228	279	1,500-2,500

Aquatic Macroinvertebrates in a Ridge and Slough Area

Benthic macroinvertebrates link primary and secondary production in the Everglades, providing an important food source for fish, juvenile alligators, ducks, and wading birds. Benthic macroinvertebrates usually inhabit inundated sediments and plant communities and therefore can help clarify relations between water levels and ground surface elevations, and any changes in these. Since 1996, district researchers have measured invertebrate populations four times per year in slough and in emergent sawgrass habitats of Water Conservation Area 2A. Differences between sloughs and sawgrass are apparent from field measurements. At present, ground elevation of the peat substrate is only 0.15-0.30 m (0.5-1 ft) higher in the sawgrass than in the sloughs. Pre-drainage observations suggest that the sawgrass ridges of the ridge and slough landscape (named by Baldwin and Hawker 1915) originally could have been elevated about 0.45 m (1.5 ft) above the adjacent slough bottoms (SFWMD, 2000).

Density of the sawgrass and the characteristic ridge shapes suggest that most of the "emergent sawgrass" sampling locations of the benthic macroinvertebrate monitoring program correspond to pre-drainage sawgrass ridges. Comparison with seasonal water levels suggests that the ridge/slough distinction is still ecologically significant: sawgrass is seasonally inundated, while sloughs are usually inundated year-round (**Figure 2-26d**). Canopy density and height on the sawgrass ridges further accentuates the ecological distinction by restricting larger predators such as fish and wading birds to the sloughs. Seasonal drying of the sawgrass ridge appears to be an important aspect of the ridge and slough landscape, forcing benthic macroinvertebrates either into the moist soil or out into the adjacent sloughs (SFWMD 2000). The observation of higher predatory fish densities along slough edges than in the center (R. Shuford, pers. comm., 2000) may reflect seasonal exclusion of invertebrates from drying sawgrass ridges.

Macroinvertebrate densities were higher in sloughs than in the "ridges" of emergent sawgrass (**Figure 2-26a** and **b**). Seasonal patterns of total density were not very strong. Diversity was similar between slough and sawgrass (**Figure 2-26c**). Diversity varied somewhat more over time in the sawgrass, and there may be a slight tendency for increased diversity in the wet season. Taxonomic richness (not shown) was similar between the two habitats, and between wet and dry seasons.

The benthic macroinvertebrates were classified into five functional groups (**Figure 2-26 a** and **b**). Grazers and herbivores were dominant in the sawgrass ridges, as expected due to high volumes of macrophyte detritus. Predators became more important when emergent habitats were inundated. Slough communities harbored a greater proportion of filter feeders and general collector gatherers. Predaceous invertebrates were consistently higher in sloughs throughout the sampling period. Chironomids were numerically important to all functional classifications. These dipterans comprised 97 percent of the filter feeders, 83 percent of the collector gatherers, 79 percent of the herbivores, 26 percent of the predators and 18 percent of the grazers in the sawgrass ridges. Amphipods, limpets and mayflies comprises 40 percent of all grazers in the sawgrass.

Taxonomic composition shifted in response to variations in water levels. Principal component analyses showed clear separation between wet season and dry season taxa at the Family level. Invertebrate communities were dominated by chironomids and amphipods, which comprised 64 percent of the wet season taxa and 70 percent of the dry season taxa, respectively. Scirtidae (Coleoptera) and Ancylidae (Gastropoda), taxa largely dependent on inundated macrophyte material, were significantly higher during the wet season. Relative densities of Asellidae (Isopoda) and Lumbricula (Oligochaeta), taxa typical found in moist soils, increase during drier conditions.

For the last five years the abundance of invertebrates has remained fairly constant. However, elevated densities occurred in emergent communities during the May 1996 sampling period. Dipteran raw densities ranged between 1700 and 12000 individuals/m^2. Gastropoda, Decapoda and Ephemeroptera also experienced greater than normal densities. It is hypothesized that this population increase was somehow related to the extended 1995-96 winter dry period and a rewetting of the soil in May 1996 to enhance rates of emergence and prevent predation by fish. However, the mechanisms driving taxonomic changes are not clearly understood and will require further study.

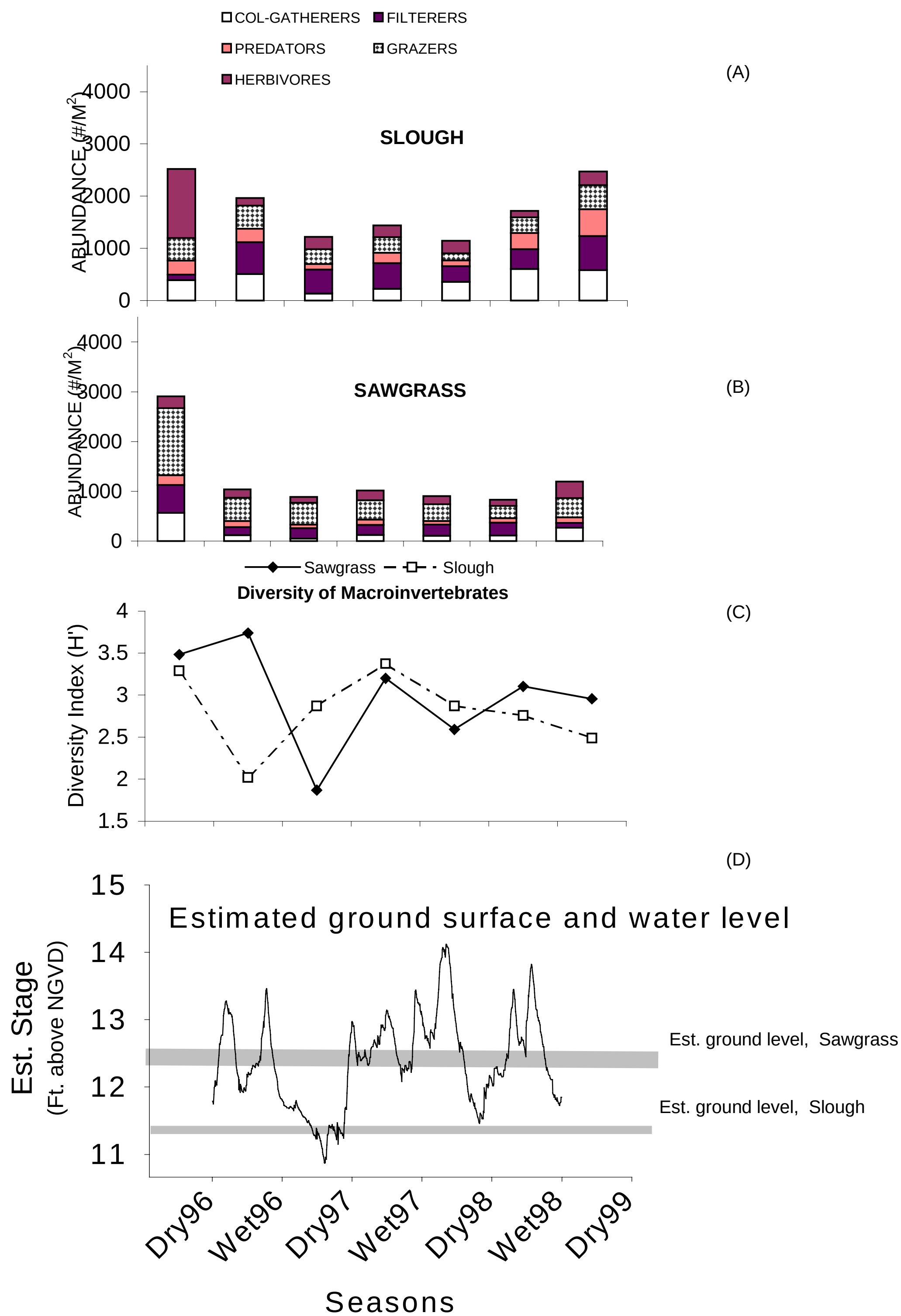


Figure 2-26. Abundance (**A** & **B**) and diversity (**C**) of benthic macro-invertebrates in sawgrass ridge and aquatic slough habitats of WCA-2A, 1996-1999. (**D**) shows relation of ground elevations in sawgrass and in sloughs to approximate water elevations for the same time period.

TOOLS FOR HYDROLOGIC MANAGEMENT AND ECOLOGICAL RESTORATION

THE EVERGLADES LANDSCAPE MODEL (ELM)

The Everglades Landscape Model (ELM) evaluates ecosystem responses to modified water and nutrient management at the landscape scale. Simulating the direct and indirect interactions associated with hydrology, phosphorus cycling, decomposition, primary production, and habitat succession, the ELM domain includes most of the remnant Everglades and Big Cypress. The first version of this model was calibrated to extensive ecological data for WCA-2A (Fitz and Sklar, 1999), and a significantly revised version is being evaluated and applied to the full model domain.

This current version (2.1) includes the full suite of ecological dynamics, but is not fully calibrated or verified for all of the soil dynamics and vegetative/periphyton community responses in all parts of the system. For the first application of the ELM to evaluate regional system response to management scenarios, the focus is primarily on phosphorus transport and fate in surface waters. For the different management alternatives in the Modified Water Deliveries project, the District is evaluating the total phosphorus (TP) in surface waters as redistributed water flows towards areas such as Northeast Shark Slough. Altered sources, and thus TP concentrations, can change the TP loading to particular areas of the Everglades system. The ELM is now being used as a quantitative indicator of any potential water quality constraints that may need consideration in implementing the Modwaters project, and will be further developed and applied in evaluating Comprehensive Everglades Restoration Plan initiatives.

Prior to applying this modeling tool, the ELM hydrology was evaluated in relation to historical observations and the South Florida Water Management Model (SFWMM) calibration/verification simulation runs. In general, water budgets and stage observations are consistent between the SFWMM and the ELM, and both models effectively predicted stage in multiple locations throughout the Everglades region. For example, under conditions of both long and short hydroperiods, the ELM predicted hydrologic behavior reasonably well (**Figure 2-27**).

Coupled to the hydrologic dynamics in the ELM is the transport and fate of phosphorus as it moves through the Everglades canal network and is transformed via biologic and biogeochemical processes. ELM was able to effectively capture the distinct gradients in TP from north to south in the Everglades, including high loading events and responses to drydowns over the 16 year calibration period (**Figure 2-28**).

In preparation for evaluating the Modified Water Deliveries project and Comprehensive Everglades Restoration Plan initiatives, the ELM's WWWeb site (http://www.sfwmd.gov/org/erd/esr/elm.html) was updated for rapid communication of model results. Using a scripting environment for model post-processing, most of the graphs and animations are generated automatically and posted to the web using PHP. The server-based PHP script language and interpreter generates dynamic web pages from these graphics for each management alternative run.

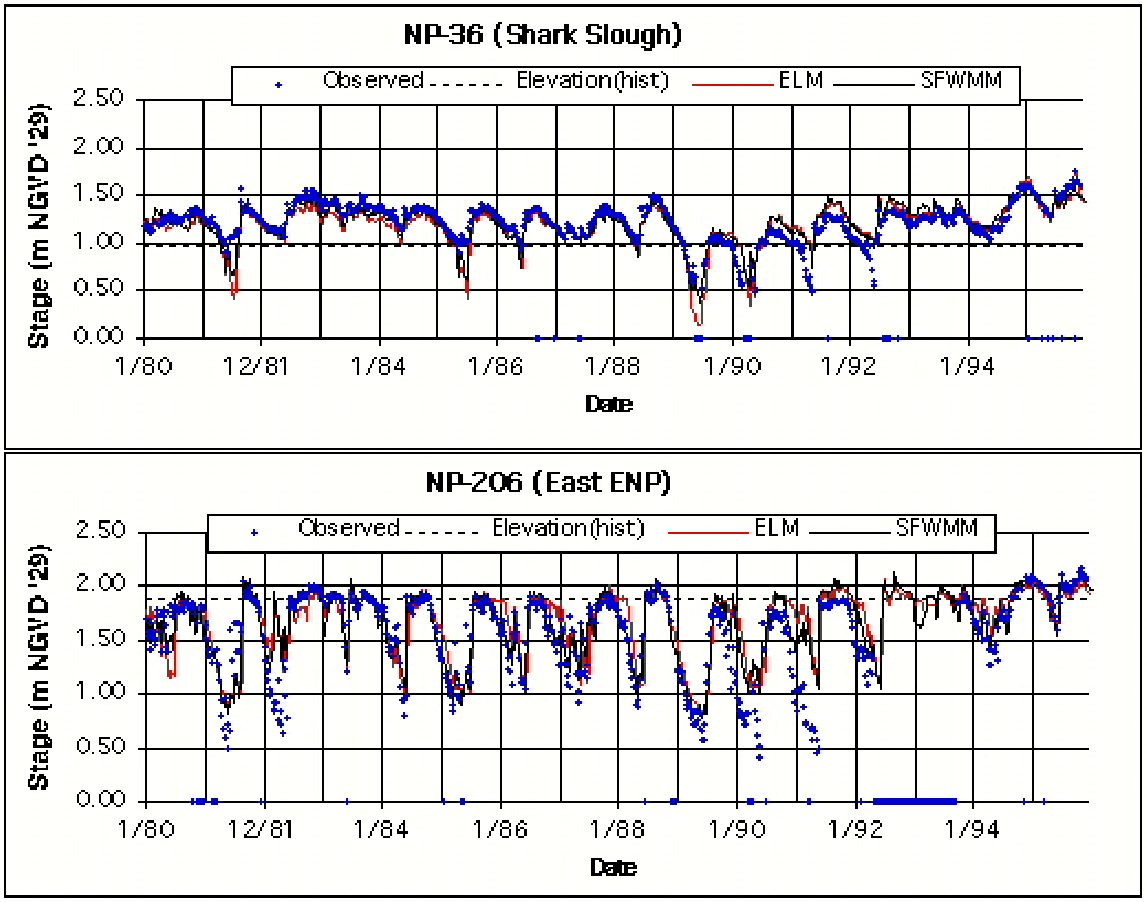


Figure 2-27. Examples of ELM calibration of water stage: comparison of model output and observed data in a long hydroperiod location (Shark Slough) and a short hydroperiod location (eastern Everglades National Park). The red lines are ELM results, the solid black lines are SFWMM results, the circles are field observations, and the dashed lines are (current) land surface elevations. Comparisons of ~40 other calibration points are found in the Results section at http://www.sfwmd.gov/org/erd/esr/elm.html.

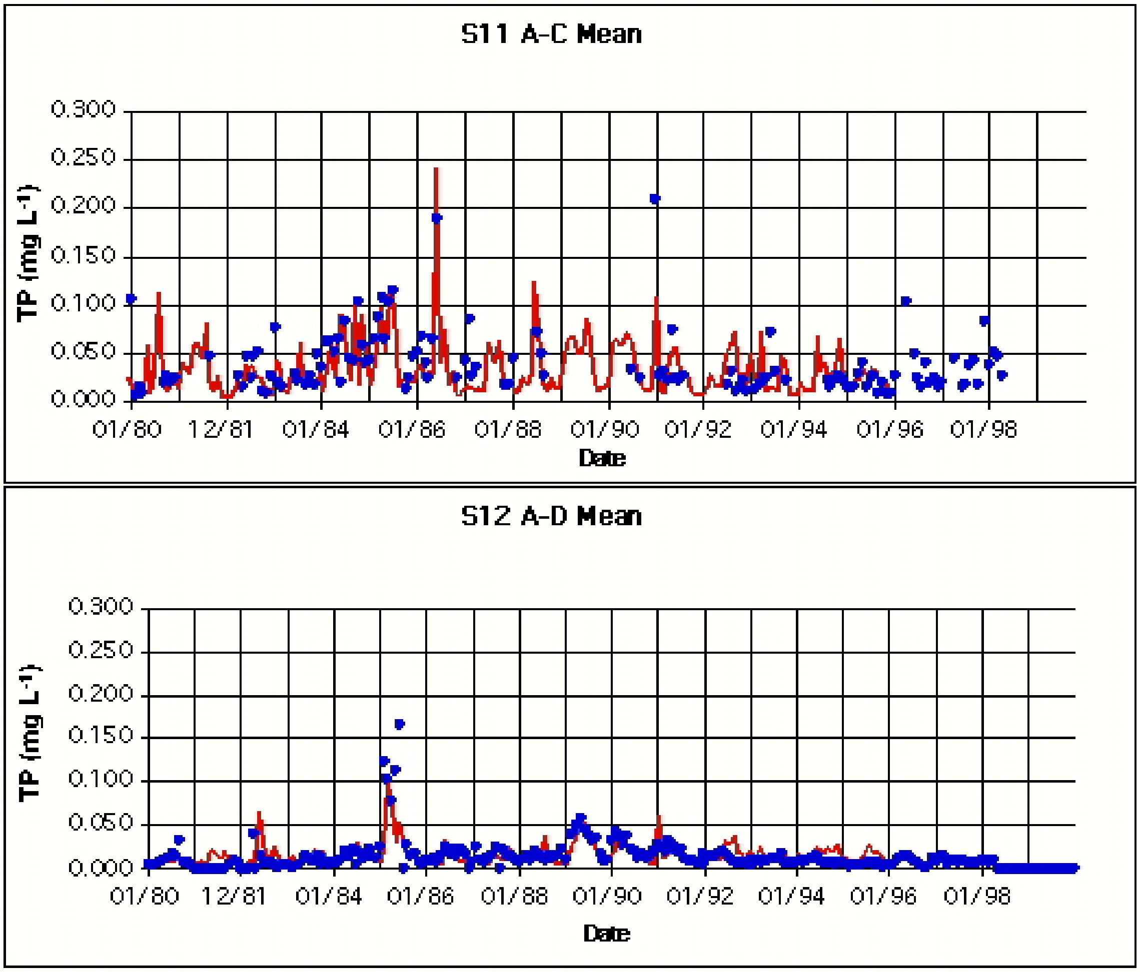


Figure 2-28. Examples of ELM calibration of surface water quality: comparison of model output and observed data in the northern Everglades (mean of observations at S-11 A-C) and in the southern Everglades (mean of observations at S-12 A-D). The lines are model results, while the circles are field observations. Comparisons of ~40 other calibration points are found in the Results section at http://www.sfwmd.gov/org/erd/esr/elm.html.

CONCEPTUAL MODELS FOR CERP

The Comprehensive Everglades Restoration Plan (CERP) has adopted the "Applied Science Strategy" as a process for linking the sciences and management during the planning and evaluation of restoration (Ogden et al., 1997). The creation of a science application strategy was motivated by the need for a better focused process for organizing and converting large amounts of existing technical information into planning and evaluation tools that would directly support the restoration program. To be successful, it was felt that the science strategy must, (1) lay out a scientifically reviewed sequence of steps and tasks for converting research and modeling results into planning objectives, performance measures and evaluation protocols, (2) serve as a strong catalyst for promoting consensus among scientists and managers regarding the nature of the ecosystem problems that must be corrected by the restoration plan, and the probable routes for resolving these problems, and (3) be a process that can contribute to the objectives and needs of both the scientific and management communities in South Florida. Thus the Applied Science Strategy is designed to organize our current understandings of the biology and ecology of natural systems in order to maximize the ways that science can both influence and support policy and management actions. The Applied Science Strategy is a total systems and multi-disciplinary process for determining the most appropriate restoration targets, and the best measures for each of these targets, during and following the planning and implementation of CERP. These tasks are prerequisite to the successful application of adaptive assessments during the implementation of the restoration program.

An essential step in the Applied Science Strategy is the creation of a set of conceptual ecological models of the major wetland landscape features in South Florida. Models are being developed for Lake Okeechobee, the ridge and slough landscape, Marl Prairie, Mangroves, and Florida Bay. These simple, non-quantitative models are an effective means for developing a consensus regarding a set of causal hypotheses, which explain the affects that the major anthropogenic stressors have on the wetland systems. The models identify the attributes in the natural systems that are the best indicators of the changes that have occurred as a result of the stressors. The models also show the ecological linkages among the stressors and attributes (**Figure 2-29)** and the most appropriate measures for each of the attributes. Conceptual models have been widely used for similar purposes in other regions of North America (e.g., pp. 31-38 in Gentile, 1996; also see Rosen et al., 1995).

The Applied Science Strategy that is being used to link the sciences and management in the South Florida ecosystem restoration programs is derived from the "Ecological Risk Assessment" process of the U.S. Environmental Protection Agency (EPA, 1992; Gentile, 1996). Risk assessments are used by the EPA and others as a guideline for conducting ecological evaluations of proposed management actions. A similar approach was used by the Man and the Biosphere Human Dominated Systems program to define sustainability goals and identify ecological endpoints for a series of restoration scenarios for South Florida (Harwell and Long, 1992, Harwell et al., 1996). Many of the same components and steps incorporated in the Applied Science Strategy, including conceptual models, have more recently been described in Margoluis and Salafsky (1998).

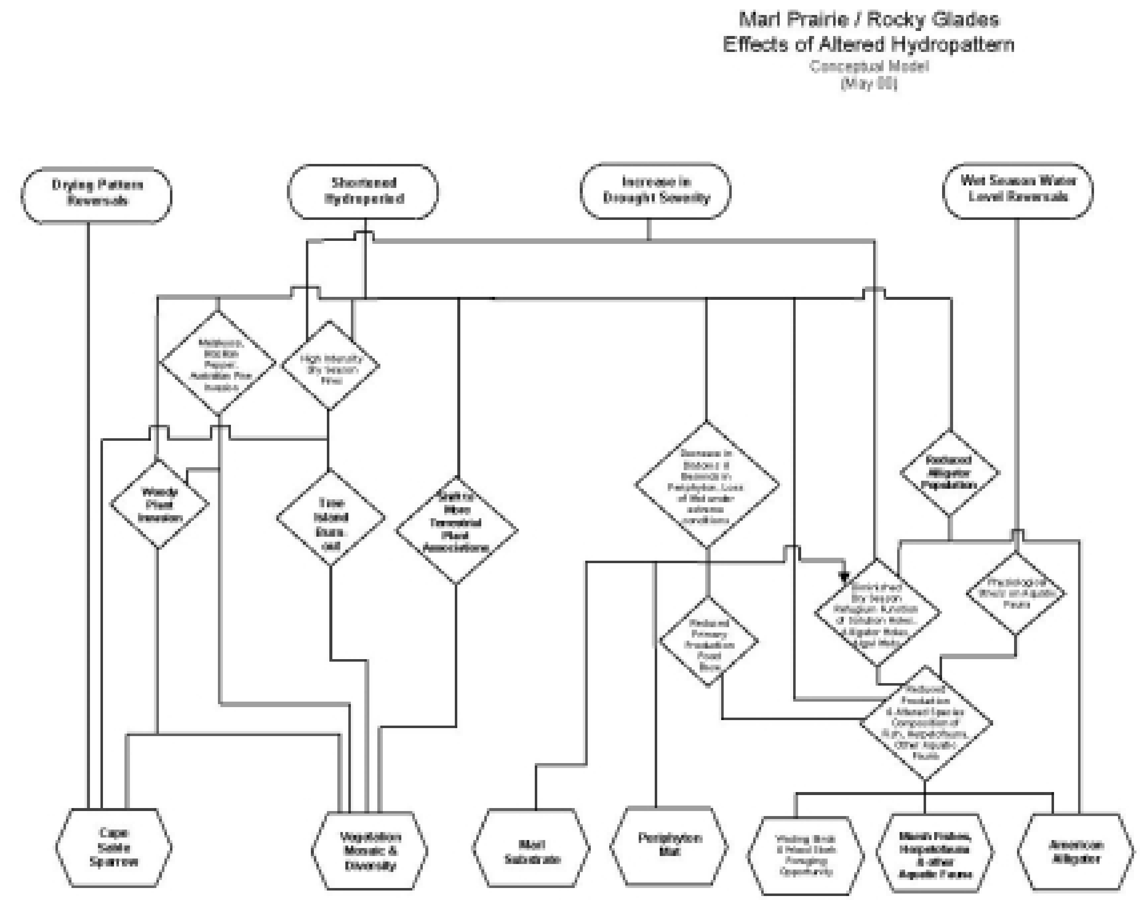


Figure 2-28. An example of a conceptual model being used to identify attributes and stresses that will be monitored to evaluate Everglades's restoration success. Example shows the pathways through which hydrologic stress is manifested in the Marl Prairie ecosystem in the Southern Everglades.

The overall planning strategy for CERP has been to use the conceptual ecological models as a basis for developing performance measures and restoration targets for the stressors and attributes in each model. These targets, collectively, describe the physical and biological conditions that are being used to define successfully restored natural systems. The rationale for having performance measures and targets for each stressor is that the stressors are known or hypothesized to be the immediate sources of the ecological problems in each landscape. A successful restoration program must remove the adverse affects created by each stressor. A performance measure identifies which elements of each stressor must be corrected, how those elements should be measured, and how those elements must change (i.e., the restoration target) to landscape. A successful restoration plan must remove the adverse affects created by each stressor. A performance measure identifies which element of each stressor must be corrected, how these elements should be measured, and how those elements must change in order to eliminate or reduce their adverse effects.

Performance measures are also developed for each attribute in the conceptual models. The attributes have been identified as the biological or ecological elements that are the best indicators of responses in the natural systems to the adverse effects of the stressors. The performance measure developed for each attribute identifies the element of that attribute which should respond, how that element should be measured, and how that element should change (i.e., the restoration target) once the affects of the stressor are removed.

The modeling teams also identified critical linkages in the conceptual models. Critical linkages were defined as those ecological links between one or more stressors and attributes, which seemed to explain much of the ecological or biological change in the systems. The assumption was that the stressors that are part of critical linkages should have a priority during restoration planning over other, less influential stressors. The Restudy team generally placed higher priority on meeting performance targets for critical linkage stressors than for other stressors in the models. For example, the ridge and slough conceptual model suggests that stresses caused by reductions in the duration of uninterrupted surface water hydroperiods may explain some of the adverse changes that have occurred in the long-hydroperiod slough systems. Correction of this stressor became the highest priority in evaluating the predicted affects of alternative restoration plans in the central sloughs of the Everglades.

The performance measures and restoration targets from both the stressors and attributes are being used for two primary purposes. Performance measures function during the planning phases of the restoration projects as evaluation tools for comparing the design of alternative plans. In this planning role, the measures and targets not only are used to measure which plan is most likely to be successful in achieving its objectives, but also are used to influence the design of the project as efforts are made to determine the combination of features which can best moderate or eliminate the adverse affects of the stressors. The second primary use of the measures and targets is in the design of a system-wide, ecological monitoring program. The purpose of system-wide monitoring is to measure how elements in the natural system actually respond following the implementation of each iteration of the restoration plan.

The key to successful implementation of a regional ecosystem restoration plan, e.g., maximizing the effectiveness of the plan and reducing uncertainty during its implementation, is an adaptive assessment strategy. The conceptual ecological models are an integral part of the overall adaptive assessment process. The conceptual models are revised as new information comes from the research and monitoring programs. These revisions in the conceptual models influence predictions of system responses for future iterations during the implementation process. As the accuracy of the hypotheses and conceptual model linkages improve, the opportunities for making pre-construction improvements in project design and in plan operations are also enhanced. Greater accuracy in the conceptual models leads to improvements in the choice of measures and targets used to refine the design and to evaluate the predicted performance of each project design.

FINDINGS

Hydrologic Trends

Hurricane Irene dropped over nine inches of rain, on average, over Palm Beach, Broward, and Miami-Dade Counties. The three-day totals at specific measuring sites ranged between 11 and 17 inches. Rainfall from Irene made the 1999 wet season the third wettest since 1960.

Despite Hurricane Irene, total annual rainfall for most of the Everglades was below average for Water Year 2000. WCA-2 was the only region with above-average precipitation. Annual precipitation throughout the Everglades has declined since Water Year 1995.

Total cumulative inflows from water management structures into each of the WCAs and the Park were above average in Water Year 2000. The structure inflows to the Park (1,066,801 ac-ft) were 120 percent greater than the 30-year average. The percent increases, relative to the average for WCA-1, WCA-2, and WCA-3, were 27, 11, and 27 percent, respectively. These structure inflows were almost twice the maximum reported in last year’s Consolidated Report.

Despite below average rainfall, average water depths in each of the WCAs were above average in Water Year 2000. These high water depth averages reflect the combined effects of Hurricane Irene, high structure inflows, and, in WCA-2A, management to protect water depths in WCA-3A.

Due to requirements in the Biological Opinion, the Corps deviated from Test 7 and implemented a Interim Structural and Operating Plan (ISOP) to move water away from Cape Sable Seaside Sparrow Subpopulation A in western Everglades National Park, while not adversely impacting private property. Successful nesting of this subpopulation required water levels below 6.0 feet at the NP-205 gage for 60 consecutive days between March 1 and July 15, 2000. Despite elimination of inflows through closure of all four S-12 structures, the 60-day goal was not achieved, as two separate rainfall events interrupted the dryout period.

ISOP likely slowed recession in WCA-2A between November and mid-February. Recession in WCA-3A does not appear to have been affected by ISOP; recession of the Irene peak was complete before S-12 closures, and reduced outflows through the S-12 structures appear to have been approximately balanced by a combination of increased S-333 outflow and reduced S-11 inflows from WCA-2A.

Pre-drainage soils (6-7 ft deep sawgrass peat) and vegetation (sawgrass marsh) bordering 40 miles of the southwest shore of Lake Okeechobee indicate that outflows from Lake to Everglades typically continued throughout much of the year, rather than being exceptional overflow events.

Analysis of the ridge and slough landscape in aerial photographs from 1940 revealed an organized pattern of long, parallel orientations, consistent with pre-drainage descriptions of Everglades flow directions, topography and outflow locations. The flow patterns suggest that WCAs 1 and 2 drained southeastward to the Atlantic Ocean. The more western areas – WCA-3A, WCA-3B, and Everglades National Park – formed a generally separate unit, draining out Shark Slough.

Pre-drainage topography, vegetation and soils indicate that the eastern Everglades sloped and drained downward toward the Peat Transverse Glades originally present north of Miami, supplying water to the coastal rivers.

Land surface in the Everglades south of present Tamiami Trail sloped upward from Shark Slough toward the Marl Transverse Glades, so these glades were lateral spillways, with overflow occurring only when water levels rose in Shark Slough. As the elevations of the Marl Transverse Glades are known, late wet season outflows provide an important performance measure for evaluating regional models of pre-drainage conditions in the Shark Slough/Marl Prairie/Marl Transverse Glades area.

A conceptual carbon balance model of the ridge and slough landscape suggests that post-drainage flattening and obscuring of this landscape may be related to man-made impedances to water and particulate matter flow, especially during transient, high-flow conditions. The conceptual model suggests that reversal of flattening of the ridge and slough microtopography would likely require unimpeded water flows in the original flow directions.

Ecological Trends

Soil analyses from areas of vegetative (surface) fires and soil (muck) fires showed large impacts associated with muck burns. These studies help guide establishment of minimum flows and levels (MFLs) to prevent muck burns. Muck fire resulted in losses of total carbon, nitrogen, and organic forms of phosphorus while inorganic phosphorus was elevated. Increases in inorganic P fractions in muck-burned areas were due to the physical reduction of soil depth while decreases in N and C were the result of volatilization. In addition, muck fire resulted in increased vertical heterogeneity in concentrations of most constituents between upper and lower sediment layers.

Analysis of plant growth and tissue nutrient analysis showed that both assayed and field-harvested plants from muck-burned soils assimilated more phosphorus than those from surface-burned or non-burned soils. Muck fire-related increases in the bioavailability of P may encourage cattail establishment and expansion in the Everglades. Absence of cattail evidence in pre-drainage soil cores suggests that muck fires were likely absent under pre-drainage conditions, prevented by higher water levels.

Ecophysiological studies of sawgrass and cattail life history emphasized the importance of hydropattern on prevalence of sawgrass or cattail. Fluctuating temperature (day:night) was required for the germination of *sawgrass* and light was required for the germination of *cattail*.

In *sawgrass*, no clear relationship was found between P availability and growth rate. In contrast, the growth rate of *cattail* increased with P availability. Cattail can survive and likely displace sawgrass under high water conditions because cattail can pump air down to its roots to compensate for low oxygen concentrations. Sawgrass has only a passive diffusion mechanism for moving air to its roots. However, it was also discovered that this greater flooding tolerance of cattail comes at an energetic cost and this cost requires additional phosphorus. This could be why the N:P ratio of cattail plant tissue was found to increase at low phosphorus concentrations.

Under flooded conditions, the total number of primary roots produced by *cattail* increased relative to the drained treatment, but *sawgrass* root numbers did not change. *Sawgrass* is subject to greater root oxygen deficiencies than *cattail*.

Dendrometer bands, measuring changes in tree diameter at breast height (dbh) were attached to 342 individual trees on 18 different tree islands. Results from two tree islands found very similar neartail areas (elevation above surrounding sloughs; and willow tree health, litterfall, and change in diameter), but the dry head on one island (>3 ft above neartail, positive Gumbo Limbo litterfall and increase in diameter) differed greatly from the wet head on the other (1.5 ft above neartail, zero Gumbo Limbo litter, decrease in diameter).

Health of tree island vegetation appears to be sensitive to the elevation difference between ground surface and surrounding water levels. For this reason, tree island number and extent has been proposed as a performance measure for the Water Conservation Areas. Subsidence of peat-based tree islands complicates analysis of water level effects, suggesting that additional performance measures for the WCAs may be required.

During the dry season, the Florida Bay estuary is generally characterized by high salinities, low turbidity, and large phytoplankton patches. Chlorophyll levels in central basins are 40-1000 percent greater than in eastern basins. Until 1997, the central basins received the earliest and strongest pulse of freshwater. After levee removal and restoration of natural sheetflow in the C-111 Basin in October 1997, flows to eastern Florida Bay became stronger, and occurred earlier, than previously.

Healthy populations of *Thalassia* were found in areas of maximum Everglades freshwater inflows, despite periodically low salinities and dark, tannin-rich water. Lower salinities in western Little Madeira Bay do not adversely affect photosynthetic properties of *Thalassia*. Calculations of light availability for *Thalassia* primary production indicate frequent potential light limitation of photosynthesis. The primary factor in light limitation appears to be a combination of carbonate particulates from marine waters and in certain central Bay areas, phytoplankton blooms. The source of the blooms in the central Bay remains uncertain.

The estimated number of wading bird nests in South Florida in 1999 (27,105), following several wet years, is a 42 percent increase over 1998, which was similar to 1997 but down 17 percent from 1996. Despite the overall good nesting effort in 1999, the only species that met numeric nesting targets proposed by the South Florida Ecosystem Restoration Task Force was the Great Egret.

Despite an increase from 1998, the number of nests in ENP is still extremely low. This is the second consecutive year in which an increase or decrease in the number of nests in the Everglades interior was the opposite of the trend in coastal areas.

This (1999) was the first year since 1992 that a survey designed to quantify Roseate Spoonbill nesting was conducted in Florida Bay. The number of nesting pairs was similar to that of 1992. However, there was a shift in the location of colonies from the NE part of the Bay to the NW region.

Elevation differences between remnant slough and sawgrass ridge habitats in WCA-2A were slight (0.15-0.30 m), but sufficient to affect hydrology. Between 1996 and 1999, slough habitats were inundated almost continuously, whereas water levels dropped below ground surface in the sawgrass ridges. Densities of aquatic macroinvertebrates were somewhat higher in the sloughs than on the sawgrass ridges. Taxonomic composition and distribution between functional groups varied between wet and dry season. Field observations suggest that the annual cycles of inundation and exposure of the sawgrass ridges may affect predation patterns within the sloughs.

Tools for Management

Everglades Landscape Model (ELM) water budgets and stage observations were consistent with historical observations and with the South Florida Water Management Model (SFWMM) calibration/verification simulation runs. The ELM's WWWeb site (http://www.sfwmd.gov/org/erd/esr/elm.html) was updated for rapid communication of model results.

The Comprehensive Everglades Restoration Plan has adopted the conceptual modeling approach for the development of performance measures and restoration targets, and the process of adaptive assessment for revising conceptual models as new information becomes available and in turn for improving project designs and operations.

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