Chapter 1B: Cross-Cutting Issues in the *2006 South Florida Environmental Report* – Impacts of the 2004 Hurricanes on the South Florida Environment

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INTRODUCTION

In their review of the *2005 South Florida Environmental Report – Volume I* (SFER), the 2005 Panel recommended that "future reports include a new chapter on cross-cutting issues that are system-wide. The subject of this chapter could change from year to year to focus on important problems that affect more than one geographic area or administrative unit of South Florida." Chapter 1B of the 2006 SFER – Volume I responds to this recommendation and focuses on the effects of the unprecedented four hurricanes (Charley, Frances, Jeanne, and Ivan) that hit Florida in August and September 2004 (**Figure 1B-1**). During the 2004 hurricane season, the South Florida region was hit by hurricanes Charley, Frances, and Jeanne and tropical storm Ivan. As detailed in Chapter 5 of this volume, this series of storms was highly unusual and rare. In fact, no combined hydrological event of this type had been recorded since records began in 1871. The 2004 hurricanes produced high wind speeds, heavy rains, high surface water flows, and rapid rises in water levels. Together, the storms drove a cascade of impacts across the northern half of the region beginning in mid-August and lasting in many areas to date.

Throughout this volume, hurricane-related effects are woven into the evaluations of most components of the greater South Florida ecosystem. This chapter will not attempt to repeat these details, but will instead provide an overview of effects in a comparative manner and emphasize impacts at the ecosystem level. Hurricanes always bring physical effects caused by high winds, water movement, water depth, and heavy rains. Such effects were widely observed in 2004 and manifested most often in the loss of vegetation, severe erosion, and suspension of materials in water. Less obvious and longer term chemical changes also have major consequences for South Florida ecosystems. These are most often discussed in terms of water quality dynamics, particularly regarding nutrient and turbidity levels, which have major consequences for ecosystem structure and function. Together, physical and chemical stresses cause major biological changes across the landscape, some with the potential to last for years. As reflected in the following sections, there was a major difference between the 2004 hurricane-related effects in the Everglades Agricultural Area (EAA) and more northern parts of the region. With this backdrop, these sections, organized by region and type of impact, summarize hurricane-related impacts on the South Florida environment.

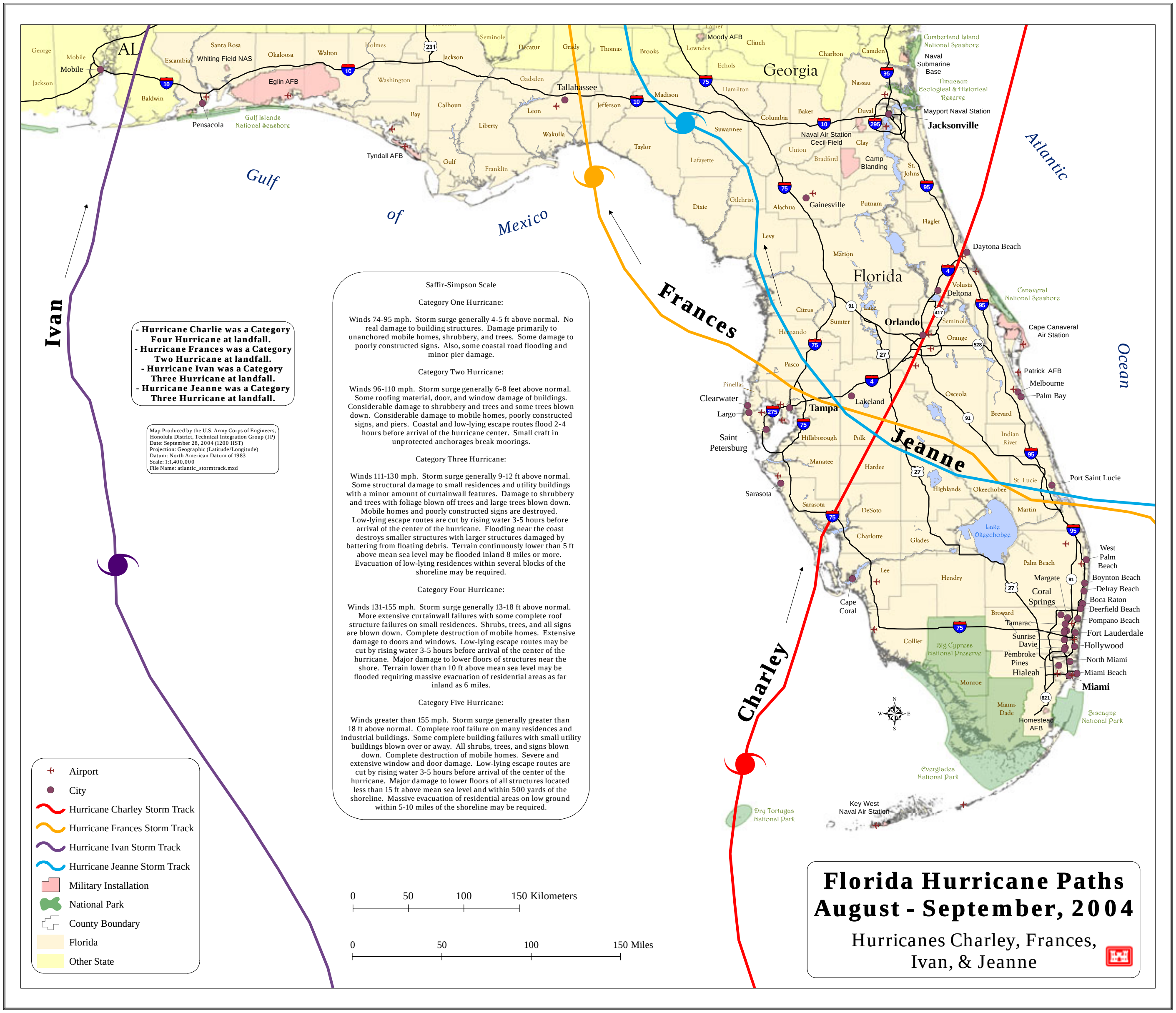

Figure 1B-1. Pathway of the four hurricanes (Charley, Frances, Jeanne, and Ivan) that hit Florida in 2004 (from USACE at http://www.hurricaneseason2004.com/images/maps/All_hurr%20tracks_w_Saffir%20Simpson%20Scale.pdf).

LAKE OKEECHOBEE

As presented in Chapter 10 of this volume, the 2004 hurricane season impacted Lake Okeechobee to a large degree both directly and indirectly. Two storms (Frances and Jeanne) went directly over the lake with sustained winds between 55 and 67 mph and gusts to 80 mph. These two storms produced seiches of up to 10 ft (Chimney, 2005). In addition to hurricanes Frances and Jeanne, Hurricane Charley impacted the Okeechobee watershed directly. Rain bands from Hurricane Ivan also crossed the watershed. The result from these four hurricanes was a total volume of inflows and rainfall to the lake for the three months (August–October 2004) of 3.2 million acre-feet (ac-ft), which is close to an average water year total volume input (3.7 million ac-ft). This large inflow resulted in high loads of phosphorus, with an estimated 792 metric tons (mt) of phosphorus added in these three months. This is 83 percent of the 950 mt of phosphorus received by the lake during the entire WY2005.

The large amount of inflowing water and rainfall changed the lake water level from 12.3 ft National Geodetic Vertical Datum (NGVD) on August 1, 2004 to 18.0 ft NGVD on October 13, 2004, an increase of approximately 2.5 million ac-ft of water. Water quality measured at the long-term monitoring stations (L001–L008) shows that suspended solids and total phosphorus (TP) more than doubled from August to October. A large amount of TP was resuspended into the water column along with the solids. Cold fronts that moved through South Florida from November to April brought winds that resuspended sediments and maintained very turbid, high nutrient conditions.

The seiches, wind-driven waves and currents and the rapid increase in lake stage, resulted in immediate uprooting and damage to much of the lake's submerged and emergent aquatic vegetation In turn, the high suspended solids and resulting low light penetrations that persisted throughout winter 2004–2005 contributed to the severe decline in submerged aquatic vegetation (SAV). Between July 2004 and April 2005, average SAV biomass declined over 30 grams dry weight per square meter (g dry wt m^{-2}) to less than 1.0 g dry wt m^{-2}, probably as a result of direct wind, wave, seiche, and lake stage impacts. This pattern has created a vicious circle with turbidity limiting the regrowth of SAV and the absence of SAV allowing sediments to be easily resuspended, creating turbid conditions and hampering recovery. Management actions were taken to lower the lake level and break this cycle.

The 2004 hurricanes had cascading effects on Lake Okeechobee and its large watershed. Winds from these hurricanes knocked down trees, damaged or destroyed hundreds of houses, damaged roofs and small buildings, and created long periods of power outages. Rainfall produced flood conditions in many areas, causing erosion around levees and canal structures as well as a few breaches in canals. Flooding of agricultural pastures also caused debris problems in secondary tributaries throughout the watershed. The high lake stages and large inflows prompted huge discharges to downstream areas, particularly the St. Lucie and Caloosahatchee estuaries to the east and west. These discharges not only acted as a stressor by delivering large amounts of fresh water to these estuarine systems, but also by transporting a suite of waterborne constituents (especially nitrogen, phosphorus, and suspended sediments) at very high concentrations. Discharges south from the lake also created serious problems by overloading the Stormwater Treatment Areas (STAs) and transporting large amounts of nutrients and other substances borne by turbid water into the Everglades Agricultural Area and Everglades Protection Area.

In the aftermath of the 2004 hurricane season, the southern part of the lake has some clarity, with low clarity in the north and west sections. Widespread surface algal blooms, particularly blue-green algae (Microcystis), have been reported from a variety of locations around the lake. The lake remains in this condition to date. The South Florida Water Management District (District or SFWMD) is continuing to work in close partnership with many other agencies to manage the lake and take whatever actions are possible to improve its condition. Our key partners in this effort are the U.S. Army Corps of Engineers (USACE), Florida Department of Environmental Protection (FDEP), Florida Fish and Wildlife Conservation Commission (FWC), and Florida Department of Agriculture and Consumer Service (FDACS).

KISSIMMEE BASIN

The 2004 hurricanes left the Kissimmee Basin with near record high water levels and flows and associated physical effects (see Chapter 11 of this volume). Of the four hurricanes that hit the state of Florida during 2004, three – Charley, Frances, and Jeanne – passed directly over the Kissimmee Basin. During August 2004, the total rainfall of 12.7 inches in the Upper Basin and 9.6 inches in the Lower Basin exceeded the 20-year and 10-year wet return periods (Ali and Abtew 1999), respectively. During September 2004, the total rainfall in of 17.4 inches in the Upper Basin and 11.8 inches for the Lower Basin both exceeded the 100-year wet return period (Ali and Abtew 1999). Almost a third of this rain was associated with the three hurricanes. As a result, discharges from S-65E from the Kissimmee River into Lake Okeechobee during WY2005 peaked near 35,000 cubic feet per second (cfs) and were the highest since 1972.

One result of the high rainfall during August and September 2004 was that stage for all lakes in the Upper Basin was above the high point of the stage regulation. To lower lake stages back to the regulation schedule, maximum practicable releases were made throughout the system. Discharges in the Kissimmee River peaked near 10,000 cfs (note the discharge estimates at S-65 are being revised upward based on stream gauging made during this event) and were among the highest on record.

In addition to rainfall, the effects of the 2004 hurricanes on the Kissimmee Basin also had damaging winds as the storms passed over the basin. For example, Hurricane Jeanne hit the Upper Basin with 75–80 miles per hour (mph) sustained winds and the Lower Basin experienced 65–75 mph. Each of the storms passing over the Upper Basin caused a seiche in Lake Kissimmee. Hurricane Charley produced a difference of six feet between stage stations on opposite sides of the lake. This seiche gradually dampened until Hurricane Frances passed over the basin and created another displacement of water. The large displacements of water, although of short duration, have the potential to move material within the lakes. A graphic example of this effect involved ripping hydrilla (*Hydrilla verticillata*) stems and rolling them into large balls that were left on the shoreline. The winds also suspended sediments in the lakes of the Upper Basin.

The combined effects of the 2004 hurricanes also lead to major changes in dissolved oxygen (DO) in the Kissimmee River. DO concentrations in the river channel were monitored, along with discharge and stage, in an attempt to understand how water management decisions affect DO concentrations. In response to rainfall from Hurricane Charley and the approach of Hurricane Frances, discharge from Lake Kissimmee through S-65 increased from approximately 300 cfs on August 13, 2004 to > 9,000 cfs on September 12, 2004. DO concentrations in the river channel decreased from > 2 mg/L to < 1 mg/L during this period, with one exception. On August 28, 2004, DO concentrations began a rapid increase and peaked at 6.7 milligrams per liter (mg/L) on September 3, 2004 when hurricane Frances passed over the Kissimmee River. Increased DO concentrations during this period were likely due to higher reaeration rates caused by turbulent mixing from high wind speeds and excessive rainfall. By September 8, 2004, DO concentrations had decreased to < 2 mg/L. A similar phenomenon occurred between September 24 and 29, 2004 when Hurricane Jeanne passed over the area. As stage and discharge decreased, DO concentrations in the river channel gradually increased and remained above 2 mg/L for the remainder of the year. DO data from the 2004 hurricane season shows that low DO concentrations coincided with rapid increases in discharge and stage except during the actual storm events when wind and rain induced reaeration caused rapid increases in DO concentrations.

COASTAL ECOSYSTEMS

Coastal ecosystems were impacted greatly by the 2004 hurricanes. Chapter 12 of this volume provides many examples of the physical, chemical, and biological impacts from the combined effects of the hurricanes on the coastal resources of South Florida. The overwhelming influence of freshwater discharges during September and October 2004 is clearly documented for the St. Lucie Estuary. Representative salinities were generally well below 5 parts per billion (ppb) during September–November 2004, a highly undesirable condition for oysters and seagrasses in this ecosystem. Hurricanes and resulting discharges adversely impacted seagrass beds in the vicinity of the St. Lucie Inlet. Monitoring documented significant seagrass damage including reduction in canopy heights and plant densities, blanketing with mud and sand, and changes in plant community composition. Similar impacts also have been noted in the Loxahatchee River. Ongoing monitoring of seagrasses is providing evidence of recovery at some sites.

Hurricane Charley came ashore near Punta Gorda on the west coast of Florida, impacting the greater Charlotte Harbor estuarine system. While the hurricane was a Category 4 storm, it was compact affecting northern portions of the harbor more severely than to the south. Hurricane Charley cut a 450-meter-wide pass through North Captiva Island, burying adjacent seagrass beds in Pine Island Sound to 130 meters off shore. Visual observations in the Caloosahatchee – San Carlos Bay region of the system indicated that most of the immediate physical damage from the storm was confined to mangrove trees and the very shallow grass beds and oyster beds that fringe the islands upon which they grow.

Additional damage may stem from the large influx of fresh water that followed the storms. For the St. Lucie Estuary, Caloosahatchee River, and Lake Worth Lagoon, releases from Lake Okeechobee prolonged and exacerbated storm related discharge. Excessive freshwater discharge to these systems lowered salinity and water clarity in areas that are normally marine, causing stress and mortality. Although a large amount of data remains to be analyzed, poor water quality was documented at sites in the Loxahatchee River, Caloosahatchee River, and St. Lucie Estuary. In addition, physical damage to marine infrastructure by wind and waves, and impacts caused by sunken vessels were evident in Lake Worth Lagoon; fortunately, most of these impacts appear to be short term.

PHOSPHORUS SOURCE CONTROLS IN THE ECP AND NON-ECP BASINS

In both agricultural and urban settings, Best Management Practices (BMPs) operate by utilizing mechanisms that retain phosphorus in local areas, thereby reducing export. The 2004 hurricanes had varied impacts on performance in the Everglades Construction Project (ECP) and non-Everglades Construction Project (non-ECP) areas being managed under BMP programs that reduce phosphorus export. Performance in the ECP basin is measured through a phosphorus load reduction performance measure tied to rainfall variability and total amount experienced during the year. In the non-ECP basins, performance is evaluated based on load and concentration trends towards achieving and maintaining compliance with state water quality standards.

The ECP basins include the EAA and C-139 basins. In the EAA, the basin-wide average rainfall was in line with long-term averages. However, the August and September 2004 hurricanes brought higher-than-average rainfall to the S-5A sub-basin. This higher-than-normal rainfall contributed to increased runoff and higher TP loads from the S-5A sub-basin. While the EAA basin TP load was higher during WY2005 in comparison to WY2004 (182 mt versus 82 mt, respectively), overall the EAA basin load reduction performance measure was still met. Likewise, the 2004 hurricanes resulted in less than an inch of additional rainfall in the C-139 basin and had minimal effects on basin compliance. In fact, TP load and discharge from the basin were reduced from the prior year by 42 and 20 percent, respectively.

TP loads were not significantly different in the non-ECP basins, with the exception of the Village of Wellington (ACME Improvement District) and the North Springs Improvement District (NSID). These two local drainage districts may have compromised limiting discharges to the EPA in favor of flood protection for their residents due to the unpredictable circumstances surrounding the hurricane events. As a BMP, the NSID changed its operational practices to reduce discharges to the EPA. Between hurricane events, on September 10, 2004, the NSID was required to cease pumping to tide by way of the Hillsboro Canal and as a result discharged approximately 354 ac-ft of water and 8.7 kg TP to Water Conservation Area 2A. Prior to this event, the most recent discharge from NSID to the EPA was in July 2002. Further north in Palm Beach County, the rainfall impacts of the hurricanes were more evident. The Village of Wellington's discharge quantity for WY2005 exceeded the combined volume for the two previous years. In September 2004, the two pump stations ran 24 hours per day for almost half the days of the month. TP concentrations from this basin appear to have also been adversely affected by the high tropical storm activity. The WY2005 flow weighted mean concentration for the basin's discharge was the highest since the Everglades Stormwater Program monitoring began in WY1998. It is difficult to quantify the effect of the highly active hurricane season on water quality in this basin and TP loads to the EPA due to the number of variables involved and the relatively short period of the data record. However, it is clear that the TP concentration was elevated during September and October 2004 as evidenced by flow-weighted mean concentrations of 153 ppb and 258 ppb at ACME1 and ACME2, respectively, compared to 69 ppb and 92 ppb for the remaining 10 months of the water year. Overall, WY2005 TP loads from the Village of Wellington did not follow what appeared to be a long-term downward trend in concentrations and loads, especially when anticipating that increased BMP implementation would further improve water quality in this basin.

STORMWATER TREATMENT AREAS

The strong winds and heavy rain from both hurricanes impacted Stormwater Treatment Areas 1 East, 1 West, and 2 (STA-1E, STA-1W, and STA-2) significantly. STA-1E and STA-1W were severely impacted and STA-2 was moderately impacted by hurricanes Frances and Jeanne, as highlighted in Chapter 4 of this volume. Hurricane Frances caused emergency conditions affecting public health that necessitated an Emergency Authorization and Order to operate STA-1E. STA-1E had erosion damage on the interior levees in Cells 4N, 4S, and 6. Major physical damage was done to STA-1W as a result of the hurricanes. Severe erosion occurred at multiple locations on levees, culverts, and the limerock berm and was especially severe in Cells 5A and 5B. Extensive damage and uprooting was also done to the SAV community in STA-1W, and there was some movement of the floating cattail tussocks. The water within this STA was highly turbid. During Hurricane Francis, some SAV in STA-2 (mostly hydrilla) was piled onto the northern levee banks of Cells 2 and 3 along with some of the cattails, and damage was also done to the northeastern levee of Cell 3. Strong winds and heavy rainfall also impacted STA-3/4, STA-5, and STA-6, although no damage was observed in these resilient wetlands.

EVERGLADES PROTECTION AREA

The remnant Everglades south of the EAA was not as heavily impacted as more northern parts of the region. Both the rains and winds associated with the hurricanes were far les severe in these southern areas. As detailed in Chapter 5 of this volume, the Water Conservation Areas did receive substantial surface water inflows in the period during and immediately following the 2004 hurricanes. WY2005 showed a unique hydrologic pattern in that lower-than-average rainfall was generally associated with higher-than-average water depths in the Everglades. This pattern appears to have been created by a dry season that lasted about two months longer than normal and limited the annual rainfall inputs. This pattern of rainfall was combined with regional inputs from the hurricanes that filled all District basins and forced them to be held at high stages due to a lack of conveyance capacity.

However, the Everglades marshes showed little change in water quality or ecosystem health following the 2004 hurricanes (see Chapter 6 of this volume). Even with the 2004 storms, remnant Everglades marshes displayed water quality very similar to previous years and with few exceptions, water quality in the EPA was in compliance with existing state water quality criteria during WY2005 (see Chapters 2A and 2C of this volume). These marshes responded to climatic extremes of hurricane rain and wind, and periods of little or no rainfall resulting in marsh dry out. During May and June 2004 and again in February and March 2005, low water conditions were associated with higher phosphorus and nitrogen levels at many sites in the EPA. Conversely, marshes tended to return to more normal nutrient levels during periods when hydrologic conditions were more typical and wetter. Data on water quality and ecology suggest that Everglades marshes did not suffer any lasting effects due to the climatic variation seen in WY2005.

INVASIVE EXOTIC SPECIES

As highlighted in Chapter 9 of this volume, invasion by exotic plants and animals is almost impossible to tie directly to a single meteorological event, such as a hurricane, given the uncertainties in exotic plant invasion biology and post-storm effects. However, hurricanes are known to impact native plant communities and exotic invasion dynamics by creating massive physical disturbance over large areas of native vegetation (Armentano et al., 1995). Such widespread physical impacts were observed throughout the South Florida region, particularly Lake Okeechobee and the Kissimmee Basin, as a result of the 2004 hurricanes.

Following the 2004 hurricanes, many trees toppled and blocked access to various areas across South Florida. For example, following Hurricane Charley, Australian pines (*Casuarina equisetifolia*) obstructed access to Sanibel and Captiva islands for post-storm relief. These tall trees also snapped powerlines and were responsible for extensive structural damage (Ferriter et al., 2005). In light of the problems encountered as the result of the hurricane, local agencies are now embracing the effort to control Australian pine on these coastal islands and much-needed Federal Emergency Management Agency funding is making broad-scale control of this species possible.

Hydrilla continues to be a priority nonindigenous aquatic plant species in Lake Okeechobee as well as the lakes of the Kissimmee Basin. Both waves and wind from hurricanes over the past decade, including the 2004 hurricanes, have kept hydrilla populations in Lake Okeechobee relatively low. As a result of management efforts and effects of the 2004 hurricanes, including uprooting by winds and persistent turbidity that limits regrowth, hydrilla infestations in the Kissimmee Chain of Lakes are also at the lowest levels in the last four years. Established beds of hydrilla are presently localized on the reflooded portion of the Kissimmee River floodplain and are being monitored to evaluate if potential treatments are warranted. The exponential growth rate of hydrilla also will require monitoring, as new water regulation schedules could allow for this invasive species to be a major concern in the future.

Old World climbing fern (*Lygodium microphyllum*) is the primary nonindigenous plant species of concern in riparian and upland habitats in the Kissimmee valley and many other areas in South Florida. Control efforts on the Kissimmee River floodplain have involved aerial and ground treatments of *Lygodium*, which have been successful in reducing cover density of this invasive exotic species on a localized scale. The thinning of tree and shrub canopy by the 2004 hurricanes has increased the visibility of *Lygodium* cover during aerial surveys and will facilitate more thorough treatments of this species' distributions in the Kissimmee Basin.

Overall, invasion biology and post-storm conditions make understanding post-storm-related invasion events complex and difficult. To date, no research studies have been established to develop an understanding of the effects of major storms on the invasion rate or potential of invasive exotic plant and animal species. Until such studies are designed and implemented, the relationships to disturbance and invasion of exotic species throughout South Florida's habitats will continue to be primarily speculation.

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