Chapter 6: Ecological Effects of Hydrology on the Everglades Protection Area

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SUMMARY

The information in this chapter is designed to update the reader on the multidisciplinary approaches currently in place to better understand and manage the hydrologic patterns of the Everglades Protection Area (EPA). The South Florida Water Management District (District or SFWMD) has begun to shift resources away from the phosphorus (P) threshold research program and toward an ecological research program to assess the influence of hydrology. This program documents how soils, plants and animals have changed over time and attempts to relate those changes to operational trends and restoration goals. It is important to note that this report does not at this time quantify the hydrologic needs of the Everglades. Such quantification can only come with a better understanding of how the depth, source, hydroperiod and flow patterns control the spatial and temporal biogeochemical processes that influence biodiversity and produce landscape structure. Since it is not possible to study all aspects of Everglades ecology, each year the hydrologic problems are dissected into more manageable pieces, such as mangrove productivity, slough vegetation, decomposition, microtopography or crayfish. Though these may appear disconnected from one another, they are, in fact, linked by food-web dynamics, ecological feedbacks, and hydrological dependencies. As discussed in the initial Everglades Consolidated Report (ECR) in 1999, these studies are designed to focus on cause-and-effect relationships, because then human impacts can be separated from natural impacts, and water quality effects can be separated from water quantity effects.

HYDROLOGIC TRENDS

Hydrologic variables, presented in ways that are relevant to ecosystem management and restoration, were collected by the Everglades National Park (ENP) and the Environmental Monitoring Division of the South Florida Water Management District (SFWMD). They serve the departments of Regulation, Operations, Planning, Restoration, and Research. Research uses these data as baselines for comparisons across time, habitats, and biogeographic regions. Most importantly, the water depth, rain, and discharge data presented in this chapter of the ECR gives the research scientists the hydrologic variables needed to develop experimental designs and test various stressor-response hypotheses. The data shown here demonstrate the spatial and temporal variance for regions that continue to be fragmented.

A year ago it was hypothesized that the full impact of the 2001 drought might not be felt until the 2002 water year. However, there was no indication of any hydrologic lag effects or delayed impacts. On average, water depths were greater than average and SFWMD managed structure inflows were below average, except for Everglades National Park (ENP or Park), where inflows were above average. It appears that ENP structure inflows were the result of regulatory releases from Water Conservation Area 3 (WCA-3), combined with a rainfall-driven schedule for inflows. Inflows to the WCAs do not yet follow a rainfall-driven schedule. In general, recession rates in the EPA were not as extreme as they were last year during the drought. They were consistent with estimates of historical averages (i.e., the Natural Systems Model; NSM), with the exception of a reversal in the dry-season recession rates due to high rainfall in February. Also, water level and hydroperiod dynamics were generally erratic. The greatest water level fluctuations occurred in WCA-2A, where water levels went down and back up five separate times during the year. There were a few minor fires in spring 2001; there were no fires in spring 2002. No direct ecological impacts of the above-average water depths or erratic hydroperiod patterns have yet been observed.

Restoration and management of estuarine systems are linked to hydrologic trends and its influence on salinity. Salinity conditions in Florida Bay, as well as rainfall and freshwater flow through the southeast Everglades, were near the average of values observed since 1991. Salinity averaged 26 parts per trillion (ppt) in eastern Florida Bay and 32 ppt in the central bay. Hypersalinity and the loss of oligohaline areas in Florida Bay and its adjacent mangrove zone remain long-term ecological concerns. Ecological restoration of the bay, as it is being planned in the Florida Bay and Florida Keys Feasibility Study (FBFKFS) of the Comprehensive Everglades Restoration Plan (CERP) is likely to entail increased freshwater flow to restore salinity patterns. However, a recent review of the relationship of Florida Bay and Everglades restoration by the Committee on Restoration of the Greater Everglades Ecosystem (CROGEE) cautioned that hydrologic restoration of the Everglades and increased freshwater flow to Florida Bay, as currently planned by CERP, may not be beneficial to Florida Bay. This conclusion is derived from evidence that increased flow may also increase nitrogen loading and stimulate algal blooms in the bay. CROGEE recommended increased research of nitrogen (N) fate and effects, particularly dissolved organic N. CROGEE also recommended that this issue be addressed within the FBFKFS, especially through the development of a set of linked hydrologic, hydrodynamic water quality models.

ECOLOGICAL TRENDS

These data were collected to understand how Everglades flora and fauna respond to water resource management. The crayfish study by the Regulation Department evaluates how the extent and intensity of the dry-downs in isolated and short-hydroperiod wetlands can harm this vital prey item. Wading bird data, critical to long-term restoration goals and short-term operations at individual structures, are collected by numerous university and state agencies and compiled by the SFWMD (Gawlik, 2001) to evaluate how regional hydroperiods and depths are effecting distributions, abundance, and nesting success. Tree island and mangrove data are also collected to establish long-term restoration goals and short-term operational guidelines (i.e., Adaptive Protocols). As mandated by the 404 Permit for STA Operations and Discharges, data are presented in this chapter on downstream ecological impacts. Work on ridge and slough habitats, their flooding tolerances, physiological requirements and sediment decomposition, has been added to our research agenda because CERP needs to know how to prevent further encroachment of sawgrass and cattail ridges into slough habitats, restore historical micotopography, and evaluate the need for canal backfilling.

Crayfish: Wetlands whose hydroperiods are closely tied to groundwater fluctuations are vulnerable to ecological impacts from consumptive water uses. These impacts include, and are not limited to, transition of wetlands to drier ecosystems and overall loss of wetland acreage. Understanding how hydrology drives wetland biota is critical to decision-making processes for compliance with state wetland protection regulations. The Everglades crayfish (*Procambarus alleni faxon*) was examined as a potential hydrobiological indicator species to determine if there was a quantifiable relationship between *P. alleni* behavior and hydrologic fluctuations. Maximum burrow depths at the end of the dry season were correlated with groundwater elevation, indicating that a survival threshold might exist and could be used to modify current minimum flows and levels. Restoring former Everglades functions requires knowledge of linkages between secondary (aquatic system) trophic levels and hydrology. Understanding the relationship between the natural survival behavior of crayfish, a key species, and natural seasonal water level fluctuations will allow water resource managers to make appropriate decisions as to the design and timing of restored water flows.

Wading Birds: The estimated number of wading bird nests (excluding cattle egrets, which are not dependent on wetlands) in South Florida in 2002 was 68,504. This is an 82 percent increase from last year and a 73 percent increase from 2000 (excluding Florida Bay) – two of the best years in a decade. This banner nesting was attributed to increased nesting by white ibises, wood storks and snowy egrets, the three species that have declined the most since the 1930s due to a large nesting effort by white ibises and snowy egrets in one colony in northern WCA-3. This colony contained 51 percent of the nests in South Florida (35,000 nests), making it one of the largest wading bird colonies seen in recent years. This high inter-annual variability in nest numbers is typical of South Florida wading birds and illustrates the close connection between wading birds and the widely fluctuating hydrologic patterns that characterize the Everglades.

Rotenberger Restoration: Stormwater Treatment Area 5 (STA-5) began discharging water into the Rotenberger Wildlife Management Area in July 2001. Hydrologic conditions previous to July 2001 were severe, since Rotenberger experienced long drought periods and a large-scale fire disturbance. Temporal and spatial surface water quality data indicate that total nitrogen (TN) and total phosphorus (TP) concentrations decreased during the post-discharging period (July 2001 through July 2002). A decrease in nutrient concentration suggests that both TN and TP were being taken up and adsorbed along the study transects. There was also a gradual shift in macrophyte species composition during the post-discharge period. Proliferation of facultative wetland species that occurred during the 2000 drought and the 2001 dry season has since declined to the point where very few of these plants or seedlings were observed.

Tree Islands: The major objectives of this research are to evaluate the spatial and temporal patterns of tree growth and primary production in relation to hydrology, and to assess total biodiversity in relation to hydrology. The results of this study (relevance) will be used as ecological tools and performance measurements for the Comprehensive Everglades Restoration Plan (CERP). A comprehensive list of Everglades herpetofauna and their use of tree islands can be found in the appendix. Total litterfall (i.e., twigs, fruit, flowers and leaves) and tree growth has been measured on nine tree islands in WCA-3A since 1998. In general, individual trees located on tree islands characterized by relatively short hydroperiods grew better than individual trees located on tree islands with long hydroperiods. Litterfall production was also higher on short hydroperiod islands than on long hydroperiod islands. Litterfall production was strongly seasonal, with higher litterfall production occurring during the rainy season and lower production during the dry season. Litterfall in mangroves, as on tree islands, was significantly greater during the rainy season. Spatially, the dwarf mangrove forest had the lowest litterfall rate, while sites along the elevated coastal ridges had the highest.

Ridges and Sloughs: Vegetation studies are just beginning to demonstrate how hydrologic factors control species dominance in sloughs and wet prairies. Results of controlled greenhouse experiments found that *Eleocharis cellulosa* (a slough species) had a significantly higher total biomass under flooded conditions than did *Rhynchospora tracyi* (a wet prairie species), while *R. tracyi* tended to have a higher total biomass under drained conditions. Shoot porosity, indicative of how plants deal with stress from flooding, was three times higher for *E. cellulosa* than for *R. tracyi*.

Soils and Sediments: Decomposition is the key process that controls peat accumulation and nutrient cycling within the Everglades landscape. It is influenced by drought, flooding, and nutrient availability and thus is a critical component of several restoration projects including the re-establishment of the ridge and slough landscape (RECOVER, and Decompartmentalization), establishment of hydrologic needs of the Everglades and tree island restoration. In addition, because of its influence on landscape elevations, decomposition responses to changing hydrology are essential to refine minimum flows and levels. Changes in hydrology can have long-lasting impacts on soil structure and processes. A soil index (EICQ) for microbial biomass, productivity and decomposition was evaluated. The enriched Everglades site demonstrated higher EICQ values in both the soil and the detrital layer, suggesting that decomposition is occurring at a faster rate in nutrient-enriched sites. The EICQ also suggests that open water habitats exhibit faster decomposition than sawgrass ridge habitats. These results appear to support a decomposition-mediated formation of sloughs and sawgrass ridges over time and contributes to the debate on the role of sheetflow in structuring the landscape (SCT White Paper, 2002).

Topography: Hydrologic restoration is directly influenced by topography. Sediment elevations continue to be measured in the dwarf mangrove habitats of Florida Bay. Mangrove wetlands, like other coastal wetlands, are considered highly vulnerable to submergence under a scenario of rising sea level. The rate of vertical accretion from 17 mangrove sites ranged from 0.9 to 16 mm yr^{-1}. The average elevation change (accretion minus subsidence) was –1.5, 0.7, and 0.1 mm yr^{-1} at the dry, marsh, and flooded environments, respectively, indicating that these mangroves would not keep up with a eustatic sea level rise. However, there is some evidence that hurricanes contribute sediments, thereby preventing the coastline from moving landward. Relative elevations were also measured along transects in WCA-3 for the first time to see if the post-drainage vegetative changes of the original ridge and slough spatial pattern are related to a flattening of the landscape (i.e., a reduction in the elevation difference between ridges and sloughs). In WCA-3A, there was a close relationship between the vegetation and the peat surface elevations. Sawgrass ridges were approximately 20 cm above the adjacent sloughs. In WCA-3B, there was no visible ridge and slough pattern and very little relief (< 10 cm). The extreme variability of the bedrock surface suggests that the peat microtopography evolved independently of the bedrock.

REMOTE SENSING AND MODELING TRENDS

Remotely sensed data are used to create vegetation maps, track habitat changes, locate gradients, identify impacts, and establish baselines. These data are used by all synoptic and modeling elements of the SFWMD research program for the testing of hydrologic hypotheses and the development of CERP performance measures. New and updated models are presented in this chapter. These combine the remote sensing data with the ecological trends data and the hydrologic data to estimate total system response (the ELM) or individual species response (the Florida Bay seagrass model and the Habitat Suitability Indices) to planned hydrologic alterations.

Because of the Everglades' size and complexity, advances in remote sensing and modeling are critical for improved hydrologic management. It is impossible to evaluate plans or assess impacts without these tools. This year, new programs to evaluate remote sensing techniques for tree islands, landscape patterns and exotics were begun. Modeling advances included a Regional Simulation Model (RSM), a Florida Bay seagrass model, a suite of habitat suitability indices, and an approach for measuring model uncertainty.

Remote Sensing

1. The Ikonos II satellite system, launched on September 24, 1999, collects higher resolution and more robust digital information of the Earth than previous satellites and will be evaluated to detect the exotic Old World climbing tree fern, as well as detailed ridge and slough landscape patterns.
2. Light Detection and Ranging (LIDAR) and hyperspectral sensor systems are being evaluated as tools to measure tree island canopy conditions efficiently and repeatedly.

Modeling

(1) The Regional Simulation Model has been developed as the next-generation South Florida Water Management Model (SFWMM). An RSM model application is currently being developed to simulate the hydrology of the southern Everglades. The objectives of this southern Everglades Model (SEM) application include understanding the influence of flooding on Cape Sable seaside sparrow habitats, investigating the impact of compartmentalization of the Southern Everglades, and studying the effect of freshwater discharges on Florida Bay salinity.

(2) A dynamic simulation model has been developed to predict the response of the submersed vascular plant assemblage in Florida Bay (*Thallasia testudinum*, *Halodule wrightii*, *Ruppia maritima*) to hydrology, eutrophication, and water quality changes. Simulations were performed to investigate the influence of high salinity, high sulfide concentrations and elevated nutrient levels. Individually, neither an increase in salinity nor an increase in nutrients produced much of a response in the *Thalassia* growth profile. However, together these stresses predicted a strong reduction in initial spring growth rate and the spring-summer biomass level.

(3) A multi-agency, interdisciplinary team identified six habitat suitability indices (HSIs) to estimate and rank the relative impacts of alternative hydrologic regimes. The six indices are periphyton, ridge and slough, tree islands, alligators, wading birds and fish. Once validated, these HSIs can be used to estimate the relative suitability of a habitat for each indicator species in each region of the Everglades associated with any specific simulated water management policy.

(4) A multi-agency workshop on model uncertainty analysis was held to provide guidelines on how to deal with uncertainties when evaluating CERP model alternatives. It was found that in the short term it is important to have a way to derive estimates of the probability distributions of uncertain output variables in a practical and transparent way. In the long run, formalism of Bayesian networks, combined with probabilities of model-estimated outcomes, was recommended.

INTRODUCTION

Previous Everglades Consolidated Reports (ECRs) have focused on the ecological, biological and geological knowledge of the Everglades in relation to historic drainage and current hydrology. In the 2002 ECR, the hydrology chapter focused on the drought and the history of the hydrologic management of Lake Okeechobee. Drought indices for wading birds, tree islands and peat fire risks were combined to evaluate the ecological risks associated with supply-side water management plans. Despite a general rainfall reduction of 23 percent last year in the WCAs, and an average reduction from structure inflows to the WCAs of 45 percent compared to the 32-year historic average, average weekly water levels in the WCAs were 0.4 ft to 0.7 ft higher than average. This disconnect between water levels and rainfall was due to water conservation and to active management to hold water in the WCAs. As a result, it was a good year for Everglades ecosystems. The fires that occurred in the Everglades were restricted to healthy surface burns and did not result in damaging muck fires. All the wading bird colonies successfully fledged young.

This year's chapter on hydrology will focus on hydrologic trends to discover any lag effects from the 2001 drought. It will also focus on new scientific efforts to better understand ridge and slough landscape structure and function. The SFWMD has begun to shift resources away from the phosphorus threshold research program and toward a hydrologic research program. As a result, this chapter will present new findings associated with tree island fauna, litterfall and growth, slough vegetation and decomposition, microtopography, mangrove productivity and crayfish. This chapter will also update the understanding of climate and water management impacts on hydrologic trends in the WCAs, wading birds, salinity patterns and sedimentation.

HYDROLOGIC TRENDS

Historic hydrologic trends, detailed in previous Everglades Consolidated Reports, explained how drainage of the Everglades reduced water tables, increased subsidence, induced fires and altered vegetation. Despite these extensive alterations, the District attempts to sustain a more natural hydroperiod throughout the Everglades by promoting distinct wet and dry seasons and by using a rainfall-driven formula for water deliveries to Everglades National Park. The recent hydrologic trends, summarized below, compare the 2002 Water Year (WY02) with a 33-year average of observed data and a 31-year average of NSM[1] output. A water year is defined as beginning May 1 (the start of the wet season) and ending April 30 (the end of the dry season).

WCA-1

The water levels in the Arthur R. Marshall Loxahatchee National Wildlife Refuge (WCA-1 or Refuge) were, for the most part, above both average (1970-2002) and NSM targets throughout the water year (**Figure 6-1**). For a short period of time in early summer, water depths were very low. This was due to the 2001 drought. This drought came to a relatively abrupt ending by August due to high summer rainfall and large quantities of structure inflows. From May to July, the water

[1] NSM: Natural Systems Model. A 2 x 2 mile grid hydrologic model that is used to estimate the water depths for the pre-drainage Everglades and thus, estimate water depth targets for restoration. However, the reader must be aware that many other criteria were used to set restoration targets for the Comprehensive Everglades Restoration Plan (CERP). CERP is being designed to mitigate ponding in the southern regions of WCAs and excessive drying in northern regions of WCAs.

levels in the marsh went from –0.5 ft to 1.5 ft. This rapid rise in water levels stopped and reversed itself in August because evapotranspiration (ET) remained high but rainfall stopped. Once the rains returned in September, water levels began to rise and a peak of 2.0 ft (1.0 ft above average) was maintained for most of October. This peak was also reached last year in October during the drought. However, last year this peak was reached due to one rainfall event. And last year this peak was followed by a relatively rapid recession (approximately 2 ft in five months). This year, the recession rate was much lower (0.5 ft in five months). The difference was due to relatively high spring rainfall patterns in 2002.

A summary of the hydrologic trends in WCA-1 (**Table 6-1**) indicated above average conditions for WCA-1. Last year, rainfall in WCA-1 was 21 percent below average. This year it was 11 percent above average. Although structure inflows this year were below average, periods of high inflows were recorded throughout the year (**Figure 6-1**) due to flood control. Water depths in WCA-1 were 47 percent above average this year.

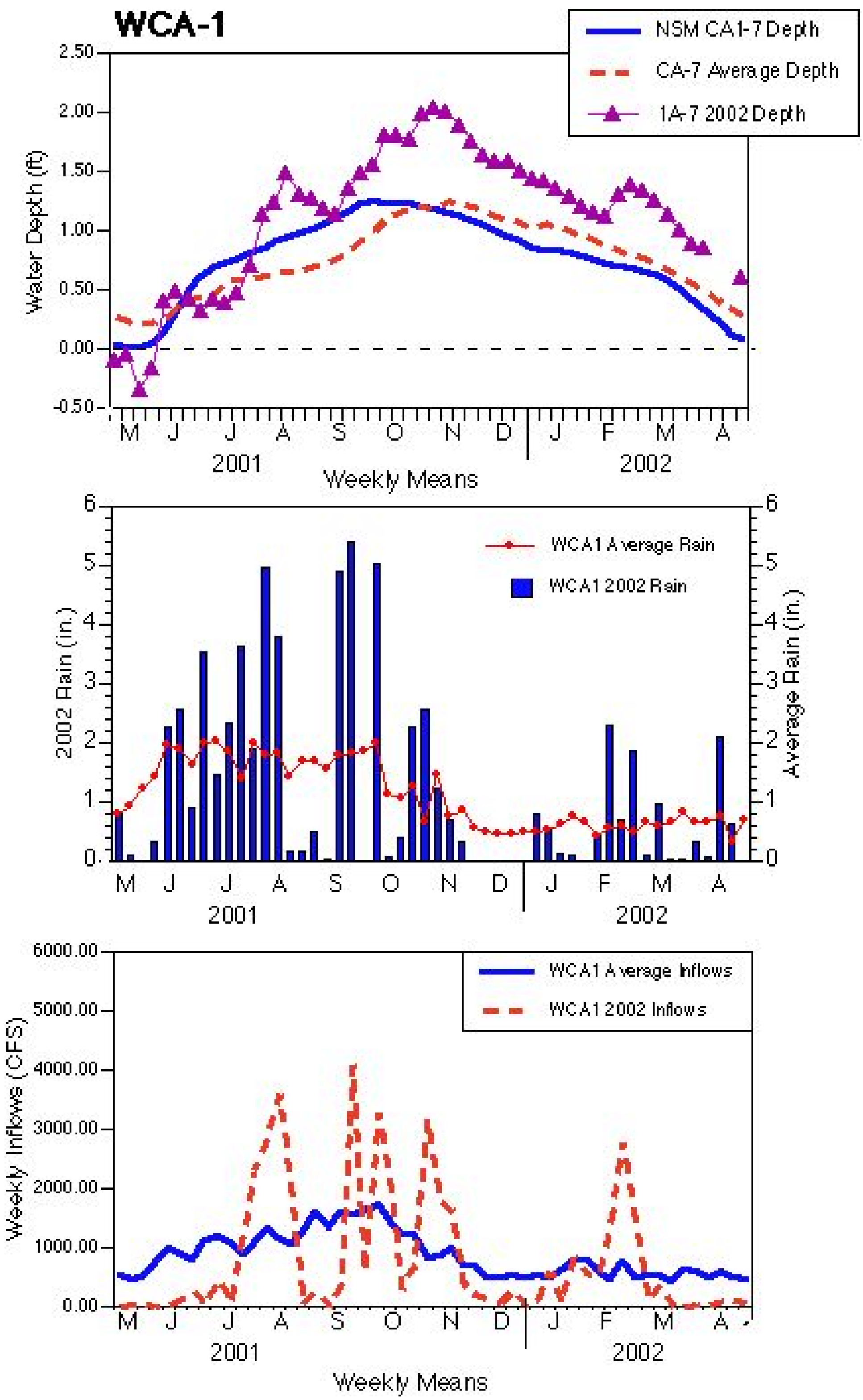

Figure 6-1. Average weekly water depth (top), rainfall (middle), and structure inflows (bottom) for WCA-1. Average values are from May 1, 1970 until April 30, 2002. The NSM average water depths (top) are based on the 1965-to-1990 base climate condition

Table 6-1. Average water depth and inflows from water control structures, and total rainfall (inches) for WY02 in WCA-1 compared to the long-term observed data. Minimums and maximums are shown in parentheses. Gauge and structure locations are shown in previous Everglades Consolidated Reports. Inflow stations = S5A, S5AS, S6, ACME1, ACME2, and G251

	CA1-7 Water Depth (ft)	Structure Inflows (CFS)	S5A_R Rainfall (in)
Weekly Average (1970 – 2002)	0.76	994	1.09
	(-1.85; 2.65)	(0; 8517)	(0; 11.17)
Weekly Average (2002)	1.12	789	1.21
	(-0.34; 2.04)	(0; 4084)	(0; 5.39)

WCA-2A

Historically, the water levels in WCA-2A have been managed approximately 1.0 ft above the NSM targets, creating an environment that can no longer sustain a healthy population of tree islands. The District lowered the regulation schedule for WCA-2A in the early 1970s in an attempt to bring it more in line with NSM. Depths are now less than they were historically. However, the 2002 water-depth trend in WCA-2A (**Figure 6-2**) was very erratic. The wet season started off very dry (−0.5 ft in May), but as in WCA-1 it quickly reached 2.0 ft by July. Water levels then went down and back up four times during the year. There was a clear connection between rainfall and water depths in WCA-2A. Lack of rain after November was responsible for the "healthy" spring recession, while a high-rainfall period in February was responsible for the reversal of the spring recession. The structure inflows were also synchronized with rainfall but did not seem excessive enough to produce these erratic water level trends. A summary of the hydrologic trends in WCA-2A (**Table 6-2**) indicated a below-average water depth despite above-average rainfall. This depth trend may be partly due to a 57 percent below-average input of structure inflows.

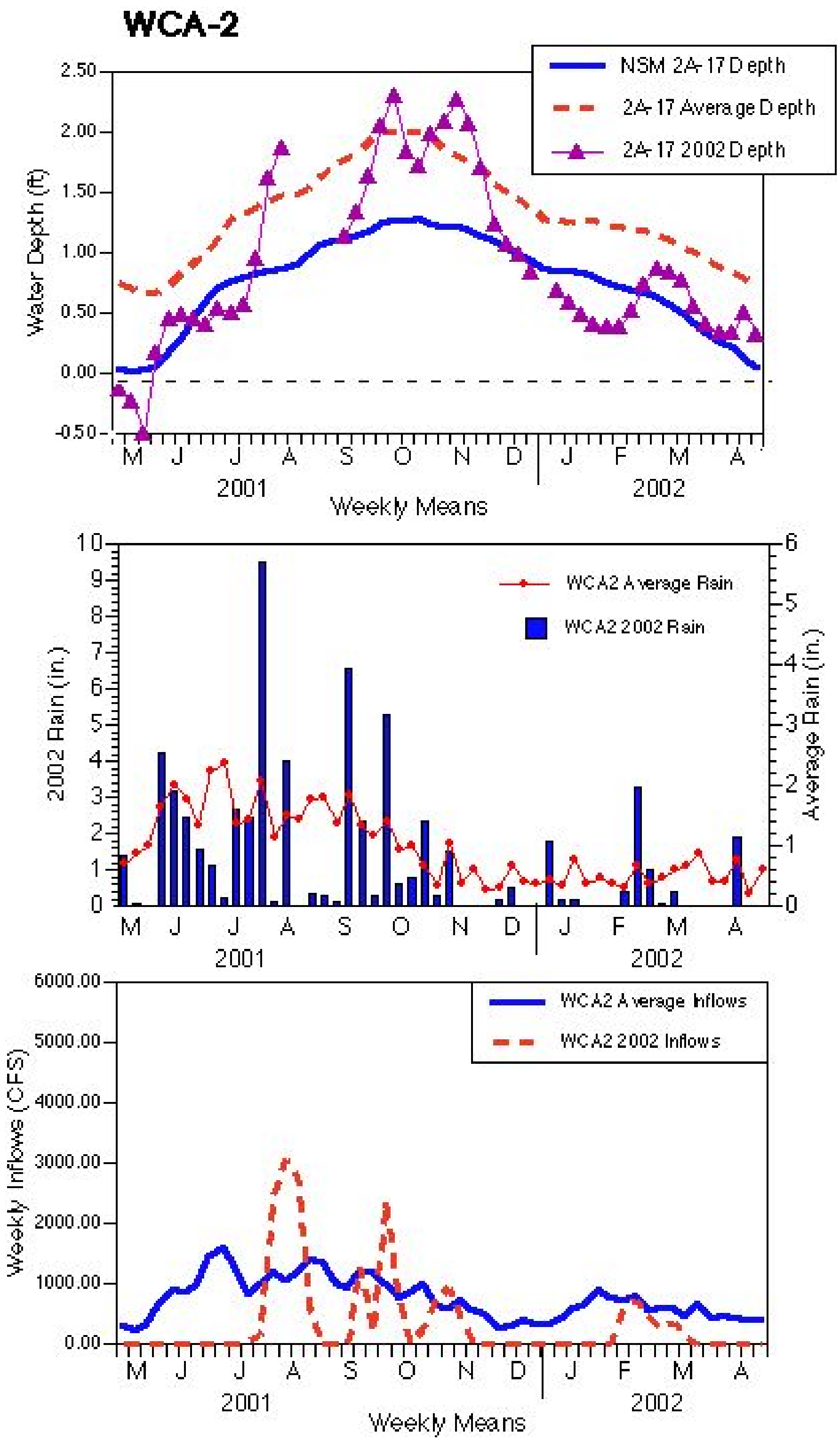

Figure 6-2. Average weekly water depth (top), rainfall (middle), and structure inflows (bottom) for WCA-2A. Average values are from May 1, 1970 until April 30, 2002. The NSM average water depths (top) are based on the 1965-to-1990 base climate condition

Table 6-2. Average water depth, inflows from water control structures, and total rainfall (inches) for WY02 in WCA-2A compared to the long-term observed data. Minimums and maximums are shown in parentheses. Gauge and structure locations are shown in previous Everglades Consolidated Reports. Inflow Stations = S7, NSPRNG_C2A, S10E, S10D, S10C and S10A

	2A-17 Water Depth (ft)	Structure Inflows (CFS)	S7_R Rainfall (in)
Weekly Average (1970 to 2002)	1.32	825	0.96
	(-1.71; 4.17)	(0; 10817)	(0; 13.86)
Weekly Average (2002)	0.90	351	1.23
	(-0.50; 2.29)	(0; 4084)	(0; 9.5)

WCA-3A

Although WCA-1 and WCA-2 began the water year with very low water levels due to the drought, WCA-3A started the year at 0.5 ft above average, in line with NSM targets (**Figure 6-3**). This was due to good WCA-3 drought management in 2001 and exceptionally high localized rainfall events. Water levels continued to increase throughout the wet season in WCA-3 due to regular rainfall and relatively high structure inflows. Depths peaked in October at 1.75 ft and stayed high for five to six weeks. During the drought the previous year, depths peaked at 1.0 ft in October and stayed high for only two to three weeks (the average NSM peak is 1.0 ft). Last year the recession rate was extreme, going from 1 ft to −0.6 ft in five months. This year the recession was moderate, going from 1.5 ft to 0.5 ft in five months. The fifth month was not typical in that there was a reversal of the recession trend instead of a further water level decline. For the most part the hydrologic trends followed those predicted for pre-drainage by the NSM. It appears that this was due to high summer rainfall and below-average structure inflows during spring 2002.

A summary of the hydrologic trends in northern WCA-3A (**Table 6-3**) indicated a relatively large deviation from the “normal” managed structure inflows and average water depth. The average weekly 2002 structure inflows to WCA-3A decreased by 36 percent. At the same time, average water levels increased by 566 percent, which was surprising since rainfall was not significantly different from the average. Therefore, this increase in depth must be due to longer residence times, which in turn are due to better hydroperiod management in the northern Everglades.

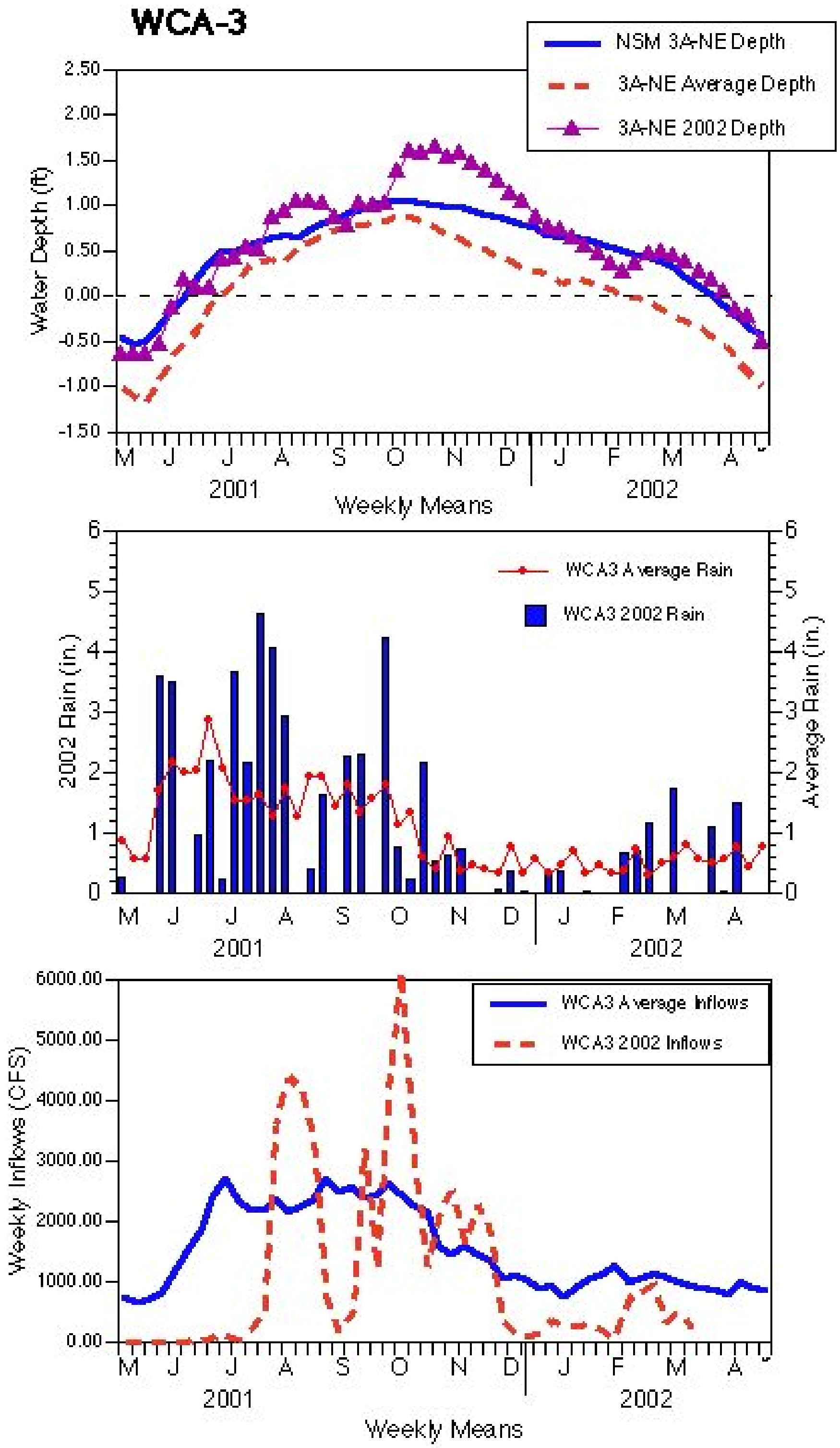

Figure 6-3. Average weekly water depth (top), rainfall (middle), and structure inflows (bottom) for northern WCA-3. Average values are from May 1, 1970 until April 30, 2002. The NSM average water depths (top) are based on the 1965 to 1990 base climate condition

Table 6-3. Average water depth and inflows from water control structures, and total rainfall (inches) for WY02 in northern WCA-3A, compared to the long-term observed data. Comparisons are based on pairing of weekly data. Minimums and maximums are shown in parentheses. Gauge and structure locations are shown in previous Everglades Consolidated Reports. Inflow stations = S-11A, S-11B, S-11C, G-155, S-140, S-190, S-9, S-8, G-204, G-205, G-206 and S-150

	3A-NE Water Depth (ft)	Structure Inflows (CFS)	3A-S_R Rainfall (in)
Weekly Average (1970 – 2002)	0.09	1794	1.02
	(-4.88; 3.38)	(0; 12989)	(0; 11.80)
Weekly Average (2002)	0.60	1141	1.05
	(-0.64; 1.64)	(0; 6152)	(0; 4.63)

EVERGLADES NATIONAL PARK

Two water depth stations in Everglades National Park, P-33 and P-34, are used in each Everglades Consolidated Report because they are considered representative of sloughs and wet prairie, respectively (**Figure 6-4**). The Shark Slough and wet prairie depths indicated some depressed water levels at the start of the wet season despite some May rainfall due to the 2001 drought. Water levels quickly returned to NSM average conditions at the P-34 station due to high summer rainfall (**Figure 6-5**). However, for Shark Slough it took five months to reach the NSM average despite high rainfall-driven structure inflows. This suggests that hydrologic requirements for marsh habitats along the Shark Slough edge may be met by localized rainfall, but that hydrologic requirements for Shark Slough itself must be met by upstream inflows. Last year during the drought, the P-34 depths were below the NSM average depths for the entire water year. This year, depths were near or above the NSM average for about 12 weeks. For prairie habitats, the dry-season recession appeared very conducive for wading bird foraging. The prairie water depth dropped from 1.5 ft to 0.0 ft in four months. Shark Slough water depths dropped from 2 ft in December to a low of 1.0 ft in February. Shark Slough depths did not recede as much as they have historically. Water depths stayed flat through February, March and April, probably as a result of the rainfall-driven schedule and abnormally high spring rainfall upstream.

Rainfall patterns in the Park were similar to those in WCA-3 (**Figure 6-5**). Rainfall amounts were typical for both the wet and dry seasons. A summary of the hydrologic trends in northern Everglades National Park (**Table 6-4**) indicated average rainfall and above-average structure inflows. The average weekly 2002 structure inflows to ENP increased 18 percent. During the wet season they increased by 100 percent. The high inflows were indicative of rainfall-driven management. The average depths at P-33 and P-34 were 0.12 ft and 0.34 ft, respectively, greater than the 33-year historic average.

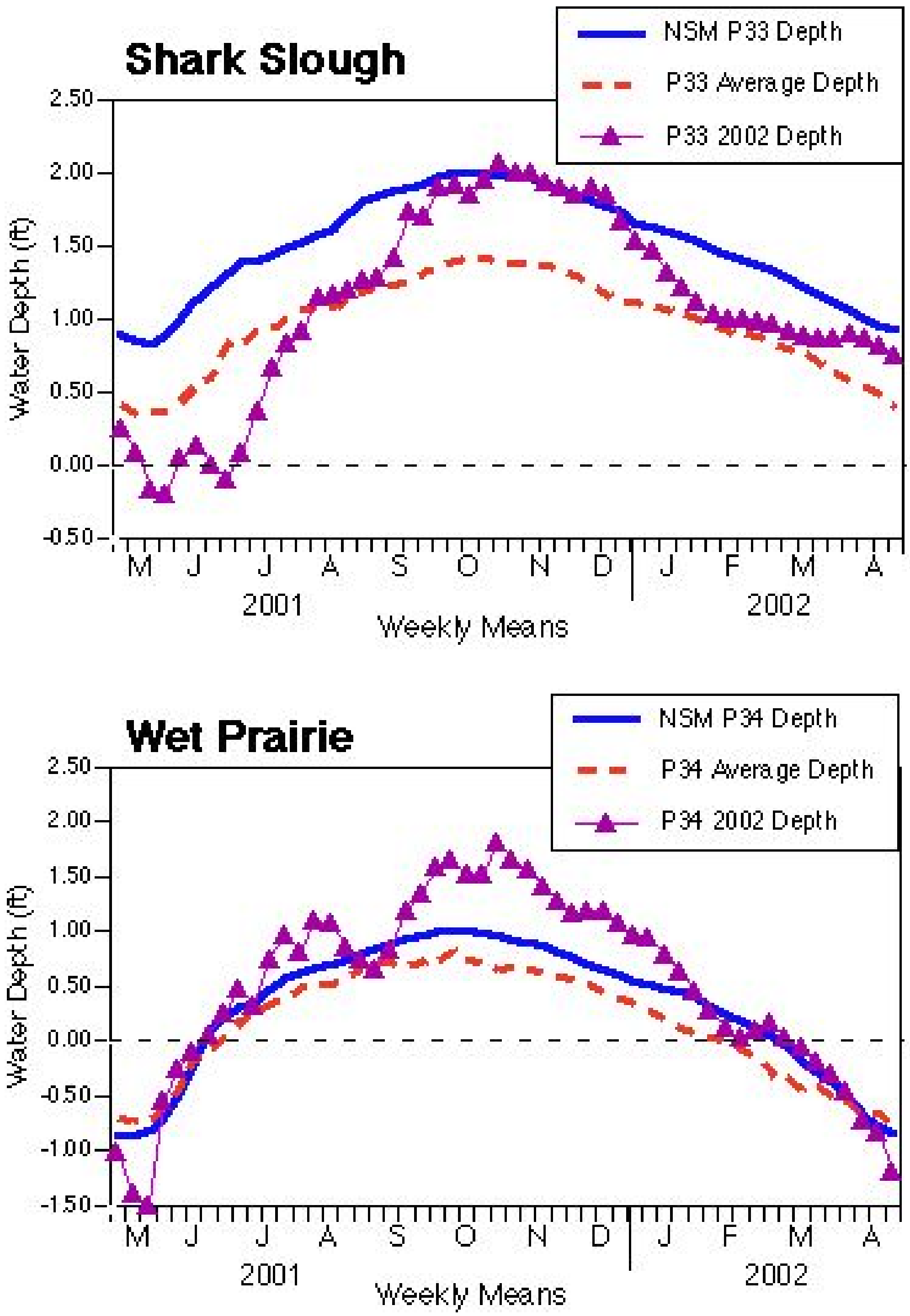

Figure 6-4. Average weekly water depths in the northern part of Shark Slough (top) and in a wet prairie habitat east of Shark Slough (bottom) in Everglades National Park. Average values are from May 1, 1970 until April 30, 2002. The NSM average water depths (top) are based on the 1965 to 1990 base climate condition

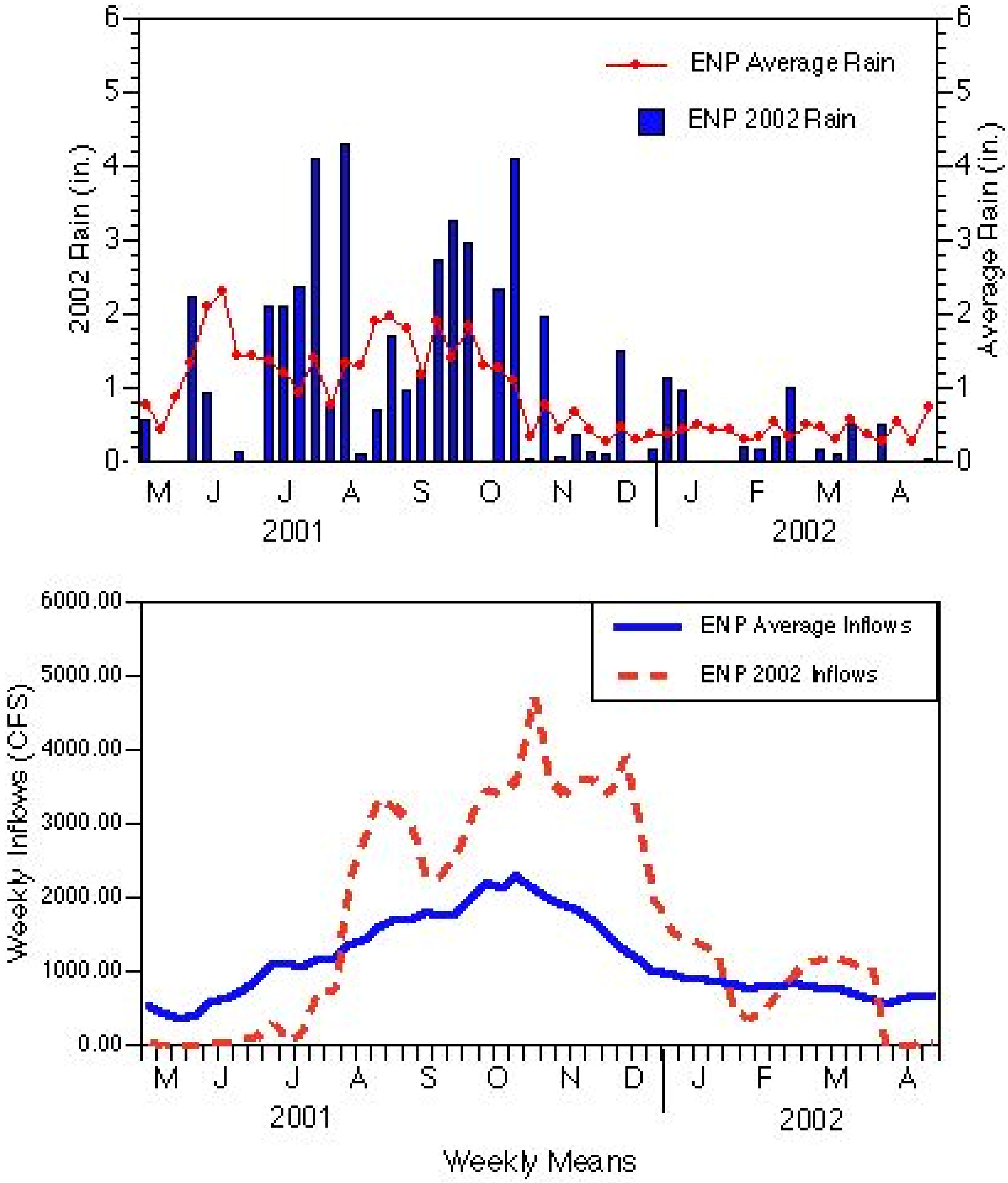

Figure 6-5. Average weekly rainfall (top) and structure inflows (bottom) for Everglades National Park. Average values are from May 1, 1970 until April 30, 2002

Table 6-4. Average water depth and inflows from water control structures, and total rainfall (inches) for WY02 in Everglades National Park, compared to the long-term observed data. Minimums and maximums are shown in parentheses. Gauge and structure locations are shown in previous Everglades Consolidated Reports. Inflow stations = S332, S18C, S12A, S12B, S12C, S12D, S333 and S175

	P33 Water Depth (ft)	P34 Water Depth (ft	Structure Inflows (CFS)	Flamingo Rainfall (in)
Weekly Average (1970 – 2002)	0.97	0.15	1343	0.90
	(-1.98; 2.87)	(-2.09; 2.67)	(0; 8388)	(0; 16.94)
Weekly Average (2002)	1.09	0.49	1580	0.95
	(-0.21; 2.06)	(-1.5; 1.80)	(0; 4705)	(0; 4.30)

Salinity Patterns in Florida Bay

In this section, salinity conditions in Florida Bay are evaluated to assess the bay's environmental status and the relationship of this status to changing Everglades hydrologic conditions. Data collected since March 1991 were used in this analysis. This date was the start of water quality monitoring (including salinity) in the bay by the District via a contract with Florida International University (FIU).

Water Year 2002 (WY02), defined as May 1, 2001 through April 30, 2002, was near the 1991 to 2002 average for salinity, rainfall and freshwater through the southeast Everglades. The quantity of rainfall in the Southeast Everglades (the mean of stations S-332 and S-18C) in 2002 was 59 inches, which is identical to the decadal mean rainfall value.

The flow of freshwater to the bay was estimated as the sum of discharges from the L-31W and C-111 canals. For 1991 through 1999, this was estimated from the sum of S-332, S-175 and S-18C discharges minus outputs from S-197, which are discharged into the Biscayne Bay system. Since February 2000, discharges from L-31W were estimated from S-332D and S-174. The time series of these summed discharges (integrated monthly from daily estimates) is presented in the top panel of **Figure 6-6**. Water discharges to the southeastern Everglades in 2002 totaled 0.38 billion m^3, which is close to the annual mean of 0.42 billion m^3 since 1991.

Likewise, salinity in Florida Bay (middle panels, **Figure 6-6**) was near the mean values of the past decade. Eastern Florida Bay had a mean of 26 ppt in 2002, which is equal to the long term mean since 1991. These values were calculated as the annual mean of monthly measurements at four stations (stations 9, 11, 23 and 24) in the SFWMD water quality monitoring network (data collected by J. Boyer of FIU). Central Florida Bay had an annual mean of 32 ppt in 2002, which is only 1 ppt lower than the long-term mean (calculated from stations 12, 13, 14 and 15). Peak salinity levels at the end of the 2001 dry season reached relatively high levels, with values of 48 ppt in the central bay and 38 ppt in the eastern bay. These values were roughly equal to the highest values observed since the severe drought of 1989 to 1990 and reflect the relatively low rainfall of 2000 (about 50 inches). These peak values also follow a trend of increasing peak salinity in the late dry season or early wet season in the central and eastern bay since 1995.

Salinity in the eastern and central bay was not well correlated with freshwater flow from the southeast Everglades. Linear regressions of monthly salinity as a function of monthly integrated flow into the southeast Everglades (from the L-31W and C-111 canals) had best fits with three-month time lags in flow, reaching maximum R^2 values of only 25 percent for the eastern bay and 20 percent for the central bay. It is generally thought that such weak relationships for bay salinity and flow are attributable to the relatively low flow rates that currently enter the bay. Local rainfall and evaporation and complex circulation patterns are thought to be significantly more important drivers of salinity levels and distributions. Supporting this inference is the finding that in central Florida Bay, 61 percent of variance among annual mean salinity values was explained by the annual variance of rainfall (lower panel, **Figure 6-6**).

However, the weak relationship between Everglades flow and salinity may also be attributable to how freshwater flow rates were estimated. Here, freshwater discharge from canals into the southeast Everglades was calculated as a surrogate for actual flows from the Everglades to the bay. It is thus assumed that water is neither gained (e.g., from groundwater or rainfall exceeding evaporation) nor lost (e.g., by seepage or net evaporation) within the wetland. This assumption can now be tested using flow data from creeks that discharge directly into Florida Bay from the southern coast of the Everglades. These data have been collected by the United States Geological Survey (USGS) since 1995 (Patino and Hittle pers. communication). For currently available data (a four year period of record), there is an excellent correspondence between discharge from canals and discharge from these mangrove creeks. From January 1996 through December 2000, discharge from canals into the southeast Everglades totaled about 1.83 billion m^3, while discharge from the mangrove creeks into Florida Bay totaled about 1.77 billion m^3. Comparisons over shorter time periods deviate more widely (annual deviations average 12 percent), but it appears that inputs to Florida Bay can be reasonably estimated from canal discharges.

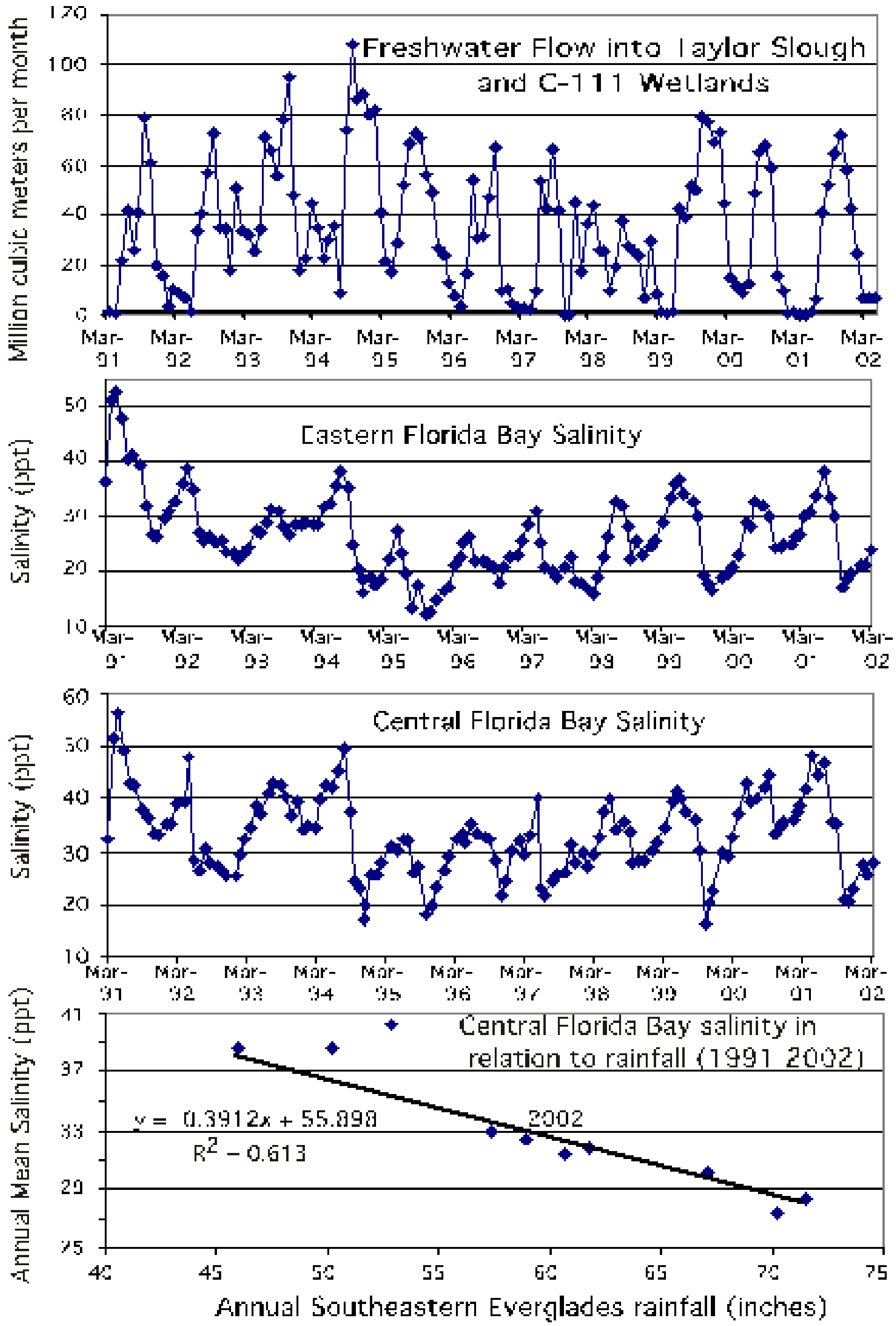

Figure 6-6. Hydrologic status and trends in Florida Bay. Top panel: monthly discharge from canals to the southeastern Everglades since March 1991. Middle panels: time series of salinity within eastern and central regions of Florida Bay. Lower panel: linear regression between annual mean salinity in central Florida Bay and rainfall over the southeastern Everglades. This panel shows that 61 percent of the interannual variance in salinity is associated with rainfall variance, and that salinity and rainfall were both near median levels in 2002

The CROGEE Florida Bay Restoration Report

A subcommittee of the Committee on Restoration of the Greater Everglades Ecosystem (CROGEE) recently released a report on Florida Bay restoration (*Florida Bay Research Program and their Relation to the Comprehensive Everglades Restoration Plan*, prepublication date August 2002, at: http://books.nap.edu/books/0309084911/html/index.html). This report assessed the relationship between the hydrologic restoration of the Everglades and the restoration of Florida Bay. The report's primary conclusion was that CERP should not assume that the current plan for Everglades restoration (restudy recommended plan, D13R) will benefit the Florida Bay ecosystem. In other words, a "win/win" situation may not exist. CROGEE found that there is sufficient scientific evidence to support the concern that increased freshwater flow toward Florida Bay will also increase nutrient loading (particularly dissolved organic nitrogen), which may stimulate algal blooms. Such blooms can result in decreased light penetration, which in turn can harm seagrass beds and coral reefs. The Florida Bay and Florida Keys Feasibility Study has a responsibility, as part of CERP, to evaluate potential restoration alternatives for Florida Bay. Recommendations provided by the CROGEE report were consistent with FBFKFS plans. Given the cautions presented by CROGEE, it is essential that water quality concerns are carefully addressed in the study and that CERP, through the Restoration Coordination and Verification (RECOVER) plan, proceed with an adaptive approach toward optimizing the restoration of the Everglades and Florida Bay.

The scientific evidence CROGEE considered was presented at the 2001 Florida Bay Science Conference and has also been presented in published literature. Findings include:

1. A positive relationship exists between freshwater discharge and nitrogen loading (Rudnick et al., 1999; Reyes et al., 2001)
2. A positive and significant correlation exists between mean annual chlorophyll-a concentrations in Florida Bay and annual freshwater discharge (Brand, 2002)
3. Algal growth in western and central Florida Bay is often limited by nitrogen availability (Tomas et al., 1999)
4. Algal blooms are most common in the central bay, where nitrogen-rich eastern bay water mixes with more phosphorus-rich water from the Gulf of Mexico (Brand, 2002). CROGEE did not consider this evidence to be sufficient enough to conclude that Everglades restoration will harm Florida Bay, but concluded only that hydrologic changes might produce undesired water quality and ecological impacts in the bay.

The CROGEE report also expressed concern regarding public expectations of clear water as an outcome of Florida Bay restoration. At this time, neither RECOVER nor the FBFKFS calls for "clear water as a restoration target, even though the public may consider such conditions desirable." Such clear water was probably an unusual and unnatural condition of the bay from the 1960s to 1980s. Based on faunal indicators of seagrass habitat, turtle grass beds apparently expanded their coverage and increased in density in the bay during this time (Cronin et al., 2001; Brewster-Wingard et al., 2001). With such an expansion, sediments would have been more strongly bound, minimizing sediment suspension. Currently, a central restoration target is a more diverse and less dense seagrass community in the bay. It is expected that restoration of freshwater flow and salinity will drive such seagrass community change. Thus, hydrologic restoration could increase turbidity.

Turbidity caused by suspended sediments should not be confused with algal blooms. If algal blooms are indeed stimulated by a potential increase in nitrogen loading associated with increased freshwater flow, then seagrasses and coral reefs might be harmed by poor light conditions. Waters that are murky because of such blooms are thus not a desired condition. A RECOVER and FBFKFS performance measure is to minimize algal blooms.

The CROGEE report also provided recommendations regarding research and modeling needed to minimize the uncertainties associated with evaluating the effects of Everglades restoration on Florida Bay. These recommendations were largely consistent with recommendations from other panels that have reviewed the Florida Bay Interagency Science Program and the initial steps of the FBFKFS (Hobbie et al., 2001; personal communication, D. Worth). Two key CROGEE recommendations were: (1) increase research on nutrient (especially N) transport, transformation, and dissolved organic nitrogen bioavailability (direct to algae and via decomposition), and (2) develop a set of linked models (upland hydrologic/ hydrodynamic/water quality) for the FBFKFS. FBFKFS is currently evaluating these needs and establishing strategies to meet them (see FBFKFS Project Management Plan at: www.evergladesplan.org). While this planning process continues, and following the possible implementation of a FBFKFS plan, RECOVER will be monitoring and assessing the status of the bay, and therefore research on the issue of CERP effects on Florida Bay should continue. If large algal blooms occur and it is demonstrated that they are stimulated by inflow of nutrients from the Everglades, then (as recommended in the CROGEE report) the source of these nutrients will need to be identified and steps must be taken to decrease the nutrient load. While not mentioned in this report, Stormwater Treatment Areas (STAs) that remove phosphorus (P) from Everglades inflows also remove nitrogen, though this removal is less efficient for nitrogen than for phosphorus. Monitoring of nitrogen removal by STAs should continue.

ECOLOGICAL STATUS AND TRENDS

FAUNA

Wading Birds

Wading birds, of special interest to the public, play a prominent role in CERP, adaptive protocols, minimum flows and levels, and day-to-day operations of the District. In the Everglades wading birds are used as indicators of wetland ecosystem conditions. The location of nests, timing of nesting, and total numbers of nests are indices of local ecosystem conditions and do not reflect regional population trends. There is increasing evidence from genetics studies that the geographic population boundary for species of wading birds that occur in the Everglades is the entire southeastern United States. Thus, changes in the wading bird indices for the Everglades do not translate directly to changes in overall population trends and vice versa.

The estimated number of wading bird nests (excluding cattle egrets, which are not dependent on wetlands) in South Florida in 2002 was 68,504. This is an 82 percent increase from last year and a 73 percent increase from 2000 (excluding Florida Bay), which were two of the best years in a decade. The banner nesting in 2002 was attributed to a large nesting effort by white ibises and snowy egrets (20,000 and 12,000 nests, respectively) in one colony in northern WCA-3. This colony contained about 51 percent of the nests in South Florida (35,000 nests), making it one of the largest wading bird colonies seen in recent years and the largest number of great egret nests seen in South Florida in over a decade, with a more than 100 percent increase compared to last year. The number of wood stork nests also increased about 27 percent compared to 2001.

Nesting effort differed among regions in the Everglades. Water Conservation Area 3 supported the largest number of nests (70 percent) in the Everglades proper (i.e., WCAs 1 through 3, Everglades National Park). WCA-1 and the Park supported 25 percent and 5 percent of the nests, respectively. In contrast, in 2001 WCA-1 supported the largest number of nests (51 percent), followed by WCA-3 (38 percent) and ENP/Florida Bay (11 percent). The shift in nesting locations between years reflects the difference in hydrologic conditions in regions of the Everglades in different hydrologic years. In the 2002 hydrologic year, there was a strong water recession in WCA-3, resulting in shallow water levels and good foraging conditions. However, in 2001 there was a severe drought, and few areas in WCA-3 had surface water at the end of the dry season. In contrast, WCA-1 retained some surface water throughout the dry season, creating good foraging conditions. In addition to hydrology, another factor affecting this year's nesting effort may have been the severe drought in 2001. Frederick and Ogden (2002) showed that wading bird nesting effort tends to be elevated during the first two years following a severe drought, possibly because of a pulse of nutrients released at the time of reflooding, leading to increased productivity.

Three species groups met the numeric nesting targets proposed by the South Florida Ecosystem Restoration Task Force (**Table 6-5**). Two other targets for the Everglades restoration are an increase in the number of nesting wading birds in the coastal Everglades and a shift in the timing of wood stork nests to earlier in the breeding season (Ogden, 1997). The 2002 nesting year showed no improvement in the shift of colony locations or the timing of wood stork nesting. The timing of nesting is important because Wood Storks require 90-120 days to complete their nesting cycle. If the young do not leave the nest before the onset of the rainy season, their chances of finding suitable foraging habitat is reduced.

Table 6-5. Numbers of wading birds in the Water Conservation Areas and Everglades National Park

Species	**Base low/ high**	**1994-1996**	**1995-1997**	**1996-1998**	**1997-1999**	**1998-2000**	**1999-2001**	**2000-2002**	**Target**
Great Egret	1,163/ 3,843	4,043	4,302	4,017	5,084	5,544	5,996	7,276	4,000
Snowy Egret/ Tri-colored Heron	903/ 2939	1,508	1,488	1,334	1,862	2,788	4,269	8,614	10,000-20,000
White Ibis	2,107/ 8,020	2,172	2,850	2,270	5,100	11,270	16,555	23,983	10,000-25,000
Wood Stork	130/294	343	283	228	279	863	1,538	1,868	1,500-2,500

Crayfish

This study was conducted to determine if a relationship existed between crayfish survival behavior (dry season burrowing) and seasonal movement of the groundwater table. In terms of District operation, this is relevant for minimum flows and levels, consumptive use permitting, and hydrologic restoration. Wetlands whose hydroperiods are closely tied to groundwater fluctuations are vulnerable to ecological impacts from consumptive water uses. These impacts include, and are not limited to, transition of wetlands to drier ecosystems and overall loss of wetland acreage. Understanding how hydrology drives wetland biota is critical to decision-making processes for compliance with state wetland protection regulations. Also, restoring former Everglades functions requires knowledge of linkages between secondary (aquatic system) trophic levels and hydrology. Understanding the relationship between the natural survival behavior of crayfish, a key species, and natural seasonal water level fluctuations will allow water resource managers to make appropriate decisions as to the design and timing of restored water flows.

The Everglades crayfish (*Procambarus alleni faxon*), an important constituent of the southern Florida wetlands, was examined as a potential indicator species to determine if there was a quantifiable relationship between *P. alleni* behavior and hydrologic fluctuations of its environment. *P. alleni* is an abundant and important prey resource for many southern Florida fauna (Kushlan and Kushlan, 1979) and is thought to be an influential species in aquatic ecosystems (Momot et al., 1978; Kushlan and Kushlan, 1979; Hogger, in Holdich and Lowery, 1988; Hobbs et al., 1989; Weber and Lodge, 1990; Nystrom et al., 1996; Figler et al., 1999).

A study site was selected from within the Flint Pen Stand, one of the District's control isolated wetland monitoring areas in southeast Lee County, Florida. A representative gradient of the regional ecosystem, consisting of hydric flatwoods, wet prairies, marsh, and cypress domes, it was selected because of its relatively pristine vegetative condition and relative lack of anthropogenic disturbances. Water levels and *P. alleni* burrow depths, numbers and microhabitat data were collected throughout the duration of a dry season to test the hypothesis that within a wetland, burrow depth is a function of the position of groundwater level. Specifically tested was the null model that the burrow depths would not change as the depth of the groundwater level changed.

Sample size, mean and median burrow depths, average groundwater levels (relative to sea level) and total rainfall for each sampling period are listed in **Table 6-6**. Increases in burrow depths were correlated with groundwater elevation. The relationship between burrow depths (n=130) across a variety of habitat types (wet prairie hydric flat pinewoods, cypress, treated melaleuca) and the change in groundwater levels (GWn=5760) was not significant. This was due to the fact that each zone has an optimum period for burrow formation when it first becomes dry. After this period, new burrows are not usually created and hence the N/A for some zones in some of the sampling events. Likewise, zones that dried out later in the study had no representation in the earlier sampling events. Also, the number listed in each cell under zones represent the number of new, active, measurable burrows per sampling event, not burrow depths. Therefore while the overall number of burrows that were measured per zone/sampling event may have been due to chance, the overall depths of these new burrows were consistently deeper over time, just as the groundwater level also was deeper below ground over time (**Figure 6-7**). However, due to the variance in soil types, animal size and habitat types, the regression on all data was not significant. Only the wet prairie sites could be sampled across all sampling events and these data clearly indicated a significant relationship between burrow depth and groundwater depth ($p<0.001$; $R^2 = 0.79$; $y=0.09094*GW + 0.57244$). It was further observed that there were significant differences

($p < 0.002$) in burrow depths across different zones and substrates. It appears that other factors could potentially contribute to the overall burrow depths.

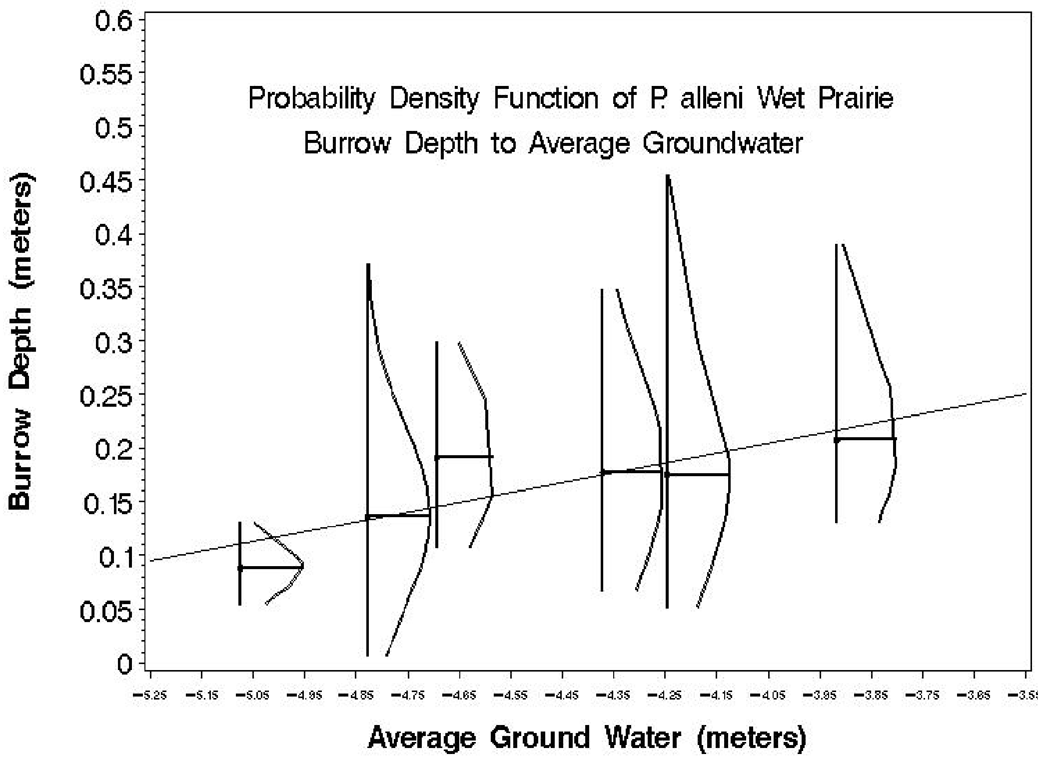

Figure 6-7. Regression of burrow depths to averaged groundwater levels showing probability distributions around the means and across all sampling events. (Sampling events are listed in Table 6-6).

Table 6-6. Water level, rainfall and burrow-depth data

Sample Event	Period Date M/D/Y	Mean ground water level (M)	Total rain (m m)	Median burrow depth (m m)	Mean burrow depth (m m)	Zone 1[1]	Zone 2[1]	Zone 3[1]	Zone 4[1]
1	9/27/99-10/27/99	5.31	150	80	80	35	N/ A	N/ A	N/ A
2	10/27/99-12/1/99	5.17	88	110	130	35	N/ A	14	N/ A
3	12/1/99-1/06/00	4.92	26	120	140	22	41	16	N/ A
4	1/06/00-2/10/00	4.79	37	190	170	6	5	2	N/ A
5	2/10/00-3/06/00	4.46	3	200	210	6	11	5	6
6	3/06/00-4/11/00	4.33	52	150	200	6	12	3	7
7	4/11/00-5/10/00	3.99	19	250	250	2	5	N/ A	22
8	5/10/00-6/10/00	3.41	32	N/ A[2]	N/ A	N/ A	N/ A	N/ A	N/ A
9	6/10/00-7/10/00	3.76	270	N/ A	N/ A	N/ A	N/ A	N/ A	N/ A

[1]:

Lists numbers of new, open active burrows found per sampling event. Zones are coded as follows:
Zone 1: Pine Flatwoods
Zone 2: Wet Prairie
Zone 3: Disturbed (treated Melaleuca)
Zone 4: Cypress

[2]: N/A= Not Available

Burrows did not appear in the zones until they started drying. Within each zone, burrow construction exhibited an initial first pulse when the water levels first fell below the surface of the ground. In this study, after the initial drydown, the number of new burrows diminished within each zone (**Table 6-6**). Because of an elevation gradient, drying first occurred in the flatwoods zone and last within the cypress zone. Appearance of new burrows within the study area roughly followed this same gradient. This difference of burrow depths among varying substrates agrees with the findings of Grow (1982) and Correria and Ferreria (1995), who studied the burrowing of the crayfish *Cambarus diogenes girard* and a species close to *P. alleni, Procambarus clarkii girard.* Grow (1982) found that the burrow complexity and resilience of burrow structures are directly related to substrate type and grain size. Correria and Ferreria (1995) found that *P. clarkii* dug "survival burrows" in sandy substrates that were typically less than 50 cm in depth. *P. alleni's* burrowing activities appear to have similar characteristics to the sand burrows of *P. clarkii and C. diogenes.* The relationship between the fall of the groundwater table and overall increase in burrow depth over time implies that these crayfish are burrowing deeper as they seek to maintain an optimal condition in which to survive (Berrill and Chenowith, 1981). In regions where peat layers are thin or where marl substrates are near the surface, these animals can not burrow very deep to prevent desiccation and death when groundwater levels decline.

The exact depth to which *P. alleni* can burrow is unknown. It is reasonable to assume that there is a limit, either by the crayfish's physiology or by physical factors, such as a bedrock layer. A measurable relationship between burrow depth and groundwater levels would potentially indicate an attempt by the crayfish to keep its burrow within a range of influence from the groundwater table. If hydrologic conditions were depressed to the level so that the crayfish were unable to adjust its burrow depth, the ability of *P. alleni* to survive the dry season may be affected. As a direct behavioral response to the environment, burrowing behavior is integrated into *P. alleni*'s lifecycle, and is critical for dry season survival. This response is currently being tested to determine an absolute survival threshold of *P. alleni* in relation to hydroperiod.

Herpetofauna of Tree Islands

This literature review suggests a need for intensive surveys and provides a starting point for obtaining ecological baseline information about the herpetofauna of tree islands through these surveys. This information can later be used to show the effects of altered hydrology and water quality on the herpetofauna of tree islands after the restoration. It is important to obtain a more complete understanding of the existing herpetofauna within the Everglades, including their uses of tree islands and their interactions with other species on tree islands. Studies of the different herpetofaunal species assemblages that occur on various types of tree islands (e.g., bay heads, cypress heads and willow heads) and marsh habitats may be used as indications of ecosystem health. Anurans can be especially sensitive indicators of ecosystem stress (Wake 1991, Welsh 1998). Long-term studies are necessary to examine natural occurring spatial and temporal variability of fluctuations in amphibian and reptile populations (Pechmann et al., 1991). The effects that exotic herpetofauna has upon other tree island species require further study as well.

There have been very few studies on the herpetofauna (reptiles and amphibians) of the Everglades. Of the few studies conducted, only a few have specifically looked at species inhabiting tree islands. Carr (1940) documented many species throughout the State of Florida. Duellman and Schwartz (1958) carried out the first complete inventory of herpetofauna in South Florida in the mid-1950s, when access to interior tree islands was very difficult; therefore, Duellman and Schwartz did not study tree island habitats. They did, however, write about tropical hammocks (tree islands) as habitats for herpetofauna, but only hypothesized whether species would exist on tree islands in the deep interior of the Everglades. Wilson and Porras (1983) updated the status of most species reported by Duellman and Schwartz (1958). Wilson and Porras also provided an overview of herpetofaunal responses to the presence of humans and their activities in South Florida. In addition, their report focused on the problem of introduced exotic species of herpetofauna in South Florida and their influence on native fauna. Other publications list reptiles and amphibians discovered during wildlife surveys in the Everglades but were not exclusive to species using tree islands surrounded by sloughs and sawgrass prairies (Dalrymple 1988; Gunderson and Loftus, 1993). Recently, Meshaka et al. (2002) presented information about tree island herpetofuana in the more southern area of Everglades National Park.

The following is a review of literature and preliminary data relating to herpetofauna species using and inhabiting tree islands, excluding crocodilians. Along with published wildlife surveys, several field guides (Anderson, 1989; Ashton, 1988, 1991; Bartlett, 1999; Conant et al., 1998; and Tennant, 1997) were used to determine probable tree island usage from listed habitats, reproduction activities and overall natural histories. Two unpublished herpetological studies performed by Tim Towles (1993, 1995) in the Rotenberger Wildlife Management Area and the Everglades Wildlife Management Area were also used in creating these lists of probable species. Towles' surveys included some specific tree island sites.

Turtles

Several aquatic species of turtle are known to inhabit the Everglades (**Appendix 6-1**, **Table 1**). Many of these Everglades turtles are primarily omnivorous and also forage underwater. Turtles such as *Trionyx ferox* are commonly seen along the edges of islands and along alligator trails on islands (Gawlik, 1999). Observed behavior is typically that of basking, which the turtles do to elevate their body temperature for proper digestion. One non-aquatic turtle that sometimes ventures out to tree islands during periods of drought is *Terrapene carolina*. This terrestrial turtle forages on dry land for vegetation and insects (Ernst and Barbour, 1989).

Raccoons and rodents commonly raid the nests of some species, such as *Chelydra serpentina* (Aston 1991). Wading birds and alligators prey on young turtles. The result is that only a few turtles from each nest ever reach adulthood (Ashton, 1991; Bartlett, 1999).

It is likely that turtles are highly dependent on the availability of Everglades tree islands for nesting (Meskaka, 2002). Several species, such as *Pseudemys nelsoni* and *T. ferox*, reportedly nest within alligator nests commonly found on or around the edges of tree islands (Ashton, 1991). Because turtle eggs must remain moist without being flooded, nesting sites are mostly limited to tree island heads. However, tree islands selected for nesting must remain high enough above water level to prevent flooding when the turtles dig their nests several centimeters down into the substrate. Turtles may also deposit eggs in rotten tree stumps that rise slightly above the tree islands (B. Garret, personal observation). A significant increase in water levels and a corresponding loss of tree island habitat in the Everglades could reduce appropriate turtle nesting sites. Conversely, insufficient water levels could lead to a reduction in foraging habitats for aquatic turtles.

Other than the red-eared slider (*Trachemys scripta elegans*), which is native to the Mississippi River, there are no known exotic turtle species that have established breeding populations in the Everglades (Bartlett 1999). It is unknown if red-eared sliders use tree islands in the northern Everglades, but they have been seen in the Rotenberger Wildlife Management Area (B. Garret, personal observation).

Lizards

Only a few lizard species are common to tree islands (**Appendix 6-1**, **Table 2**) and include *Anolis carolinensis*, *Eumeces inexpectatus* and *Scincella lateralis*. These species, along with the rarer *Anolis segrei,* nest and forage on the islands (Towles, 1993, 1995). All these species usually nest in moist but not saturated areas, such as rotting logs or moist soil, and forage for arthropods on the island (Ashton 1991, Bartlett 1999).

Snakes, birds, many mammals and small alligators all prey on the lizard species found on tree islands. *Scincella lateralis* uses the water surrounding tree islands as an escape route when it is being preyed upon (Carr 1940, Bartlett 1999). *Ophisaurus ventralis* may forage in or around tree islands during extreme low-water and drought periods, but typicallly does not nest on tree islands.

Anolis segrei is considered an exotic species from the Caribbean. When Dalrymple (1988) did herpetofaunal surveys on Long Pine Key in Everglades National Park, *A. segrei* generally was common in areas that have been heavily disturbed by humans. Therefore, one would not expect to find many *A. segrei* in the interior, more pristine areas of the Everglades. Another exotic species, the green iguana (*Iguana iguana*), has also been observed in the Everglades (Meshaka, 2000). However, the presence of this species is most likely the result of having been acquired as a pet, which then either escaped or was released, and it has not established strong breeding populations on tree islands. Further south in Everglades National Park are several more species of exotic anole that have not migrated north to the Water Conservation Areas and established breeding populations.

Snakes

There are more species of snakes in the State of Florida and in the Everglades than any other order of reptile or amphibian (Duellman and Schwartz 1958, Bartlett 1999, Gunderson and Loftus

1993, Meshaka 2000). Several snakes, such as the cottonmouth (*Agkistrodon piscivorus*) and the watersnake (*Nerodia* spp.), depend on water for their food supply of fish, frogs, salamanders and large aquatic arthropods (Ashton 1988; Tennet, 1997). Other snake species prefer to forage on trees or tree island heads for lizards, rodents, anurans and soft-bodied arthropods, such as spiders (Tennet, 1997).

It is not uncommon to observe a raptors flying with a snake in its talons. Wading birds, alligators and other snakes, such as the kingsnake (*Lampropeltis getulus*) and the indigo snake (*Drymarchon corais*), are also snake predators (Moler, 1992; Gunderson and Loftus, 1993; Tennet, 1997).

Many semi-aquatic snakes are live-bearing and do not require a terrestrial environment for nesting. Others, such as *Elaphe obsoleta* and *Opheodrys aestivus,* require drier terrain to lay their eggs (see **Appendix 6-**1, **Table 3** for a list of probable nesting species).

Like the green iguana, several species of tropical exotic snakes, such as the Burmese python (*Python molurus bivittatus*), can survive in the Everglades following escape or release from captivity (Meshaka, 2000). However, little is known about breeding populations of these exotic snakes.

Salamanders

There are no known exotic species of salamanders in the Everglades. Of the six salamander species found south of Lake Okeechobee (**Appendix 6-1**, **Table 4**), four exist within the Everglades (Meshaka, 2000). With the exception of the peninsula newt (*Notophthalmus viridenscens*), the probability that salamanders use tree islands is low. Species of salamander may occur on tree islands during rainy nights or periods in which the tree islands are inundated with water (Duellman and Schwartz, 1958). Alligator holes and open pools may be important microhabitats for salamanders for the same reasons as they are important for anurans.

Aquatic salamanders, such as *Amphiuma means* and *Siren lacertina*, are commonly preyed upon by *Farancia abacura* and many snakes species of the genus Nerodia (Tennant, 1997). These salamander species, in turn, feed mostly on crayfish and occasionally other arthropods, such as dragonfly larva (Hamilton, 1950; Hanlin, 1978; Ashton, 1988).

Frogs and Toads

Like turtles, many anurans (frogs and toads) (**Appendix 6-1**, **Table 5**) may depend on the availability of Everglades tree islands. All native species lay clusters of eggs or individual eggs in the water, where the larvae (tadpoles) also develop into adults. As adults, certain species, such as *Bufo terrestris*, would use the water only for breeding and occasionally for predator avoidance. Other species, such as *Rana grylio* and *Rana sphenocephala*, spend almost all of their life in the water and would therefore rarely use tree island heads (Ashton, 1991; Bartlett, 1999). *Hyla cinerea* and *Hyla squirella* are two similar-looking arboreal species of tree frog that commonly use the vegetation of tree island fringes and tails (B. Garret, personal observation). Tree island tails are usually flooded during the wet season and may be breeding grounds for certain species, such as the highly aquatic *R.. sphenocephala*. Since tree islands are relatively moist environments, they are ideal habitats for many anurans to avoid dessication while still avoiding predation.

Alligator holes, associated with tree islands and solution holes, are important environments for anurans. Fish, especially larger species, consume anuran larvae, thereby drastically reducing adult frog and toad populations. Besides fish, several other predators feed on frogs and toads in the Everglades. For example, certain snakes, such as *Thamnophis sitalis*, commonly feed on *Bufo* *terristris* (Tennet 1997). Humans are also known to hunt *R. grylio* (commonly called the Everglades bullfrog, or the pig frog) for the meat from its legs (Ligas 1960). An exotic species from Cuba, *Osteopilus septentrionalis*, is known to prey on some of the native species of Florida tree frogs, including the smaller *H. cinerea* and *H. squirella* (Meshaka, 2000; Ashton, 1988). The greenhouse frog, *Eleutherodactylus planirostris* (also from Cuba), is widespread throughout Florida, including the Everglades tree islands (Meshaka, 2002).

CONCLUSIONS

It is obvious that Everglades aggregations of herpetofauna may make a significant contribution to the overall biodiversity. Further losses of tree islands could potentially result in losses of species that depend on these habitats. It should be noted that there are several types of tree islands, each of which may include different assemblages. For instance, some snakes, such as the mud snake (*F. abacura*), swamp snake (*Seminiatrix pygaea*), striped crayfish snake (*Regina alleni*), cottonmouth (*Agkistrodon piscivorus*), and water snake (genus Nerodia) might exist on one type of island that is inundated with water most of the year. Other types of snakes, including the rat snake (genus Elaphe), the rough green snake (*Opheodrys aestvus*) and the Florida kingsnake (*Lampropeltis getulus)* would prefer short hydroperiod islands.

It is extremely important to obtain a more complete understanding of the existing herpetofauna within the Everglades, including their use of tree islands and their interactions with other species. Studies of the different herpetofaunal species assemblages found on various types of islands and marsh habitats can be used as indicators of ecosystem health (e.g., bay heads, cypress heads and willow heads) and the various tree island features. Anurans can be especially sensitive indicators of ecosystem stress (Wake 1991, Welsh 1998). Long-term studies are necessary to examine spatial and temporal variability of fluctuations in amphibian and reptile populations (Pechmann et al., 1991).

SOILS AND SEDIMENTS

Sedimentation and Erosion Trends

Mangrove wetlands, like other coastal wetlands, are considered highly vulnerable to submergence under a scenario of rising sea level (Gornitz, 1991). The eustatic global mean sea level has risen approximately 1 to 2 mm yr^{-1} during the past 100 years (Gornitz, 1995). Additionally, sea level rise is enhanced on a local scale relative to the land surface by subsidence. Thus, relative sea level rise (RSLR) is referred to as the combined effect of eustatic sea level and land subsidence. Under a rising sea level scenario, mangrove wetlands need to maintain their intertidal characteristics relative to local mean water level. This means that with a higher sea level there must be a relatively high rate of accretion and vertical elevation gain of the soil surface.

Accretion (the buildup of material on the forest floor) is affected by changes in hydrologic and geomorphologic (erosion) conditions. The persistence of mangrove wetlands in their current location depends on the ability to maintain vertical accretion such that the rate of vertical elevation gain is greater than or equal to the rise in sea level. In terrigenous coastal environments, mangrove wetlands are considered excellent land builders due to litterfall, the soil-binding capacity of mangrove roots (Augustinous, 1995), and organic soil formation by belowground production. In contrast, in Florida's carbonate coastal environment, the soil binding capacity is minimal and belowground production of mangrove peat is considered the primary soil building mechanism (Snedaker, 1993; Parkinson et al., 1994).

Sedimentation and erosion stations were established at 17 sites within the Florida Bay fringe and basin zones. At each site, sediment elevation measurements were made using Boumans and Day's (1993) Sedimentation Erosion Table (SET). The SET is attached to a benchmark pipe driven into the soil surface 3 to 4 m, and it is assumed to be a stable datum over the period of study (Cahoon et al., 1995). Nine pins, located at the end of an accurately leveled horizontal arm, are lowered to the soil surface to measure elevation, with an accuracy of ± 1.5 mm (Boumans and Day, 1993). Vertical accretion was measured as the rate of accumulation above feldspar marker horizons laid on the soil surface in June 1996. Three feldspar marker horizons were laid around each SET platform in the fringe and basin zones of each study site. Elevation change and vertical accretion have been measured every year since 1996. Two soil cores were collected at each study site to a depth of 20 cm for soil characterization. Each core sample was sectioned at 5-cm intervals, dried at 60° C to constant weight, and weighed for bulk density. Soil samples were burned at 550 °C for four hours. After burning, samples were analyzed for ash and organic matter content. Based on the soil core analyses, all study sites were grouped into three hydrological environments: dry (occasional inundation), marsh (occasional dry periods) and flooded.

All marker horizons deployed at the marsh and flooded forest sites were buried over the study period. Burial indicated that deposition was greater than erosion, contributing to the vertical accretion of the forest floor. In contrast, the markers deployed in the dry forest sites either disappeared or were slightly buried.

The rate of vertical accretion at all study sites ranged from 0.9 to 16 mm yr^{-1}. The average vertical accretion was 2.5, 9.2 and 10 mm yr^{-1} at the dry, marsh, and flooded environments, respectively (**Figure 6-8**). These rates are similar to those reported by Cahoon and Lynch (1997). The vertical accretion rate observed at the dry environment was significantly lower relative to the accretion rates observed at the marsh and flooded environments ($p < 0.05$).

Elevation change, measured using the SET device of Cahoon and Lynch (1997) at each study site, was small. At the dry environment, elevation change over the duration of the study period was -1.5 mm yr^{-1}. The negative elevation change suggests that erosion may play an important role in controlling changes in elevation in this environment (**Figure 6-8**). Elevation changes at the marsh and flooded environments were 0.7 and -0.1 mm yr^{-1}, respectively. Those values suggest that hydrostatic shrinking and swelling processes, along with root decomposition, may control elevation changes in these environments. Due to the great variability in the data, there were no significant elevation change differences among the three environmental settings ($p > 0.05$). Shallow subsidence (the difference between accretion and elevation change) was 4, 8.5 and 10.1 mm yr^{-1} at the dry, marsh and flooded environments, respectively. Even though shallow subsidence was lowest at the dry environment and highest at the flooded environment, there were no significant differences among the three environments ($p > 0.05$).

These data indicate that the dwarf mangroves along the borders of Florida Bay will be slow to respond to rising sea levels. The dry (ridge) environment may be the least persistent coastal habitat despite its hard carbonate rock structure. If the stability and height of the coastal ridge becomes compromised, then the marsh and flooded mangroves will develop a greater connectivity to ocean influences and less connectivity with upstream freshwater influences. The result may be a further expansion of Florida Bay into the Everglades and a loss or movement of mangrove habitat.

As for why this ridge degradation and transgression hasn't occurred in light of the fact that sea level has been rising for the last 100 years, the answer may be that pulsing events, such as hurricanes and thunderstorms, nourish the ridge environment with inorganic matter imported from Florida Bay. Evidence for this pulsing was discovered five days after the passing of

Hurricane Irene on October 20, 1999 (**Figure 6-9**). After the hurricane we observed that the entire coastal ridge was covered by a layer of marl, a gray carbonate mud found throughout Florida Bay. The extent and depth of this deposition was measured, October 25, 1999, along a single transect that ran from Little Madeira Bay in the south to the dwarf mangroves in the north, in the Taylor River Basin. Starting at the bay's edge and moving north in increments of 5 meters, the depth of the marl and the depth of the storm surge were measured. The depth of the storm surge was estimated from marl deposits on tree trunks along the transect. **Figure 6-9** indicates a lack of sediment deposition at the beginning and toward the back of the transect. At this location, the Buttonwood Ridge is 250 to 300 meters wide, indicating that the bay mud carried by the storm surge did not get deposited in the dwarf mangrove zone behind the ridge. Most of the deposition due to Hurricane Irene was confined to a 60-meter zone in the center of Buttonwood Ridge. Secondly, **Figure 6-9** also indicates a high degree of deposition. Though Hurricane Irene was only a category 2 hurricane, it nonetheless deposited up to 50 mm of bay mud onto Buttonwood Ridge. Considering the dynamics of sedimentation and subsidence in a karst system like Florida, these deposition numbers appear high. This may be a karst system's only way of keeping pace with rising sea levels. These numbers suggest that natural disturbances, of low intensity (such as hurricane Irene), play an important role by depositing marl sediment in the mangrove forest helping them to keep pace with rising sea level.

Unlike the dry ridge environments, the marsh and flooded environments had high subsidence and very little change in elevation, indicating that these sites are very susceptible to a rise in sea level. The data indicate that these environments are not keeping pace with the current rise in sea level. This is particularly true for the flooded environment where shallow subsidence is the highest but without being statistically significant. Biogeochemical processes, such as organic matter decomposition, and physical processes, such as hydrostatic shrinking and swelling of the soil, seem to dominate the mechanisms that control soil formation and elevation change. Despite a relatively high accretion rate in the flooded environments, these sites did not increase in elevation. This is probably due to the lack of any belowground root production (as there are no trees in these sites) and a relatively high rate of decomposition (though data are lacking). Accretion rates in the marsh sites were relatively constant but lower then in the flooded sites, suggesting that marsh sites receive localized deposition, while flooded sites receive more allochthonous (external) inputs. These results suggest the need to have a better understanding of belowground processes, such as roots production and decomposition, and their contribution to the maintenance of mangrove elevations in the face of rising sea levels.

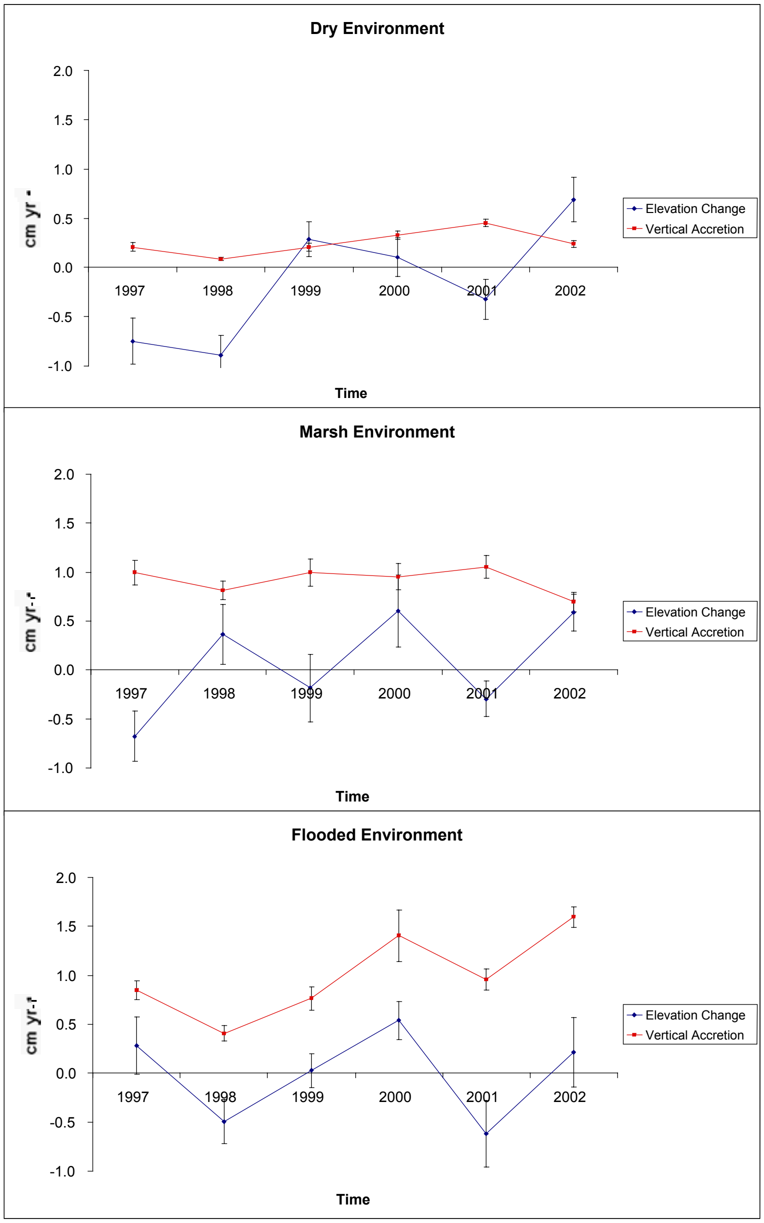

Figure 6-8. The rate of vertical accretion at all study sites ranged from 0.9 to 16 mm yr^{-1}. The average vertical accretion was 2.5, 9.2 and 10 mm yr^{-1} at the dry, marsh and flooded environments, respectively

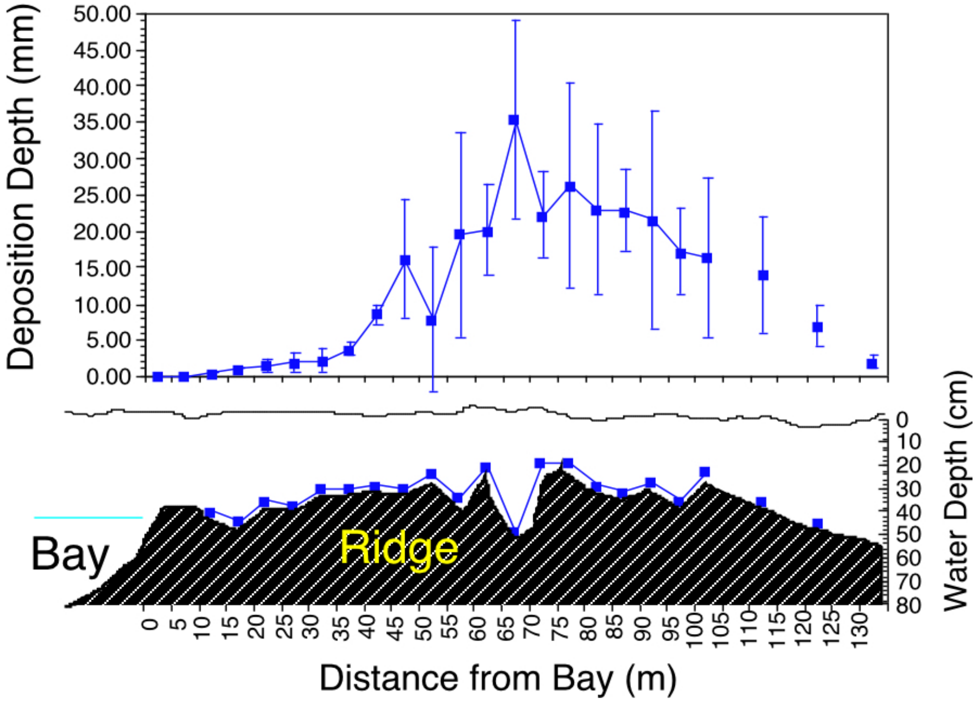

Figure 6-9. The average deposition of Florida Bay sediments on the Buttonwood Ridge at Taylor Creek five days after Hurricane Irene, which passed over Florida Bay on October 15, 1999. The depth of the storm surge during the hurricane was estimated from marl deposits on tree trunks along a transect. If one assumes that these high water marks were relatively flat (the zero depth line), then one can estimate the relative ridge topography (the shaded area)

Peat Microtopography and Spatial Pattern in the Ridge and Slough Landscape

Historical descriptions, as well as analysis of aerial photographs from the 1940s and 1960s, suggests that most of the remaining Everglades was originally part of a "ridge and slough" landscape (SCT White Paper). Pre-drainage accounts of the Everglades environment describe long ridges of tall, dense sawgrass (*Cladium jamaicense*) alternating with navigable, open areas of slough. Although specific measurements are not available, knowledgeable early observers refer to differences of "one to three feet" and "two to three feet" between the peat elevations in the sloughs and on the ridges (McVoy et al., in prep.). Together, the long, narrow, and generally parallel ridges and surrounding sloughs formed a strongly directional pattern oriented in the downstream direction. Previous Consolidated Reports and the 1999 Interim Report have discussed the need to preserve this pattern to sustain healthy food-web dynamics, fish, and wading birds.

Aerial photographs and vegetation maps of the present-day ridge and slough landscape suggest a blurring of the original pattern. In some locations, sawgrass ridges have fragmented, but in most cases it is the sloughs that have degraded and become more ridge-like. Emergent species, such as spike rush (*Eleocharis cellulosa*), maidencane (*Panicum hemitomon*), beak rush (*Rhynchospora* sp.), and even sawgrass, have expanded into former sloughs. In contrast to the original, highly directional pattern, the post-drainage vegetative changes tend to occur as randomly oriented, non-directional patches.

It has been hypothesized that the post-drainage vegetative changes and the associated blurring of the original ridge and slough spatial pattern are related to a flattening of the landscape, that is, to a reduction in the elevation difference between ridges and sloughs (2000 Everglades Consolidated Report, McVoy et al. in prep). This hypothesis was evaluated by measuring relative peat elevations along transects sufficient in length to cross multiple ridges and sloughs. Three replicate transects were located in each of two areas, one where the vegetation pattern still appears to resemble its pre-drainage form (central Water Conservation Area 3A, south of Alligator Alley and west of the Miami Canal), and the other where the original pattern has been almost completely replaced by uniform sawgrass (Water Conservation Area 3B). Relative elevations of the peat and underlying bedrock relative to the water surface were measured in triplicate with 1.0 meter spacing every 50 m along the 2 km-long transects. The types of vegetation growing at each point were recorded and classified as either slough or sawgrass. Global positioning system (GPS) waypoints were recorded to allow comparison of field observations with rectified aerial and satellite imagery. In WCA-3A, the locations of the sawgrass/slough interfaces were recorded in addition to the regularly spaced elevation measurements. **Figures 6-10** and **6-11** present two transects representative of six that were measured.

Figure 6-10 shows the close relationships between field and aerial observed vegetation and between the vegetation and the peat surface elevations. These transect data reflect a slice through sawgrass ridges, each elevated approximately 20 cm above the adjacent sloughs. The combination of this elevation difference and the prevailing water regime (hydropattern) may be sufficient to keep sawgrass from invading the sloughs. However, most sloughs in this area were covered with emergent wet prairie species. Pollen studies of soil cores from other ridge and slough locations suggest that wet prairie species became abundant in sloughs only after the onset of drainage (Willard et al., in press). Note also that the 20-cm elevation difference is much smaller than the pre-drainage reports of 30 to 90 or 60 to 90 cm, suggesting that even though the spatial pattern appears to have been preserved, the landscape may be flatter than it was historically. Additionally, it is important to note that the pattern of peat surface microtopography appears to be largely independent of the variations in bedrock microtopography.

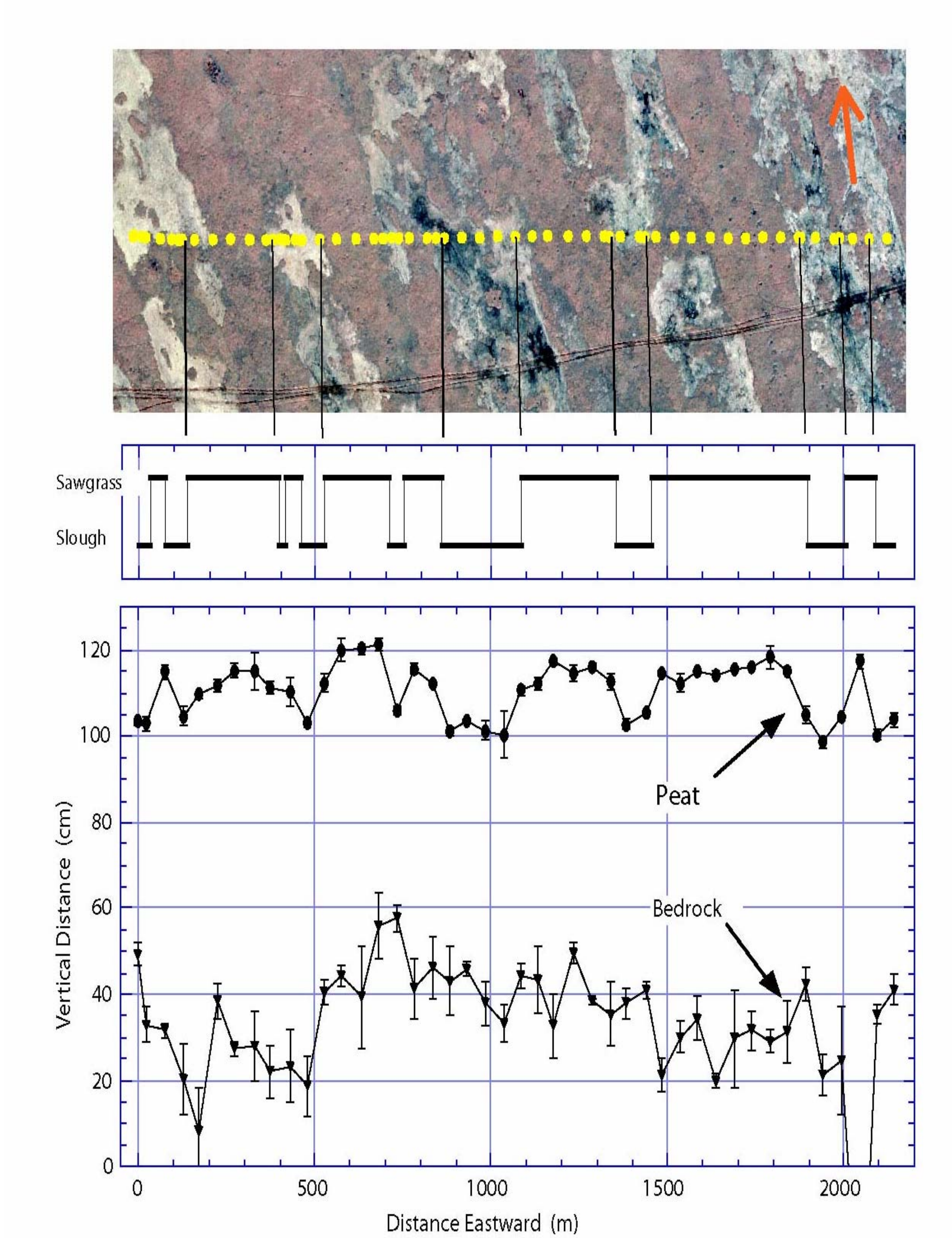

Figure 6-10. Vegetation type, peat surface elevation and bedrock elevation along 2-km transect in area where ridge and slough pattern is considered similar to pre-drainage condition (WCA-3A). Error bars = ±1 S.D.; n = 3. Note close correspondence between locations of sawgrass ridges observed in field (middle panel), ridges observed from the air (top panel), and ridge elevations observed in the peat (bottom panel; circles). Airboat trails are visible south of the transect

In contrast to **Figure 6-10**, **Figure 6-11** shows no visible ridge and slough pattern. Vegetation maps, near completion at the SFWMD, indicate that essentially the full transect (and much of WCA-3B) is covered with sawgrass of medium to high density. Remaining slough-like openings are very small and irregularly shaped. There is very little relief (< 10 cm), and with the exception of a slight high spot associated with a former, small tree island (800 m eastward), there is little correlation between the peat microtopography and the vegetation. As in all six transects, the extreme variability of the bedrock surface suggests that the peat microtopography evolved independently of the bedrock, unless upstream bedrock patterns have an influence.

The other four transects (not shown) reflected similar results. Overall, the six transects suggest a post-drainage loss of microtopographic relief. These data indicate that without hydrologic restoration, the ultimate endpoint of the last 60 years of water management may be the conversion of the original ridge and slough microtopographic and vegetation patterns into a monotonic, flat landscape of sawgrass only.

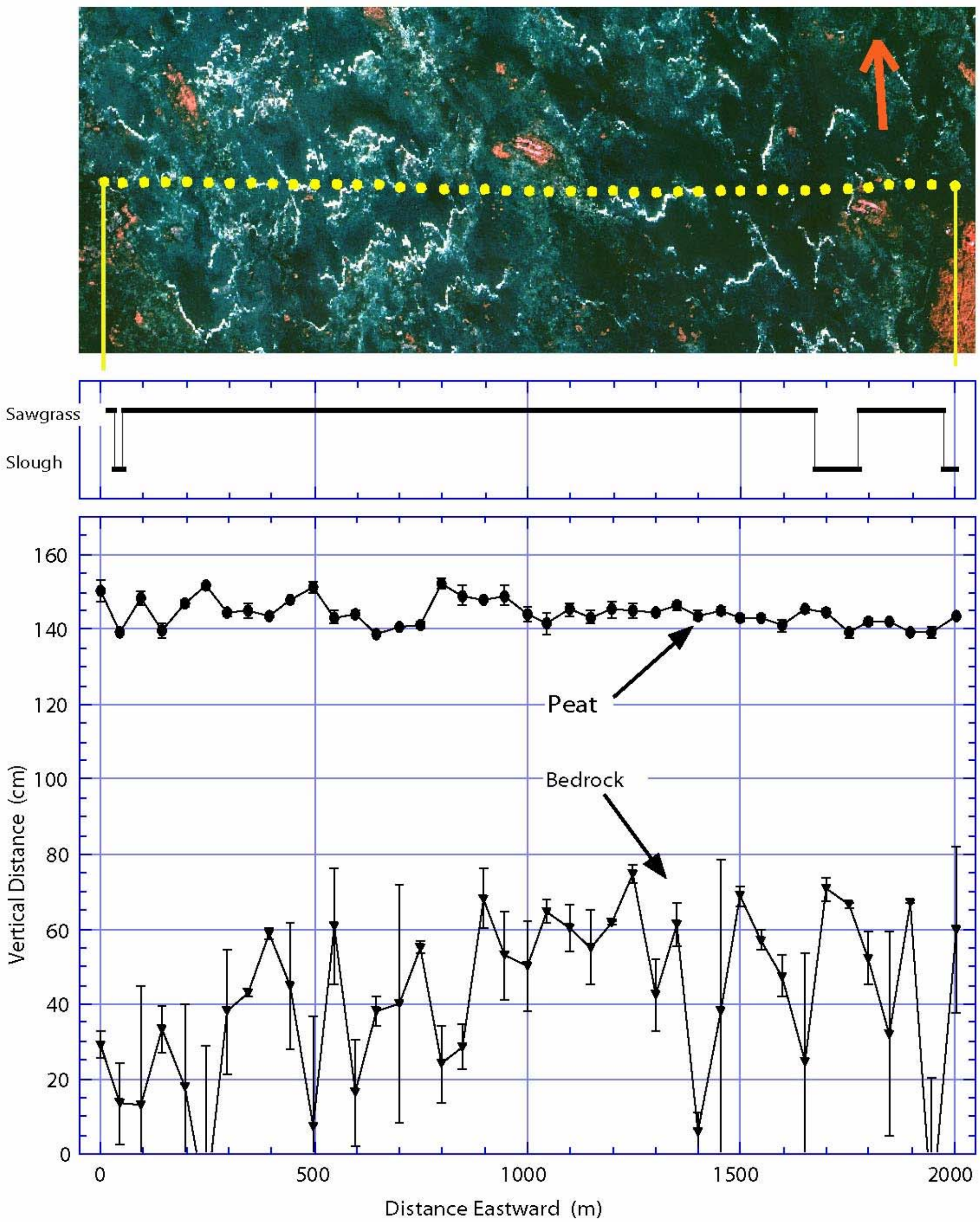

Figure 6-11. Vegetation type, peat surface elevation and bedrock elevation along 2-km transect in area where ridge and slough pattern has been almost completely replaced by uniform sawgrass (WCA-3B). Error bars = ±1 S.D.; n = 3. Peat surface varies by about 10 cm instead of 20 cm, as in WCA-3A transect; variations are not reflected in vegetation

Decomposition

Decomposition is the key process that controls peat accumulation and nutrient cycling within the Everglades landscape. It is influenced by drought, flooding, and nutrient availability and thus is a critical component of several restoration projects including the re-establishment of the ridge and slough landscape (RECOVER, and Decompartmentalization), establishment of hydrologic needs of the Everglades and tree island restoration. In addition, because of its influence on landscape elevations, decomposition responses to changing hydrology are essential to refine minimum flows and levels. It has been hypothesized that the differential decomposition of sawgrass versus slough communities is one of the primary factors influencing the development of the ridge and slough landscape (SCT White Paper). The breakdown of organic matter by enzymes is often the rate-limiting step in decomposition. In a recent study, enzymes involved in the cycling and acquisition of carbon, nitrogen and phosphorus were analyzed to determine the apparent activity of the microbial decomposers in ridge and slough vegetation (Penton and Newman, in prep.). Soil cores were collected from cattail (*Typha* spp.), sawgrass (*Cladium* sp.) and open water communities at two sites, unenriched and phosphorus-enriched, in WCA-3A. The activity of phosphatase, the enzyme involved in the acquisition of phosphorus, was negatively correlated with surface water and soil TP concentrations, with significantly lower values at the nutrient-enriched site ($\alpha = 0.05$). All three habitats had significantly different phosphatase activities ($\alpha = 0.05$). The open water habitat exhibited the highest, and sawgrass exhibited the lowest phosphatase activity at both sites. This suggests that the acquisition of phosphorus occurred at significantly different rates in each habitat.

Nitrogen cycling was also influenced by habitat and enrichment. Leucine aminopeptidase (En), an enzyme involved in nitrogen acquisition, was analyzed as a change in available nitrogen content between the detrital and soil layer. These layers represent the progression of decomposition from litter fall to eventual burial. When En ratios are greater than 1, nitrogen mineralization is occurring. When the ratios are less than 1, nitrogen immobilization is occurring. Results indicated that nitrogen mineralization (ammonification) processes dominate nutrient-enriched sites in each habitat (**Figure 6-12** and **6-13**). In contrast, nitrogen immobilization dominates the unenriched site. This suggests a shift in nitrogen cycling in response to phosphorus enrichment.

The Enzyme Index of Carbon Quality (EICQ) combines the activities of all the enzymes involved in nutrient cycling and lignin degradation. EICQ values have been shown to be positively correlated with microbial biomass, productivity, and negatively correlated with particulate organic carbon turnover times (Sinsabaugh, 1995). Therefore, the larger the EICQ value, the faster organic carbon is decomposed. In this study, the enriched site demonstrated higher EICQ values in both the soil and the detrital layer, suggesting that decomposition is occurring at a faster rate in nutrient enriched sites (**Figures 6-12** and **6-13**). However, the greater productivity that occurs in the plant communities results in a net accumulation of peat.

The EICQ values exhibited clear trends among the habitats at each site in both the soil and the detrital layer. The open water community had the higher EICQ values, while the sawgrass habitat exhibited the slower EICQ values. These results suggest that open water habitats exhibit the fastest organic carbon turnover times, resulting in faster decomposition. The faster decomposition, coupled with less-dense, more easily degradable plant matter, may result in the formation of a lower elevation over time. Conversely, the sawgrass community exhibited slower organic carbon turnover time, and thus slower decomposition. This slower decomposition, coupled with a greater input of a more complex plant matter, may result in a higher elevation over time. These results appear to support a decomposition-mediated formation of sloughs and sawgrass ridges over time.

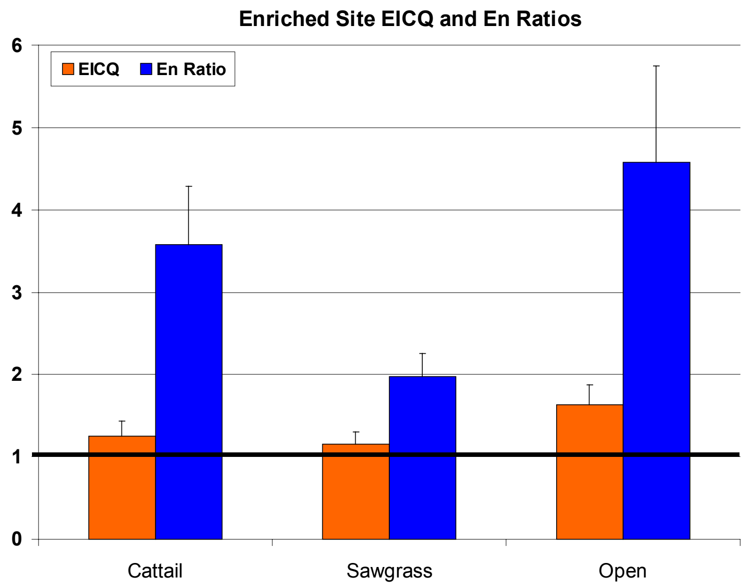

Figure 6-12. Carbon quality and perceived nitrogen availability at phosphorus-enriched sites in WCA-3A

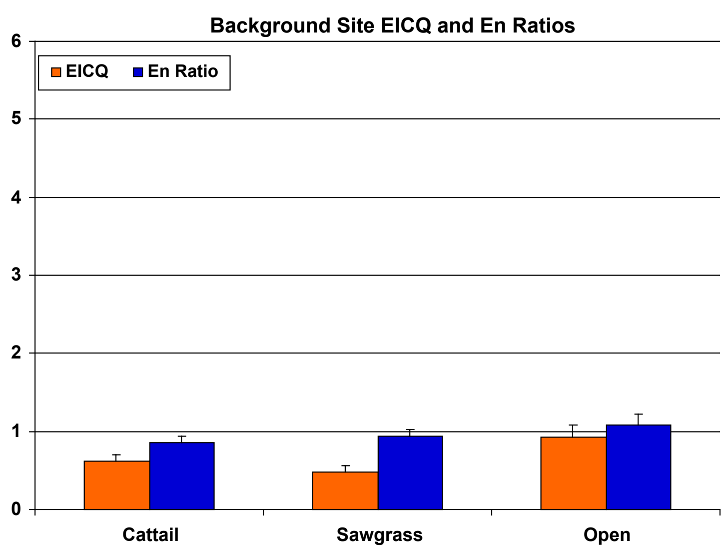

Figure 6-13. Carbon quality and perceived nitrogen availability at phosphorus-enriched sites in WCA-3A

VEGETATION

Ridge and Slough

While the response of *Cladium* and *Typha* in the sawgrass community of the Everglades to changes in water level and increased phosphorus availability has received considerable attention (e.g., Davis, 1989; Davis, 1991; Koch and Rawlik, 1993; Urban et al., 1993; Craft et al., 1995; Kludze and DeLaune, 1996; Newman et al., 1996; Pezeshki et al., 1996; Craft and Richardson, 1997; van der Valk and Rosburg, 1997; Wu et al., 1997; Miao and Sklar, 1998; Miao and DeBusk, 1999; Chabbi et al., 2000; Miao et al., 2000; Miao et al., 2001; Lorenzen et al., 2001), little information is available concerning the factors controlling the relative dominance of wet prairie/slough-community species, such as *Eleocharis cellulosa* (Spikerush) and *Rhynchospora tracyi* (Beakrush). In particular, literature concerning the importance of water level (David, 1996; Newman et al., 1996; Jordan et al., 1997; Busch et al., 1998) and nutrients (Craft et al., 1995; Newman et al., 1996; Daoust and Childers, 1999) on the relative success of these species are less numerous.

A controlled experiment was conducted by Louisiana State University via contract to investigate the influence of phosphorus and water level on the growth of *R. tracyi* and *E. cellulosa.* The experiment was a completely randomized 3 (water levels) x 2 (phosphorus) x 2 (species) factorial block design, replicated four times, for a total of 48 growth chambers (rhizotrons). Treatments and levels were as follows: water levels ([a] drained but moist [b] flooded to a 10 cm depth, and [c] flooded to a 45-cm depth); available phosphorus (target interstitial water P level was: [a] 10 and [b] 500 $\mu g\ P\ l^{-1}$); and species ([a] *Rhynchospora tracyi* and [b] *Eleocharis cellulosa*). The rhizotrons, constructed of 0.64-cm (1/4 in.) clear acrylic for the front and back, and 1.27-cm (1/2 in.) clear acrylic for the sides and bottom, were specifically developed for the quantification of both aboveground and belowground growth dynamics. They were positioned at a 20° angle to promote root growth at the viewing face (**Figure 6-14**). A summary of the methods can be found in the *2003 Everglades Consolidated Report*, **Appendix 6-1**, and in reports for contract C-E11655 at the South Florida Water Management District.

Preliminary statistical analyses of the data showed that the two species, *Eleocharis cellulosa* and *Rhynchospora tracyi*, differ in their response to different water and phosphorus levels. Canopy height (**Figure 6-15**) at the end of the experiment differed significantly between species ($p = 0.0047$) and water level ($p < 0.0001$); however, the effect of water level on canopy height differed by species (significant water level x species interaction, $p = 0.0014$). The canopy height of *E. cellulosa* was greatest in the flooded treatment, while there was no significant difference between the other water levels for this species. The canopy height of *R. tracyi* was also significantly greater ($p = 0.0177$) in the flooded treatment compared to the drained treatment, but this difference was not nearly as large as that found for *E. cellulosa*.

Figure 6-14. Root tracking with permanent marker on the transparency attached to the viewing face of the rhizotron

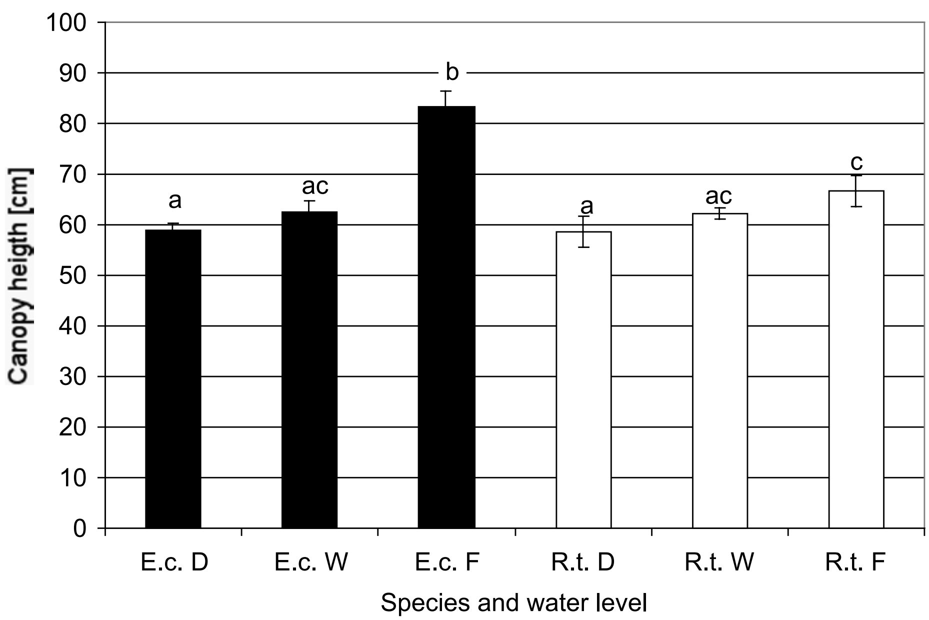

Figure 6-15. Canopy height of *E. cellulosa* (E.c.) and *R. tracyi* (R.t.) under different water regimes (drained [D], waterlogged [W], and flooded [F]) 112 days after planting. Mean ± SE, n = 8. Means with the same letter are not significantly different

Total biomass of *E. cellulosa* was significantly greater ($p < 0.0001$) than total biomass of *R. tracyi* (**Figure 6-16**). While *E. cellulosa* had a significantly higher total biomass under flooded conditions, *R. tracyi* tended ($p = 0.0824$) to have a higher total biomass under drained conditions (species x water level interaction, $p = 0.0006$). Total biomass of *R. tracyi* was significantly greater ($p = 0.0079$) with high P availability (P+) than with ambient P (P-) (**Figure 6-16**).

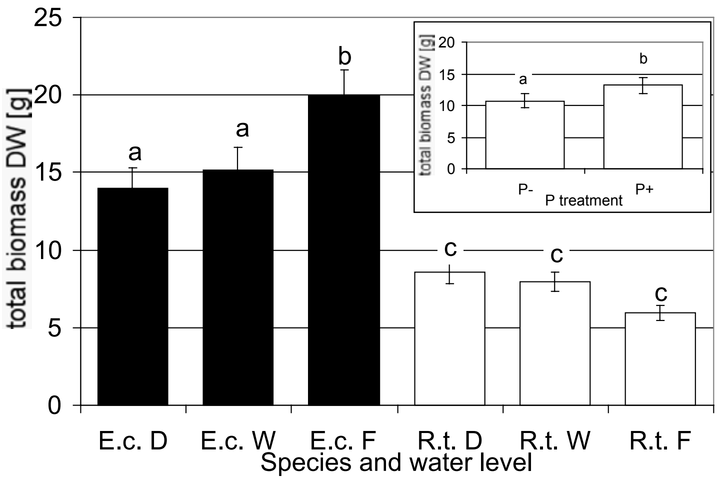

Figure 6-16. Final total biomass of *E. cellulosa* (E.c.) and *R. tracyi* (R.t.) under different water regimes (drained [D], waterlogged [W] and flooded [F]) and under different P treatments (insets, P-, P+) 112 days after planting. Mean ± SE, n = 8. Means with the same letter are not significantly different within each group

Shoot porosity (**Figure 6-17**, top) differed significantly between the two species ($p < 0.0001$) and water level treatments ($p = 0.0088$) without interaction effects. The shoot porosity of *E. cellulosa* was three times higher than for *R. tracyi* (74 ±1 percent versus 26 ±2 percent). Plants under the drained treatment had lower shoot porosity (45 ±1 percent) than plants from waterlogged (53 ±8 percent) and flooded treatments (52 ±8 percent), regardless of species. Root porosity (**Figure 6-17, bottom**) differed with species and water level (interaction $p = 0.0312$) but the differences were less dramatic. In *E. cellulosa*, root porosity increased with increasing water level, while in *R. tracyi*, root porosity showed no consistent trend with increasing water level. There was no phosphorus effect on shoot or root porosity.

Overall, these preliminary results are consistent with the habitat preferences that have been observed for these two species in the greater Everglades. *E. cellulosa* is better adapted to higher water levels than is *R. tracyi*. Consistently, *E. cellulosa* performed better under flooded conditions, while *R. tracyi* growth was better under drained conditions. As a consequence of the different species-specific responses to water level and P availability, the relative success of *E. cellulosa* and *R. tracyi* in the field may alter with changes in site hydrology and P availability. However, work of this nature is just beginning and more information concerning the competitiveness of these two species in relation to other plants is needed for a better understanding of the impact of hydroperiod and phosphorus availability on wet prairie and slough communities in the Florida Everglades.

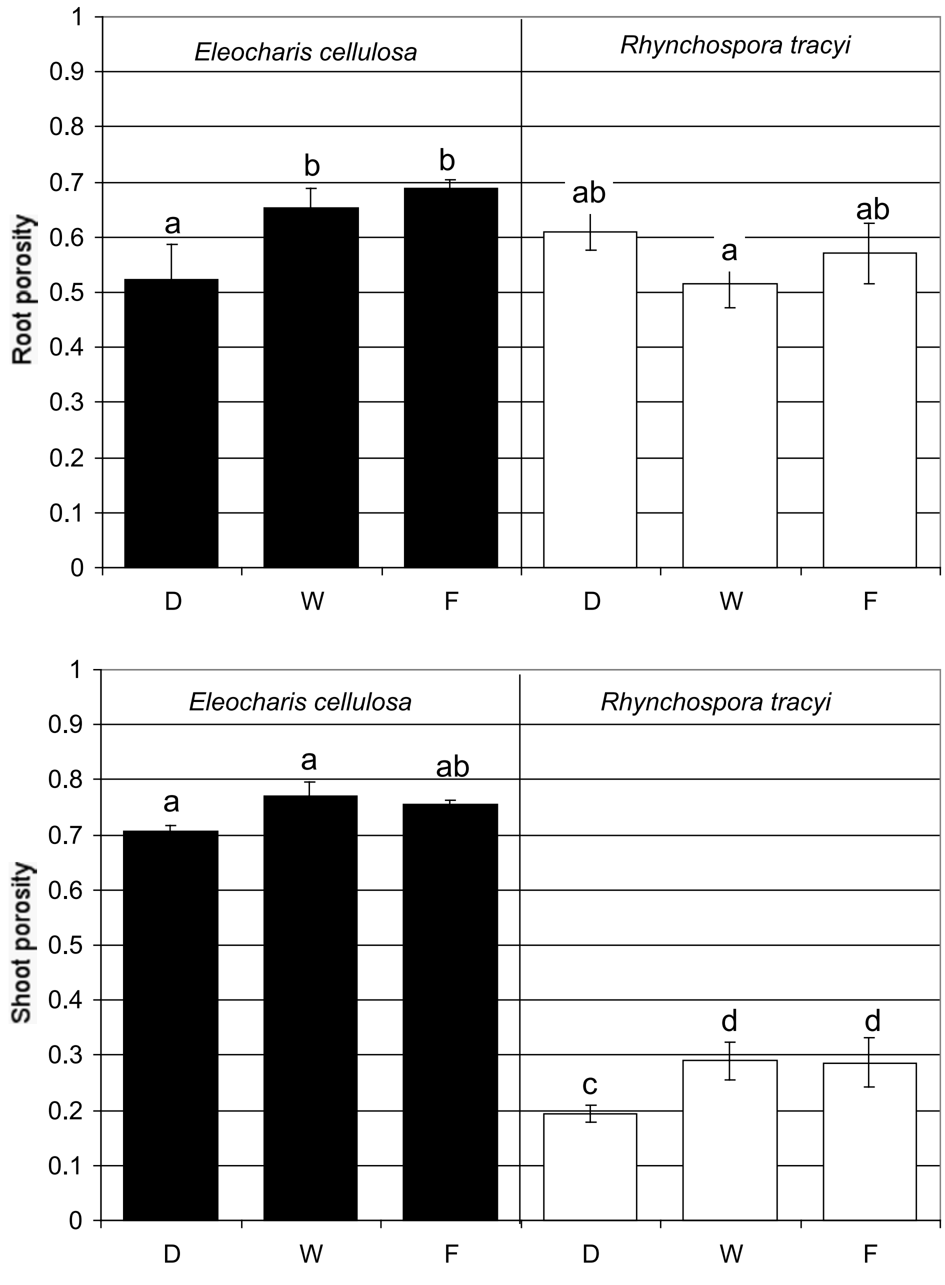

Figure 6-17. Shoot (top graph) and root porosity (bottom graph) expressed as percent of *E. cellulosa* and *R. tracyi* under water regimes drained (D), waterlogged (W) and flooded (F) 112 days after planting. Mean ± SE, n = 8. Means with the same letter are not significantly different

Vegetation Community Changes in Rotenberger

The objectivesof this 404 Permit program are: a) provide provision of clean water during both wet and dry seasons and in quantities suitable to provide for natural hydropatterns, b) assess how to avoid extreme high-water events that would drown remaining tree islands and promote cattail proliferation, and c) define extreme drought conditions that cause soil oxidation and risk of muck fires. The success (or failure) of restoring the hydrology pattern in Rotenberger can show us the importance of hydrology in restoring the ecological functions of the Everglades. The Rotenberger Wildlife Management Area (RWMA) is an extensive sawgrass marsh wherein the native plant community has experienced marked changes due to increased drainage, decreased hydroperiod, drought and fire. In accordance with the Everglades Forever Act (EFA) operating permit, the SFWMD has been operating the RWMA to achieve an interim hydropattern restoration target based on a 31-year average stage predicted by the Natural System Model (NSM).

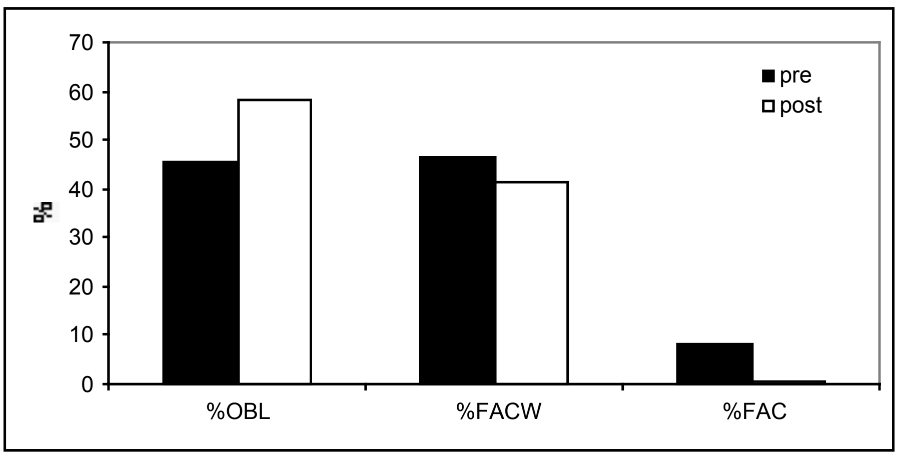

Figure 6-18. As a result of the change in hydrology in the Rotenberger Wildlife Management Area, there was a gradual qualitative shift in macrophyte species composition from facultative and facultative wetland to obligate (see text for details)

In July 2001, STA-5 began discharging into the Rotenberger area, extending the hydroperiod and increasing the average depth of the surface water. Hydrologic conditions prior to July 2001 were severe since Rotenberger experienced long drought periods (spring and summer of 1998 and spring of 1999 and 2000) and a large-scale fire disturbance (May 1999). However, after July 2001, the Rotenberger area experienced a more natural wet/dry cycle similar to the hydropattern predicted by the Natural System Model (NSM). As a result of the change in hydrology, there was a gradual qualitative shift in macrophyte species composition (**Figure 6-18**). The proliferation of *Eupatorium capillifolium* (dog fennel) during the 2000 drought and the 2001 dry season has since declined to the point where very few of these plants or seedlings are being observed. Data from macrophyte surveys[2] taken in the past five years suggest that species, such as *Eupatorium capillifolium* (facultative wetland), *Senecio glabelus* (facultative wetland), *Teucrium canadense* (facultative wetland) and *Erigeron quercifolius*, (facultative) were dominant. As of July 2002, very few to none of these species have been observed. Instead, species typically found in traditional Everglades wetlands were recorded, such as *Utricularia foliosa* (obligate), *Eleocharis cellulosa* (obligate), *Pontederia cordata* (obligate), *Panicum rigidulum* (obligate) and *Sagittaria lancifolia* (obligate). Prior to STA-5 discharge, there was an equal percentage of obligate to facultative wetland species; however, in the past year a higher percentage of obligate plants has occurred, and there has been a decrease in facultative wetland plants. Thus, the occurrence of *Utricularia* (bladderwort) is ecologically significant in that it has not been recorded here in the past five years. While the data for the species composition is not statistically significant it does suggest a persistent seedbank of desirable Everglades plants. In addition, there has been a significant decline in cattail live leaf production in post-discharge measurements versus pre-discharge measurements, and there has been no new significant cattail growth observed in the past year since STA-5 began discharging. Conversely there has been an increase in sawgrass live leaf production of post-discharge measurements versus pre-discharge measurements (**Table 6-7**).

Table 6-7. Plant structural parameters before and after water discharge into the Rotenberger Wildlife Management Area. Data are means (SE) with n=12 (pre-discharge) and n=9 (post-discharge)

	Sawgrass		Cattail	
Parameter	Pre-discharge	Post-discharge	Pre-discharge	Post-discharge
Shoot Density (ind m^{-2})	28.4 (5.3)	25.8 (3.5)	5.2 (3.10)	3.1 (0.45)
Shoot Height (cm)	110.3 (36.5)	153 (9.0)	63.3 (37.2)	114 (15)
Live Leaves (No. of leaves)	33.6 (13.7)	43.5 (10.5)	12 (2.3)	3.5 (0.5)
Dead Leaves (No. of leaves)	13 (7.9)	21 (5.0)	8 (2.5)	1.5 (0.5)

[2] Twice a year (wet and dry season) a general macrophyte species survey was taken within a 50 meter radius at each monitoring platform located within the Rotenberger tract. All species found within this radius were recorded and identified to genus and type of habitat designation (Tobe et al 1998).

Temporal and spatial surface water quality data indicate that TN and TP concentrations decreased during the post-discharging period (July 2001 through July 2002). A decrease in nutrient concentration suggests both nutrients are being taken up and adsorbed along the study transects that were established in 1998 to meet the requirements of the 404 and EFA Permits. Similarly, during the post-discharge period, TN and TP increased in both cattail and sawgrass live tissue and in soil samples. These results suggest that the nutrient storage capacity by the Rotenberger area's plant and microbial community has increased in response to water discharge from STA-5. However, more data are needed to better estimate long-term ecological effects indicating a return to the original state.

Tree Island Ecology

The South Florida Water Management District, as part of both an ongoing tree island research program and as part of its responsibilities under the CERP, will be following the effects of modified, more natural hydropatterns by monitoring specific ecological indicators. Within the matrix of wetland communities that make up most of the greater Everglades are small, topographic high areas called tree islands that historically have provided suitable habitat for a variety of terrestrial plants and animals. Because the maximum elevations of the highest tree islands are only slightly above mean annual maximum water levels, tree islands, with their less flood-tolerant vegetation, are more sensitive to changes in hydrology than any other Everglades component. One of the earliest indicators of problems caused by modified water management practices has been changes in the physical and biological character of tree islands. Tree island degradation and loss can be caused by exposure to either prolonged excessively high water, which drowns many intolerant tree and shrub species, and/or low water, which increases the vulnerability of these habitats to muck fires.

Tree Growth

A primary production monitoring program was initiated in 1998. Since then, the District has collected litterfall every six weeks and measured tree growth every eight weeks on nine tree islands in WCA-3A. The program's objectives include determining the spatial and temporal patterns of litterfall production and defining the relationship between litterfall production and hydroperiods. Based on historical hydrological patterns, the nine tree islands were grouped into two hydrologic categories: wet tree islands, characterized by a "normal" hydroperiod of about seven months of inundation and 20 cm of water depth, and flooded tree islands, characterized by a longer hydroperiod of about nine months of inundation and 30 to 50 cm of water depth.

Flooding on forested wetlands is a natural occurrence (Messina and Conner, 1998). However, the alteration on the flooding regime has been shown to affect tree growth and forest production (Keeland and Young, 1997). Previous studies show that tree growth and production are higher in seasonally flooded, forested wetlands relative to upland, drained, or permanently flooded sites (Conner and Day, 1982). The benefits of seasonal flooding are attributed to increased soil moisture and nutrient inputs. Short hydroperiods can increase soil moisture and nutrient input, but long hydroperiods can reduce dissolved oxygen, increase toxic components in the soil and reduce water and nutrient uptake (Kozlowski, 1982). Long-term studies of the effect of fluctuating hydroperiod on individual tree growth in the Everglades are lacking. In general, individual trees located on tree islands characterized by short hydroperiods (wet) grew better ($p < 0.05$) than individual trees located on tree islands with longer hydroperiods (flooded). The tree growth of four tree species (*Annona glabra*, *Chrysoblanus icaco*, *Myrica cerifera*, *and Salix caroliniana*) located on tree islands of WCA-3A are shown as examples (**Figure 6-19**) and indicate a relationship between hydrology and tree growth rates. For example, the lower water depths associated with wet tree islands relative to flooded tree islands were associated with greater growth rates for *A. glabra* and *S. caroliniana.* In contrast, relatively high water depths associated with flooded tree islands appear to have a positive effect on growth rates for *M. cerifera*.

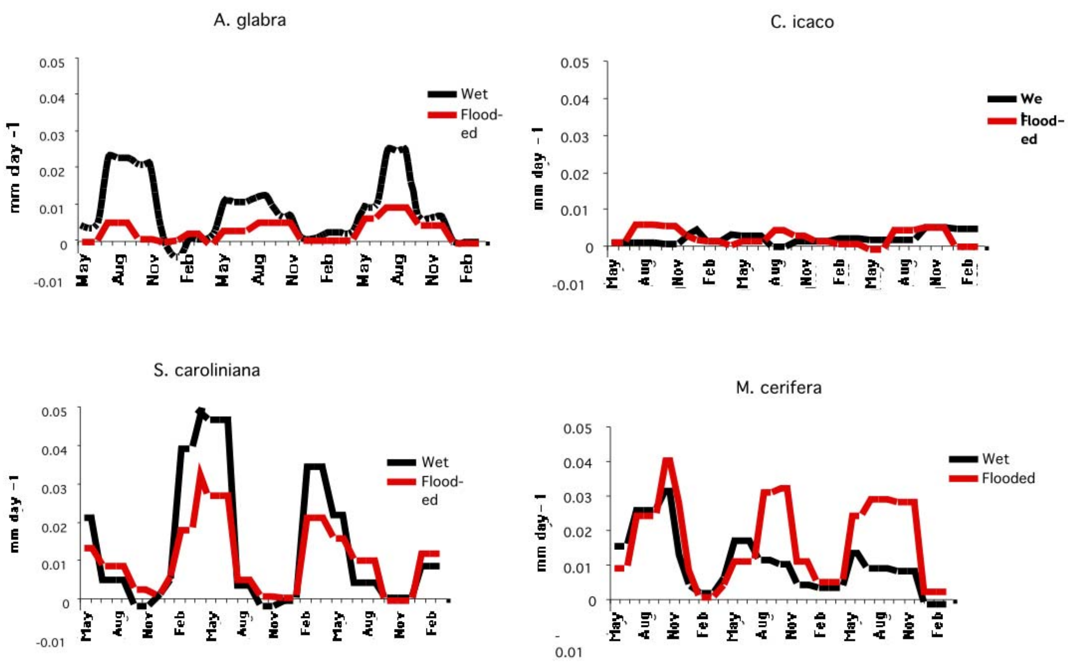

Figure 6-19. Tree growth rate (mm/day) for *Annona glabra* (pond apple), *Salix caroliniana* (willow), *Chrysoblanus icaco* (cocoplum) and *Myrica cerifera* (wax myrtle) at tree islands under short-hydroperiod (wet) and long-hydroperiod (flooded) conditions

Not all tree species respond to hydrology in the same way. *A. glabra* and *M. cerifera* had higher growth rates during the rainy season compared to the dry season. In contrast, *S. caroliniana* (willow) had higher growth rates during the dry season, and *C. icaco* showed no seasonal pattern. Similarly, although flooded islands have lower tree growth rates, individual tree species respond differently to fluctuations in water depth and flooding. In particular, *Myrica cerifera* responded better to a longer hydroperiod than did either *S. caroliniana* or *A. glabra*. (**Table 6-8**). These results are interesting because those three species are considered to have similar tolerances to fluctuating water depths and flooding (Armentano et al., 2002).

Table 6-8. Tree growth rate (mm/day) correlation with water depth (cm) and hydroperiod (number of days a tree island has been flooded)

Species	Water Depth	Hydroperiod
Annona glabra	-0.12	-0.04
Chrysoblanus icaco	0.33 *	0.28*
Myrica cerifera	0.41*	0.40*
Salix caroliniana	-0.57**	-0.53**

* Significant at alpha = 0.05

** Significant at alpha = 0.001

Tree Island Litterfall

Measurement of litterfall in wetland forests is a useful approach for describing ecosystem function and to test hypotheses about primary production under a variety of environmental conditions. Litterfall dynamics can help with the understanding of temporal and spatial patterns of primary production and the effects of hydroperiod fluctuations on litterfall contributions to short-term peat accumulation and nutrient cycling.

Results indicate that litterfall production was strongly seasonal, with higher litterfall production occurring during the rainy season, and lower litterfall production occurring during the dry season ($p < 0.05$) (**Figure 6-20**). Results also show litterfall production was significantly higher ($p < 0.05$) in tree islands subjected to shorter hydroperiods (average 1.9 g m^{-2} day^{-1}) than tree islands subjected to longer hydroperiods (average 1.1 g m^{-2} day^{-1}). It is also interesting that the reproductive litterfall components (seeds, flowers and fruits) are relatively higher on wet tree islands. Higher litterfall production on wet tree islands relative to flooded tree islands was also indicated by a significant negative correlation ($R^{-2} = -0.33$ $p < 0.05$) between litterfall and water depth.

Species composition is an important factor in determining litterfall patterns. Results indicate that out of 15 tree species, four contributed more than 50 percent of the total leaf fall production (**Figure 6-21**). *A. glabra* (pond apple) and *S. caroliniana* (willow) contributed 71.6 percent of the total leaf fall observed on flooded tree islands. *C. icaco* (cocoplum) and *M. cerifera* (wax myrtle) contributed 59 percent of the total leaf fall recorded on wet tree islands. The higher leaf fall production of cocoplum and wax myrtle on wet tree islands seems to indicate a preference for shorter hydroperiods. In contrast, pond apple and willow seem to be more tolerant of longer hydroperiods. Understanding litter's role in tree island ecology, as well as the effects of depth, hydroperiod, air temperature, rainfall and wind, will require further study. Processes measured on individual trees have not yet been translated into an understanding of ecosystem health, for example an explanation for why willow growth rates are so negatively related to water depths and hydroperiods, (**Table 6-8)** while litterfall, and hence productivity, on flooded islands is dominated by willow (**Figure 6-22**). Studies of community structure, which are just now beginning, will help to clarify these types of "contradictions."

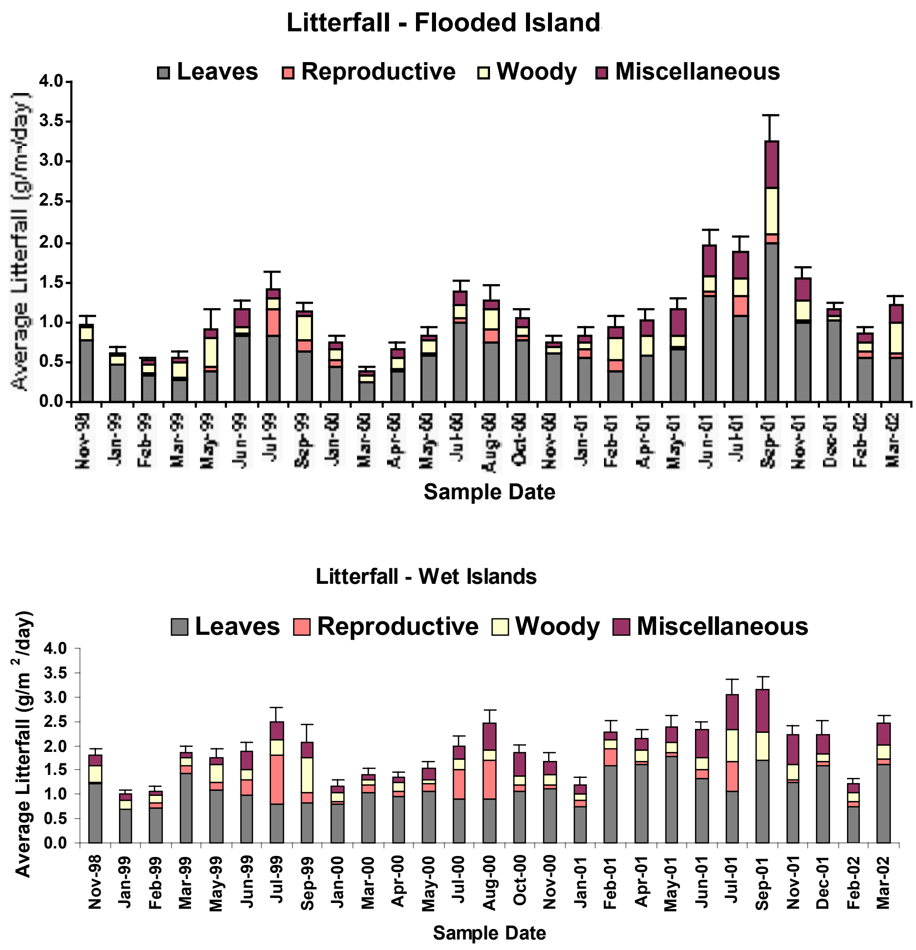

Figure 6-20. Temporal and spatial pattern of total litterfall at tree islands under short hydroperiods (wet) and long hydroperiods (flooded). Litterfall is composed of leaves, reproductive structures (seeds and flowers), woody structures (branches and woody vines) and miscellaneous structures (vines, moss, and pieces that cannot be identified)

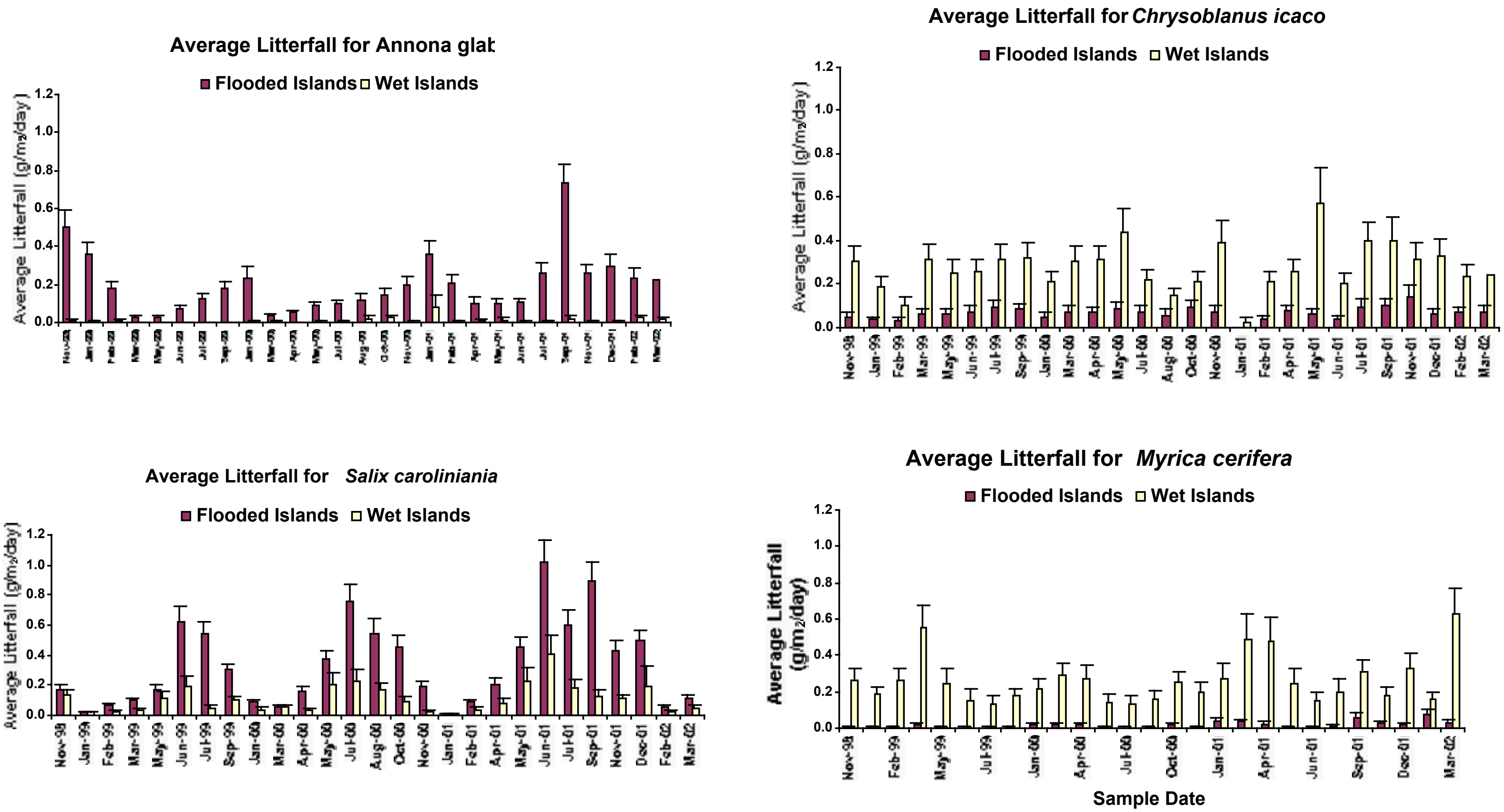

Figure 6-21. Leaf fall production (g/m2/day) for Annona glabra (pond apple), Salix caroliniana (willow), Chrysoblanus icaco (cocoplum) and Myrica cerifera (wax myrtle) at tree islands under short hydroperiod (wet) and long hydroperiod (flooded)

MANGROVES

Tropical evergreen forests, including mangrove forests, have developed a strategy of shedding leaves continuously throughout the year (Proctor, 1984). Generally, mangrove forests have higher litterfall rates during the rainy season and lower rates during the dry season (Twilley et al., 1986; Mackey and Smail, 1995; Day et al., 1997; Wafar et al., 1997). Also, though mangrove leaves are shed continuously throughout the year, litterfall rates vary from habitat to habitat. Annual litterfall rates in mangrove forests worldwide range from 1.2 mg ha^{-1} yr^{-1} for dwarf mangroves in South Florida (Pool et al., 1975) to 23.4 mg ha^{-1} yr^{-1} for a 20-year-old managed riverine forest in Malaysia (Ong et al., 1982). Pool et al. (1975) suggested that litterfall production is a function of the hydrologic characteristics within the forest. It has been suggested that microtopography, rainfall, tides, and river discharge are the most important forcing functions that make mangrove forests highly productive (Lugo and Snedaker 1974). River discharge and tides are important forcing functions because not only are they sources of nutrient-rich water and sediments, but they are also a source of oxygen. Nutrients and oxygen enhance fertility and aeration in the soils, promoting optimal plant growth (Brown and Lugo 1982).

Litterfall rates for a wide range of fringe mangrove forests in southern Florida and Puerto Rico are remarkably uniform, with a rate of about 700 $g/m^{-2}/yr^{-1}$. However, litterfall rates in Florida and Puerto Rico are lower when compared with other *Avicennia*-dominated mangrove forests, such as those in Australia, where the average litterfall rate is 831 $g/m^{-2}/yr^{-1}$. (Mackey and Smail, 1995). High rates of litterfall that characterize better-developed mangroves in non-calcareous, warmer climates imply high rates of primary production and a more productive ecosystem. Litterfall production in dwarf, fringe and basin mangrove sites in the southeast Everglades are herein described as a way to understand the spatial and temporal patterns of ecosystem productivity in relation to freshwater inflows and environmental conditions. Station location maps can be found in the 2001 and 2002 ECRs.

Peaks of litterfall in Florida mangrove forests are strongly correlated with leaf production, indicating a common internal mechanism for both processes (Gill and Tomlinson, 1971). Mangrove litterfall rates in the southeast Everglades were found to be much more seasonal than had been anticipated from current knowledge of more tropical systems. Litterfall during the rainy season was significantly higher than during the dry season ($p < 0.001$). At the Taylor Creek dwarf site, high values of litterfall occurred during August and November, and low values occurred in July (**Figure 6-22**). At the Taylor Creek Ridge site, litterfall peaks occurred during the onset of the rainy season (July through September), and low values occurred in the middle of the dry season (January). A similar seasonal pattern was observed at McCormick Creek. However, this seasonal pattern was not observed at the Trout Creek site, where high values of litterfall occurred at the end of the dry season and low values occurred at the end of the rainy season.

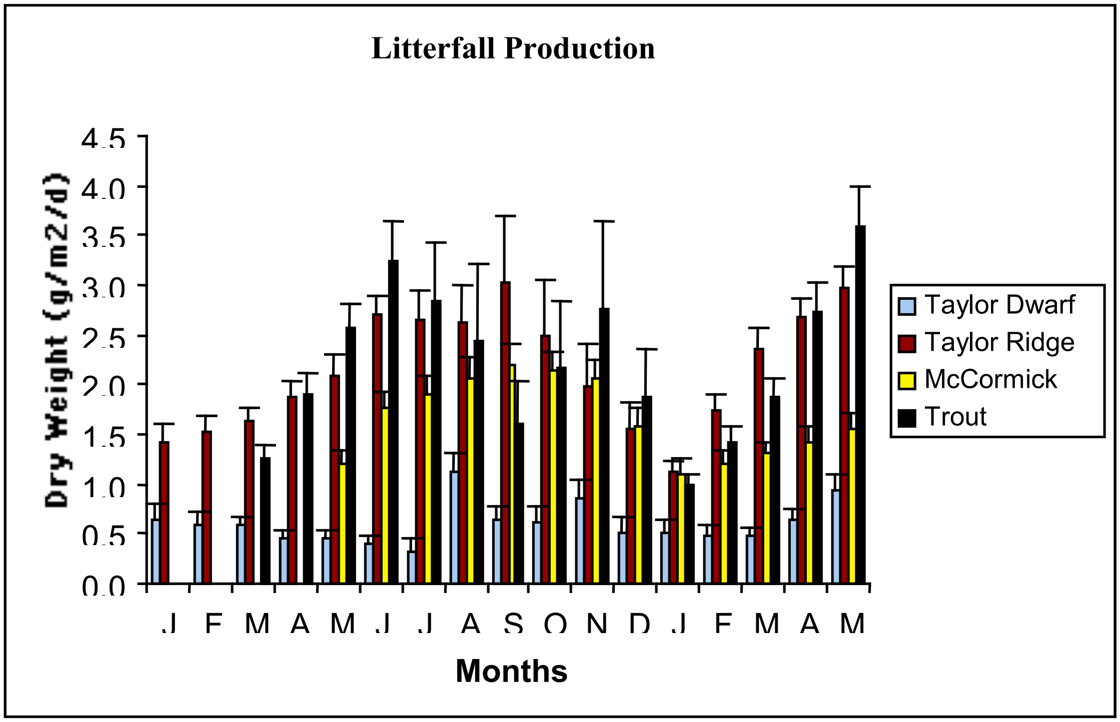

Figure 6-22. Temporal pattern of litterfall (g m^{-2} d^{-1}) at the Taylor Creek Dwarf site, the Taylor Creek Ridge, McCormick Creek, and Trout Creek in the SE section of Everglades National Park

Spatially, the dwarf forest had the lowest litterfall rate (0.69 $g/m^{-2}/d^{-1}$), Taylor Ridge and Trout Creek had the highest (2.29 and 2.26 g m^{-2} d^{-1}, respectively), and McCormick had 1.65 $g/m^{-2}/d^{-1}$. This spatial variability in litterfall production among sites was significant ($p < 0.001$). This spatial variability in litterfall production among sites was significantly lower at the dwarf site ($p<0.001$) relative to the other three sites whose litterfall production was statistically similar ($p>0.05$).

Twilley et al. (1986) found that mean ranks of litterfall production follow the order of riverine > fringe > basin > dwarf. Results from the present study followed this same ranking. Annual litterfall production increased from the dwarf forest to the fringe forests. These results also support the early hypothesis proposed by Pool et al. (1975), indicating that hydrology affects litterfall production.

Interstitial salinity has been postulated to be a factor that could influence litterfall production (Pool et al., 1975). At Terminos Lagoon in Mexico, litterfall production was inversely related to interstitial salinity and explained 77 percent of the litterfall variability (Day et al., 1997). Twilley et al. (1986) have also shown an inverse relationship between litter production and soil salinity in Rookery Bay, Florida. However, Twilley's equation relating both variables explained only 41 percent of the litterfall variability. For the southeast Everglades sites, the interstitial salinity ranged from 12 to 33 ppt. The Taylor Creek dwarf site had the lowest values, and the Trout Creek site had the highest interstitial salinity. Even though the correlation between litterfall and salinity in the southeast Everglades was significant, it explained only 12 percent of the litterfall variability. Although the Trout Creek site had the highest soil salinities (33 ppt), its litterfall rates were similar or higher than those of Taylor Ridge and McCormick, where soil salinity averaged 23 ppt. Thus, other environmental conditions could be responsible for leaf production and litterfall. Nutrients, particularly phosphorus, are known to influence leaf production in carbonate-dominated systems. Phosphorus-enrichment experiments, carried out with dwarf *R. mangle* in carbonate environments of Belize and the southeast Everglades, have shown enhanced growth and leaf production (Feller 1995; Feller et al. 1999). It has also been experimentally demonstrated that waterlogging, reducing conditions, and high sulfide concentrations affected growth in mangrove species (McKee 1995). Thus, local environmental conditions, including permanent flooding, poor-water flushing, and poor-phosphorus soils, could be influencing the observed pattern of litterfall production seen in the southeast Everglades.

REMOTE SENSING AND MODELING TRENDS

REMOTE SENSING

Everglades Tree Island Canopy Measurements Using Lidar and Hyperspectral Data

One measure of the response of tree island vegetation to changes in water depth and hydroperiod can be found by monitoring the size, condition and density of the tree/shrub canopy. Recent remote sensing technologies that may provide a way to efficiently and repeatedly measure canopy conditions include the utilization of Light Detection and Ranging (LIDAR) and hyperspectral sensor systems. These systems collect data either by aircraft or satellites. LIDAR generates relatively accurate 3-dimensional data sets by measuring the time it takes for a laser pulse to reach the ground, or any other obstruction, and reflect back to the sensor, thereby generating relative and absolute terrain and landcover profiles of a study area. Hyperspectral systems, which utilize several tens or hundreds of bands, is also being studied because it could have the advantage of providing data at high spectral resolution over a large number of bandwidths. The SFWMD is currently evaluating the utility of these emerging technologies for monitoring Everglades tree island topography, vegetation characteristics, canopy structure, biovolume, and/or biomass for the purpose of modeling the effects of changes in water management practices on the South Florida ecosystem. This work includes applying up-to-date airborne LIDAR techniques with hyperspectral digital imagery, together with field measurements of vegetation characteristics to develop a prototype monitoring program to enhance the ongoing District tree island research program and assist in evaluating the effectiveness of the CERP.

This project is focused primarily on 13 widely separated tree islands of various vegetation compositions ranging in size from less than 5 acres up to 200 acres and distributed over an area of approximately 630 square miles. These islands are remotely located in WCA-3A. **Figure 6-23** and **6-24** depict some preliminary images from these efforts.

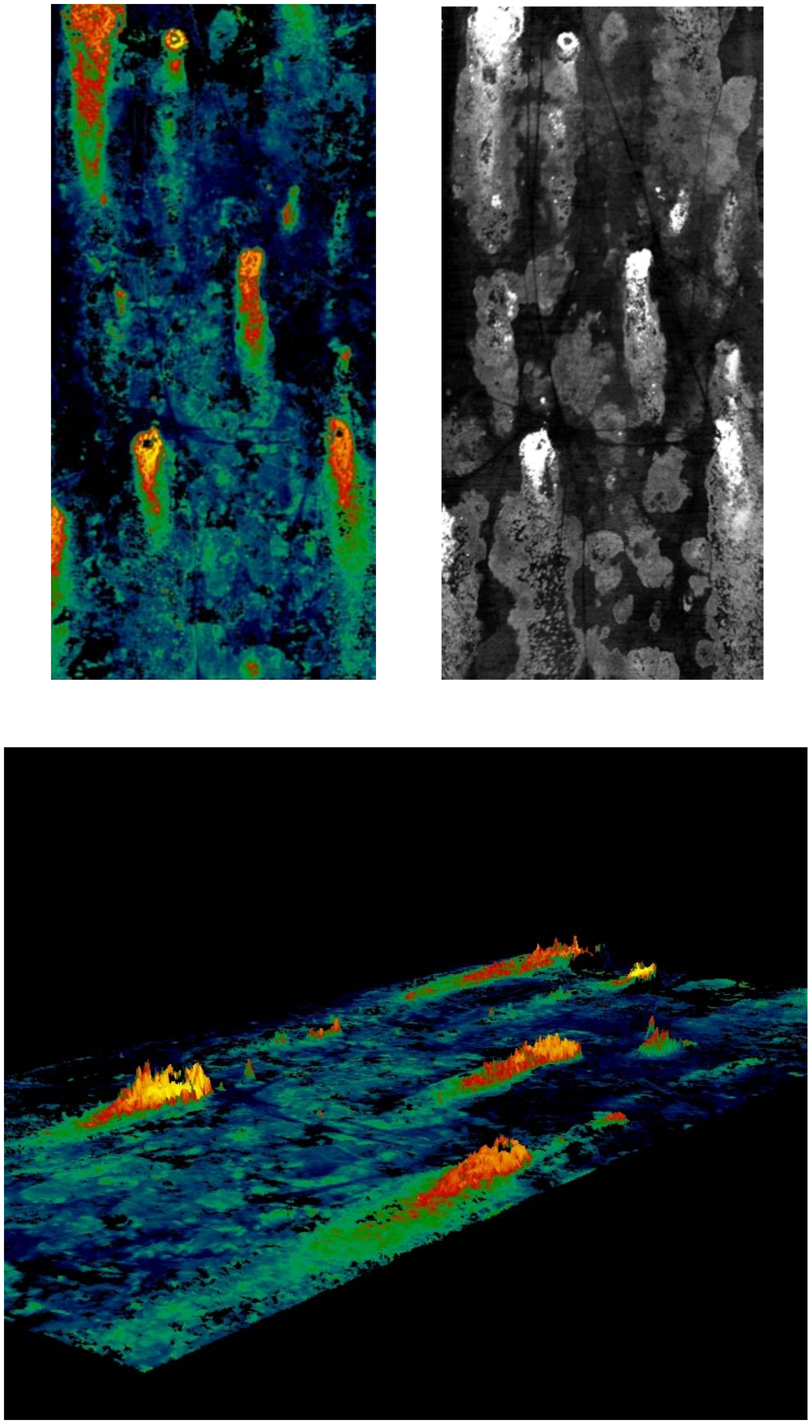

Figure 6-23. The lower three-dimensional image was produced by integrating LIDAR canopy height data (upper left image) with biomass intensity data (upper right image)

Figure 6-24. Hyperspectral data of tree island 3AS4. Note the fine resolution showing a fish camp as a white polygon in the north end of the tree island, complete with its own airboat access trail right to the front door

IKONOS Satellite Vegetation Mapping Evaluation

Old World climbing fern (Lygodium sp.) is an exotic species that is currently being established system-wide in extremely remote and undisturbed areas such as the Everglades. It has reached a critical mass in south Florida where it is expected to exponentially increase its rate of expansion. IKONOS satellite imagery is being investigated as a tool to map Old World climbing fern (Lygodium sp.) to give land managers a better way of tracking and developing site specific methods for eradication.

The IKONOS II satellite system, launched on September 24, 1999, is one of several newer satellite systems that collects higher resolution and more robust digital information of the Earth than previous satellites, such as SPOT or LandSat TM. The IKONOS II orbits the Earth once every 98 minutes at an altitude of approximately 680 kilometers and is sun-synchronous so it will pass a given longitude at about the same local time each day (10:30 a.m. for the Everglades). The sensor is capable of being programmed to view land far from the area directly below it, allowing almost any site to be imaged daily. It collects high-resolution, one-meter panchromatic and four-meter, multi-spectral information, with digital information of 11 bits per pixel, which results in a dynamic range of up to 2,048 unique values per pixel. Previous satellite-based systems were collected at resolutions of 10 to 30 meters and at 8 bits per pixel.

Currently, the SFWMD is using conventional aerial photography methods for mapping vegetation. These methods are producing precise and accurate maps, though at a high cost in terms of personnel. The IKONOS II satellite data might offer the District the opportunity to obtain land-cover information in a more cost-effective way and is being evaluated for use in mapping Everglades vegetation. Image processing techniques will be applied to the imagery to allow for classifying individual pixels and groups of pixels based on the spectral reflectance characteristics of the vegetation species represented by a location. Results will be compared to those derived from more standard aerial photography mapping methods to gauge the utility and benefit derived from the less-costly and more time-efficient image processing procedure.

Figure 6-25 represents one of the first IKONOS satellite data sets the South Florida Water Management District has obtained. The image is a false color-infrared composite of WCA-1 and has four bands of information with a spectral resolution of four meters. Five separate images make up this composite, with four collected on March 21, 2002 and one collected on March 10, 2002. Spectral characteristics were matched between the images using band ratio techniques to produce a relatively seamless scene. Cloud cover and shadow effects account for approximately 8.5 percent of area coverage. Work is currently being conducted to see if this data will be suitable for classifying both the exotic *Lygodium* sp. and also cattail coverage.

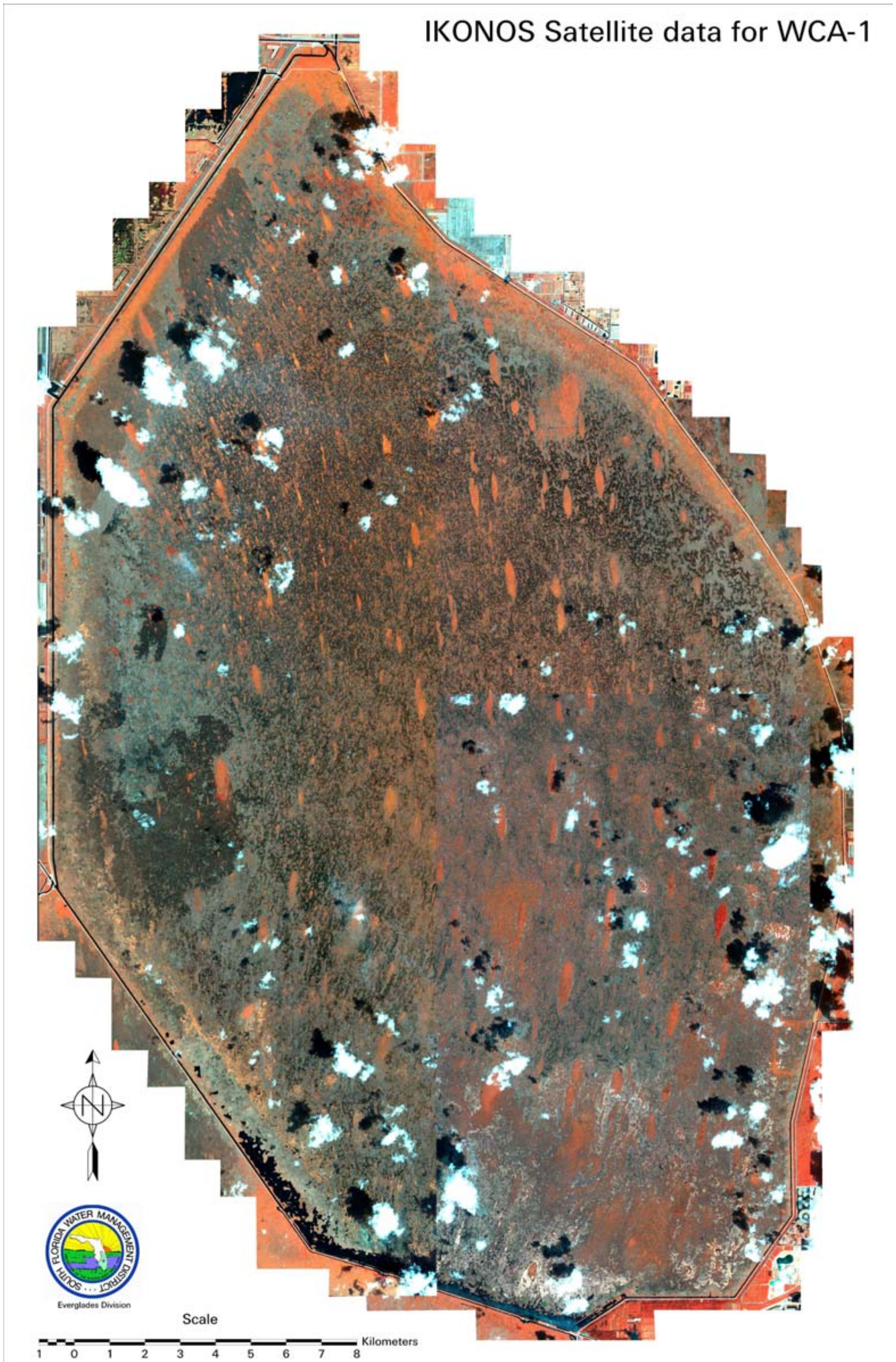

Figure 6-25. One of the first IKONOS satellite data sets that the South Florida Water Management District has obtained

REGIONAL SIMULATION MODEL (RSM)

The South Florida Water Management Model (SFWMM) was developed during the late 1970s and early 1980s and has served as the primary regional simulation model in South Florida for nearly two decades. New initiatives, such as Everglades restoration and water supply planning, have placed new demands for information from regional simulation models. The Regional Simulation Model (RSM) was envisioned with the intent of filling this need and serving as the "next generation SFWMM." The RSM is a weighted, implicit, finite-volume, distributed, integrated surface/groundwater model capable of simulating two-dimensional flow in arbitrarily shaped areas using a variable mesh structure. Its hydrologic simulation engine (HSE) simulates the natural hydrology of the system. It has physically based formulation for the simulation of overland and groundwater flow, evapotranspiration, infiltration, levee seepage and canal and structure flow. The RSM's Management Simulation Engine (MSE) interacts with the HSE and simulates the management components of the system. It formulates the assessment of demand and flood control needs within the system and the resolution of these needs through structure releases. This component of the model is currently under development. Once MSE is completed or fully developed, the RSM can be used to predict the consequences of implementing physical and operational alternatives designed to address changing water management priorities and issues in South Florida. The HSE or the natural hydrology simulation module of the RSM was completed in 1998. Since then, this module has been successfully applied to portions of the remnant Everglades.

Model Conceptualization and Design

From the beginning, the RSM was envisioned to be both flexible and adaptable in its operation and design. It is difficult to predict exactly how this model will be required to perform in the future. Because of this uncertainty, technologies are being used with an eye toward component-based modeling. The RSM will be an assembly of different components that can be swapped in and out as the model evolves. Individual components are being developed independently and are in various stages of completion. In addition, a user-friendly Graphical User Interface (GUI) and a versatile database are currently being developed. The RSM has a more efficient numerical solver than the SFWMM. The RSM's mesh can also conform to a variety of man-made features and natural landforms. In addition, it could accommodate a number of temporal and spatial resolutions. This makes the RSM more amenable for flood modeling than the SFWMM. The existing algorithms and procedures in SFWMM that are efficient and accurate have been duplicated in the RSM as well. In addition, many new features have been added to it to enhance its utility and versatility. It is expected that the RSM will eventually replace the existing SFWMM. However, years of development and testing will be needed before RSM becomes fully operational for the entire South Florida system.

Application of RSM to the Southern Everglades

Accurate hydrologic modeling is crucial for evaluating the flow dynamics in the Everglades. The Everglades is the only remaining subtropical wilderness in the continental United States. The pre-drainage Everglades extended from Lake Okeechobee to Florida Bay. Today, due to urbanization and farming, the Everglades area has been reduced by approximately 50 percent. The remnant Everglades is adversely affected by exotic species, nutrient enrichment, contaminants and altered freshwater flows. The restoration of the remnant Everglades depends heavily on the hydrologic understanding of the quantity, timing and distribution of its freshwater flow. A new RSM model application is currently being developed to simulate the hydrology in the southern Everglades (including Everglades National Park and Water Conservation Area 3) and the Big Cypress National Preserve areas. The objectives of this southern Everglades Model (SEM) application include, but are not limited to:

1. Understanding the influence of flooding on Cape Sable seaside sparrow habitats
2. Investigating the impact of compartmentalization of the southern Everglades
3. Studying the effect of freshwater discharges on Florida Bay salinity.

The SEM may also be used in the Florida Bay and Florida Keys feasibility study to provide boundary condition data for fine-scale hydrological models, as well as large- and small-scale ecological, estuarine and hydraulic/hydrodynamic models.

The domain of the SEM covers about 3,922 square miles. This RSM application will use recently acquired land-use and topography data. Since the Management Simulation Engine of the RSM is still not fully developed, this modeling study will be conducted exclusively by using the Hydrologic Simulation Engine of the RSM. Consequently, the SEM will obtain its eastern boundary condition data from the SFWMM for all scenario simulations. The remaining boundary condition data will be obtained from or based on historical records. The SEM's mesh has over 52,000 elements and an average cell size of 0.7 square miles. This mesh conforms to most of the significant highways, levees and canals within the SEM model domain. The key highways within the model domain, such as Alligator Alley, the Tamiami Trail, SR-9336, and the Loop Road, have approximately 500 bridges and culverts. The SEM will simulate the flow across most of these structures, as well. The SEM will use stage data from 1988 to 1995 for model calibration and stage and flow data from 1996 to 2000 for model validation. The calibration and validation of the SEM is currently scheduled for completion in December 2002.

SEAGRASS MODELING

Since 1987, several large and small fluctuations in the areal extent and condition of the *Thalassia testudinum* community have occurred in Florida Bay. An intensive research effort is underway by state, federal and private institutions to determine the causes and mechanisms for the loss of the seagrass community. As Everglades and Florida Bay restoration efforts proceed, it is imperative to understand how the plant community responds to changes in salinity, nutrient inputs, temperature and other environmental variables.

A dynamic simulation model is currently under development at the South Florida Water Management District as a means of synthesizing research and monitoring results to predict the response of the submersed vascular plant assemblage in Florida Bay (*T. testudinum*, *Halodule wrightii*, *Ruppia maritima*) to eutrophication and water quality changes. The objectives are to understand mechanisms responsible for seagrass decline at the organismal level and extrapolate this information to a unit level (basin scale), and then a landscape level (estuary scale). The model will be used to evaluate conditions required for plant survival and community restoration, particularly with respect to freshwater inputs from the Everglades. Among other things, seagrass responses to variations in magnitude, timing and variability of freshwater inputs, as planned in restoration and to be stipulated by the Florida Bay minimum flows and levels rulemaking process, will be projected.

State variables in the model are (**Figure 6-26**): seagrass aboveground material (leaves, leaf sheaths, flowers), seagrass belowground material (roots, rhizomes), a generalized phytoplankton community, epiphytes, detrital material, sediment porewater phosphorus, sediment phosphorus in geochemically sequestered form (apatite), and particulate phosphorus in the detrital pool. Nitrogen biogeochemistry is currently being added to the model. Forcing functions in the model include: water temperature, salinity, organic material, phosphorus and water inputs from the Everglades, and light (PAR). Sediment porewater sulfide is a metavariable whose concentration is calculated based on the modeled concentration of organic matter in the sediments. It is also dependent on the rate of decomposition of organic matter as determined by temperature. The variable hydrogen sulfide is important to the outcome of the model calculations because, above a certain threshold, sulfide is toxic to seagrasses.

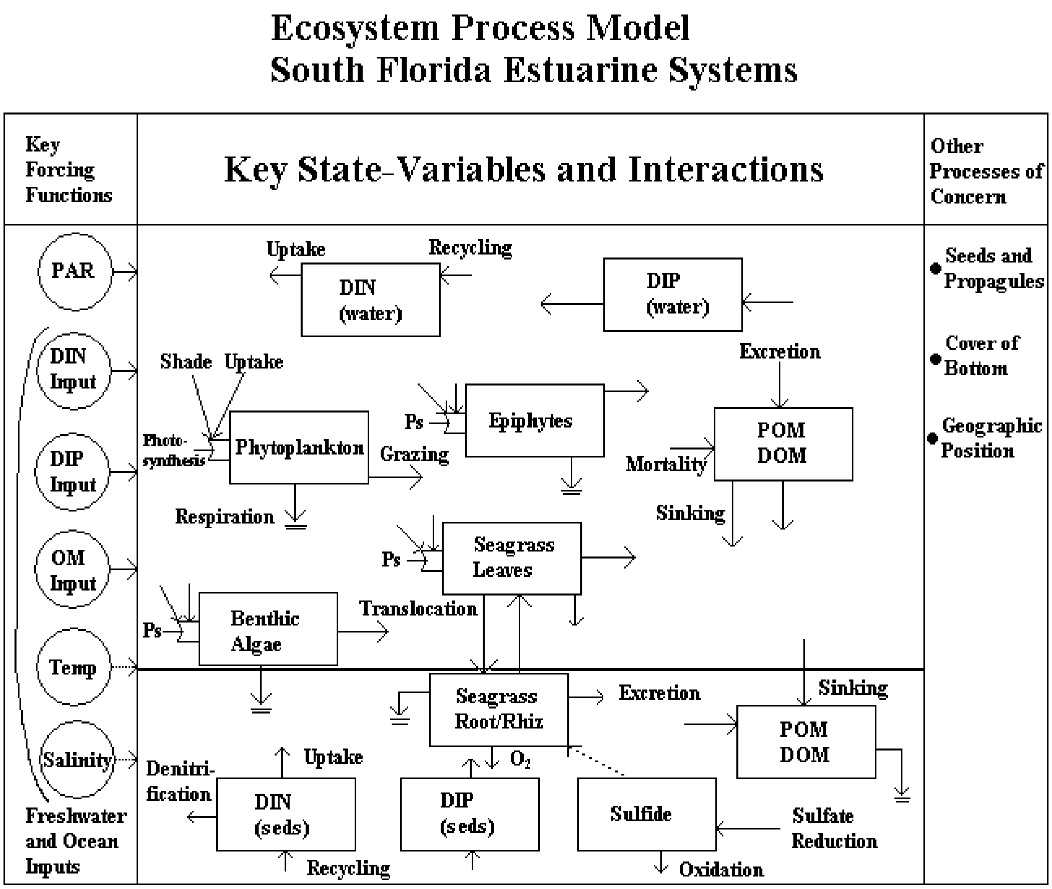

Figure 6-26. The basic design of the Seagrass Unit Model, currently under development for Florida Bay, showing state variables and forcing functions

The model operates in the currency of carbon units, and calculates daily biomass pools and biogeochemical rate processes over an annual cycle with a time step (dt) of 3 hours. The nitrogen and phosphorus content of each plant compartment is calculated via a fixed stoichiometric relationship between carbon, nitrogen and phosphorus unique to each plant type.

Using the model, simulations were performed to investigate the influence of different stresses common to plants in Florida Bay on the performance of *T. testudinum* (**Figure 6-27**): high salinity, high sulfide concentrations and elevated nutrient levels. Although all stresses produced changes in the annual cycle of plant production, elevations in nutrients and salinity merely shifted the period of maximum biomass to later in the growing season without significantly reducing peak productivity. Elevations in sediment sulfide, however, caused a steep decline in both plant biomass and productivity, resulting in a loss of over half the annual productivity and peak standing crop.

It should be noted that in the case of salinity and sulfide, stresses applied in the model scenarios were within the upper ranges currently observed in Florida Bay for these parameters. The level of nutrient "stress" (inorganic N and P) applied in the model, a quintupling of baseline observed levels, has not been observed in Florida Bay. However, given the low concentrations of each of these nutrients currently measured, an increase by a factor of five is not very extreme and still places the modeled concentrations of these nutrients well below the levels commonly observed in many estuaries and within the range that could occur under certain conditions in the bay.

In addition to individual stress scenarios, the model was also used to test the effects of simultaneous multiple stressors as more realistically occur *in situ*. For these runs, stresses were applied in combination at the levels at which they had been applied individually (**Figure 6-28**). Interestingly, whereas individually neither salinity nor nutrient increases caused much response in the *Thalassia* growth profile, together these stresses caused a strong reduction in spring initial growth rate and the spring-summer biomass level. The model community recovered to "normal" peak biomass levels by fall, but overall, annual production was reduced by half in response to elevated nutrients and salinity.

Application of a multiple-stress condition involving elevated nutrients, salinity and elevated sulfide concentrations produced more dramatic results in the *Thalassia* growth profile. Biomass declined continuously from the point of stress application in January throughout the growing season, as *Thalassia* rapidly died off. Examination of processes underlying this model behavior revealed that photosynthesis, though operational, was impaired and functioning at such a low level that the net daily production was negative throughout the growing season. Interaction of the aboveground and belowground compartments plays a strong role in the trajectory of the seasonal biomass curve in the model. Exchanges of organic carbon and nutrients between leaf and root compartments are seasonally variable and are critical for survival of submersed plants. The modeled plants can mobilize belowground resources to supplement carbon input to the aboveground compartment should autotrophic assimilation become deficient. The amount of carbon available for growth supplementation in the root/rhizome material can control the outcome of plants subjected to stress conditions. Therefore, the status of the belowground compartment can determine the survival of the entire plant. Conversely, when conditions are unfavorable to growth and belowground resources are depleted, the existence of aboveground plant material can mask a plant community in fragile condition. It is believed that this model conceptualization is realistic and is likely close to the physiological and community behavior that occurs in the real system, emphasizing the importance of thresholds and non-linear behaviors, which can be tracked and revealed by model analysis.

The model is being used as a research tool to interpret ecological relationships. Eventually it will be used by the South Florida Water Management District as an evaluation tool for operational and restoration alternatives. The final phase of development of this model will culminate in the linking of numerous versions of the unit model into a landscape level model capable of horizontal transfer of materials and energy among cells based on hydrological forcing and concentration gradients. In this configuration, each spatial cell will contain a fully calibrated unit model serving as a resident kernel, while environmental variables and forcing functions operating on this kernel will vary depending on the location of the cell.

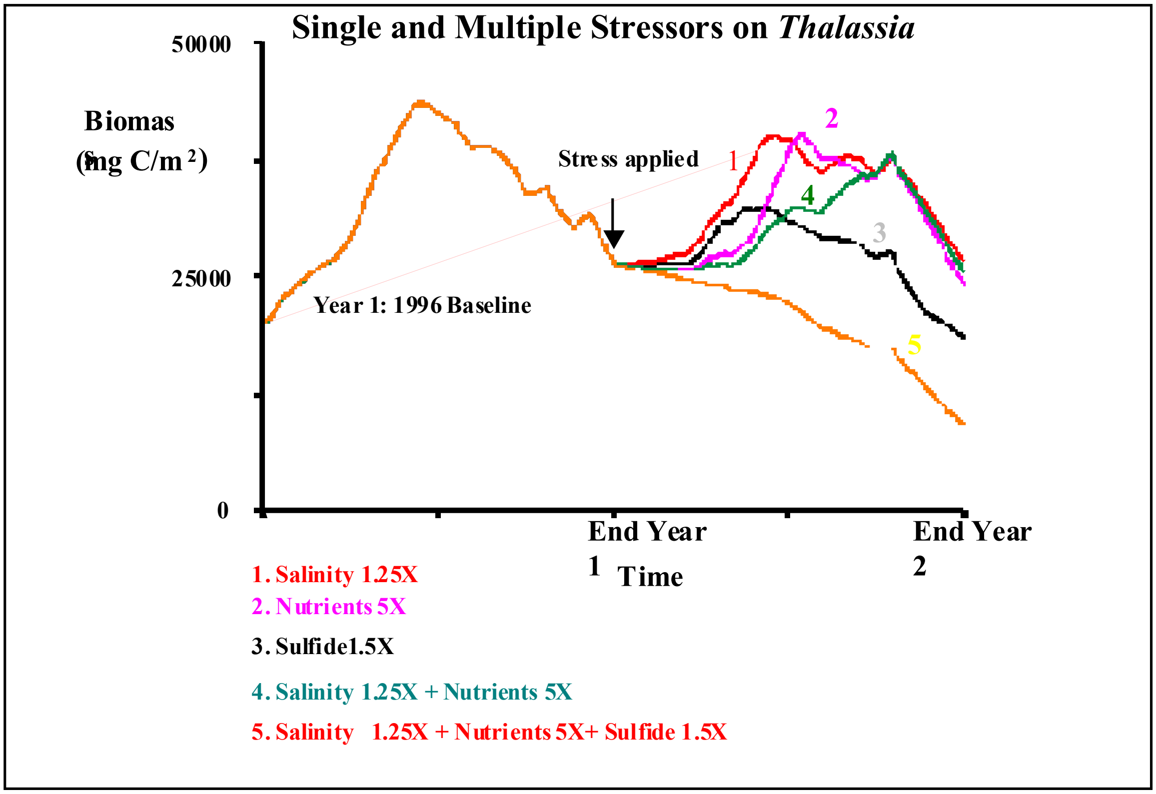

Figure 6-27. Thalassia biomass response to stresses applied in year 2 to the Rankin Lake sub-population using the Seagrass Unit Model

HABITAT SUITABILITY INDICES

Hydrological restoration is considered the key to Everglades restoration. Water, in the right place at the right time, in the right quantity and quality, and with the right water depth, hydroperiod, and flow rate, is considered a major determinant of the ecosystem that supports life in the Everglades. Both the problems of declining ecosystem health and the solutions to Everglades restoration are framed by these interrelated hydrologic factors. Significantly less water flows through the Everglades ecosystem today compared to a half century ago. For example, according to the NSM, an average of about 1.7 billion gallons of water that once flowed through the ecosystem each year are currently discharged to the ocean or Gulf of Mexico.

Obviously, "getting the water right" is a surrogate for "getting the ecosystem right." Unfortunately, this may not be true or easy because:

- Other factors, such as fire, interact with hydrology, vegetation and soils, affecting the general health of the ecosystem

- The “right water” may have a significant time lag before it can have an affect on the “right ecosystem”
- It is difficult for scientists and managers to determine what is “right”

Considerable effort has been spent conducting field research, discussing conceptual models, and developing ecological models (Fitz et al. 1996; DeAngelis et al. 1998; Sklar et al. 2001; Wu et al. 2002) to define the linkages between water and ecosystem structure and function for specific regions within the Everglades (Ogden and Davis 1999). Habitat Suitability Indices (HSIs) have grown out of this effort.

Habitat Suitability Index models are being developed by District, state and federal scientists to estimate and rank the relative impacts of alternative hydrologic regimes on various species, habitats and landscape features in the Everglades. HSIs have been in use since the early 1980s to define, in relative terms, the quality of the habitat for various fish and other wildlife species (Bain and Bain, 1982). The U.S. Fish and Wildlife Service developed a series of HSIs to be used with habitat-based evaluation techniques, such as the Habitat Evaluation Procedures (HEP) and the Instream Flow Incremental Methodology (IFIM). These techniques are designed for inventory, impact assessment, and the development of fish and wildlife management plans (See www.nwrc.gov/wdb/pub/hsi/hsiintro.htm). Habitat Suitability Indices (U.S. Fish and Wildlife Service, 1981) were used as a first approximation toward quantifying the relationships identified in the various ecological conceptual models.

The first step in creating these indices for the Everglades was to select a number of important indicator species and landscape features for specific regions. Six Habitat Suitability Indices (HSIs) were identified by a multi-agency interdisciplinary team (coordinated by Pete Loucks, Steve Davis, Don DeAngelis, Fred Sklar, and Ken Tarboton) for development:

- Periphyton (coordinated by Joan Browder, Dan Childers, Sue Newman, Linda Blum, Evelyn Gaiser and Rebecca Sharitz);
- Ridge and Slough (coordinated by Christopher McVoy);
- Tree Islands (coordinated by Lorraine Heisler, Yegang Wu, Tim Towles and Michelle Irizarry);
- Alligators (coordinated by Kenneth G. Rice, Frank J. Mazzotti, and Laura A. Brandt);
- Wading Birds (coordinated by Dale Gawlik and Gaea Crozier);
- Fish (coordinated by Joel Trexler and Bill Loftus).

The second step was to identify the hydrological attributes of each HSI in a series of workshops attended by population and ecosystem experts. Hydrological functions and attributes included water quantity, quality, timing, hydroperiod, flow rate and distribution. The establishment of these functions was based on field research (fish and wading birds), historical references (ridge and slough), and models (periphyton, tree islands and alligators). Thirdly, these hydrological functions were designed to range from 0 (death or destruction) to 1 (optimum condition). Like all models, HSIs have limitations. For example:

- HSIs cannot provide an overall and integrated evaluation of ecosystem health because “optimum condition” for a single HSI may not be good for the system or even for another HSI

- HSIs tend to simplify ecological responses. If there is a high degree of uncertainty, this simplification can be misleading

The goal of HSI development is to create simple indices that evaluate ecological responses to hydrologic stresses and water management alternatives. Once defined, these HSIs can be used to estimate the relative suitability of a habitat for each indicator species in each region of the Everglades associated with any specific simulated water management policy. The development of HSIs will not displace the use and development of process-based, ecological models, such as the Everglades Landscape Model (ELM). A detailed description of the six indices and their components currently being considered as tools to evaluate CERP restoration plans can be found in **Appendix 6-1**. All six indices are works in progress.

COMMUNICATING MODEL UNCERTAINTY

The CERP is highly dependent on the results of dynamic regional hydrologic and ecologic simulation models. Even though these models and those that may eventually replace them are, and will continue to be, relatively complex and sophisticated, like all such models they only crudely approximate what takes place in the Everglades. Their predictive abilities, even in a statistical sense, are not and will never be perfect. Thus, there is uncertainty in the predictions derived from these models. This uncertainty should be considered when evaluating model results.

To identify the types of uncertainty analyses that might be most appropriate, a multi-agency workshop was held on model uncertainty analysis at the South Florida Water Management District in West Palm Beach January 15 through 17, 2002. In general, the workshop's goal was to provide guidelines on how to deal with uncertainty to those responsible for evaluating model alternatives. A summary of the major findings of the workshop is included below.

Uncertainty in models that predict impacts over time and space resides largely within four components of model structure (Sklar and Hunsaker 2001). These components are the inputs, the spatial and temporal interpolation of point data, the initial and boundary conditions, and the calibration and verification procedures.

In the short term, it is important to have some way to derive estimates of the probability distributions of uncertain output variables in a practical and transparent way. Short-term steps involve:

- Selecting the significant independent input variables (including model parameters) that contribute most significantly to the final model prediction
- Constructing probability density functions for each parameter to reflect the likelihood that the selected variable will take on various values within its possible range
- Propagating the uncertainties through the model to generate probability density distributions of predicted output values and subsequently of the hydrologic attributes that impact important ecosystem indicators and features
- Deriving, if desired, confidence limits associated with the functions that convert hydrological attributes to indices indicating the relative suitability of conditions for the ecosystem indicators or features
- Using these confidence intervals plus the derived probability distributions of the hydrological attributes to make quantitative statements about the probabilities

(and the confidence in these probabilities) of meeting selected suitability index levels for each index

In the long run, it is imperative that the focus of uncertainty analysis shifts to address major uncertainties that have traditionally not received as much attention as those for model parameterization. These relate to model structure under changing conditions, climate and landscape. It is likely that it will not be possible to develop uncertainty analysis of the traditional sort, that is, quantification of probability distributions of state variables, in a meaningful way.

The use of the models for making long-term planning decisions must first begin with the recognition that for most decision problems, it will not be possible to directly quantify the uncertainty in performance measures or indicators. Thus, belief structures may be necessary to guide scenario analysis and development. The formalism of Bayesian networks could be used to combine formal information on probabilities of model-estimated outcomes with beliefs as to climate or potential landscape changes.

The following procedures are recommended when a determination of statistically different model outcomes on a performance measure must be made between two management scenarios:

- Decide upon the smallest level of practical significance in model outcomes. If results from alternative management scenarios are less than this, ignore the question of statistical significance for this performance measure and choose between the alternatives based on other performance measures or cost.
- If generalized confidence bands are available for the model outcomes from uncertainty analyses, a conservative test for significant differences may be made by visual inspection of whether the confidence bands of each alternative overlap the mean of the other alternative.
- If possible, perform a Monte Carlo uncertainty analysis for both management alternatives. Pair the results for both alternatives based on identical model parameter and input values.

The following computation techniques can be used in uncertainty analyses for CERP modeling projects:

- **Analytical Solution**: When there are few stochastic input parameters, and when the model is not too complicated, one can sometimes obtain an analytic form for the output statistical distribution. With a hydrologic system as complex as the Everglades where the transport of water and contaminants is over a large surface area constantly interacting with the groundwater aquifer, this approach becomes infeasible.
- **First-Order Analyses**: As outlined in Loucks and Stedinger (1994) and as implemented for some of the water management models used by SFWMD by Trimble (1995) and Lal (1995), this method is a way to obtain the variances of the parameter values in a model in order to obtain an estimate of the relative contribution of each parameter to the uncertainty in the model outputs. This approach is best suited to situations when the computed outputs respond linearly to parameter changes and the correlations among parameters is small.
- **Stochastic Numerical Models**: Developing and solving stochastic models using numerical methods is another approach to uncertainty analyses. For example stochastic differential equations defining a water quantity, quality or ecological

model can include random parameter values as well as random variables reflecting limitations in model structure. Actual applications of these stochastic numerical models have been for relatively simple systems compared to the Everglades. It is unlikely the development of specialized numerical algorithms to handle the solution of stochastic differential equations instead of deterministic ones in the existing CERP models will be worth the considerable effort. The other disadvantage of this approach is that it is not very transparent to those unfamiliar with such methods.

- **Monte Carlo with Random Sampling**: This approach assumes that some of the model input variables and model parameters are random. Distributions of these input variables and parameters are defined using expert judgment and by calibration exercises. Once defined, the actual values of these random variables and parameters are drawn from these distributions for each simulation time step. Many simulations are performed, each using values drawn from these probability distributions, to generate a distribution of output values. After simulating a considerable number of time steps, one has a set of equally likely outputs that define a probability distribution for each selected performance measure. Although conceptually simple, a shortcoming is that a large number of simulations may be required to obtain a satisfactory description of the output distribution. Many parameters and inputs may have correlations. The proper specification of these uncertainty distributions to drive the Monte Carlo process is not easy.
- **Bayesian Monte Carlo (BMC) analysis.** Variants to Monte Carlo analysis have been developed that use Bayesian inference to generate improved estimates of parameter uncertainty by considering the ability of different parameter values to describe observed data (Spear and Hornberger, 1980; Fedra, 1983; Dilks et al, 1992). The approach starts out like traditional Monte Carlo analyses through the specification of statistical distributions for each uncertain model parameter. These distributions are based upon prior knowledge of the variability in each parameter, literature reviews, professional judgment, etc. As with traditional Monte Carlo analyses, numerous iterations are performed with model inputs randomly selected from their pre-specified distributions. The unique aspect of Bayesian Monte Carlo analyses is that the results of each simulation are compared to field observations of model state variables, and "scored" with respect to the ability of a given parameter set to describe the observed data.

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