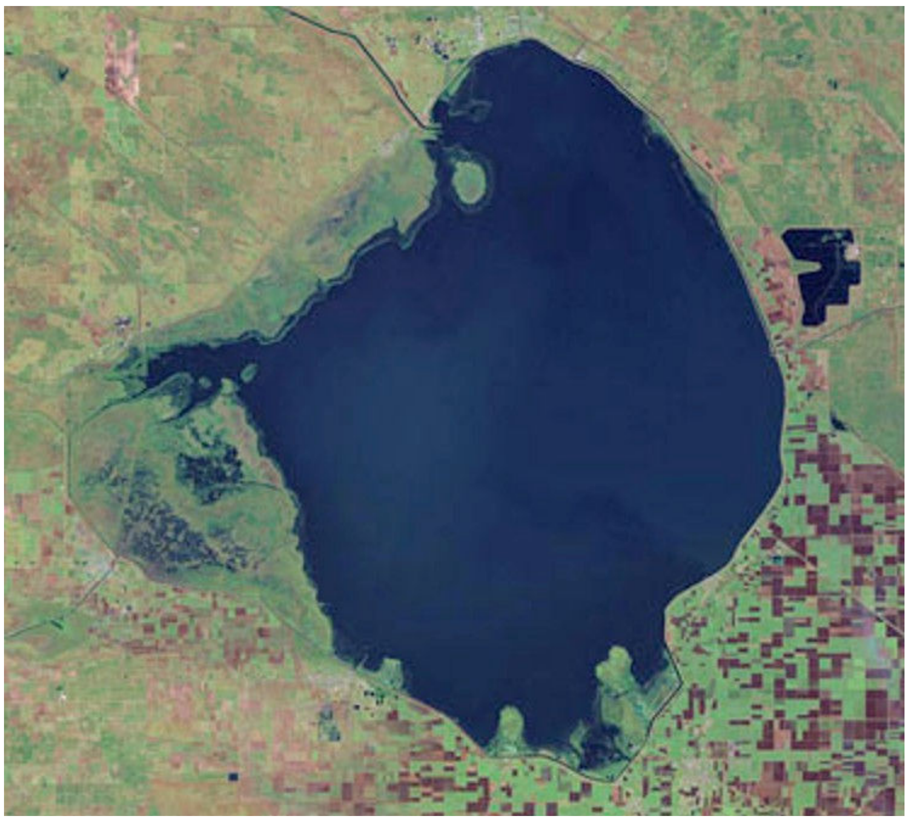
LAKE OKEECHOBEE:

A Synthesis of Information and Recommendations for its Restoration



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Cover Photo: Satellite Image of Lake Okeechobee
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To create an environmental ethic in all our citizens and to conserve and restore natural ecosystems, focusing on birds and other wildlife for the benefit of humanity and the earth's biological diversity.

Our special thanks to

The Batchelor Foundation

and

The Everglades Foundation

for their generous support of this important project

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SYNOPSIS

Amidst all the complexity and confusion surrounding Lake Okeechobee's problems, there are three fundamental goals that must be achieved to put the lake on the path towards restoration.

1) ***Manage water levels for the ecological health of the lake's 100,000 acres of wetland habitats.***
2) ***Achieve nutrient levels in the lake and its watershed that support the health of the lake and the downstream Everglades ecosystem.***
3) ***Minimize or eliminate populations of invasive exotic species within the lake.***

Ideally, Lake Okeechobee should never rise above 15.5 feet and should drop to about 12 feet most dry seasons. Until alternative water storage and water supply projects are completed, water supply concerns will most likely preclude Lake Okeechobee from being managed to reach 12 feet each year. In the interim, management should strive to reach approximately 13 feet at the end of most dry seasons since this level results in minimal risk to water supply. Such a dry-season level would benefit the lake and help protect the estuaries from massive summer releases.

Nutrient levels may take some time to correct fully, but there is much that can be done now to prevent the problem from worsening. The most important action that can be taken is to stop the importation of additional phosphorus into the watershed. At the same time that Comprehensive Everglades Restoration Plan (CERP) and the Lake Okeechobee Protection Plan (LOPP) are being designed to reduce phosphorus inflows to Lake Okeechobee by about 400 tons per year, at a cost nearing a billion dollars or more, an additional 5000 tons of phosphorus are imported to the watershed each year. The benefits from restoration programs will not be sustainable with continued nutrient-loading of the watershed.

There are several invasive exotic species within the lake that are major concerns. An integrated strategy of physical and chemical management along with the development of biological controls is necessary to minimize the extent and impact of invasive exotic species. Significant progress has been made on several species, including melaleuca, but a comprehensive program is required to maintain populations at low levels and prevent new species from becoming widespread problems. Torpedo grass is the largest single management concern today, forming thick stands over thousands of acres of wetland habitat. Techniques have been developed to control it, funding is needed to complete that control.

A long-term combination of aggressive and wide-ranging programs is necessary to achieve the restoration of Lake Okeechobee. Restoring Lake Okeechobee is a necessary component of restoration and protection for the estuaries and the greater Everglades ecosystem. Current state and federal programs, including the CERP and the LOPP, are important components of these efforts. Additionally, the Governor recently announced a suite of strategies that is renewing and strengthening efforts to restore the lake. Though it is a daunting task, growing public support and additional government commitments are bringing the dream of a restored Lake Okeechobee closer to reality.

EXECUTIVE SUMMARY

Lake Okeechobee is Florida's premier lake. It is the largest lake in the southeastern United States, an incredible 730 square miles with more than 100,000 acres of wetland habitats. The lake is located in the center of the Everglades ecosystem, a critical link between lakes and rivers to the north and wetlands and bays to the south. The environmental health of the lake has been degraded from decades of management that has placed the wants of some humans above the needs of wildlife and the environment. Drainage and development in South Florida have not only harmed natural environments, but have also wreaked havoc on a lake that could generate tourism revenue in perpetuity, and made clean water a scarce commodity.

The long-term fate of Lake Okeechobee may be sealed within the next few years as options for meaningful restoration are either planned and implemented, or permanently foreclosed by ongoing development and pollution within the region. The problems caused by the competing demands placed on the lake cannot be corrected through improved management protocols alone. Additional infrastructure is required to store floodwaters, clean up pollution, and supply water to cities, agriculture, and the environment. The demands of society must be moved away from the lake and towards solutions designed specifically to meet those demands; only then can the lake's health be restored and its role in a healthy Everglades ecosystem be reestablished.

The History of Lake Okeechobee

In its pristine condition, Lake Okeechobee was deeper and larger than it is today. Water levels in the lake commonly reached 18 to 21 ft above mean sea level. The area surrounding Lake Okeechobee was a mosaic of habitats including cypress forests, sawgrass prairies, expansive marshes, and custard apple swamps. To the north were dry prairie and pine flatwood uplands, to the south, wetlands of the Everglades. Lake Okeechobee was a part of a diverse landscape that supported Florida's phenomenal array of wildlife, including the millions of wading birds in South Florida during the late 1800s.

The lake's water levels were forever lowered by a series of major drainage projects started in the 1880s that reduced the lake's average high level from around 20 feet to a current average in the 16 to 18 foot range. Habitats were cleared for agriculture and cities and a simple muck dike was built along the southern rim of the lake. Many people died during major hurricanes in the 1920s when the muck dike failed. Widespread flooding in the 1940s caused further human suffering. These catastrophes spurred numerous large-scale water management projects that facilitated human settlement, but had severe impacts to the greater Everglades ecosystem. Water management projects included the construction of the Hoover Dike around Lake Okeechobee, the channelization of the Kissimmee River, and the dredging of numerous drainage canals as part of the Central and Southern Florida Project for Flood Control and Other Purposes. This infrastructure, in turn, significantly drained areas north and south of the lake by diverting the lake's beneficial outflows to the Everglades to the St. Lucie and Caloosahatchee Estuaries, where they have caused considerable harm.

The water management projects greatly changed Lake Okeechobee itself. The Hoover Dike reduced the lake to a fraction of its original size. A new marsh zone formed inside the boundaries

of the Hoover Dike though it was much smaller and less diverse than the original wetland habitats bordering the lake. Water quality in the lake started changing rapidly during the 1950s and 1960s. Nutrient levels in the lake have continually increased creating a eutrophic (nutrient rich) system that is now nitrogen limited rather than phosphorus limited. Numerous exotic species established themselves within the marsh zone, including 21 plant species that are classified as Category I invasive exotics (species known to alter native plant communities) by the Florida Exotic Pest Plant Council. Each of these changes has negatively impacted the wildlife that depend on the health of Lake Okeechobee and the Everglades ecosystem.

Issues with Water Level Management on Lake Okeechobee

Before the system of dikes, ditches, and levees was constructed in South Florida, Lake Okeechobee was the wellspring of the Everglades. With no east or west estuary connections, the lake's water flowed over and through the muck soils on its south end, sending a never-ending supply of water southward. The estimated 866,000 acre-feet of water that flowed southward from Lake Okeechobee in an average year has been reduced to approximately 664,000 acre-feet of water. About 65% of this water is taken for human use, mostly agricultural irrigation, and only about 25% (165,000 ac-ft) goes to the Everglades, some one-fifth of the historic flow.

The irony of water management in South Florida is that rainfall provides more water than is needed for environmental and human uses, yet water shortages frequently occur and Everglades habitats are frequently drawn below desirable levels. This situation results from the numerous drainage projects that were implemented without the concomitant development of water storage projects. Now, agriculture and development rely on the drained natural systems of the Everglades to provide their water. The present system's largest deficiency is the frequent need to discharge (i.e., dump and waste) large amounts of freshwater, because the places that formerly held water are now developed and the remaining natural areas cannot store this water in an environmentally sound manner.

Almost all water flowing into and out of the lake is controlled by human decisions to open or close various gates and locks. In an attempt to meet varied, and often conflicting, water requirements, the South Florida Water Management District (SFWMD) and the US Army Corps of Engineers (USACE) jointly operate the lake's water control structures according to a "regulation schedule" that defines target water levels for different times of the year. The goal of the regulation schedule is to achieve water levels in Lake Okeechobee that, in theory, balance the competing needs of water supply, flood protection, and environmental health. In practice, however, this strategy has led to the continued degradation of the lake's plant and animal communities and created three harmful patterns: sustained high water levels, sustained low water levels, and unnatural fluctuations in water levels.

The impact of sustained high water levels

From an ecological standpoint, water levels in Lake Okeechobee are considered high when they go above 15 feet, the level at which the entire marsh is inundated. Marshes require alternate wetting and drying to maintain health, thus sustained water levels in Okeechobee above 15 feet can harm the wetlands and the wildlife that use them. The effects of high water were evident

after years of levels above 15 feet in the late 1990s. An estimated 50,000 acres of submerged and emergent plant communities were lost. Chronic low light and intense wave action prevented reestablishment of these communities. This loss of habitat resulted in numerous impacts to the wildlife that use Lake Okeechobee's marshes. Large-mouth bass and Black Crappie numbers diminished as plant communities disappeared. The numbers of ducks on the lake plummeted to yearly averages in the hundreds rather than in the thousands. Water depth in most of the marsh habitats prohibited effective foraging or breeding by wading birds. Snail Kite nesting was completely eliminated, despite the lake being designated as critical habitat for this endangered species.

High lake levels also harm the estuaries. Lake levels must be prevented from exceeding 18.5 feet because of concerns regarding the structural integrity of the Hoover Dike. This constraint means that as lake levels approach 17 feet, very large freshwater discharges are made to the estuaries. These large releases severely disrupt salinity patterns and harm the estuarine fauna and flora.

The impact of sustained low water levels

Lake Okeechobee is not purposefully managed for sustained low water levels. However, the lake's wetlands experience many ecological problems when the water management system amplifies natural droughts into extended droughts. When water levels fall below 11 feet, approximately 94% of the marsh zone is exposed. Organic soils within the marsh zone oxidize at a rate much faster than that at which they are formed, causing permanent soil loss and changes in topography. Submerged plants dry and perish. Exotic plant species like torpedo grass, melaleuca, hyacinth, and water lettuce expand rapidly, requiring expensive, time consuming chemical and mechanical removal.

There are also many negative impacts on wetland fauna during extended droughts. Bulrush stands become too dry for fish spawning or shelter and small fish suffer heavy mortality from predation in the lake's open waters. Wading birds and other aquatic birds cannot nest because of lack of water in the marsh and under nesting trees. The endangered Snail Kite cannot breed during the drought and may suffer after the drought due to virtual elimination of the population of apple snails. Alligator nesting decreases or ceases altogether during drought. Wetland-dependent organisms including turtles, frogs, marsh rabbits, snakes, crayfish, round-tailed muskrats, and others suffer population declines. The ability of various populations to recover after droughts depends on the length of the drought (the longer the dry period the greater the mortality rate), and is inhibited by the Herbert Hoover Dike which separates the lake's marshes from nearby habitats. Genetic diversity can be diminished in small, isolated populations and can lead to additional problems.

The impact of unnatural water level fluctuations

Wading birds in Florida breed during the dry season. During the dry season, water levels in the Everglades and on Lake Okeechobee gradually decline, concentrating aquatic prey into smaller, shallow areas, where hiding places are reduced and foraging efficiency is greatly increased. South Florida's topography and seasonal rainfall patterns provided these conditions reliably, and were important reasons behind the incredible abundance of wading birds found in the Everglades ecosystem. The increased feeding efficiency realized by wading birds during these natural

drawdowns allowed them to effectively feed their growing young. During the wet season, rising water levels expanded the wetland acres and habitat area that could grow a new "crop" of wading bird food.

Human water management creates many disruptions to natural hydrological patterns on Lake Okeechobee. Water management dampens natural patterns by holding water levels artificially high during the dry season, eliminating natural drawdowns to ensure water supply. Keeping the lake deep far into the dry season can delay the start of breeding long enough that birds do not have time to complete their breeding cycle. Birds that start breeding too late have their effort truncated by rising water levels at the beginning of the wet season, and leave their fledglings to starve. Even in years when the drawdown starts soon enough for the birds, brief rain events in the over-drained watershed can raise the lake abruptly, and can cause abandonment. Conversely, if water levels drop too quickly, prey species may die from exposure or wetlands may dry completely. Historically, natural variations in weather could produce poor conditions for wading birds, but such years were few compared to favorable years. Unfortunately, the lake's altered and unfavorable water pattern is one reason why 90% of the wading birds have disappeared even though approximately 50% of the historic acreage of Everglades wetlands still remain—Okeechobee's marshes are still "there" but often do not function correctly.

Inspecting the life history patterns of plants and animals in Florida reveals that they are not merely adapted to the annual wet and dry cycles of Florida, but like wading birds, many require these cycles to complete their annual cycle. The human pattern of draining water during the wet season, and storing (stacking) water during the dry season, tends to be the opposite of the natural cycle these organisms need.

Efforts to improve water level management

Significant harm to the marsh zone was detected in the 1980s, shortly after the average water level in the lake was raised about 2 feet, keeping the lake above 15 feet almost all the time. The reason to raise it was to increase water storage in the lake, and the result was harm to the lake marshes and frequent harmful discharges to the estuaries. Since then, there has been strong competition between high water level and low water level philosophies. The current regulation schedule, called the Water Supply and Environmental (WSE) schedule, was adopted in 2000 after chronic high-water stress in the 1980s and severe stress in the late 1990s. WSE was an attempt to keep lake levels somewhat lower without impinging upon water supply.

WSE has kept Lake Okeechobee somewhat lower than previous schedules, but still allows the lake to stay harmfully deep (from an ecological perspective) much of the time. During 2004 and 2005, formal deviations from the schedule were adopted by the SFWMD and USACE to allow the lake to be lowered more than WSE calls for. Additionally, an amendment to WSE to create more gradual and persistent releases was added in 2004. In spite of these revisions, WSE still needs improvement and the USACE announced in 2005 that they would begin the process to replace WSE, or at least revise it substantially.

The Comprehensive Everglades Restoration Plan (CERP) identifies ideal Lake Okeechobee water levels as a high of about 15 feet at the end of the summer wet season, and a low of about

12 feet in June, at the end of the spring dry season. If Okeechobee dropped to 12 feet each year with present infrastructure, there would be water shortages during drought years. Thus, until CERP is built, Okeechobee's ideal low levels will not be attained. The most common compromise levels suggested are a low of 13.5 feet and a high of 15.5 feet. While not ideal for lake health, these general guidelines can prevent the most severe harm to the lake while not unduly threatening water supply concerns. A proposal to install "forward pumps" in Lake Okeechobee to enable access to water at very low levels might prove unwise if it could cause harmfully low water conditions.

As noted, until infrastructure is built to store more water in the system, Lake Okeechobee's water level management will remain impaired. CERP projects that will increase regional storage include: EAA reservoir (south of Okeechobee); St. Lucie (east of Okeechobee) reservoir(s); Caloosahatchee Reservoir (west); Lake Okeechobee watershed reservoirs (north); and possibly Aquifer Storage and Recovery wells (termed ASR--the idea is to pump large amounts of water underground during wet periods for later use during dry). Other important storage projects include the Kissimmee River Headwaters Revitalization Project and increased storage as part of Best Management Practices on private lands. As water storage facilities are constructed, drainage can be diverted to the new facilities and away from the lake, thus allowing Lake Okeechobee to function more as a lake and less as a reservoir.

Issues with Water Quality on Lake Okeechobee

Lake Okeechobee originally was a relatively low-nutrient ecosystem as evidenced by a relatively nutrient-poor watershed and early descriptions of the lake's sandy bottom, clear water, and adjacent sawgrass marshes. The lake's water quality started changing rapidly during the 1950s and 1960s. Modern agricultural methods called for draining the land and applying large amounts of chemicals, including fertilizers (primarily phosphorus and nitrogen), sulfur, calcium carbonate, and pesticides. Phosphorus levels that averaged about 40 parts-per-billion (ppb) in the lake in 1970 increased to more than 130 ppb by the 1990s. Most of the phosphorus loads to Lake Okeechobee come from truck and field crops, improved pasture, and dairy operations. Pasture has a relatively low load of phosphorus per acre, but is the largest land use in the watershed, thus its large contribution to the lake. Dairies and row crops, on the other hand, occupy only about 4% of the watershed yet bring in more than half the annual phosphorus additions to Okeechobee's lower watershed. Phosphorus imports are not the only nutrient problem. Backpumping of water from the Everglades Agricultural Area can contribute large amounts of nitrogen to the lake, as well as un-needed phosphorus and other chemicals.

Decades of phosphorus loading have resulted in the accumulation of a thick layer of organic muck over 300 square miles of the lake's bottom, which contains an estimated 51,000 tons of phosphorus. Lake Okeechobee is so shallow that this muck is constantly stirred by wind and waves and creates turbidity problems in the lake. The muck center contains so much phosphorus that it is estimated that even if "clean' water were entering the lake today, the middle of the lake would remain above target phosphorus levels for decades due to phosphorus coming out of the mud.

The elevated levels of phosphorus in Lake Okeechobee have changed the species composition of the algal community and increased algae blooms. Turbidity from the mud limits algae somewhat,

but low light conditions also select for buoyant plankton species, such as *Anabaena* spp., *Microcystis* spp., and *Cylindrospermopsis* spp. These are species of cyanobacteria (bluegreen algae) that produce toxins that make them unpalatable and therefore a poor base of the aquatic food chain. The toxins occasionally can reach high enough concentrations to harm animals, including humans. The largest algae blooms have spread over 150 square miles at a time. Algal blooms can create problems with odors, aesthetics, turbidity, low oxygen levels, algal toxins, high ammonia, and can kill aquatic organisms.

Nutrient enrichment also changes vascular plant communities. Dense stands of cattail have colonized large parts of Okeechobee, replacing more desirable plants. Exotic plants such as water lettuce, hyacinth, and hydrilla grow rapidly in nutrient enriched waters, impairing boating and degrading ecosystems. When Okeechobee is deep, turbidity resulting from the nutrient-enriched mud center can shade out submerged plants. Combined with wind action, turbid water can eliminate much or all of the 40,000+ acre submerged plant community in the lake. Once lost, it often takes years before low-water conditions can allow for recovery of these communities.

Nutrient enrichment and the accumulation of muck within the lake stimulates increases in oligochaetes (sludge worms), while important groups of insects like mayflies, caddisflies, and midges suffer lowered abundance and species diversity. These latter species create immense blooms in which billions of larvae transform into flying adults. Blooms of billions of insects furnish a pulse of food for fish, frogs, lizards, birds, mammals, turtles, and other insects. Reductions in the populations of these species decreases food availability for their predators, including migratory birds from eastern North America that must increase body mass as they fly through Florida toward the tropics. When blooming insect communities give way to oligochaete communities, their role as a food source is lost without replacement.

Nutrient enrichment has also caused problems for the people that depend on the lake for water supply. Small towns, such as Pahokee and South Bay, have simple water treatment plants that use water from Lake Okeechobee. The organic buildup within the lake and algal blooms require high levels of treatment with chlorine. Chlorine reacts with organic molecules to create a group of compounds called trihalomethanes (THMs, one THM is chloroform), which are suspected carcinogens. The EPA standard for THMs is 100 ppb, yet samples taken during periods of water-supply backpumping have had THM concentrations between 1200-1300 ppb in South Bay. Even when backpumping is not conducted, windy days can cause turbidity and lead to THM problems.

Efforts to improve water quality in Lake Okeechobee

Since the 1970s, many government programs have been established to address nutrient problems in Lake Okeechobee. These included: the Rural Clean Water Program; the Interim Action Plan (for pumps on the south end); the Surface Water Improvement and Management (SWIM) Act; the Dairy Rule and Dairy Buy-Out Program; the Works of the District; and other efforts. There were some successes in individual programs, but Lake Okeechobee's phosphorus levels continue to increase and are at the highest levels ever. In 2000, the Florida legislature passed, "The Lake Okeechobee Protection Act." This legislation resulted in the "Lake Okeechobee Protection Plan" (LOPP) that, combined with Everglades Restoration efforts, spells out how to meet Lake Okeechobee's phosphorus goal (TMDL) by the year 2015.

The CERP and the Lake Okeechobee Protection Plan are, by far, the most ambitious plans ever for meeting Lake Okeechobee's phosphorus goals. However, the challenges are formidable. The SWIM plan phosphorus goal for the lake was 361 metric tons per year, which was never attained. The new phosphorus inflow goal for the lake is 140 metric tons per year (105 tons of inflow and 35 tons from rain and dust fall). Recent annual average inflows have been between 500-600 tons per year. Although some kinds of land uses (urban and agricultural) have mostly stopped importing excess phosphorus (such as cow-calf operations), many continue to import large amounts. The most recent assessments of imports into the watershed indicate as much as 5000 tons of new phosphorus are added to the watershed each year. It will be extremely difficult to meet the present goal of reducing phosphorus loads from 500 tons per year to 105 tons per year considering that ten times this amount of phosphorus is being added to the basin each year by current practices. Net phosphorus import must be stopped, and no program at present achieves that.

Other, less obvious challenges exist as well. The watershed has received so much phosphorus over the years that some areas have phosphorus levels ten times as high as Okeechobee's goals, even 15 years after fertilizer use was stopped. Residual phosphorus will be a decades-long problem. Additionally, rainfall in the watershed tends to fall in a short period of time, sometimes creating huge amounts of runoff quickly. Building facilities to clean water before it enters the lake requires stopping runoff before it flows in, yet preliminary designs for the Okeechobee component of CERP appear inadequate to catch this water. Best Management Practices also should require specific amounts of water storage on private property, however no such requirement presently exists.

A study was done to determine if the polluted mud in the center of the lake could be removed or neutralized. The study found that present technology could not remove the material effectively and the project may cost $3 billion. Similarly, neutralizing it with phosphorus-binding chemicals would be costly and could be undone if a hurricane significantly stirred the lake. Some good news is that although the center of the lake's high-nutrient bottom may keep it polluted for decades, at levels below 15 feet, lake marshes are rainfall-driven and retain relatively good water quality. When lake levels rise above about 16 feet however, polluted water from the center can wash into the marsh with concomitant water quality concerns. Keeping Lake Okeechobee below 15 feet not only gives the marsh a better hydrology, but makes the marsh cleaner and healthier.

A final concern with Lake Okeechobee is its role in Everglades restoration. A central feature of CERP is to divert Okeechobee outflows from the estuaries where it causes problems, to the Everglades, where it is needed. However, at recent levels of 130 ppb P, or more, Okeechobee water is far too polluted to put in the Everglades, which needs water at 10 ppb P or less. Part of the solution is treating Okeechobee water before it goes into the Everglades, but at present levels, attaining the 10 ppb standard is problematic. On-going efforts to improve Lake Okeechobee's phosphorus levels are warranted for the future of the lake itself, and for the long-term success of Everglades restoration. In addition, the Kissimmee Chain of Lakes was considered in the CERP project, but no projects were envisioned for the region. This area is 40% of Okeechobee's watershed and thus should be reconsidered in the CERP process.

Issues with Exotic Species on Lake Okeechobee

Human activity is moving species around the world at unprecedented rates. Whether plant or animal, species arriving in new regions often become very important in ecosystem interactions in their new environment, often at the expense of the native organisms. Animal invaders can cause problems through predation, grazing, competition and/or habitat alteration, while plant invaders can alter fire regimes, nutrient movement, hydrology, and energy budgets; diminish abundance or survival of native plants; block navigation; and even enhance flooding. Both plant and animal invaders may, under some circumstances, hybridize with closely related native species. In Florida, all of these effects seem to have occurred.

Approximately 50 species of exotic plants have been observed at Lake Okeechobee. Twenty-one of these species are listed by the Florida Exotic Pest Plant Council as Category I invasive exotics. Category I species are those known to alter native plant communities. Seven of the Category I species at Lake Okeechobee are widely distributed (found on >100 acres) and occur within natural habitats. These seven species are Brazilian pepper (*Schinus terebinthifolius*), hydrilla (*Hydrilla verticillata*), melaleuca (*Melaleuca quinquenervia*), torpedo grass (*Panicum repens*), water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*), and wild taro (*Colocasia esculenta*).

In general, the spread of invasive or nuisance plant species within Lake Okeechobee appears to have been aided by elevated nutrient levels and unnatural water level management. Torpedo grass covers more than 15,000 acres of Okeechobee marsh and is currently the largest management concern. Torpedo grass can form such thick stands that there is little room for wildlife use. The water in stands of torpedo grass usually has little oxygen, severely impacting aquatic organisms and truncating the base of the food chain.

Lake Okeechobee has numerous species of exotic animals. It is difficult to assess, however, the abundance of these species or their ecological impacts. The suite of exotic animals includes invertebrates (e.g., spiney water flea, clams, and snails) and vertebrates (e.g., hogs, Purple Swamp Hens, feral Mallards, and more than 16 species of fish). Collecting basic distribution and abundance data should be incorporated into existing monitoring and research programs within the lake.

The key to controlling the invasive species of Lake Okeechobee is the development and refinement of a comprehensive management program. The exotic species control program for the lake prepared in 2003 is critical to this effort. The program targets the most problematic species, which is logical, but additional efforts are needed to ensure a rapid response if other species exhibit troublesome characteristics. The program should include the following components to be successful: a comprehensive scope; adequate and consistent funding; integrated approach to management; research on invasion biology; coordination and integration with existing management programs; and an education component.

Other critical parts of Okeechobee's watershed: The Kissimmee River, Chain of Lakes, and Lake Istokpoga

Kissimmee River restoration

The Kissimmee River was unique among North American river systems in that not only did the main channel flow, but the adjacent floodplains also were inundated almost all of the time, with an estimated 94% of the floodplain remaining wet more than 50% of the time. In the 1960s the floodplain was channelized. The meandering Kissimmee River was replaced by the C-38 canal measuring 30 feet (9 m) deep and 110 yards (100 m) wide; about 10 times the size of the natural river channel. About 30,000 to 35,000 acres of wetlands were drained, covered with canal spoil, or converted into canal. With the wetlands gone, winter waterfowl use dropped 92%, wading bird use dropped drastically, fish spawning and foraging habitat was lost, Bald Eagle numbers dropped, and the river no longer supported its famous bass fishery.

After years of tests, it was determined feasible to restore part of the river to its original meandering condition. Current plans will restore about 26,500 acres of floodplain wetlands and about 43 miles of meandering river channel. The Headwaters Revitalization project is an often-overlooked part of the larger restoration effort. This project will raise seasonal water levels around Lakes Kissimmee, Hatchinehaw, and Cypress by about 1.5 feet, resulting in the re-flooding and restoration of about 30,000 acres of marshes around the lakes.

As of 2005, only the first of four phases of channel backfilling was complete. Land acquisition must proceed so backfilling can continue and the headwaters project can be completed. The Kissimmee River restoration project is not part of the CERP, but the CERP assumed the project would be completed. This project must receive separate and continued state and federal support.

Kissimmee Chain of Lakes

The Kissimmee Chain of Lakes (KCOL) watershed covers an area of about 1,633 square miles, some 40% of Lake Okeechobee's watershed. The KCOL is not explicitly considered in most of Lake Okeechobee's restoration plans even though it contributes water and nutrients to Lake Okeechobee and suffers from the same nutrient, water level management, exotic species encroachment, and general human-related degradation problems. This region also has witnessed human population increases of 100,000 people per year over the past decade.

The lack of attention to this region is of concern for the lakes themselves, and for their impacts to downstream areas. The University of Florida recently estimated that Lakes Kissimmee, Cypress, Hatchinehaw, and West Tohopekaliga, could become phosphorus saturated within a decade or so. If that happened, these lakes would be subject to algae blooms (with attendant turbidity, odors, and muck accumulation), accelerated noxious plant growth, and other nutrient-related problems. Additionally, phosphorus outflows would increase, further polluting downstream resources.

Water management resulting in stabilized water levels on these lakes also has created problems. The result has been over-development of dense, long-hydroperiod plant communities along the shores (often called tussocks), accumulation of organic material in the marsh, and reduced

development of short-hydroperiod marsh plant communities. Agency responses to deal with tussocks have consisted of occasional, extreme water level drawdowns. During the low water the marsh is bulldozed to remove plant communities and organic material. Refilling is followed by intense herbicide treatments of any marsh regrowth. Most of the spraying in the marsh is on native plants. While these tactics temporarily reverse some of the problems in the lakes, they are extremely expensive, create acres of spoil piles in former wetlands, and create environmental problems of their own. These problems include virtual elimination of tussock communities and the wildlife species associated with them, loss of marsh vegetation, loss of Sandhill Crane nesting habitats, and apparent harm to Snail Kite breeding efforts. The projects are touted to improve the bass fishery, but research has failed to detect these benefits. Downstream, the drawdowns create severe droughts in the floodplain of the restored section of the Kissimmee River, essentially negating the goals of that project during drawdown years. Unfortunately, there are no attempts to correct the poor lake hydrology that created the problems in the first place. Since the cause of the problems remains in place, the problems reoccur and managers continue to use harmful extreme drawdowns to treat the symptoms.

The KCOL also are plagued by hydrilla infestation. Being shallow, the lakes are vulnerable to being completely covered with dense stands of hydrilla that impede navigation, cause environmental problems, and block discharge structures, potentially creating severe flooding problems during hurricanes. Treatment has been problematic partly because it required water level drawdowns in unnatural patterns, with attendant conflicts. Further, hydrilla has developed herbicide resistance, compromising the ability to treat it adequately.

To address these problems, the SFWMD and several cooperating agencies are working on a “Long Term Management Plan” for the KCOL. An initial charge is to design water level management plans that enhance the lake ecosystems rather than harm them. This plan goes further, however, and along with water level management includes four other areas: water quality, exotic species control, recreation, and conservation issues. This plan may be one of the most import restoration efforts in South Florida and deserves greater attention, both for the potential benefits that can be gained for these lakes, and also for the potential benefit to downstream systems.

Lake Istokpoga

Lake Istokpoga is Florida’s 5th largest lake and its watershed covers some 609 square miles, about 10% of Lake Okeechobee’s watershed. It is very shallow, and has water level stabilization problems like the Kissimmee Chain of Lakes. Until the mid 1990s, water quality was very good (phosphorus levels about 30 ppb). Phosphorus levels have increased in the past decade and there is an estimate that at present loading rates the lake could be phosphorus saturated in as little as 15 years. To address these challenges, the Everglades restoration team decided to include the Lake Istokpoga watershed in the Lake Okeechobee Watershed project. This action has increased planning around Lake Istokpoga, and has considerable promise to improve water level management. Unfortunately, budget concerns might preclude CERP from including projects upstream that could protect Lake Istokpoga’s water quality. Lake Istokpoga deserves more attention for its own merits, and to protect this sizable portion of Lake Okeechobee’s watershed from degradation.

THE FUTURE OF LAKE OKEECHOBEE

Lake Okeechobee is at a cross-roads. Experience with shallow lakes throughout the world has demonstrated that once nutrient enriched, they are extremely hard to restore. Lake Apopka in Florida, which for 50 years has suffered continuous algae blooms, is one example of this. The present suite of programs to prevent Lake Okeechobee from being overwhelmed by nutrients is impressive, but as outlined in more detail in this monograph, will need continued support and scrutiny to succeed. Lake Okeechobee's water level problems are no less daunting. Drainage-enhanced water inflows to the lake are so great they threaten to by-pass water treatment facilities, harm vegetative communities, and continue creating downstream havoc to the estuaries and Southern Everglades.

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Photo: Paul Gray

INTRODUCTION

Lake Okeechobee is Florida's premier lake. It is the largest lake in the southeastern United States, an incredible 730 square miles with more than 100,000 acres of wetland habitats. The lake is located in the center of the Everglades ecosystem, a critical link between lakes and rivers to the north and wetlands and bays to the south. The environmental health of the lake has been degraded from decades of mismanagement that has placed the wants of some humans above the needs of wildlife and the environment. Drainage and development in South Florida have not only harmed natural environments, but have also wreaked havoc on a lake that could generate tourism revenue in perpetuity, and made clean water a scarce commodity.

The long-term fate of Lake Okeechobee may be sealed within the next few years as options for meaningful restoration are either planned and implemented, or permanently foreclosed by ongoing development and pollution within the region. The problems caused by the competing demands placed on the lake cannot be corrected through improved management protocols alone. Additional infrastructure is required to store floodwaters, clean up pollution, and supply water to cities, agriculture, and the environment. The demands of society must be moved away from the lake and towards solutions designed specifically to meet those demands; only then can the lake's health be restored and its role in a healthy Everglades ecosystem be reestablished.

All Floridians share in the goal to restore and protect this great lake. However, understanding the myriad problems, including how they started, how to fix them, and which agency to work with, is a daunting task. Information is fragmented into many documents and much of it is highly technical and difficult to interpret. This document is Audubon's attempt to consolidate information about Lake Okeechobee's main issues in understandable terms.

RESOURCES OF LAKE OKEECHOBEE

A BRIEF HISTORY OF LAKE OKEECHOBEE

Florida is different in many ways from the rest of the United States because of its low latitude, subtropical temperatures, rainfall patterns, and unique plants and animals. Indeed, the continental plate that makes up Florida apparently separated from North Africa near present day Senegal sometime in the Triassic era (about 200 million years ago), as the supercontinent Pangaea was breaking apart (Smith and Lord 1997). This geological event opened up the Atlantic Ocean and eventually sent Florida colliding into the landmasses that now make up North America.

At 6,000 years old, Lake Okeechobee is young by geological standards (Brooks 1984). The bottom of the lake, and the Everglades, are former marine sediments deposited in at least seven separate cycles of deposition. To the south of the lake, where the Everglades Agricultural Area (EAA) is today, there is uneven bedrock (mostly limestone) about 6 to 7 feet above sea level in most places (Gleason and Stone 1994). The elevation of the bottom of Lake Okeechobee is very close to sea level, having subsided more than the limestone south of it (Brooks 1984). Atop the limestone to the south, about 13-14 feet of organic soils developed over time, which effectively dammed Lake Okeechobee's water.

In its pristine condition, Lake Okeechobee was deeper and larger than today. In the early 1900s, prior to construction of major drainage canals, water levels in Lake Okeechobee commonly reached 18 to 21 ft above mean sea level (msl)(Pesnell and Brown 1977) and virtually all water flowing from the lake flowed south, into the Everglades. There are a few technical descriptions of the physical and biological character of Lake Okeechobee's original wetlands that, when combined with other general accounts of the area, create a picture of the lake's historical conditions. Col. Zachary Taylor was the first to give a "credible" account that the legendary Lake Okeechobee (also called Lake Macaco and Lake Mayaimi) did indeed exist in Florida's wild interior (Sprague 1848, Sunderman 1963).

In 1914, Harshberger published a vegetation map of South Florida that included the area surrounding Lake Okeechobee (see Pesnell and Brown 1977, p. 6). A custard apple swamp (*Annona glabra*) up to three miles wide bordered the southern portion of the lake. Beyond the custard apple grew stands of elderberries (*Sambuca canadensis*)(Snyder 1994) and coastal plain willow (*Salix caroliniana*), which then led into the vast sawgrass marshes (*Cladium jamaicensis*) that formed the beginning of the northern Everglades. Sawgrass marshes continued north in thin bands along the eastern and western portions of the lake. The sawgrass in the northeast was bordered by pinelands. On the western side of the lake, however, the sawgrass gave way to extended areas of intermixed marsh and wet and dry prairies. The marshes and prairies extended towards the northern portion of the lake that was bordered by bald cypress swamps (*Taxodium distichum*) near Taylor Creek.

Lake Okeechobee was a part of a diverse landscape that supported a phenomenal array of wildlife. In 1891, an explorer noted, "curlew in thousands, duck, (teal & mallard) snipe ordinary & whistling, any quantity of herons of all descriptions & simply armies of scout-abouts (coots), & a great number of hooper" (Dodson 1973). The "curlew" seen by the explorer were probably White Ibis, the "whistling snipe" were possibly yellowlegs, and the "hooper" could have been native Sandhill Cranes, or Whooping Cranes, the latter a species being reintroduced in Okeechobee's watershed today. Lake Okeechobee was undoubtedly important to sustaining the large numbers of wading birds, numbering approximately 2,500,000 in South Florida during the late 1800s (Robertson and Kushlan 1974). Alligators and river otters also were abundant around Lake Okeechobee and their skins were commonly listed among the freight aboard vessels traveling through the region. Indians would often use these skins as currency to purchase supplies at local stores (Van Landingham and Hetherington 1978). One alligator hunter reported that he captured 120 alligators in one week on Lake Okeechobee (Anon. 1883).

The lake was forever lowered by a series of major drainage projects starting in the late 1880s. The first project connected the lake to the Caloosahatchee River near Moore Haven, sending water to the Gulf Coast. The North New River, Palm Beach, Hillsbororo, Miami, and St. Lucie Canals were completed by 1924 and drained water toward the Atlantic Coast (Hannah and Hannah 1948, Pesnell and Brown 1977). These drainage projects reduced the lake's average high water level from around 20 feet to a current average in the 16 to 18 foot range (Steinman et al. 2002).

The custard apple swamp was cleared for farming and a simple muck dike was built along the southern rim of the lake to help keep the new fields dry (Snyder 2004). A major hurricane in

1926 breached the dike in Moore Haven and hundreds of people died. Two years later, another hurricane breached the dike in Belle Glade and perhaps 3000 people died (Will 1978b, Mykle 2002). Out of these tragedies came understandable cries for strong action. The Hoover Dike, named after the President of the time, was started in 1930. The US Army Corps of Engineers "prosecuted the task with vigor and expedition" and by 1937, the bulk of the work along the south side of the lake was finished (Will 1978b). Work continued on the Hoover Dike for decades and by the 1960s, the dike had been built completely around the lake.

The Hoover Dike was tested by major hurricanes in 1947 and 1949 (Will 1978b). The 1949 hurricane was reminiscent of the 1928 hurricane with winds of 75-122 miles per hour. The dike held. However, the 1947 hurricane was one of the wettest on record, flooding the entire watershed and sending the lake to its highest levels in 40 years. Out of the massive flooding arose the Central and Southern Florida Flood Control District (C&SF), whose multi-purpose mission emphasized flood control (i.e., drainage). The present system of canals and structures, including the channelized Kissimmee River, arose out of this project. It is this system, the C&SF project, that the Comprehensive Everglades Restoration Plan (CERP) is designed to upgrade to current needs and philosophies.

The Hoover Dike reduced the size of the lake leaving it a fraction of its former self (Steinman et al. 2002, see Figure 1). Lower average lake levels allowed the formation of the marsh zone at a lower average elevation inside the dike (Pesnell and Brown 1977). At approximately 98,000 acres, the new marsh is not only smaller, but contains fewer types of plant communities (Steinman et al. 2002, see Figure 2).

A common perception of the pre-drainage lake is that when the water got deep enough, "it overflowed into the Everglades." While it is true that the lake did overflow into the Everglades when deep enough, that was not the only time Okeechobee served as the Everglades' wellspring. Organic soils, limestone, and sand deposits can be extremely porous (Snyder 1994); even when Lake Okeechobee was not deep enough to flow above the muck soils it probably always flowed through and under them.

Lake Okeechobee has a special relationship with the muck soils. Muck soils are made primarily of the tissues of dead plants. Muck soils (also called peat) form under water, in areas with almost continuous inundation where there is little oxygen and decomposition is inefficient. During the past 6000 years, water has steadily streamed southward from Lake Okeechobee's basin, which created continuously wet conditions and allowed the formation of muck soils. As the muck got deeper, it made the lake deeper, which in turn, allowed the muck to get ever deeper (Brooks 1984). This is a slow process and it is estimated that the soils rose about 3.3 inches (8.38 cm) each century (Snyder 1994). In essence, Lake Okeechobee's water helped form the muck of the Everglades, which in turn, helped form Lake Okeechobee. This means Lake Okeechobee was built largely by biological processes. After the construction of the Hoover Dike, the muck soils were drained and farmed, which made them decompose and subside. The soils of the EAA (the former muck soils of the northern Everglades) have been dropping at an average of 1 inch per year (Snyder 1994). A marker at the University of Florida's Everglades Experiment Station near Belle Glade records a loss of more than 6 feet.

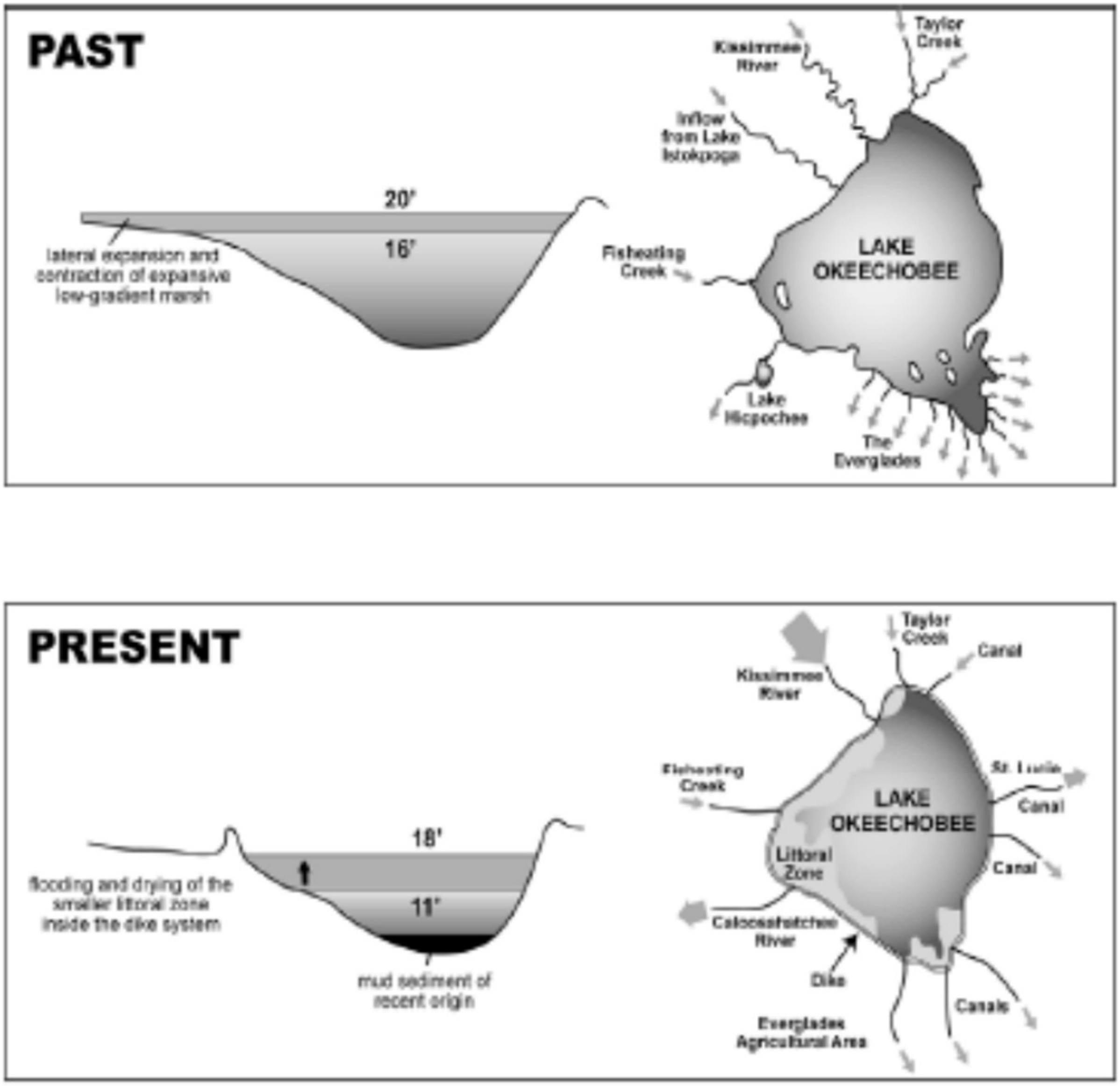

Figure 1. Diagrams showing the effects of the Hoover Dike and numerous drainage canals on the size and water depths of Lake Okeechobee (from the 2005 South Florida Environmental Report, South Florida Water Management District).

Today, instead of ranging from 16 to 20 feet deep, the lake usually fluctuates between 11 and 18 feet deep (Steinman et al. 2002). The total area has been reduced by about one-third and locks and gates control water levels. Instead of the entire outflow going to the Everglades, most excess water now is diverted to the St. Lucie and Caloosahatchee Rivers. This makes for efficient drainage, but during wet periods causes severe damage to the estuaries by turning their brackish water fresh. Ironically, the Everglades has chronic water shortages, as do people. Restoration requires additional places to store water other than in Lake Okeechobee, and a system that can divert the stored water away from the estuaries where it does harm, and back to the Everglades or to people as necessary.

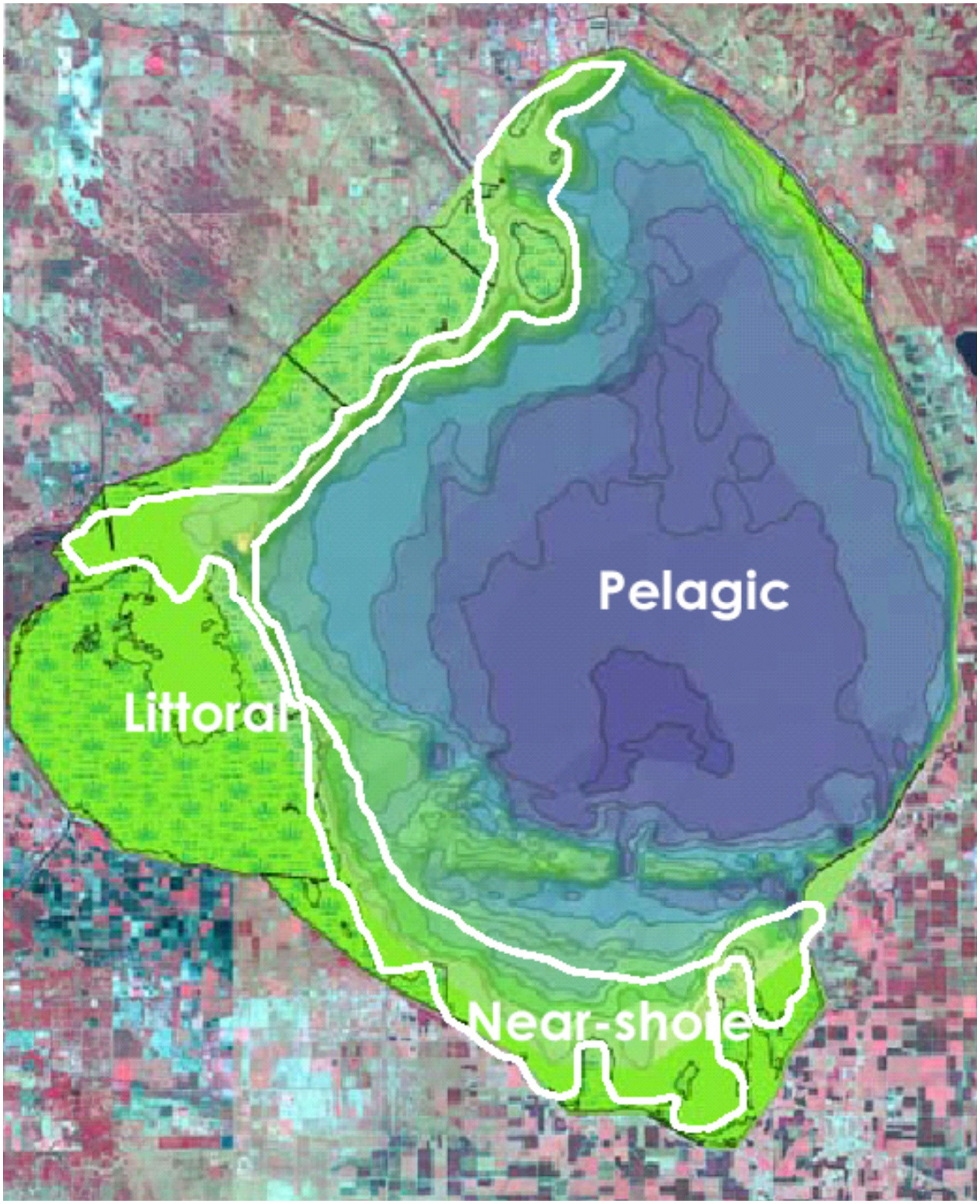

Figure 2. Habitat zones within Lake Okeechobee (from the 2005 South Florida Environmental Report, South Florida Water Management District).

Lake Okeechobee’s Watershed

Lake Okeechobee's watershed is about five times the size of the lake itself, covering almost 4,400 square miles (Figure 2). The Kissimmee River Basin contributes about half the flow to the lake. It is divided into an upper basin, approximately 1600 square miles containing the Chain of Lakes, and a lower basin, approximately 750 square miles containing the Kissimmee River. West of the Kissimmee River basin is the Lake Istokpoga basin, covering approximately 600 square miles. Lake Okeechobee also receives inflows from the mostly-agricultural Fisheating Creek watershed on its west side, and the Taylor Creek-Nubbin Slough area on its north side. The watershed has many drainage features (mainly for flood protection) which have increased the land area tributary to the lake, the rate of inflow to the lake, and the overall volume of water entering the lake.

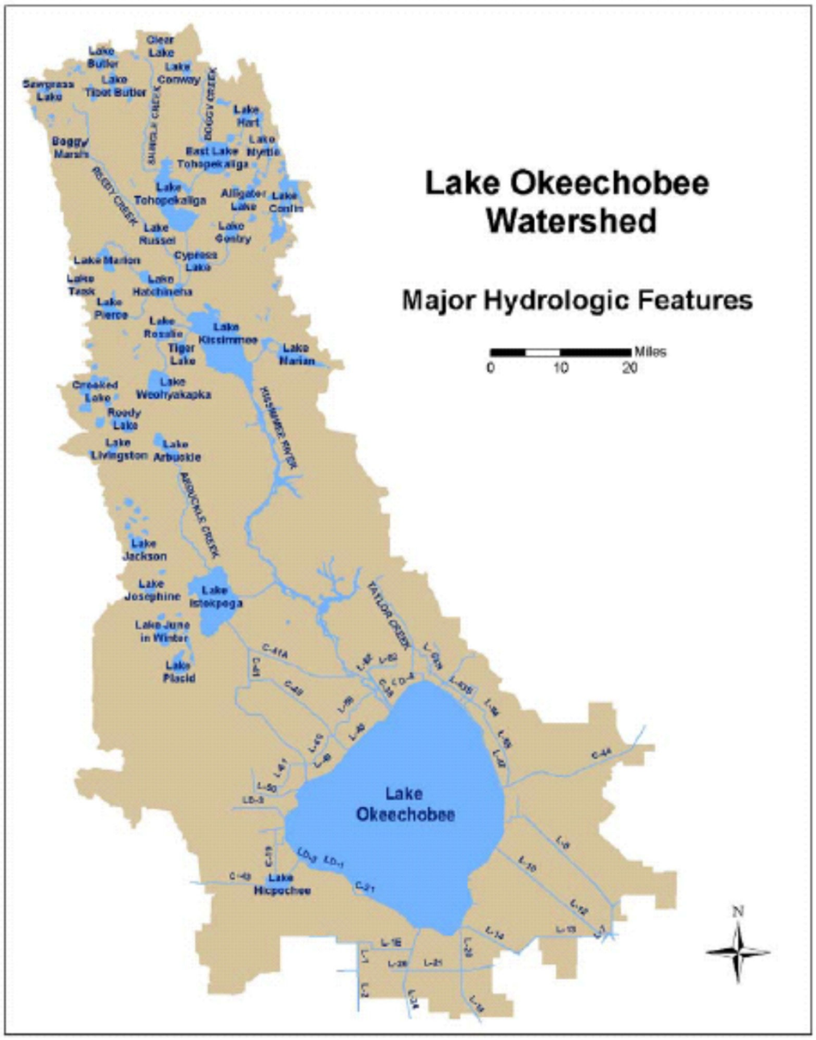

Figure 3. Diagram of Lake Okeechobee’s watershed (from the 2005 South Florida Environmental Report, South Florida Water Management District).

LAKE OKEECHOBEE'S CLIMATE

Lake Okeechobee is so large it influences its own climate. Central Florida receives about 50 inches of rain per year, making it the driest region in Florida (Henry 1998). Some 70% of the rain falls during the 4-5 month summer rainy season (Winsberg 1990). Each day during the summer the land heats to such an extent it warms the air above it, which rises and creates thunderstorm clouds. Sea breezes from either coast inject moisture into these storms. However, the daily heating effect over Lake Okeechobee's water is less pronounced than over adjacent lands, which impedes thunderstorm formation above the lake and actually results in less rain falling on Lake Okeechobee than surrounding areas (VanArman et al. 1988). This phenomenon can be seen in many satellite photos of Florida where the lake is not cloud covered and surrounding areas are.

LAKE OKEECHOBEE WATERWAY

The Lake Okeechobee Waterway connects the Atlantic Ocean to the Gulf of Mexico, through Lake Okeechobee. Boaters who use the St. Lucie and Caloosahatchee Canals to cross Florida save an estimated 206 miles of travel compared with sailing around the southern tip of the state. Most traffic through the waterway is recreational with more lockages than almost any other Corps inland lock. There are some 600,000 registered boats in the waterway area. Additionally, about 728,000 tons of commercial traffic plied the waterway in 2000. Some 6.6 million people visit the waterway each year, generating an estimated value of more than $55 million annually. If maintenance of the waterway ceased, projections show visitation would drop by 2.2 million visitors and economic activity would decrease by $22 million (USACE 2002b).

PLANT COMMUNITIES—THE BASE OF THE FOOD CHAIN

Virtually all animals rely on plants for food, either by eating them, or by eating other animals that eat plants. Because of the central importance of plants, most of the ecosystem goals and models for Lake Okeechobee (and other parts of the Everglades ecosystem) focus on plant communities. In open water, nutrient standards are based on supporting desirable algae communities. In the marshes, water level management and nutrient standards are based on supporting desirable plants. This section discusses plant communities with emphasis on desirable plant communities and the conditions needed to support them.

Algal communities

Algae are ubiquitous in aquatic ecosystems and form a surprisingly large part of the food chain. Algae are eaten by zooplankton that are eaten by larger zooplankton and larval fish. All of these feed larger fish still, including largemouth bass, black crappie, bluegill, and other sunfish. Most algal species, such as diatoms and green algae, are considered beneficial. However, as water bodies become eutrophic (nutrient enriched), many species of algae are replaced by less desirable species of cyanobacteria (blue-green algae).

Lake Okeechobee presently has phosphorus (P) levels above 100 parts per billion (ppb), making it ripe for algal blooms (Havens et al. 1995b). Presently, Lake Okeechobee does not experience algal blooms as frequently as the nutrient loading might allow because the organic material and

silt in the water column block so much light that plant and algal growth is limited (Phlips et al. 1997). Unfortunately, limited-light conditions also select for buoyant plankton species, such as *Anabaena* spp., *Microcystis* spp., and *Cylindrospermopsis* spp. These cyanobacteria can produce toxins that make them unpalatable and therefore a poor base of the aquatic food chain (Paerl et al. 2001). Of growing concern is the fact that *Cylindrospermopsis* is present in Lake Okeechobee and has been implicated in causing illness in humans (from water supply) and livestock (Paerl et al. 2001), in other regions.

The ratio of nitrogen to phosphorus, called the N:P ratio, is another factor in algal community composition. In the 1970s, the lake's N:P ratio averaged about 35:1 and phytoplankton communities had desirable species (green algae and diatoms). By the 1990s, the ratio had dropped to 15:1 and cyanobacteria had become a nuisance (SFWMD 2002). Research indicates that desirable algal species dominated when N:P ratios were above 22:1, but cyanobacteria increased in numbers at lower ratios (Maceina and Soballe 1989). The recent change in Lake Okeechobee's N:P ratio was caused by the increase in P from fertilizers and a decrease in N when backpumping from the Everglades Agricultural Area (EAA) was curtailed.

Submerged plants

Submerged plants are those that are rooted, but grow under the water, never protruding much higher than the water surface. Examples include pondweed (*Potamogeton* spp., also called pepper grass), eel grass (*Vallisineria* spp., also called tape grass), shrimpgrass (*Chara* spp.), and the exotic species, *Hydrilla*. Submerged plants are most abundant in the deeper edges of Okeechobee's vast marshes. Under favorable conditions, about 50,000 acres (more than 75 square miles) of submerged aquatic vegetation (SAV) occurs in Lake Okeechobee (SFWMD 2003).

Lake Okeechobee's SAV community declined to about 5,000 acres by the end of the 1990s, due primarily to prolonged high water (Havens et al. 2001). When water remains deep and turbid, plants can be stressed from lack of light and wave action. Light also cannot reach the bottom, preventing new seeds from germinating and broken plants from re-growing. Once lost, the SAV community cannot regenerate until lower, clearer water conditions return, which may not occur for years. Conditions were so poor in the late 1990s that not only beneficial native species such as pondweed and eel grass were lost, but even the hardy, invasive hydrilla lost significant acreage around the lake.

SAV performs many ecosystem functions. They are extremely valuable habitat for waterfowl (Johnson and Montalabano 1984) and young fish (Furse and Fox 1994) and SAV loss was a large contributor to declines in waterfowl and fish on Lake Okeechobee in the late 1990s. In addition, SAV helps attenuate waves, reducing erosion of shoreline and other plants. These plants also help reduce turbidity and improve water clarity both by attenuating waves and erosion, and by absorbing nutrients from the water column that otherwise might fuel algal blooms. Conversely, when SAV is lost, a cycle of turbidity and erosion sets in that further suppresses their ability to regrow. Lastly, loss of SAV also probably contributed the formation of the organic "berm" that developed along the edge of the littoral areas of the lake in the late 1990s, effectively separating the marsh from the open water (Havens et al. 2001). The many ecological and structural values of SAV make them a leading indicator of environmental health in Lake Okeechobee.

Emergent plants/nuisance exotic species

The 1914 map by Harshberger (reproduced in Pesnell and Brown 1977, p. 6) depicts the western marshes of Lake Okeechobee as the same plant community type as the regions south of Lake Okeechobee, labeled "everglades." An expedition in 1882 described a "saw-grass marsh" resembling a vast plain on the western shore of the lake (Peoples and Davis 1951). Another plant community very similar to the Everglades occurs in Moonshine Bay today, a spikerush (*Eleocharis cellulsoa*), periphyton, water lily, and sawgrass community. Most of the early vegetation of Lake Okeechobee was probably similar to Everglades habitats of today.

The plant communities in Lake Okeechobee's littoral zone have changed profoundly. The Hoover Dike cut off large areas of marsh from Lake Okeechobee, and with present water levels, the emergent marsh zone lies at a lower elevation than before (Steinman et al. 2002). By 1970, many changes in the plant community were recorded including: the replacement of annual plants by perennial plants, an increase in submerged plant species, and a decrease in plant species diversity (Ager and Kerce 1970). By 1976, a broad band of cattails was established along the edge of the marsh (Pesnell and Brown 1977). After 1978, the lake was intentionally managed for higher water levels, virtually eliminating the spikerush community and facilitating cattail expansion (Milleson 1987). Two exotic species, torpedo grass (*Panicum repens*) and melaleuca (*Melaleuca quinqenervia*) were increasing in abundance. High water levels continued through the 1980s and by 1988 the Lake Okeechobee Littoral Zone Technical Group (LOLZTG 1988) declared an emergency for wading birds due to degradation of their habitat.

The emergent plant community continued to change during the high water levels of the late 1990s. Bulrush, which supports the highest abundance and biomass of important recreational fish (Furse and Fox 1994), dropped from an estimated 4,700 acres in the early 1990s to less than 1000 acres by 2000 (SFWMD 2003). Once eliminated, bulrush was unable to recover because of low light conditions in the lake's deep, turbid water. Nutrient-rich water pushed far into the marshes, fueled by the deep-water conditions, further increasing the cattail acreage (Richardson and Harris 1995, Lake Okeechobee Issue Team 1999). Willows, which cannot tolerate flooding for much more than a year without harm, and moist soil plants, which need mudflats to germinate on, declined as well, with concomitant harm to wildlife and fish. Another emergency was declared and the South Florida Water Management District (SFWMD) conducted a drawdown in 2000, in an attempt to revive the lake (Havens et al. 2001).

The 2000 drawdown, assisted by a great drought, greatly improved plant communities on Lake Okeechobee. A new water level regulation schedule (named "WSE") was adopted to keep the lake lower on average in order to improve the health of the littoral zone (SFWMD 2003). Bulrush, willow, submerged plants, and moist soils plants rebounded strongly after the extended drawdown. Melaleuca have declined significantly following dedicated control efforts. Torpedo grass remains a problem and research on its eradication is continuing.

Okeechobee Gourd

Okeechobee has an endangered, endemic, gourd named after it, the Okeechobee Gourd (*Cucurbita okeechobeensis okeechobeensis* Small)(Muller et al. 1989). This gourd has only 2 known locations in the world, on Lake Okeechobee and in Volusia County, Florida along the St.

Johns River (USFWS 1998). Formerly living in the extensive custard apple (*Annona glabra*) forests on the southern end of the lake, the gourd is endangered by its restricted range, habitat loss, and water management practices (USFWS 1998). The islands on the southern end of the lake hold remnant populations, and some have colonized the spoil piles on the northwestern shores of the lake (created during the berm removal project). The gourds represent a valuable source of germplasm for gourd cultivation since the gourd is resistant to many plant diseases (Nabham 2002). Extremely deep water prevents germination, and very low water destroys the organic soils of the island, making the soil shallower and the islands lower. It is necessary to manage lake levels in the 12 to 15 foot range to protect these gourds.

ANIMAL COMMUNITIES

Invertebrates

Lake Okeechobee supports a great abundance of invertebrates including insects, crustaceans, worms, snails, clams, and sponges. Many invertebrates are primary consumers, helping make the energy harnessed by photosynthesis available to a variety of other invertebrates and vertebrates. Others are decomposers helping to recycle nutrients within the lake ecosystem. Several elements of the invertebrate community are worthy of independent discussion.

Apple snails

Apple snails (*Pomacea palludosa*) are large (>1" diameter), round, snails. Although quite remarkable in their own right, they gain extra attention as the primary food of Snail Kites and Limpkins as well as young alligators and other animals (Darby 1999). While the snails themselves live under water and are not commonly observed, their white, B-B sized eggs are laid in clusters on plant stems above water during the spring and early summer. Apple Snails live for only about 18 months, therefore must successfully produce a new generation each year (Darby et al. 1997). Apple snails can tolerate drying for brief periods, but prolonged droughts decrease their populations dramatically (Darby et al. 2002).

There is an exotic apple snail that is becoming established in Florida, *Pomacea canaliculata*. It grows to twice the size of native apple snails and has been reported from lake. It is unclear what effects, if any, this new species will have on native apple snails, vegetation, or Snail Kites.

Benthic Invertebrates

There is an apparent trend between 1970 and 1990 of decreasing species richness (number of species) in benthic (bottom) communities and concomitant increases in oligochaete abundance (also called sludge worms)(Warren et al. 1995). During this period, oligochaetes increased in percent abundance from 24% to 74% of invertebrates, while "other taxa" decreased from 53% to 5% (Warren et al. 1995). Notably, mayflies (*Ephemeroptera* spp.) and caddisflies (*Tricoptera* spp.) now have low abundance and species diversity in Okeechobee, although they persist in nearby, cleaner lakes (Warren et al. 1995, Warren and Hohlt 2002). These insects have larval forms that live in the water and emerge as flying adults, thereby participating in both aquatic and terrestrial food chains. The cause of these changes appears to be nutrient pollution.

Midges (Chironomidae) are an insect of interest in Lake Okeechobee because of their great abundance and because many midge species cannot tolerate hyper-eutrophic (nutrient rich) waters. Chironomids have similar life histories to mayflies and caddisflies in that their immature stage is an aquatic, worm-like creature that leaves the water as a flying adult (Merritt and Cummins 1978). Adult hatches are synchronized and can release literally billions of midges, thus are called “blooms.” They are so abundant they create nuisances by fouling windshields (Hostetler 1996) and swarming around lighted buildings such that their carcasses must be regularly cleaned up. Blooms of billions of insects may be considered an inconvenience to humans, but they furnish a pulse of food for fish, frogs, lizards, birds, mammals, other insects, and turtles. Florida funnels migratory birds from the entire eastern side of North America, from the arctic to the tropics. When migratory bug-eating birds encounter a chironomid bloom they can quickly obtain the 30-50% body fat they need to fuel their flight across the Gulf of Mexico (Terborgh 1989). In contrast, oligochaetes are completely aquatic and do not bloom. When chironomid, mayfly, caddisfly, or other blooming insect communities give way to oligochaete communities, their role as a food source for surrounding ecosystems, and the hundreds of millions of birds that fly through Florida each year, is lost without replacement. On Okeechobee, one dominant chironomid species, *Coclotanyopus tricolor*, declined 54% between 1970 and 1990. The phantom midge *Chaoborus punctipennis* is abundant near the lake, but rare in it, presumably due to shifting mud sediments (Warren et al. 1995). It must be noted that some pollution-tolerant chironomids, such as *Chironomus crassicaudatus* and *Rheotanytatsus* spp. remain fairly abundant in the lake, and are important food species of many fish (Bull et al. 1995), but changes in such fundamental components of ecosystems bear monitoring.

The oligochaete of greatest abundance in Lake Okeechobee, *Limnodrilus hoffmeisterii*, is very tolerant of high nutrients and low dissolved oxygen levels (Warren and Hohlt 1995, Warren et al. 1995), and has a characteristic that contributes to water column phosphorus (P) problems. Oligochaetes are essentially aquatic earthworms (Pennack 1978). Like their terrestrial cousins, most oligochaetes feed on mud and the organisms it contains (algae, diatoms, detrital material or other small organisms). However, unlike earthworms, they live with their vents protruding into the water above. Therefore, after feeding on the mud, they excrete their wastes directly into the water column, which moves P and other materials from the mud into the water. There are so many oligochaetes in Lake Okeechobee (ranging from several hundred, to thousands per square meter, in mud areas) that they increase P concentrations in the water column compared with areas with few or no oligochaetes (Rees et al. 1996). The differences are great enough that computer models estimating P movement in Lake Okeechobee now account for invertebrate effects.

Fish communities

Florida is considered the premiere fishing destination in the world (FWC 2003). In addition to 2.1 million resident fishermen, about one million people come to Florida each year to fish. These people spend about 48.4 million "fishing-days," generate about $5.5 billion for Florida's economy and sustain about 75,000 jobs. Lake Okeechobee is a significant part of the fishing lore of the state.

Okeechobee has a mix of freshwater and saltwater fish (such as tarpon, snook, and mullet, Table 1), as well as exotics (such as oscars and plecostomus catfish, Table 2). About 70% of Lake

Okeechobee's area is open water (pelagic zone). Unlike deeper lakes, and most northern lakes, Okeechobee's water column mixes constantly; hence it does not develop strong temperature stratification. The Florida Fish and Wildlife Conservation Commission (FWC) conducted a four-year study of fish communities in the pelagic zone of the lake and found that threadfin shad, bluegill and black crappie accounted for 92% of the fish (Bull et al. 1995). In all, Bull et al. (1995) netted 25 fish species in the pelagic areas.

Table 1. Native fish species list for Lake Okeechobee and Kissimmee River (updated January 2003 by D. D. Fox, FWC, Okeechobee)

Common Name	Scientific Name	Common Name	Scientific Name
American Eel	*Anguilla rostra*	Eastern mosquitofish	*Gambusia holbrooki*
Atlantic needlefish	*Strongylura marina*	Naked goby	*Gobiosoma bosc*
Black crappie	*Pomoxis nigromaculatus*	Opossum pipefish	*Microphis brachyurus*
Bluefin killifish	*Lacuna goodei*	Okeefenokee pygmy sunfish	*Elassoma okefenokee*
Bluegill	*Lepomis macrochirus*	Pirate perch	*Aphredoderus sayanus*
Bowfin	*Amia calva*	Pugnose minnow	*Opsopoeodus emiliae*
Brown bullhead	*Ameiurus nebulosus*	Redbreast sunfish	*Lepomis auritus*
Brook silverside	*Labidesthes sicculus*	Redear sunfish	*Lepomis microlophus*
Bluespotted sunfish	*Enneacanthus gloriosus*	Redface topminnow	*Fundulus rubifrons*
Chain pickerel	*Esox niger*	Redfin pickerel	*Esox americanus*
Channel catfish	*Ictalurus punctatus*	Sailfin molly	*Poecilia latipinna*
Clown goby	*Microgobius gulosus*	Seminole killifish	*Fundulus seminolis*
Dollar sunfish	*Lepomis marginatus*	Sheepshead minnow	*Cyprinodon variegatus*
Everglades pygmy sunfish	*Elassoma evergladei*	Snook	*Centropomus undecimalis*
Florida gar	*Lepisosteus platyrhincus*	Spotted sunfish	*Lepomis punctatus*
Flagfish	*Jordanella floridae*	Striped mullet	*Mugil cephalus*
Gizzard shad	*Dorosoma cepedianum*	Swamp darter	*Etheostoma fusiforme*
Golden shiner	*Notemigonus crysoleucas*	Tadpole madtom	*Noturus gyrinus*
Golden topminnow	*Fundulus chrysotus*	Taillight shiner	*Notropis maculatus*
Inland silverside	*Menidia beryllina*	Threadfin shad	*Dorosoma petenense*
Lake chubsucker	*Erimyzon sucetta*	Tarpon	*Megalops atlanticus*
Least killifish	*Heterandria formosa*	Warmouth	*Lepomis gulosus*
Longnose gar	*Lepisosteus osseus*	White catfish	*Ameiurus catus*
Lined topminnow	*Fundulus lineolatus*	Yellow bullhead	*Ameiurus natalis*
Largemouth bass	*Micropterus salmoides*		

Table 2. Exotic fish species list for Lake Okeechobee and the Kissimmee River (compiled by D. D. Fox, FWC, 2003).

Common Name	Scientific Name	Common Name	Scientific Name
Blue tilapia	*Oreochromis aurus*	Jewelfish	*Hemichromis bimaculatus*
Peacock bass	*Cichla ocellaris*	Sailfin Catfish	*Liposarcus multiradiatus*
Callichthyid catfish	*Hoplosternum littorale*	Mayan cichlid	*Cichlasoma urophthalmus*
Common carp	*Cyprinus carpio*	Oscar	*Astronotus ocellatus*
Convict cichlid	*Cichlasoma nigrofasciatum*	Pacu	*Colossoma spp.*
Grass carp	*Ctenopharyngodon idella*	Spotted tilapia	*Tilapia mariae*
Green sunfish	*Lepomis cyanellus*	Suckermouth catfish	*Hypostomus plecostomus*
Jack Dempsey	*Cichlasoma octofasciatum*	Walking catfish	*Clarias batrachus*

Fish in vegetated areas of the lake tend to have higher densities than in open water areas. Block net samples in vegetated areas yielded about 100,000 fish per acre. Small fish such as the bluefin killifish (39,000 individuals per acre), mosquitofish (21,000/acre), sailfin molly (11,000/acre) and least killifish (9,000/acre) were the most abundant (Fox et al. 1992). Bluegill were the most abundant of the larger fish at 4000 per acre (4% of all fish), but comprised about 24% of the total fish biomass, the greatest biomass of any species. Largemouth bass averaged 141 fish per acre, weighing a total of 34 pounds.

Largemouth bass and black crappie are the most sought-after game fish in Lake Okeechobee's multi-million dollar fishery (Bell 1987). In the late 1990's, when water levels in the lake had been kept high, spawning by both these fish species appeared normal, but most of young fish "disappeared" before reaching harvestable size. For example, one-year old large-mouthed bass formed about 35% of bass caught through electroshocking between 1992-1995. Between 1996 and 1999, one-year old bass constituted 20% of the fish caught, a 43% decrease in this age group (Steve Gornak, FWC, pers. comm.). Similarly, one-year old crappie formed 75% of all crappie caught in net pulls in January 1999. By January of 2000, one-year old crappie constituted 34% of the population (Steve Gornak, FWC, pers. comm.). It is suspected that the loss of submerged plants in the lake made these young fish vulnerable to predation. Concern for these fish was one of several factors leading to the declaration of an emergency and subsequent drawdown in 2000.

An economic analysis of plant communities in relation to fish communities in Lake Okeechobee concluded that an acre of vegetation ranged in value from $110,000 acre ($44,000/hectare) for Illinois pondweed, to $150,000 acre ($60,000/hectare) for hydrilla (Furse and Fox 1994). These values are based upon the cost of replacing these communities and their fish, if lost. The recreational value of these plant communities also was estimated, based upon the value of the recreational potential of the fish in the plant communities. Recreational values for several plant communities were: eel grass, $1,117/acre ($447/hectare); yellow water-lily, $1400/acre ($558/ha); Illinois pondweed, $2,735/acre ($1,094/ha); hydrilla, $3,047/acre ($1,219/ha); and bulrush, $13,695/acre ($5,478/ha). Adding the value of these 5 plant communities on the lake yields a value of more than $25 million, and these communities occupied about 25% of the lake's entire marsh area (Furse and Fox 1994).

Amphibians

Amphibians are very abundant in many ecosystems and many species are commonly observed on Lake Okeechobee. Amphibians can be extremely important in food webs due to their great abundance. A commercially important frog on Lake Okeechobee is the pig frog (*Rana grylio*), a close relative of the bullfrog (*Rana catesbeiana*). Pig frogs are somewhat smaller than bullfrogs, but have large legs and are more aquatic as adults. The lake also supports large numbers of leopard frogs (*Rana sphenocephala*), green treefrogs (*Hyla cinerea*) and Florida cricket frogs (*Acris gryllus*). Salamanders are common within the vegetation of the littoral zone; species include the greater siren (*Siren lacertina*), two-toed amphiuma (*Amphiuma means*), and the peninsula newt (*Notophthalmus viridescens piaropicola*).

Alligators

Alligators are common on Lake Okeechobee, and although it appears their populations are stable, there are data that suggest increased monitoring is warranted. Eggs in alligator nests on Lake Okeechobee have a hatch rate of about 40-60% (Woodward et al. 1989). This rate is lower than the 70-80% rates found in less nutrient-enriched lakes in Florida such as Lake Woodruff, Orange Lake, or Lake Monroe, but is higher than hatch rates found in more nutrient-enriched lakes like Lake Apopka and Lake Griffin (Franklin Percival, Univ. Florida, pers. comm.). Hormone levels, particularly plasma testosterone and thyroid hormones, in alligators on Lake Okeechobee also are significantly different than those found in alligators on other Florida lakes (Crain, et al. 1998, Guillette et al. 1999). Hormone disruptions are potentially serious and the precise reason for this discrepancy is not well understood, therefore continued research on the alligator populations is warranted to elucidate the causes of these differences.

Other reptiles

Lake Okeechobee hosts many turtles, snakes, and lizards. Common snapping turtles (*Chelydra serpentina*), softshell turtles (*Apalone ferox*), and several cooters and sliders are harvested commercially. In addition to large turtles, Lake Okeechobee has many small species such as musk turtles (*Sternotherus odoratus*, also called stinkpots) and Florida mud turtles (*Kinosternum subrubrum*).

Lake Okeechobee supports several species of water snakes (*Nerodia sp.*) that often are mistaken for the venomous cottonmouth (*Agkistrodon piscivorus*). Other snakes common in wetlands of the region include eastern ribbon snakes (*Thamnophis sauritus sauritus*) and South Florida swamp snakes (*Seminatrix pygaea cyclas*) and mud snakes (*Farancia abacura*).

Birds

Florida is world famous for its bird life, and was one of the cradles of the Audubon Society in the last years of the 19th century. Not only is Florida famous for resident birds, many of them endemic to the peninsula, but it also hosts myriad migratory birds. Of the approximately 800 species of birds that breed in North America, about half can be found in Florida with regularity. The Okeechobee region was one of the last holdouts for Carolina Parakeets and Ivory-billed Woodpeckers (Jackson 2004, Snyder 2004); apparently supporting the former until the 1930s, decades after the demise of parakeets often is presumed (Snyder 2004). Pranty (1996) lists 117 species of year-round residents, 35 summer (breeding) residents, 49 migrants, and 154 winter residents.

A notable feature of the bird species list for Florida is that there are more species of migrants than residents. Indeed, North America has a greater percentage of migratory birds than any continent (Welty 1979). The importance of Florida to migratory birds is further magnified because of its location. Birds coming to, or through Florida, originate from as far north as the Arctic Circle, and as far west as Alaska. For many neotropical migrants (some 250 species), Florida is a last fueling point before crossing the Gulf of Mexico, and the place they must recover from that flight on their way back north. Because of Florida's location, the concentration effect of birds, and the importance of birds finding ample food supplies while migrating, it is not

an exaggeration to say that Florida bird habitat has great importance to the bird populations of South and North America, as well as the Caribbean Islands.

Lake Okeechobee is part of the Everglades ecosystem and has a large influence on a variety of resident and migratory birds. Many wetland bird species are discussed below, but other birds use the lake as well. During low water, shore birds by the thousands occupy the mudflats of Lake Okeechobee. Raptors such as Peregrine Falcons follow the shorebirds. Black Skimmers winter on Okeechobee, with 300-500 hundred regularly loafing near the city of Okeechobee's fishing pier (Paul Gray, unpub. data). Brown Pelicans even nested on Lake Okeechobee one year (Smith and Goguen 1993) and the first Cattle Egret nest found in the United States (and perhaps the new world) was located on Lake Okeechobee in 1953 (Sprunt 1954). As discussed in the water quality section, insect blooms from the lake can feed vast numbers of migrating and resident songbirds, as long as water quality in the lake permits. Declines in North American birds are attributed partly to deterioration of bird habitats in breeding, wintering, and migratory areas (Terborgh 1992), and protecting the ecological integrity of Lake Okeechobee and South Florida is critical.

Waterfowl

Lake Okeechobee's variety of habitat types hosts a variety of waterfowl year round. Tens of thousands of wintering ducks can be found on the lake from September to April and unknown numbers of ducks use the lake as a stopover and foraging area as they migrate (Bellrose 1976). Diving ducks use the open center of the lake, dabbling ducks use the extensive marshes, and both kinds of ducks use submerged plant beds. During summer, Wood Ducks (*Aix sponsa*) and Mottled Ducks (*Anas fulvigula fulvigula*) are common breeders, and both also undergo their wing molt and flightless period on the lake in late summer.

Okeechobee's sub-tropical location yields ducks not found in most of the United States. Fulvous Whistling Ducks (*Dendrocygna bicolor*), unreported 60 years ago (Howell 1932, Kortright 1943), averaged about 330 ducks on mid-winter inventories between 1990 and 2000 and now are abundant breeders in the rice fields of the EAA (Wyss 1996). Black-bellied Whistling Ducks (*Dendrocygna autumnalis*) are becoming increasingly common in Central Florida, apparently from releases (Pranty 1996) and are becoming the second whistling duck species common on Lake Okeechobee. FWC banding crews captured a Masked Duck (*Oxyura dominica*) in Fish-eating Bay in the early 1990s and a pair of Ruddy Shelducks (*Tadorna ferruginia*) was photographed on the north end of the lake in 1991 (P. Gray, pers. obs.). The origin of these birds is unknown, but because of the great mobility of waterfowl and Florida's southern location, unusual birds often are observed.

Of the better-known ducks that inhabit Lake Okeechobee, the most abundant duck species spends its winters in the middle and is rarely encountered by most people. Between 1990 and 2000, an average of 70,000 Lesser Scaup (*Aythya affinis*) were counted in the pelagic zone of the lake (FWC, unpub. data). This annual survey does a one-time waterfowl count on major waterbodies across the United States during January. Because it is a single count, it is vulnerable to daily conditions and the numbers reported should only be considered as very general trends. Lesser Scaup are diving ducks, and presumably are feeding on clams and other invertebrates from the bottom. Many of the Scaup nesting in Alaska and western Canada journey across the

continent and southward to reach Florida (Bellrose 1976). Unfortunately, Scaup populations have been declining since the 1980s for reasons that are not understood (Austin et al. 2000).

The Ring-necked Duck (*Aythya collaris*) is the most harvested duck in Florida, and Lake Okeechobee hosts many of them. More than half the Ring-necks in the Atlantic Flyway winter in Florida, and Lake Okeechobee formerly was the single most important wintering area, hosting some 35,000 birds per year (one-fourth the flyway Population)(Bellrose 1976). Ring-necked Ducks are divers that use submerged vegetation communities, particularly *Hydrilla*. Winter counts on Lake Okeechobee have dropped to an average of about 7,000 per year between 1990 and 2000 (FWC, unpub. data). During the late 1990s, when water levels were kept deep on Lake Okeechobee and *Hydrilla* was virtually eliminated, the numbers of Ring-necked Ducks on part of Lake Okeechobee fell from an average of 5,807 from 1991-1995, to an average of 489 from 1996-2000, a 92% decline (FWC, unpub. data). Fish-eating Bay is surveyed independently of the rest of the lake and Ring-necked Duck numbers declined there from a 5-year average of 5,190 in 1991-1995 to 2,798 in 1996-2000, a 46% decline (no data from 1999).

An average of 700 dabbling ducks was detected on the entire lake between 1991-2000 (FWC, unpub. data). Considering there are a potential 90,000 acres of marsh habitat for these birds, this is extremely low and reflected seriously impaired habitat conditions. For comparison, Johnson and Montalbano (1984) detected an average of 11,886 dabbling ducks in Fisheating Bay alone, during 1981-82. High water levels effectively prevent dabbling ducks from using the lake because they rarely dive to feed and prefer water less than 12" deep (White and James 1978, Johnson and Montalbano 1984, Gray 1993). High water levels also prevent the growth of "moist soil" vegetation, which is important in producing the seeds many of these ducks prefer (Goodwin 1979, Fredrickson and Taylor 1982, Gray and Bohlen 1987).

Coots (*Fulica americana*) are not closely related to the ducks, geese and swans that are commonly considered "waterfowl," but share habitats with them and winter in large numbers on the lake. Like many of the waterfowl above, Coots declined 77% during the late 1990s on the larger part of the lake, from a 5-year average of 15,303 between 1991-1995, to an average of 3,508 from 1996-2000. In Fisheating Bay, coots increased from 13,805 in 1991-1995 to 19,546 in 1996-200 (no data from 1999), although lake-wide, there still was an overall downward trend (21%). Coots feed on submerged vegetation (Bellrose 1976, Montalbano et al. 1979, Esler 1990) and their declining numbers mirrored the declining acres of submerged vegetation on the lake.

The noticeable declines in waterfowl and Coots on Lake Okeechobee in the late 1990s were the result of high water damage to the plant communities and concomitant habitat deterioration. These declines are made more dramatic due to the fact that waterfowl populations in North America during the late 1990s were among the highest ever recorded (Williams et al. 1999). To maintain Lake Okeechobee's plant communities in healthy conditions for waterfowl, annual drawdowns to at least 13.5 feet are essential (between 12-13 feet would be better but the present regulation schedule, WSE, does not call for that). At 13.5 feet, submerged plant seeds can germinate in shallow, clear water, and moist soil plants can germinate on the mudflats exposed in higher parts of the marsh. The exposed mudflats also are a key habitat for Mottled Duck broods in May and June (Gray 1993).

Wading Birds

The 150 square miles (about 100,000 acres or 400 square kilometers) of marshes in Lake Okeechobee form a huge amount of habitat for wading birds. Recent maximum counts of feeding (non-cattle egret) wading birds have been as high as 20,000 to 50,000 birds in a single day (Zaffke 1984, David 1994a, Smith et al. 1995). In the 20-year period between 1979 and 1998, an average of about 17,600 wading birds were present in breeding colonies in the Everglades (Frederick and Ogden 2001), indicating virtually all of the waders in the Everglades could use the lake at the same time, if needed. During the 1930s and 1940s, a rookery of about 2000 Glossy Ibis (*Plegadis falcinelles*) nested on Lake Okeechobee, almost the entire US population (Sprunt 1954). Roseate Spoonbills nested on Observation Island in the early 1900s (Allen 1942), and although still frequently observed on the lake, they do not nest. Today, Okeechobee typically hosts 2000-5000 nesting wading birds (David 1994b, Smith and Collopy 1995). These data lend credence to the statement that the lake is important not only for wading birds in South Florida, but even for birds throughout the southeastern United States (Smith et al. 1995).

Wading birds nest during Florida's dry season as water recedes in wetlands and feeding efficiency increases. Reasons for increased efficiency when water drops include: the birds can wade effectively (taller wading birds can use somewhat deeper water); prey are concentrated (as compared with a deeper water column); and prey cannot hide or flee as effectively in the short water column. Wading birds take advantage of this improved feeding efficiency by raising their young during these abundant times. Even birds such as White Ibis, which do not prefer fish, but rather probe mud sediments for invertebrates, benefit from dropping water levels by gaining access to new feeding areas that formerly were too deep to reach. An experimental study on wading birds in the Everglades found feeding efficiency was greater in water 4 and 8 inches deep (10 and 19 cm) than in water 1 foot deep (28 cm) and that White Ibis, Wood Storks, and Snowy Egrets (three species that have suffered great declines recently) are especially sensitive to deeper water levels, abandoning 1-foot deep feeding areas even when prey densities remain relatively high (Gawlik 2002).

Not only is shallow water needed for feeding, but the timing and pattern of water recession also is critical to wading bird nesting success. As in all birds, breeding takes preparation. Birds put on weight to prepare for the rigors of breeding and tending young. Pair bonds must be formed, which requires courtship. Nests must be built and defended, eggs must be laid and incubated, and nestlings must be fed, sheltered and protected. All these activities take large amounts of energy (food), and large amounts of time, which in turn, reduces time for foraging. Great Blue Herons have been documented matching their breeding efforts to food availability (Butler 1993), as all wading birds appear to do. A model of wading bird breeding in the Everglades concluded that a 15% loss of short-hydroperiod wetlands could virtually stop all nesting success (DeAngelis et al. 2002). The model showed that short-hydroperiod wetlands were the first to dry in the spring and their loss removed an early concentration of prey, which delayed breeding initiation by as much as two months. Birds that delayed breeding for two months bred so late that the wet season could start and rising water levels would disperse prey to such an extent that nesting failed. This chain of events decreased overall nesting success in the model.

Numbers of nesting wading birds on Lake Okeechobee declined from 1957-1988 (David 1994a). A detailed study of the causes of this decline found wading bird nests dropped from 6000 during

a relatively low-water period (1987-1988) to between 725-1812 nests during the following 5 years of higher water levels (David 1994b). David (1994b) concluded that high water levels interfered with feeding and were a major factor in these declines. Subsequent studies have confirmed that high water levels and lack of "natural water recession rates," on Lake Okeechobee contribute to lower nesting success and reduced feeding efforts (Smith 1995, Smith and Collopy 1995, Smith et al. 1995). The large decline in wading birds nesting on Lake Okeechobee shows the same pattern of unhealthy ecosystem management found across the Everglades, where wading birds declined by an estimated 90%, although wetland acres have declined only by about 50% (Science Sub-Group 1993).

Lake Okeechobee does not begin to have significant amounts of habitat suitable to these birds (<6 inches deep) until it drops to at least 14.5 feet, when about 5% of the littoral zone is exposed (~5,000 acres). Because the breeding cycle for these waders requires at least a 3 month time period for completion, with abundant food supplies throughout (DeAngelis et al. 2002, very roughly a month for feeding, courtship, and nest building, a month for egg-laying and incubation, and a month to grow fledglings), it can be concluded that at a minimum, Lake Okeechobee should reach a suitable feeding level (at least 14.5 feet) before March 1, to allow 3 months of low water before the wet season.

Although reaching 14.5 feet by March 1 might meet the minimum requirements for wading birds, reaching 14 feet by this date would make about three times the habitat area available to them (Table 3). At lake levels from 14 feet to about 11.5 feet, 10,000-20,000 acres of habitat are available at any given time and this range can be considered the optimal range for wading birds. Because gates and structures control all water leaving Okeechobee, it is clear that management decisions can affect the suitability of habitat for wading birds.

Table 3. Average number of nesting wading birds on Lake Okeechobee during a period when water levels were lower and fluctuated more (1957-1978) and a period when water management intentionally kept the lake deeper and discouraged natural drawdown patterns (1979-1988)(from David 1994b).

Years	White Ibis	Great Egret	Snowy Egret	Glossy Ibis	Great Blue Heron	Total
1957-1978	2810	1172	416	235	134	4767
1979-1988	745	530	440	40	120	1928

<u>Snail Kites</u>

Lake Okeechobee is designated "Critical Habitat" for Snail Kites by the United States Fish and Wildlife Service (USFWS 1998) because it is one of the most important nesting and feeding habitats in Florida for this endangered bird, whose breeding success can be extremely variable (Snyder et al. 1989, Rodgers 1998). Lake Okeechobee can host between 20-40% of the State's population in any given year, and counts during the 1970s and 1980s averaged around 45 birds (range 3-214)(Rodgers et al. 1988). The numbers of nests dropped from 35 nests in 1996, to 3 in 1997, to 6 in 1998, to none from 1999 through 2003 (Martin et al. 2003). Snail Kite populations plummeted throughout Florida between 1996 and 2003, increasing the need for Lake Okeechobee to function as kite habitat. In the "Snail Kite Demography annual report" to the United States Fish and Wildlife Service (Martin et al. 2003), it was stated that,

> The results presented in this report, suggest that the snail kite population in Florida is going through an alarming declining phase. In particular, the population size of snail kites in Florida appears to have progressively and substantially decreased since 1999. In 1999 the kite population was estimated at 3577 individuals, whereas in 2003 this estimate had dropped to 1610 individuals.

Further,

> However, we can confidently assert that Lake Okeechobee which was previously one of the most productive breeding sites of the system (from 1985 to 1995), has been severely altered, to the point that almost no fledglings have been produced since 1996 (Figure 3). Lake stages have been either too high or too low to sustain viable breeding habitat conditions post-1996. Lake Okeechobee was a critical "hub" to the network of habitat for foraging and nesting in the early 1990's (Bennetts and Kitchens 1997).

Much of the vegetation in Moonshine Bay and other parts of the lake disappeared during the high water of the late 1990s and snails and kites simply had no habitat in these areas. The drought of 2001 and a good drawdown in 2002 (below 12 feet) allowed the recovery of the marshes on Lake Okeechobee such that in 2003 a few kites nested near Henry Creek on the northeast side and near Moore Haven on the southwest. Significant numbers of Kites did not return to Lake Okeechobee until the 2005 breeding season (P. Gray, pers. obs.).

Because lakes retain water after wetlands dry out, the conservation value of Lake Okeechobee, and the Kissimmee Chain of Lakes as a nesting and feeding refuge during droughts is often emphasized (1998). During the drought of 2001, only 49 Snail Kite nests were found in Florida, with 48 of these on Lake Tohopekaliga, East Lake Tohopekaliga, and Lake Kissimmee (Kitchens et al. 2002).

Mammals

There are not a great number of mammal species in Florida that can utilize the vast marshes of Lake Okeechobee. Many common mammals such as raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), spotted skunks (*Spilogale putorius*), eastern cottontail rabbits (*Sylvilagus floridanus*), wild hogs (*Sus scrofa*), white-tailed deer (*Odocoileus virginianus*), and others can be found along the edges of the lake, and out into the marshes during periods of low water.

Okeechobee does host river otters (*Lutra canadensis*), the large fish-eating member of the weasel family. Although otters have been suspected of harming game fish populations, they also have been credited with benefiting game fish by removing non-game competitors (Toweill and Tabor 1982). Otters feed on a variety of invertebrates (especially crayfish), turtles, amphibians (especially frogs), snakes, birds and mammals. Otters use land extensively and therefore probably are somewhat restricted from large areas of Lake Okeechobee's marshes during high water periods.

Round-tailed muskrats (*Neofiber alleni*) are another notable Okeechobee resident and are more closely related to voles (mice), than muskrats (Brown 1977). They are the only species in their genus, and unique in the world. Like muskrats, they are largely aquatic in habitats, primarily vegetarian, and make lodges of grass and marsh vegetation over the water. During low water, they maintain a network of burrows and runways. They are slightly smaller than the unrelated house rats (*Rattus* spp.). Their huts are about 1-2 feet tall, 1-2 feet wide, with a small internal chamber and usually have two underwater tunnel entrances (LeFebvre and Tilmant 1992). Round-tailed muskrats presently are listed as a "Species of Special Concern" in Florida.

Chapter 2

Water Level Management

Photo: SFWMD

WATER LEVEL MANAGEMENT

INTRODUCTION

Historically, Lake Okeechobee was connected to a diverse array of habitats. The inflows from the northern and eastern regions of the lake, around the Kissimmee River, Taylor Creek, Henry Creek, and eastward to Port Mayaca, were grassy, low-lying prairie and flatwood regions that flooded widely each summer. The border of the lake had a fringe of bald cypress swamp (*Taxodium distichum*)(Harshberger 1914). To the northwest, the lake seamlessly melded into marshes flowing from Lake Istokpoga, containing sawgrass peat marshes, tree islands, and other Everglades habitats. This region formerly was called Flathlopopkahatchee Marsh and has since been renamed Indian Prairie. The braided Fisheating Creek, a watershed of prairies, flatwoods, and cypress forests, fed Okeechobee from the west. Most famously, water flowed southward from the lake toward the Everglades, not through a river channel, but rather across a broad peat rim, extending from Port Mayaca on the east to near the Caloosahatchee River on the west. This rim had channels, termed “dead rivers” by the locals (Lodge 2005), extending short distances before ending in vegetation. The southern rim had a fringing custard apple swamp (*Annona glabra*) that extended as far as three miles southward from the lake. Beyond the custard apple grew stands of elderberries (*Sambuca canadensis*) and coastal plain willow (*Salix caroliniana*), which then led into a vast sawgrass (*Cladium jamaicensis*) prairie (Snyder 1994).

Today, Lake Okeechobee is completely surrounded by the Hoover Dike and almost all water flowing into, and out of the lake is controlled by human decisions about when to open or close various gates and locks. Lake Okeechobee also is the single most important element of the water management system in South Florida. During wet periods, excess water is shunted to the lake to protect human interests. When Lake Okeechobee gets extremely deep, it threatens the integrity of the Hoover Dike and massive amounts of water must be shunted to the coast, which harms the estuaries, or to the south, harming the Southern Everglades. During droughts, people draw water from the lake, often to harmfully low levels.

In an attempt to meet varied, and often conflicting, water requirements, the SFWMD and the USACE jointly operate the lake’s water control structures according to a regulation schedule that defines target water levels for different times of the year (USACE 1999b). The goal of the regulation schedule is to achieve water levels in Lake Okeechobee that balance the competing needs of water supply, flood protection, environmental health, recreation, and navigation. Environmental health includes not just the health of the lake but also the health of the downstream ecosystems that are greatly affected by lake discharges.

HISTORY OF WATER MANAGEMENT

In a pristine state, virtually all of Lake Okeechobee’s outflows flowed to the Everglades and the lake commonly reached 18 to 21 ft above mean sea level (msl)(Pesnell and Brown 1977). The first project that greatly affected these conditions was construction of a canal connecting the lake to the Caloosahatchee River in the late 1800's. By 1921, the North New River, Palm Beach, Hillsboro, and Miami Canals connected the lake to the Atlantic Ocean, followed by the St. Lucie Canal in 1924 (Hannah and Hannah 1948, Pesnell and Brown 1977). These high-capacity

drainage canals forever lowered the lake's stages from highs of over 20 ft down to highs between 16 to 18 ft, depending on variations in rainfall and operations.

Hurricanes in 1926 and 1928 killed thousands of people in Moore Haven and Belle Glade and generated arguments about the management of lake levels. In response to charges that the lake had been left too deep in front of the advancing storm in 1926, Florida Attorney General Johnson noted, “If every lock on the lake had been wide open for thirty days before the storm, it would not have saved Moore Haven, but it would have meant flooding the lower Glades.” The Broward and Dade Drainage Districts argued against releases from the north and communities around the lake argued to drain more water to the south. Some people in the lower everglades noted that if the lake only reached 15 feet during wet times, there would not be enough water remaining during dry times to protect the everglades from the unstoppable muck fires which were becoming common (Hannah and Hannah 1948). Similar arguments continue today.

Construction of the Hoover Dike on the southern rim of the lake was started in the 1930’s to help protect people from hurricane surges and keep the Everglades soils south of the lake dry enough to farm. Ecologically, the dike severed Lake Okeechobee’s broad connection to the Everglades. Extremely wet hurricanes in the 1940s created calls for further drainage work throughout south Florida and as part of the Central and Southern Florida (C&SF) Project, the Hoover Dike was extended entirely around Lake Okeechobee, being finished in the 1960s. The action cut Lake Okeechobee off from more surrounding wetlands, and further reduced its size (Steinman et al. 2002). With lake levels lower than before, marsh vegetation inside the dike moved to lower elevations, between 11-15 feet (Pesnell and Brown 1977). At approximately 100,000 acres, the “relocated” marsh is not only smaller, but also has less biological diversity (Steinman et al. 2002).

The C&SF project also transformed water movement patterns in Lake Okeechobee’s watershed by creating more and larger canals, and more efficient drainage. Water control structures were placed on major lakes in the Kissimmee Chain of Lakes and the larger lakes were lowered (this region is about 40% of Okeechobee’s watershed). The Kissimmee River was channelized to more efficiently drain the river and its watershed. Lake Istokpoga (the Istokpoga watershed is about 10% of Okeechobee’s watershed) also had a structure placed upon it to control water movement, and the canals through Indian Prairie were enlarged such that almost the entire Flathlopopkahatchee Marsh region was drained. Today, Fisheating Creek remains the only free-flowing part of Okeechobee’s watershed that has not been altered significantly by public works projects.

Increasing drainage in a watershed changes water movement patterns. Without drainage, water that fell on the land moved slowly through wide sloughs, toward rivers and lakes. During this slow transit, large amounts of transpiration, evaporation, and percolation into groundwater, occurred. In a drained system, water moves more quickly through ditches, experiences less time for evaporation or percolation, and therefore flows off the land in greater volumes. In the Indian River Lagoon region, which is more highly drained than most of the Okeechobee watershed, it is estimated that runoff now is about 40% greater than historically due to the drainage effect (USACE 2001). Rapid drainage affects the dry season as well. Because water flowed from the system more quickly during the wet season, less water remains for dry season flows. For

receiving bodies such as Lake Okeechobee, these patterns mean faster water level rises during summer and faster water level drops during winter.

Although building the C&SF project installed a system of gates and canals that allowed more human control over water levels in Lake Okeechobee, the altered drainage patterns in the watershed added new challenges. The likelihood of increased summer flows, resulting from drainage and the lowering of major lakes (leaving fewer places to store storm-surge water), means lakes, including Okeechobee, need to be lowered more than before to be able to store peak flows (flood protection). The likelihood of decreased dry season flows means lakes need to be kept filled as much as possible during the dry season to prevent drought impacts to downstream natural systems and human water users. Management of water levels in Lake Okeechobee and other natural systems in South Florida tends to stabilize water levels and often eliminates natural patterns resulting seasonally and from variation in rainfall.

In 1978, the Lake's regulation schedule was increased from the 13.5-15.5 foot msl range (1973-1978) to 15.5-17.5 ft. msl (Milleson 1987). The highest marsh elevations inside the Hoover Dike are about 15 msl, and after 1978, lake stages routinely exceeded 15 ft msl, effectively keeping 100% of the marsh inundated. By 1981, substantial changes in plant communities were evident in the Indian Prairie transect, including elimination of the spikerush community, expansion of cattails, and domination of the grass community by the exotic species, torpedo grass. In 1982, measurements along the Moore Haven transect showed fewer changes, apparently due to a drought-induced drawdown that year (Milleson 1987).

In 1988, after 10 years of high water, the Lake Okeechobee Littoral Zone Technical Group concluded that the regulation schedule (15.5-17.5 feet) in Lake Okeechobee had induced changes in the littoral zone including: "loss of wading bird feeding habitat, decline in willow, and loss of moist soil annual plant production" (LOLZTG 1988). LOLZTG concluded that the prolonged high water had created an emergency condition and recommended "lowering the present schedule to improve fish and wildlife habitat in the littoral zone." In addition to in-lake problems, the high water levels required frequent, large-volume discharges of fresh water to the St. Lucie and Caloosahatchee Estuaries after rain events to protect the structural integrity of the Hoover Dike. These discharges frequently caused the brackish estuary water to turn fresh, with concomitant problems to those ecosystems.

Under pressure from various interests, the Corps re-evaluated the Lake's regulation schedule and implemented "Run 25" (15.65-16.75 feet) as a trial run in 1992. In 1994, the Corps had finished its Environmental Assessment of lake regulation alternatives that concluded Run 25 would decrease harmful releases to the estuaries because its upper level was not as close to the Hoover Dike stress zone. Run 25 still maintained lake levels above 15 feet and continued to inundate the marshes almost continuously. A "Run 22aze" schedule was analyzed that would have kept lake stages between 13.5 and 15.5 feet, but was opposed by water supply interests who favored deeper water to maintain more water storage in the lake. The Corps adopted the deeper-water, Run 25, in 1994 and the lake suffered extreme harm during the ensuing 5 years. In 1999, the Corps issued an Environmental Impact Statement on lake level management (USACE 1999b) that recommended adopting a schedule called "Water Supply and Environment" (WSE), which

could keep lake levels closer to the 13.5-15.5 foot range. The Corps adopted the WSE schedule in 2000.

Before WSE could be officially approved however, the Governing Board of the SFWMD concluded conditions on Lake Okeechobee were so severe that an emergency drawdown was needed to rejuvenate the lake. On April 25, 2000, water releases were initiated with the goal of dropping the lake from its level of 14.7 feet, to 13 feet. Massive releases to the estuaries were accompanied by high evaporation (the driest May in history) and water withdrawals for irrigation. By May 21, 2000, the lake had reached the 13 foot goal and releases terminated. Dry weather continued, and in the ensuing month, evaporation and irrigation releases dropped the lake down to about 12 feet, where it essentially stayed all summer. In spite of a weather prediction of a "wetter than average wet season" the summer rains were not sufficient to raise the lake and during the ensuing "worst drought on record," the lake dropped to a new record low of 8.97 feet. (see SSM and MFL sections for Audubon recommendations for drought management).

After water levels returned to normal after the drought, experience in 2002 and 2003 demonstrated that WSE tended to allow the lake to remain too deep, leading to marsh harm and large estuary releases. In 2003 and 2004 the agencies enacted "deviations" from the schedule to try to keep the lake closer to a 13.5'-15.5' line. While WSE remains the present regulation schedule, the agencies are scheduled to start a process in 2005 to develop a new schedule.

LAKE OKEECHOBEE AND ITS EFFECTS ON DOWNSTREAM ECOSYSTEMS

As mentioned previously, in a pristine state almost all of Lake Okeechobee's outflow went to the Everglades. Today, most of the outflow is diverted toward the St. Lucie and Caloosahatchee estuaries. The following sections briefly describe the effects of increased Okeechobee flows to the estuaries, and decreased flows to the Everglades.

St. Lucie and Caloosahatchee Estuaries

The Central and South Florida flood control project (C&SF project) was designed primarily to drain South Florida. To drain Lake Okeechobee engineers had the option of draining the water on its natural route, south through the Everglades where it must travel about 100 miles at a slope of about 2 inches per mile, or drain it through large canals to the east and west coasts at roughly twice the slope and half the distance, with no vegetation slowing the water flow. They chose the latter option and connected the vast waters of Lake Okeechobee to estuaries that formerly did not receive this water (Fernald and Purdum 1998).

Estuaries are phenomenally productive systems and occur in areas where fresh water and ocean water mix, producing brackish water. The Indian River Lagoon is considered the most bio-diverse estuary in North America (USACE 2001). The value of the fishery supported by the Indian River Lagoon is estimated at about a billion dollars a year (Virnstein and Morris 1996). Estuaries have values that expand beyond their borders as well; most sport fish and approximately 65% of the commercial fish in the South Atlantic area are dependent on estuaries during some part of their development (Bollman 1975). In addition, listed species such as manatees (*Trichecus manatus*) and sea turtles (Cheloniidae and Dermochelyidae) move into and out of estuarine systems.

Salinity is considered a "master" ecological variable in controlling estuary community structure and food web organization. Both daily (tides) and seasonal patterns change salinity gradients and influence what organisms will persist in what areas of the estuary (Haunert and Steward 1994). Freshwater releases from Lake Okeechobee can completely change these gradients and adversely affect the flora and fauna of the estuary. During a release to the St. Lucie estuary in 1978 (of 2,500 cubic feet per second), the salinity of the estuary changed from a range of 11 to 33 parts per thousand (ppt), depending on location, to a salinity of less than 5 ppt throughout (Haunert and Startzman 1985). This drop in salinity was accompanied by a 44% reduction in the number of benthic organisms, especially the bivalve (clam) *Mulina lateralis*, which cannot tolerate extended periods of low salinities. Similarly, seagrass beds can be harmed, or killed entirely, by fresh water. As salinities declined, mobile estuarine species of invertebrates and fish either emigrated or perished, and freshwater species immigrated (Haunert and Startzman 1985). Additional effects of the release included increased nitrogen in the estuary and a bloom of cyanobacteria belonging to the genus *Anabaena* (toxin forming algae).

In today's altered systems, the watersheds of the estuaries themselves also are contributing water and nutrients. For example, it is estimated that watershed drainage has added about 40% more runoff water to the St. Lucie estuary than during pre-drainage conditions (USACE 2001). As with Okeechobee, the extra volume results from faster transit time that no longer allows significant evaporation or percolation, and allows water to reach the estuary at different times than natural. More water flows during the wet season, with less water remaining during the dry. Therefore, before any Lake Okeechobee water is released, the estuary is already impacted.

The Caloosahatchee estuary is somewhat different in its needs than the St. Lucie. Its watershed also is drained, however the Caloosahatchee has a very wide mouth and salt water can move far upstream during no-flow conditions, converting freshwater areas (with freshwater plants) into brackish or salt water systems. During dry periods, Lake Okeechobee releases to the Caloosahatchee should amount to no less than 300 cfs, and more preferably between 500-800 cfs. A flow of 600 cfs translates to about 36,000 acre-feet of water from Okeechobee in one month, or about an inch of Lake Okeechobee water per month. It is estimated that under present management (the WSE schedule) the Caloosahatchee estuary will have water shortages in about 40% of the months (SFWMD 2002).

When Lake Okeechobee is managed with high regulation schedules, the estuaries tend to suffer harm more often than at lower levels. An "average" summer can see increases in lake water levels of 1 to 2 feet. When the summer starts with lake levels at 15 feet or above, the increase in water levels can threaten the structural integrity of the dike and necessitate massive releases to the estuaries. Conversely, when lake levels are lower at the start of the wet season, a 2-3 foot rise during the summer does not create dike stress, and subsequent releases can be done in a slower, less harmful manner. This pattern is better for the lake and the estuaries.

Everglades

Before the system of dikes, ditches, and levees was constructed in South Florida, Lake Okeechobee was the wellspring of the Everglades (Hannah and Hannah 1948). With no east or west estuary connections, the lake's water flowed over, or through the muck soils on its south end, sending water southward. The estimated 866,000 acre-feet of water that flowed southward

from Lake Okeechobee in an average year has been reduced to about 664,000 acre-feet of water (Steinman et al. 2002). Not only is this less water than before, but about 65% of it goes to human use, mostly agricultural irrigation. Of the total southward flow, about 25% (165,000 ac-ft) goes to the Everglades (Steinman et al. 2002), some 1/5th of the historic flow.

Under the present WSE schedule, an estimated 157,000 acre-feet of water is predicted to enter the Water Conservation Areas (WCAs) each year, which is more than entered when Run 25 was the regulation schedule (USACE 1999b). While the Everglades need more water to regain their historic hydropatterns, the lake's water presently is too high in phosphorus for the health of the Everglades. Sending more polluted water is predicted to cause more than 500 acres of sawgrass communities to be overrun by cattails annually (USACE 1999b). Additionally, about 10,000 acres of plant communities are projected to suffer harmfully high phosphorus levels. These problems are projected to continue until additional Stormwater Treatment Areas (STAs) are constructed. Decades of problems with lake, estuary, and Everglades management clearly demonstrate the need for new solutions to water storage and distribution in South Florida.

LAKE OKEECHOBEE'S WATER BUDGET

The irony of water management in south Florida is that there is more water runoff than humans presently use, yet water shortages occur. This situation stems primarily from the 1950s-era C&SF goal of substantially draining south Florida (USACE 1999a). Now that large amounts of fresh water are "discharged" (dumped) to the ocean most years, there frequently is not enough remaining in the system for later use. The inability to store enough water in an environmentally sound manner is the present system's largest deficiency.

In an average year, Lake Okeechobee receives enough rain and inflow to raise it about 7.5 feet (Table 4)(note: this discussion of the water budget uses rounded numbers for simplicity). This water does not come in at once, but is spread over the entire year, thus the lake does not actually rise 7.5 feet each year. Roughly 5 feet of this water will evaporate, leaving 2.5 feet of water in the lake. On average, irrigation and municipal demands use 1 to 2 feet of lake water per year, leaving an "excess" of about 1 one foot of water that must be discharged (approximately 470,000 acre feet).

Water that needs to be discharged from Lake Okeechobee to prevent it from becoming too deep is termed a "regulatory release" and although these releases can go to the Everglades or estuaries, the largest volume goes to estuaries. Estuary releases generally are made in 10-day pulses ranging in size from I to III, with Level I pulses releasing about 0.1 feet of Okeechobee water and creating minimal estuary stress. Level III pulses release about 0.2 feet of Okeechobee water and creating substantial stress. Therefore, to drain an extra foot of water from Lake Okeechobee, it would take about 10 Level I pulse releases over 100 days. During the dry season there usually are not large flows going to the estuaries, which makes it a good time to attempt releases. Because the dry season lasts more than 200 days (from November to June), in an "average" year, with the present C&SF system, the agencies can schedule 10 Level I releases to the estuaries at times that can minimize disruption. Therefore, adaptively managing Lake Okeechobee releases during normal years should be able to meet human water supply and flood control needs, while protecting natural systems from harm (SFWMD 2002a).

Table 4. Water budget of Lake Okeechobee expressed as feet of water level change, during average, wet and dry years.

Rainfall year	Total Inflow	Evaporation	Irrigation use	Urban use	Releases	Result
Average	7.5 feet	5 feet	1-1.5 foot	0-6 inches	~1 foot	Moderate estuary stress
20% driest years	<4.5 feet	>5 feet	1.5 feet	0-6 inches	0	At least a 2 foot deficit
20% wettest years	>10 feet	<5 feet	1 foot	0 inches	~4 feet	Severe estuary and/or lake harm

*Assume the lake area is 470,000 acres. Inflow data set from Trimble et al. 1997 and cover a 66 year period.
*Outflow data for agriculture and urban uses are estimated from the "Lake O Regulation Schedule Study" Appendix B, page B-5 "Total EAA/LOSA Irrigation Demands and Demands Not Met for the 1965-1995 simulation period."
*Evaporation figure from William Walker's DRAFT model of Lake O phosphorus dynamics—LOTAC committee

However, annual rainfall in south Florida varies greatly. In the driest 20% of the years, approximately 4.5 feet or less of water enters the lake (Table 4). Assuming evaporation remains at 5 feet (it usually is higher during dry periods), the lake loses at least 0.5 feet of elevation before any human water use occurs. Agricultural demand increases during dry periods, requiring about 1.5 feet of lake water (SFWMD 2002d). If the municipalities, the Everglades, or estuaries require water deliveries from the lake as well, the lake drops even further. Therefore, during a moderate drought (1-in-5 years), Okeechobee's water levels will drop at least 2 feet. During the worst drought on record, between April 2000, and May 2001, Lake Okeechobee dropped from about a 15 feet elevation, to a record low of 8.97 feet. This translated to a 6-foot drop and Lake Okeechobee losing 55% of its water volume in just over one year (about 2.2 million acre-feet).

Between 1978 and 2000, Lake Okeechobee was kept relatively deep to maximize storage and avoid water shortages during droughts. This strategy caused serious harm to the lake from chronic deep water, harm to the estuaries from frequent and large releases, and apparently weakened the Hoover Dike due to water piping through and under it. It also did not prevent rationing events; there still was not enough water stored.

In the wettest 20% of the years, the lake receives more than 10 feet of inflow (Table 4). Assuming the same water loss occurs from evaporation and discharge (5 feet), and human use is low (~1 foot), then about 4 feet of water must be released to the estuaries. It would take 40 Level I pulses over 400 days to drain this water to the estuaries. In reality, during these wet years there is so much rain in the watershed of the estuaries themselves, and so much drainage, that the estuary suffers harm from its own watershed's outflows. At these times, adding Okeechobee water greatly exacerbates these problems and releases often are restricted. In these years, Lake Okeechobee gets harmfully deep, and downstream releases are also required, harming both systems. Between 1978 and 2000, when the lake was kept deep most of the time, these types of discharges were common and extremely problematic.

Considering that the above 20% dry and wet season scenarios describe significant problems in 40% of the years, and allude to lesser problems in other years, it is clear that with the present C&SF system, Lake Okeechobee cannot hold enough water during wet years to fully protect south Florida from flooding, or during dry years to meet irrigation and other water supply demands. Not only is the lake inadequate to meet these human needs, but huge areas of habitat in the lake and estuaries are harmed in the process. For the SFWMD and USACE managers trying to "balance" all the competing needs around Lake Okeechobee, these are almost intractable problems.

The Comprehensive Everglades Restoration Project (CERP) was designed to correct these problems, and unless constructed, problems will continue. One of the principal goals of CERP is to increase water storage capacity in south Florida. Having more storage can help wet year problems by storing problem water in locations that are not harmful, and help dry year problems by having water stored in more locations. Instead of discharging (wasting) extra water, water will be saved and either sent to the Everglades or other ecosystems in a healthy pattern, and/or used by humans for useful purposes.

EFFECTS OF HYDROPATTERN ON WETLANDS

Many factors influence the distribution and species composition of wetland plant communities including hydrology, slope, nutrients, substrate type, exposure to wave action or current, competition for resources, and herbivory. Of these, the single most important factor usually is considered water level fluctuation (Gosselink and Turner 1978, Weller 1978, Mitsch and Gosselink 1986, Keddy and Fraser 2000). Changing water levels interact strongly with fundamental patterns such as seed germination, plant distribution (depending on hydroperiod tolerance and/or preference), organic material decomposition, fire frequency, animal movement and use, and other factors. In Florida, these changes follow a strong pattern of wet seasons that lasts about 4-5 months (June-September) and usually have rising water levels, and a 7-8 month dry season (October-May) when water levels tend to decrease.

For example, plant decomposition is strongly influenced by hydrology, which in turn influences nutrient cycling and succession. When a plant dies on land, it has an atmosphere of 20% oxygen surrounding it. In this environment, decomposers such as worms, snails, insects, bacteria, fungi, and other organisms, can efficiently consume it and return its nutrients to the food chain. Conversely, a plant that dies and falls in the water enters an oxygen-poor environment. Decomposition in water is so inefficient that in areas that rarely dry, partly decomposed organic material builds up and can eventually fill the water body with peat, changing the lake into a marsh or bog. This process formed the organic soils of the islands on the southern end of Lake Okeechobee and the peat soils of the Everglades. Much of the nutrient-poor nature of these systems resulted from the sequestering of nutrients in peat soils (Snyder 1994).

Seeds also are sensitive to water level patterns. Many seeds germinate only on exposed mudflats and will subsequently grow in water as it rises (Fredrickson and Taylor 1982). Other aquatic plant seeds can germinate and grow under the water, but only with adequate sunlight (sunlight is needed both for seed germination and seedling growth), which in Okeechobee's turbid water, requires water levels to drop substantially (Havens 2003, Havens et al. 2004). Plants also

germinate seasonally, requiring optimal conditions during specific months, usually in spring (Fredrickson and Taylor 1982).

High water periods also affect plant community structure. Wave action can uproot shoreline plants, move organic material, and set back succession (Keddy and Reznick 1986, Havens et al. 2001). Continuous deep water also tends to reduce the occurrence of short-hydroperiod plant communities (Milleson 1987, Hill et al. 1998, USACE 2001).

The importance of maintaining natural water level fluctuations can be seen through recent management of Lake Istokpoga. This lake formerly fluctuated over a multi-year range of about 7.5 feet, averaged about 3.25 feet per year, and normally had about 7 months of declining water per year. Now, it fluctuates over about a 1.25 foot range both in multi-year and annual timeframes, and has about 2 months of declining water. The reduction of the magnitude, duration, and timing of water levels, resulted in dominance by a small number of long-hydroperiod "tussock-forming" plant species in near-shore (1-3 foot deep) areas, the water column filling with organic material (peat succession), and short-hydroperiod plant communities virtually disappearing (Champeau et al. 2000). These problems also have been experienced in the Kissimmee Chain of Lakes due to stabilized water levels (USACE 2001b).

Keddy and Fraser (2000) propose that the greatest diversity of lakeshore plant communities occurs in locations exhibiting both with-in year, and between-year, variations assuming the variation is not too extreme. For Lake Okeechobee to maintain diversity, it requires mean annual changes of 2-3 feet, and multi-year ranges of 6 feet or more. Unfortunately, the lake has recently been affected by chronically high water levels, and is threatened in the future, as human water demand increases, by chronically low water levels, both of which could reduce annual and multi-year variation.

Impacts from prolonged low water levels

Periods of low water and drying are beneficial to wetlands. However, extended periods of low water or drought can unduly disrupt normal cycles and degrade wetland habitat. In the current water management system of South Florida, many downstream users are dependent on water supply from Lake Okeechobee. These demands increase during drought, and can lead to extended periods of low lake stage. The Lower East Coast Regional Water Supply plan also projects these demands will increase significantly as Florida's population continues to grow (SFWMD 2000).

Lake Okeechobee's wetlands can experience many ecological problems during extended periods of low water or drying. The organic soils on the south end of the lake that form Tory, Kreamer, and Ritta Islands can oxidize, with permanent loss of soil and possible harm to populations of the endangered Okeechobee Gourd. Submerged plants may dry and perish, diminishing this habitat within the lake and decreasing sediment stability. Also, exotic plant species like torpedo grass and melaleuca expand more rapidly, out competing native plants and requiring expensive, time consuming chemical and mechanical removal.

There are also many negative impacts on wetland fauna during extended droughts. Bulrush stands become too dry for fish spawning or shelter, and small fish suffer heavy mortality from

predation in the lake's open waters. Waterfowl and wading birds cannot feed and wading birds cannot nest (because of low prey availability and increased predator access to nesting trees). The federally endangered Everglade Snail Kite cannot breed during the drought and may suffer after the drought due to decreased numbers of apple snails. Apples Snail appear to be able to survive drying for as much as 3 months (Darby et al. 1997) but the drought on Okeechobee dried the entire littoral zone for longer than this period, severely impacting snail populations. Alligator (*Alligator mississippiensis*) nesting decreases or ceases altogether during drought (nests on Okeechobee declined from an estimated 1,174 in 2000, to 32 in the 2001 drought) (Lindsey Hord, FWC, pers. comm.). Wetland-dependent organisms including turtles, frogs, marsh rabbits, snakes, crayfish, round-tailed muskrats, and others suffer huge population declines. The ability of various populations to recover after droughts is inhibited somewhat by the separation from adjacent habitats created by the Herbert Hoover Dike. Population declines become more severe as the drought increases, and take longer to recover from. Reduced population numbers, and isolation of some populations may also reduce genetic diversity, causing other problems.

During droughts, additional impacts occur when the lake is used to supply irrigation or urban needs, lowering levels more than normal. After the drought, agricultural wastewater can be pumped into the lake, increasing loads of nutrients, pesticides, and heavy metals (this is termed “backpumping” because much of the water is pumped from farms downstream of the lake), and harming drinking water of lake-dependant communities. The levels of pollutants in the backpumped water often exceed permit criteria or other government standards, yet these restrictions are often overlooked because of the "emergency" nature of this action.

Importance of the Spring Recession

Natural drawdowns occur annually in Florida during the dry season and usually lower lake levels around 1-3 feet. During droughts, that recently have occurred in 10-year cycles in Florida, the lowest stage during the drought may be as much as 10 feet below flood levels. The pattern of small annual drawdowns, and occasional large drawdowns are part of a natural cycle to which Florida’s wildlife and plants are not only adapted, but in many cases, dependent. Human modification of natural systems can create unnatural hydrologic patterns including mistimed, extended, and extreme drawdowns.

Wading birds require efficient feeding to be able to breed and feed young. Smith (1994) noted, “foraging birds were less common during late surveys when surface-water levels were rising than during early surveys when water levels were declining. This was true despite the fact that areas of suitable depth were equally or more abundant late in the season.” Smith’s observation that declining water levels are essential for wading bird breeding has been documented in myriad studies (Zaffke 1984, Frederick and Collopy 1989, David 1994b, Smith et al. 1995, Gawlik 2002). Declining water levels increase feeding efficiency by concentrating aquatic prey (fish and crustaceans) into smaller areas, leave fewer spaces for the prey to hide or escape, and provide optimal “footing” for wading birds to maneuver. For species such as White Ibis, which probe the bottom, decreasing water levels make new areas accessible for foraging each day. Water level declines in the range of 6-12 inches per month appear to have the greatest advantage in the Everglades (Fredrick and Collopy 1989) and on Lake Okeechobee (David 1994b). If water levels drop too quickly, prey species may die from exposure or wetlands may completely dry. If water levels are temporarily increased, even short periods of poor foraging can cause birds to abandon

their nests, disrupting chances for successful breeding in that season (Frederick and Collopy 1989).

The spring recession drives other wetland processes. “Moist soil” plants produce seeds that are important to many kinds of wildlife and of particular value to migrant waterfowl and other seed eating birds the following winter. Declines in acreage of mudflats created when seasonal drawdowns do not occur (Sincock and Powell 1957, Milleson 1987, LOLZTG 1988), limits seed production and results in reduced food supplies for migrating and wintering species. In addition, low water, during and after the recession allows for organic soil decomposition and fires.

PRESENT PROGRAMS AND THEIR CONTRIBUTION TO HELPING

The system of drainage canals and storage areas in south Florida are not adequate to store or move enough water to prevent flooding during wet periods, and are not adequate to store enough water to meet human needs during dry periods. Ironically, in order to address the problems during both wet and dry periods, the same solution is needed: build more storage in the system. With more storage, water can be diverted during wet periods to prevent flooding, and extra water can be stored for dry-period uses. Increased storage is one of the central goals of the Everglades restoration (CERP).

However, Everglades restoration will not be completed until at least 2020. In the interim, there are management actions that can be undertaken to manage the system as well as possible, given its limitations. This section is divided into short-term goals and long-term goals.

Short-term actions: WSE, SSM, and MFLs

<u>Lake Okeechobee Regulation Schedules</u>

The water level management plan for Lake Okeechobee is called the “Regulation Schedule.” The current Regulation Schedule is called Water Supply and Environment (WSE) and lays down the rules to operate Lake Okeechobee under normal and high water levels. In the simplest sense, WSE is a graph that has the ideal water level plotted against time of year (USACE 1999b, Figure 5.2.5-1). The various inlets and outlets around the Lake are opened or closed each day based on the water level in the lake, the day of the year, and the weather forecast. If water is very deep, WSE will call for large releases. If growers need water, it is released according to needs. If water is low, small or no releases may occur. If water falls very low due to severe drought, then the lake is managed by a drought (water rationing) plan entitled Supply Side Management (see SSM section below).

There are two general kinds of water releases: “water supply” and “regulatory.” Water supply releases include human needs in the form of agriculture, golf courses, cities and public utilities, but include the environment too. For example, if the Caloosahatchee estuary needs fresh water to protect it from high salinity levels, a water supply release is made to the estuary. Or, Lake Okeechobee’s marshes may need a drawdown and a water supply release could be made from the lake, to help the marshes (SFWMD 2002a). No matter how dry conditions are, water supply releases can be made (assuming water is available).

Regulatory releases are made for flood control. Releases from the lake often are needed to keep it from getting too deep, for the safety of the dike, and to regain storage capacity in case very wet weather continues. WSE was adopted to replace another schedule called "Run 25." That schedule kept Lake Okeechobee above 15 feet virtually all the time and created greater harm to the lake and estuaries. WSE is designed to keep the lake shallower and while it is a healthier schedule for Lake Okeechobee, it still cannot prevent all problems. Even with WSE, when the Lake becomes very deep, large regulatory releases are required and the estuaries are harmed (Table 5). Flood prevention pre-empts estuary or lake protection in extreme cases.

Table 5. South Florida does not have enough places to store water during very wet periods, which allows Lake Okeechobee to get dangerously deep. The result is vast amounts of water must be released quickly and the estuaries are harmed. This problem is not the fault of the WSE schedule, but rather the flood control system of dikes and canals, which the Everglades restoration will attempt to address.

WSE predicted events over a 31-year period*
The Caloosahatchee River will have damaging releases (>2800 cfs) 27 times
The St. Lucie River will have 31 damaging releases (>1600 cfs)
Lake Okeechobee will have prolonged deep water events 4 times

*Data for this table were taken from "Lake O Regulation Schedule Study" presentation to SFWMD Governing Board April 15, 1998. Several "damaging" events can occur in one year.

WSE guidelines have considerable flexibility. For example, if the date is March 31, and the Lake stage is 15.0 feet, the decision tree for the WSE Regulation Schedule (see Fig. 6.1-2 and 6.1-3 in USACE 1999b) states releases to the Agricultural Canals to the WCAs should be, "as needed to minimize adverse impacts to the littoral zone while not adversely impacting the Everglades." The SFWMD and Corps must first evaluate littoral zone trends and needs and water level trends in the WCAs, and then decide how much water, if any, to release. This somewhat subjective evaluation leaves considerable discretion to water managers.

To maintain the health of Lake Okeechobee's littoral zone, perhaps the most important action that can be taken is to recreate the natural wet/dry cycle as accurately as possible, including the long period of declining water levels during the spring dry season. Benefits of an annual spring recession and descriptions of a "good" recession in Lake Okeechobee are outlined in the Everglades restoration, "Restudy" (USACE 1999a, Vol. II, pages IV-9 to 15). Similarly, absence of a healthy spring recession was one of the parameters used to eliminate undesirable lake regulation schedules when WSE was selected (USACE 1999a).

The Everglades restoration Restudy (1999b) envisioned an ideal water schedule as a recession from 15 ft. (0% of the marsh dry) on January 1, to 12 feet on June 1 (74% of the marsh dry)(see Table 6)(Havens et al. 1999). The present lake regulation schedule, WSE, only contemplates a drop to 13.5 feet in most years, because the present system does not have enough perceived back-up water storage to drop the Lake to 12 feet every year.

Table 6. Volumes and areas of Lake Okeechobee at different water levels (USACE 1999b, SFWMD 1998).

Lake level (NGVD)	Area (acres)	% of marsh exposed	volume of lake (1000 acre/feet)
8.0	278,000	100	1,442
8.5	278,000	100	1,586
9.0	288,000	100	1,729
9.5	298,000	100	1,884
10.0	310,000	99	2,039
10.5	319,000	97	2,203
11.0	328,000	94	2,366
11.5	340,000	83	2,544
12.0	356,000	74	2,722
12.5	371,000	62	2,915
13.0	386,000	42	3,108
13.5	403,000	19	3,317
14.0	418,000	5	3,527
14.5	441,000	2	3,755
15.0	450,000	0	3,980
15.5	450,000	0	4,200
16.0	450,000	0	4,425
16.5	450,000	0	4,650
17.0	450,000	0	4,875
17.5	450,000	0	5,106
18.0	450,000	0	5,335
18.5	450,000	0	5,565

Simply ending up at 13.5 feet at the end of the dry season does not ensure an optimal drawdown. It is important that when possible (weather permitting):

1. the recession will be initiated in November of the preceding year,
2. factors accounted for will include: long range weather forecast (including water supply needs associated with the forecast); not violating appropriate salinity envelopes in the estuaries; and preventing excess flooding or nutrients to the Water Conservation Areas and Everglades water needs,
3. the recession should proceed with no reversals greater than 0.5 feet (to protect apple snail eggs and wading bird rookeries where young can be abandoned if water levels reverse too much), and,
4. water should recede at a rate of about 6 inches per month in April and May.

Although a drawdown to 13.5 feet each year is a beneficial goal, in the spring of 2003, WSE protocols were interpreted such that few releases to lower the lake were made during the spring and the dry season ended with a lake level of about 15 feet. There was no beneficial drawdown, the marsh stayed wet, large amounts of submerged plants were lost, wading birds could not utilize the marshes for breeding and torpedo grass control was impeded (no ability to burn). The lake was so deep that additional water from summer rains raised it to about 17 feet (a summer increase of about 2 feet is average) and forced managers into making harmful estuary releases.

Adaptive Protocols for Lake Okeechobee Operations

In 2002, the SFWMD Governing Board approved the final draft of the "Adaptive Protocols for Lake Okeechobee Operations (http://www.sfwmd.gov/org/ wrp/wrp_okee/2_wrp_okee_inlake/ adapt_protocols.html)." It appeared to be a significant step in improving lake level management and benefiting downstream ecosystems. This document was consistent with the WSE schedule and its authority, giving needed short-term flexibility to improve lake health. These Protocols simply elaborated on that authority for environmental releases, without changing the WSE schedule. The Protocols included goals and consideration for the lake, estuaries, agricultural and urban water supplies, and the Everglades Protection Area.

The Protocols contained technically sound measures for healthy biological attributes for Lake Okeechobee and the estuaries. However, there was no requirement that the SFWMD follow them, and they reserved the right to abandon the Adaptive Protocols. The protocols also made delivering water to benefit the Caloosahatchee estuary difficult. When Lake Okeechobee is in "Zone E" of the WSE, which means agriculture and other users are getting 100% of their water supply need met, the Caloosahatchee can get no water at all, unless specifically approved by the Governing Board. The SFWMD should develop clearer protocols for delivering at least 500 cubic feet per second (cfs) of water to the Caloosahatchee unless water rationing is invoked, whereupon the estuary should be rationed too.

Due to the continuing problems with deep water in 2003, and the ineffectiveness of the WSE schedule and Adaptive Protocols to correct them, the Corps and SFWMD officially deviated from the WSE schedule in 2003-04 (SFWMD 2003b). The lake at the beginning of the dry season remained at least 1 foot deeper than desired and the agencies made releases to the estuaries even when WSE did not explicitly call for them. These releases were relatively small (usually Level I pulses) and were made over a long period of time. The result was the lake was successfully lowered back to the target 13.5-15.5 line by the wet season, no water rationing occurred, the estuaries received minimal impacts, and as of summer 2004, lost plant communities (more than 12,000 acres, or about 19 square miles) were being re-established. The agencies relied on weekly reports on the status of the estuaries, and delayed releases if they were too fresh, made smaller releases when oysters were spawning, made different volume releases to either estuary as needed, and generally performed the drawdown with great environmental sensitivity.

Supply-side Management (SSM)

SSM is only enacted when water levels in Lake Okeechobee drop to 13 feet or lower, depending on the date. Because the lake is so low at this stage, regulatory (flood control) releases are halted and water supply releases are curtailed to some extent. The original SSM plan was written in 1991 based upon experiences with previous droughts (Hall 1991). The SSM plan was adopted as the drought management plan for Lake Okeechobee in the Lower East Coast Regional Water Supply Plan (with a slight lowering of the trigger lines)(SFWMD 2000d). Not only does SSM ration water, it also is supposed to protect Lake Okeechobee from low water harm, known as Minimum Flows and Levels violations (MFLs, see next section). During the drought of 2000-

2001, the SFWMD did not follow the SSM plan, and implemented a rationing plan that was fundamentally different.

The fundamental assumption of the original SSM (Hall 1991) is stated on page 8 as, "…the minimum lake stage at the end of the dry season should not be allowed to fall below 11.0' NGVD." During the development of the Lower East Coast Regional Water Supply Plan (LEC Plan) and the low water rules (MFL rule), this minimum lake stage was changed to 10.5 feet. Actually, Lake Okeechobee can be drawn down to about 9.5 feet during SSM, but that "extra water" between 10.5 and 9.5 feet is reserved for the Lower East Coast utilities deliveries only, not for agricultural irrigation releases (Hall 1991, p. 16).

During the drought of 2000, SSM was not implemented on October 1, as called for, but rather on November 27. When implemented, the "Reference Stage" (lowest possible level that will be managed for) was lowered to 9.8 feet NGVD, instead of normal 10.5 feet. Lowering the Reference Stage to 9.8 feet was justified by stating that the emergency drawdown conducted earlier in the year had released about "one-foot" of water from the Lake, therefore the SFWMD was "giving back" some water to users by lowering the Reference Stage. An adjustment of this sort is not part of the SSM protocol. Specifically, the SSM states on page 16, "If some of this water is required throughout the dry season by the Lower East Coast then the Target Level on June 1st can be lowered an equivalent amount in order to balance the distribution among all of the users". This is the only specified reason for lowering the Reference Stage, and only for deliveries required by the Lower East Coast.

On December 11, 2000, the Reference Stage was adjusted downward again, from 9.8 feet to 9.6 feet, allowing greater releases from Lake Okeechobee for irrigation rather than deliveries to the Lower East Coast. This was the first of 13 changes in the Reference Stage made during the rest of the dry season that allowed increased water losses from the Lake, ultimately taking the Lake to its record low. Adjusting the Reference Stage to allow increased irrigation allocations was not part of the procedures outlined in the SSM plan or LEC plan.

Difference between SSM and the method SFWMD used to allocate water

Changing the Reference Stage each week is still a form of rationing, but is fundamentally different from SSM. SSM allocations are calculated with a logic process that sets a bottom threshold for lake elevation (10.5 feet in the LEC) then determines how much water can be allocated in a given week without forcing the Lake below that level. It bases allocations on available "supply." This decision process prevents the Lake from dropping below the Reference Stage and is why SSM is described as a "live within our means concept" (Hall 1991, p. 8).

Instead, the SFWMD switched to a demand-based system, allocating about 50% of the user's perceived needs each week. Allocating a certain percent of demand does not include a provision for how low the lake is dropping. Therefore, even when the lake was down to 9 feet, almost a foot lower than previous records, more than 20,000 acre-feet of water was allocated weekly for irrigation (dropping the lake more than one-half inch a week). When allocating water based on demand (rather than available supply), the lake is not protected from low water, or MFL violations.

Results of changing allocation procedures

No matter what procedure was used to manage water, the lake would have dropped to low levels during this drought period. The volume of water in the lake dropped from about 2.7 million acre-feet, in October 2000, to 1.7 million acre-feet by June 2001, a decrease of one million acre-feet of storage. Indeed, the loss of storage in the lake from the 14.9 foot April 2000 level (3.9 million acre-feet) through June 2000 reflected a loss of more than half the lake's water in a little more than one year. Low water reserves are a concern for myriad reasons, arguably the greatest concern is that Lake Okeechobee is the last source of water to protect Lower East Coast utility company well fields from salt-water intrusion during extreme droughts. Had a second year of drought conditions ensued, damage would have been worse than it was.

By abandoning SSM and adopting a new allocation method, the lake dropped about an extra foot. The extra depletion had carry-over effects to the following wet season in the form of a greater refill deficit. Water-supply backpumping was then used to compensate for the water depletion, which added significant amounts of nutrient-pollution (especially nitrogen) to the Lake and contributed to trihalomethane levels reaching 10 times their EPA standard in the drinking water of the community of South Bay. People who depended on lake-related tourism suffered until the lake became deep enough for navigation. Cross-Florida navigation essentially stopped.

When discussing low water impacts, the Lower East Coast Regional Water Supply Plan (SFWMD 2000d) states, "a recovery plan is not required for Lake Okeechobee. The prevention strategy consists of implementation of the Water Shortage Plan, including supply-side management, as simulated in the LEC Plan." However, because SSM was not implemented, the prevention strategy did not function as modeled in the LEC Plan.

The LEC also states (page 224),

> Lake Okeechobee provides water storage for multiple purposes, including consumptive uses of water and a number of water resource protection purposes. It will store and provide water for several reservations including the Everglades, the STAs, the Biscayne Aquifer, and the St. Lucie and Caloosahatchee Estuaries. However, the lake has its own demand for water supplies to protect fish and wildlife. Therefore, the management of the lake must address its function as a natural system, as well as a water supply source. At the time of completion of this plan, a reservation proposed for the lake had not yet been quantified. It is recommended that the protection of the lake's fish and wildlife be considered and the lake reservation developed in concert with the reservations for the water bodies that rely on the lake…

Because of the changes in lake management, this reservation appears more important than before, yet development will not occur until an undetermined time in the future. SFWMD must make a reservation for Lake Okeechobee.

SSM recommendation

The proposed new Supply-side Management Plan (see SFWMD 2002d) actually reflects a Demand-side Management Plan. Promising a certain level of supply (50% in this case) gives users better predictability during droughts, which is beneficial. At the same time, it takes predictability away from Lake Okeechobee; water will be drawn as low as needed to meet demand. Extremely low water (less than 11 feet) creates many undesirable outcomes including severely depleted water supply (more than half the lake's water volume was lost in 14 months, and almost no reserve was saved for a longer drought), harm to the lake's ecological health (outlined earlier in this chapter), and harm to tourism interests around the Lake. These impacts are in addition to the high water impacts the lake so regularly experiences.

Lake Okeechobee recently has been kept too deep every year (above the desired 12-15 foot range) to ensure water is available during droughts. The infrequent use of forward pumps for water supply has been suggested as a mechanism to allow management at lower lake levels in most years. Forward pumps would result in occasional extra drought-period harm as a tradeoff for better management in other years (lower average levels). Because pumping the lake lower during droughts (about once every ten years) causes an added threat to the health of the lake, assurances would need to be made that the lake would indeed be managed for improved ecological health in other years. Installing pumps for use in droughts also cannot be seen as a tool to relax year-to-year rationing rules, but rather to be used only in emergency drought scenarios.

Minimum Flows and Levels (MFL)

MFLs are designed to protect the biological and soil resources of water bodies from "significant harm" resulting from low water. Significant harm's legal definition is, "…the temporary loss of water resource functions which result from a change in surface or ground water hydrology that takes more than two years to recover…" For lakes, criteria are based on water "levels," not "flows."

The MFL for Lake Okeechobee was established in 2001 as "A MFL violation occurs in Lake Okeechobee when an exceedance, as defined herein, occurs more than once every six years. An "exceedance" is a decline below 11 feet NGVD for more than 80, non-consecutive or consecutive days, during an eighteen-month period. The eighteen month period shall be initiated following the first day Lake Okeechobee falls below 11 feet NGVD, and shall not include more than one wet season, defined as May 31st through October 31st of any given calendar year."

This recommendation is similar to that agreed upon in the LEC (SFWMD 2000d), except it allows the Lake to drop below 11 feet in two consecutive years in six years, as opposed to one. Therefore, if the lake drops below 11 feet in two consecutive years, it will not be until the lake drops below 11 feet a third time that the MFL will be violated and action taken. Lake Okeechobee should not drop lower than 11 feet (94% of the marsh is dry at 11 feet) except under extreme drought conditions, and dropping below 11 feet three times in six years creates more than significant harm, it causes "Serious Harm," the long-term loss of water resource functions.

MFLs must be revisited every 5 years and Lake Okeechobee's MFL needs to be changed. Page 76 of the draft MFL document stated that,

> the District proposes to use the 1952-1995 historical period of record (period of time following construction of the Herbert Hoover Dike) to calculate an interim duration and return frequency component for the Lake Okeechobee MFL. The historical record (Table 4 and figure 15) shows that water levels fell below 11 ft. NGVD a total of seven times over the 43-year period of record (once every 6.1 years) in response to low rainfall periods with an average duration of 82 days. Based on these data, the interim water supply planning criteria for Lake Okeechobee is water levels should not fall below 11.0 feet NGVD more often than once every 6 years (on average) with a duration no greater than 80 consecutive days.

Therefore, the adopted MFL was designed to match historic water levels instead of being designed to protect existing ecological resources, which defies the intent of the MFL. This leads to the distinct possibility that the MFL will cause more than 2 years of harm (significant harm) to several of Lake Okeechobee's resources. Further, this MFL did not consider effects of low water levels on the peat soils in the lake. Peat soils form and persist in anoxic environments (i.e., under water) and once exposed to the atmosphere, they oxidize. Peat soils are also prone to burning when allowed to dry. The MFL rule specifically protects peat-forming wetlands in the Everglades by not allowing water levels to "fall 1.0 feet or more below ground surface, as measured at a key gage, for one or more days during a period in which the water level has remained below ground for a minimum of 30 days…" At a level of 12 feet in Lake Okeechobee, the peat soils of Kreamer, Torry and Ritta Islands are largely exposed, at 11 feet, the water table is more than a foot below the surface of these islands, yet these soils receive no protection in the MFL rule.

Projected biological harm to Lake Okeechobee associated with low water levels was quantified in the Central and Southern Florida Project Comprehensive Restudy (Havens et al. 1999) and in the Lake Okeechobee Regulation Schedule (WSE) (USACE 1999b). WSE was designed to avoid having water levels in Lake Okeechobee drop below 12 feet for more than a year, or below 11 feet for 100 days. With regard to the 12-foot criteria, one of the important factors was loss of nesting habitat by bird species (at 12 feet 73% of the marsh is dry), including the endangered Snail Kite and Wood Storks (*Mycteria Americana*), and species of special concern including Little Blue Herons, Tri-colored Herons, Snowy Egrets, White Ibis, and Limpkins, all of which nest over water. The 12-foot criteria reflects loss of an annual breeding event, which depresses populations such that it may take several years to recover (significant harm). The Restudy also used separate 11-foot and 12 foot criteria, ranking the number of events in a 10-year period as progressively more serious ("Priority hydrological performance measures for Lake Okeechobee" in Restudy Vol. II, pages IV-9 to 15). This 2-level consideration can protect the lake from different kinds of low water events (specifically, impacts associated with intermittent extreme low-water events and chronic low-water).

To protect Lake Okeechobee from significant harm due to low water events, the MFL must protect the Lake not only from occasional low water, but also from chronic low water.

Projections on water demands from Lake Okeechobee in the future indicate a chronic low water scenario is possible (Lower East Coast Water Supply Plan). The present MFL allows the lake to remain at or below 12 feet indefinitely, without any protection criteria being triggered. Snail Kites and other marsh-dependent species could be extirpated from Lake Okeechobee in this scenario.

Because the present MFL does not protect the Lake's wildlife resources from significant harm due to chronic low water levels, the MFL should include provisions to ensure water levels do not fall below 12 feet NGVD for more than 80 days duration, or more often than two of every six years.

Had this criterion been in effect over the past 50 years, it would have been invoked twice, during the droughts of 1981-82 and 1989-90. Similar to the above example for the proposed MFL (11 feet for 80 days), MFL-related restrictions would not have had any effect because there were no more events below 12 feet within the 6-year boundary period. Lake Okeechobee has dropped below 12 feet for more than 80 consecutive days, a total of 7 times in the last 50 years (as of 2004). The average low in each of those events was 10.4 feet (range 9.89 to 11.13).

Long-term actions—CERP, LOWP, LOPP

Perhaps the single most important feature of CERP is the resulting increase water storage capacity in South Florida. With increased capacity, floods and droughts can be managed better, and water can be cleaned before release to natural systems. CERP was based on the "Restudy" (USACE 1999a), which envisioned the ideal Lake Okeechobee regulation schedule as the Lake fluctuating between 12 and 15 feet each year, with the high level at the end of the wet season (October) and low at the end of the dry season (June) (Havens et al. 1999). The water also drops in the spring with no reversals of more than 6 inches (to protect apple snail eggs and wading bird habitat).

Unlike a post-CERP Florida, the present system does not have enough backup water storage to allow Lake Okeechobee to drop to 12 feet every year without risking water shortages in the following dry season. Without the additional storage, the compromise low for now (WSE) is about 13.5 feet.

CERP plans to increase storage using 3 principle methods: reservoirs, Aquifer Storage and Recovery wells (ASR), and restored wetlands. Each of these methods has unique advantages and disadvantages. In general, reservoirs efficiently store large amounts of water in a relatively small area, relatively cheaply. The technology is simple and reliable but has long-term management costs and can destroy habitats if not sited carefully. ASR is more complicated and expensive, but has the potential for inter-annual storage due to low evaporative losses (assuming recovery efficiencies are adequate). Wetlands have the advantage of creating habitat as they store water and having low maintenance costs, but because the water is shallow it does not last through multi-year droughts.

Around Lake Okeechobee, the Restudy goal was to add about a 1.1 million acre-feet of storage capacity (about 2 feet 4 inches of lake water)(Table 7).

Table 7. Proposed storage around Lake Okeechobee

Site	Area (acres)	Capacity (acre-feet)	STA area (acres)	STA capacity (acre-feet)
North Lake	17,500	175,000	2,500	12,500
TCNS	5000	50,000	5000	20,000
LO watershed	~4000	~16,000		
EAA		360,000		
C-41		160,000		
C-44		40,000		
ASR		264,000 ac-ft/yr.		

During the 20% of the wettest years, more than 3.5 feet of "extra" water presently enters the lake and subsequently harms the estuaries if released, or harms the lake if held. With CERP's additional storage ability, most of this water can be stored outside of Lake Okeechobee (about "2 feet 4 inches"). Therefore, even with CERP, not all water is likely to be captured and harmful releases to the estuaries occasionally will occur. However, the models predict harmful releases will be reduced from a present estimated rate of 98 times, to 14 times, in 31 years (in this case, the 14 harmful releases would likely all occur during 2-3 very wet years and no harm would occur in the other years)(USACE 1999a, Fig. B.3-11).

During the 20% driest years, the extra stored water could be used to meet water supply needs. For the Caloosahatchee Estuary, the number of months when too little fresh water would flow (less than 300 cubic feet per second) would be reduced during the 31 year period from an estimated 107 months, to about 36 months (USACE 1999a, Fig. B.3-10). Irrigation demand in the Lake Okeechobee Service Area (LOSA) has an estimated 14% demand that is not met, which should drop to about 6% (USACE 1999a, Fig. B.3-15a).

The above estimates demonstrate the advantages of CERP to the estuaries, and to humans (more flood storage capacity and better water supply reliability), but the lake benefits greatly as well. Not only will water levels be in a healthy range between 12 to 15 feet, but the number of harmful high or low water events will be reduced from 12, to 4, in 31 years (USACE 1999a, Fig. B. 3-21).

Of course, the above estimates are based on computer models. The question is not if the models are inaccurate, it is "how inaccurate are the models?" Additionally, many uncertainties exist in implementing these projects. Will funding be available every year from the State and Federal Governments? Can enough land be bought in the right spot to fulfill each component? Will ASR work? If ASR does not work, many of the other CERP components will need to be changed significantly. Will future land-use and human populations predictions be correct? If not, the system may have to deliver water to different places in different amounts.

CERP projects cover a large area, and have differing functions and inter-relationships. They will occur over long time frames, and are massive in scale. Lake Okeechobee is one of the most important considerations in CERP because it is the largest water body in south Florida; if Lake

Okeechobee cannot be managed well, the rest of the water management system will be negatively affected.

The CERP's Lake Okeechobee Watershed Project

The Lake Okeechobee Watershed Project (LOW) is the north-of-the-lake part of CERP. The conceptual plan from the Restudy envisioned 4 components designed to improve water storage capacity and water quality. These include:

1) North lake reservoir and STA (RaSTA): An estimated 20,000 acre structure with a storage capacity of about 200,000 acre-feet, and consisting of a 17,500 acre reservoir with adjacent 2,500 acre STA.
2) Taylor Creek/Nubbin Slough RaSTA: An estimated 10,000 acre structure with a 5,000 acre reservoir (50,000 acre-foot capacity) and 5,000 acre STA (20,000 acre-foot capacity).
3) Other structures: STAs in the S-154 basin (1,775 acres) and the S65D basin (2,600 acres) and 3,500 acres of wetland restoration projects.
4) Tributary dredging: Dredging about 10 miles of the major canals (e.g., Kissimmee River, Taylor Creek, Nubbin Slough) leading into Lake Okeechobee to remove about 150 tons of P.

The Restudy outlined these general plans and commissioned a multi-agency Lake Okeechobee Watershed Project Team to refine these features and recommend more specific measures, and changes where appropriate. That team is scheduled to have alternatives selected in late 2005.

Unfortunately, the Lake Okeechobee Watershed Project did not include the entire watershed. The study team was constrained to work in only about half of the watershed area. The Kissimmee Chain of Lakes (Lake Kissimmee upward) was omitted, as was the Kissimmee floodplain from Pool C upward. Water storage and nutrient control opportunities exist in these areas and omitting them from consideration unduly limits restoration options. Fortunately, the agencies decided to include the Istokpoga watershed (609 square miles) in the Lake Okeechobee Watershed Project in 2004. The Kissimmee Chain of Lakes also will undergo a "Long-term Management Plan" which may be able to identify needs for CERP-like projects to improve the health of that region and prevent continuing downstream impacts from there.

Another concern was that there was virtually no habitat component to the LOW. The Restudy footprint for reservoirs and filter marshes (Reservoir Assisted Storm Water Treatment Areas, known as RaSTAS) is more than 30,000 acres, which will cover more habitat than is being restored in the Kissimmee River floodplain (27,000 acres). Without change, the Lake Okeechobee watershed (>4000 square miles) could end up with a net habitat loss after the Everglades Restoration occurs. Additionally, the LOW project only had performance measures for water storage and water quality improvements. The LOW team has now included habitat considerations, particularly wetland restoration.

Wetland restoration in the Okeechobee watershed was a missing link in the Restudy and is now being considered. Habitat restoration is an over-riding goal of CERP and it is logical to include a habitat restoration component in the LOW project. Restoring wetlands throughout the watershed can help meet habitat restoration goals, improve water quality, and increase water storage capacity. This essential component to a sound LOW project is greatly endangered by rapidly

escalating land prices. The agencies must move quickly to identify and acquire appropriate lands to ensure habitat benefits from the LOW project.

It is important to consider that ASR is one of the primary CERP components that will be used to store water around the lake (an estimated 200 wells with a total capacity of 1 billion gallons per day). There are many uncertainties surrounding the efficiency and appropriateness of ASR storage; contingency plans must be made in case ASR wells do not function as planned.

Lake Okeechobee Protection Act

The Lake Okeechobee Protection Act was passed by the Florida Legislature in 2000 and mandated development of the "Lake Okeechobee Protection Plan" by the year 2004, which was completed (SFWMD et al. 2004). This plan focuses primarily on controlling nutrients, but will affect water level management in Lake Okeechobee mostly through implementation of Best Management Practices (BMPs). Unfortunately, it remains unclear how much water will be stored during BMP implementation. Present drafts of the BMP rule do not require any water storage component. This is a great omission. If every landowner installed the capacity to hold 2 inches of rain water on their property before outflows began, the over 4000 square mile watershed could have a capacity to store more than 400,000 acre-feet of water or twice the amount that of the north of lake storage reservoir will hold and more than ASR is projected to supply. For a citrus grove, two inches of water falling on a 640 acres of property (a square mile), could be stored in an 18 acre reservoir, 6 feet deep (3% of the property area). This water could be used later for irrigation, and would not be a water quality threat off the property. Unless water storage is required in BMPs, this option likely will not achieve its potential.

WATER LEVEL MANAGEMENT GOALS

Desired Outcome: Manage water level fluctuations in Lake Okeechobee to foster a healthy marsh and lake community, and release water in patterns that enhance downstream ecosystems and provide for human needs.

Short-term (before CERP) Goals:

1. **Manage water levels between a maximum high of about 15.5 feet at the end of the wet season (October), and a low of at least 13.0 feet at the end of the dry season (June)(weather permitting).**

2. **Prevent water levels from rising above 15 feet for more than 4 consecutive months.**

3. **Ensure water levels in spring recede steadily downward with no reversals of more than six inches.**

4. **Prevent water levels from falling below 12 feet for more than 12 months, or 11 feet ever, except under extreme circumstances.**

Action Items:

A. Revise WSE to allow the above, and ensure drought management plans (SSM and MFL) prevent this and if it does occur, develop a recovery plan for Lake Okeechobee after droughts.

5. **Reduce harmful releases to the St. Lucie and Caloosahatchee Estuaries. To protect estuary salinities, releases should remain below 1600 cfs to the St. Lucie Estuary and 2,800 for the Caloosahatchee Estuary, and occur in "pulses."**

   Action Items:

   A. Ensure Lake Okeechobee drops to at least 13.0 feet every year (using Level I pulses as much as possible) to help prevent high-water problems.

6. **Use Lake Okeechobee water to avoid MFL violations (less than 300 cfs) in the Caloosahatchee River.**

   Action Item:

   A. Ensure deliveries of at least 800 cfs unless water rationing is occurring, when the estuary would be rationed too.

Long-term (after CERP) Goals:

1. **Manage water levels between a high of about 15 feet at the end of the wet season (October), and a low between 12-13 feet at the end of the dry season (June)(weather permitting).**

2. **Prevent water levels from rising above 15 feet for more than consecutive 4 months.**

3. **Ensure water levels in spring recede steadily downward with no reversals of more than six inches.**

4. **Prevent water levels from falling below 12 feet for more than 12 months, or 11 feet ever, except under extreme circumstances.**

5. **Stop all harmful water releases from Lake Okeechobee to the estuaries.**

6. **Achieve 2" of water storage capacity in Best Management Practices throughout the watershed.**

   Action Item:

   A. Insure the CERP and other watershed projects gain adequate water storage ability to allow more precise management of Lake Okeechobee.

7. Release Lake Okeechobee water to help restore the Everglades.

Action Items:

A. Insure southward canals have appropriate capacity, that there is adequate water cleansing abilities, and that regional storage is adequate to allow precise management.

8. Release Lake Okeechobee water to help protect the Caloosahatchee estuary.

Action Items:

A. Insure regional storage is adequate to allow releases when needed.

9. Protect the Habitat within the Watershed

Action Items:

A. Complete the Kissimmee River restoration, which will give more natural flows to Lake Okeechobee.

B. Maintain a habitat component in the CERP Lake Okeechobee Watershed project.

C. Ensure the Kissimmee Chain of Lakes Long Term Management Plan cleans and stores water, throughout that region.

Chapter 3

Water Quality

Photo: SFWMD

WATER QUALITY

INTRODUCTION

Although early reports on the natural conditions of Lake Okeechobee are scarce and often anecdotal, they appear to describe a relatively low-nutrient ecosystem. An expedition funded by the New Orleans Times-Democrat in the early 1880's, met one of Hamilton Disston's dredges, operated by a Capt. Menge, moving into Lake Okeechobee from the Caloosahatchee. Standing atop the dredge they noted, "A vast level plain, unrelieved by woods, except on the borders of the lake, stretches for miles to the right and left of the canal. To us from our lofty perch, it resembles a vast plain, but we know in reality, that we are gazing across saw-grass marsh…" (Peoples and Davis 1951). One of the earliest technical reporters was Dr. Angelo Heilprin (1887), a geologist and naturalist. Heilprin described Lake Okeechobee as a sand-bottomed, clear-water lake, surrounded by sawgrass. A sandy bottom reflects a lake with little organic build-up, clear water reflects little algae growth or turbidity, and sawgrass indicates low levels of nutrients - particularly phosphorus. Lawrence Will, a commercial boat captain in the early 1900's, wrote several books about the Lake Okeechobee region (1965, 1977, 1978) and frequently mentioned clear water and sandy bottoms.

Although water levels in Lake Okeechobee were greatly affected by the major canals and Hoover Dike in the first half of the 1900's, water quality probably started changing most rapidly during the 1950s and 1960s. Modern agricultural methods called for draining the land and applying large amounts of chemicals, including fertilizers (primarily phosphorus and nitrogen), calcium carbonate, and pesticides (McCollum and Pendleton 1971). In response to concerns that nutrient pollution was already affecting the lake, the SFWMD systematically sampled the lake for nutrients from 1969-1971 (Joyner 1971). Phosphorus (P) levels averaged about 40 parts-per-billion (ppb), and the growth rate of plant communities in Lake Okeechobee, including algae, was most likely P limited. P levels also were lower in the lake than in the water flowing into it from the tributaries, indicating P uptake was occurring within the lake. Dissolved solids in the lake had increased since 1940-41, another sign of increasing nutrients (Joyner 1971). Lake nutrient levels subsequently increased from a level of about 48 ppb P in 1973, to an average of 97 ppb in 1979 (Federico et al. 1981). Federico et al. (1981) concluded the lake had become a eutrophic (nutrient rich) system and plant growth potential had changed from a P-limited ecosystem to a nitrogen-limited ecosystem.

Although P presently is found in such great quantities that it receives most of the attention, nitrogen (N) enrichment and other water quality problems are a continuing concern. In 1979, the Department of Environmental Regulation (now the Department of Environmental Protection, DEP) was forced to issue a Temporary Operating Permit to the SFWMD for the primary structures around Lake Okeechobee. A lawsuit was filed over N inputs to Lake Okeechobee from water being pumped out of the EAA and into the lake (an action termed "backpumping"). These inputs were linked to algal blooms and changes in the invertebrate communities near the backpumping areas (Jones 1985; Warren et al. 1995). This spurred the development of an Interim Action Plan to reduce backpumping from the EAA. N levels did drop after that action, but N enrichment remains a concern.

A final consideration in Lake Okeechobee is that it is considered a "Class I" water body, which means its water is expected to meet drinking water standards. This classification is warranted because 5 municipalities take water from the lake for drinking water use. These cities include: Okeechobee, South Bay, Pahokee, Belle Glade, and Clewiston. Many of the standards have been exceeded over the years (SFWMD 2002b).

PHOSPHORUS

Lake Okeechobee's phosphorus budget

The amount of phosphorus (P) that enters and exits Lake Okeechobee each year varies with amount of rain (the more water that flows in, the more P it can carry), amount of outflow, wind events (stirring the mud core into the water column where it can flow out), water levels, and other factors. In spite of the variability, the trend has been much greater amounts of P flowing into the lake than "normal," and much smaller amounts flowing out. The result has been the accumulation of a P-rich, mud bottom in the center of the lake that contributes to increasing P concentrations in the water column.

The recent average annual input has been about 570 metric tons of P, and 150 tons have exited the lake (FDEP 2000). This resulted in about 420 metric tons of P accumulation in the lake (primarily in the sediments) annually. Thus, more than 70% of the P entering Lake Okeechobee stays there. This accumulation helped create a mud bottom in the middle of the lake that now contains an estimated 51,000 tons of P, covers more than 300 square miles of bottom, and has an estimated volume of 200 million cubic meters. This mud core now has so much P in it, that even if all P inflows were stopped today, the lake would remain P enriched for decades (FDEP 2000). P enrichment from the mud center is termed "internal loading." It is estimated that only about 10% of the P spread in the watershed each year reaches the lake (Boggess et al. 1995). If the 50,000 tons of P in the lake is indeed 10% of what has been spread, then there would be some 450,000 tons of additional P in the watershed that could eventually reach the lake. To clean Lake Okeechobee of its P problem, now two problems must be fixed: 1) the inflows from the watershed (external loading), and 2) the internal loading. The result of long-term loading has been increasing levels of P in the water column of Lake Okeechobee (Figure 4).

A "modified Vollenweider model" was used to calculate the SWIM goal of 361 metric tons P and average inflow concentration of 180 ppb P flowing into Lake Okeechobee (Federico et al. 1981). The Vollenweider model uses an assumption that as P enters the lake it is used by algae and other plants, or is bound by inorganic chemicals in the lake (e.g., iron or calcium). In theory, this bound-up plant or inorganic P will end up in the bottom sediments, where it will be buried by successive layers of sediments and not be available to plants or interact with the water column (no "internal loading"). The overall process of P entering the lake and becoming sequestered, either in mud, plant life, or organic soils, is termed "assimilation." In theory, P assimilation in the lake allows greater concentrations of P to flow into the lake than the water column goal. Using this assumption, the modified Vollenweider predicted that the lake could sustain inflows averaging 180 ppb P. Through assimilation of P, the lake's water column concentrations of about 100 ppb P should then show a reduction in P back to 40 ppb.

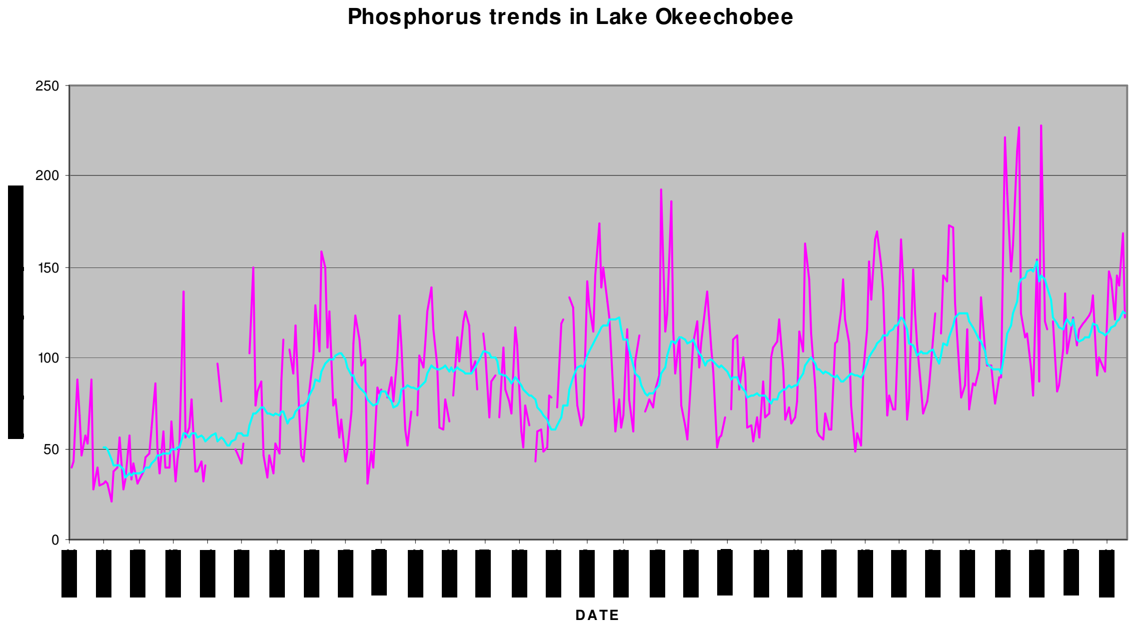

Figure 4. Phosphorus levels in Lake Okeechobee have risen steadily since the 1970s and appear to still be increasing. The pink line represents the monthly average and the blue line is the 12-month moving average. The goal is to have P levels average 40 ppb.

Although, Federico et al. (1981) predicted that the assumption of no internal loading might not apply to Lake Okeechobee, the SWIM plan relied on that assumption and set Okeechobee's P goal (TMDL) as 397 tons per year. Fourteen years later, with lake P concentrations still increasing, James and Bierman (1995) re-examined the Vollenweider model and noted that three main assumptions: 1) that the lake's P load was in a steady state; 2) that the lake is homogenous and steadily stirred, and 3) that there is low internal loading, all are violated in Lake Okeechobee.

Perhaps the greatest reason the Vollenweider goal turned out to be inappropriate was that the assumption that P would be assimilated did not work in Lake Okeechobee. This assumption had worked in deep lakes where wind, waves, or currents never disturbed the bottom sediments, and where mixing between the cold deeper water and warmer surface waters did not occur most of the year (Federico et al. 1981). However, it has not worked in shallow lakes in general (Van der Molen 1991, Carpenter et al. 1999), or in Lake Okeechobee, where not only hurricanes, but even 2-foot waves can mix the entire water column and stir the bottom (Hanlon 1999, Havens et al. 2001). Therefore, during the first 12 years of the SWIM plan, while attempting to restore the lake, approximately 4,200 tons of P were added to the lake. This P is now part of the 50,000 tons of P in the lake's sediments that are interacting with the water column and helping maintain elevated P levels.

The approach to set P concentration goals on lands upstream of Lake Okeechobee also relied on assimilation assumptions. To set nutrient standards for properties, the SFWMD relied on the theory that P would be assimilated as it flowed through tributaries toward the lake. By assuming

assimilation would occur, higher levels of P could be allowed from individual properties than the lake's goal, and in theory, by the time the water reached the lake, it's P levels would be within standards. An assimilation coefficient of 0.64/mile was estimated for the Okeechobee area (Reddy et al. 1995a, Wagner et al. 1996). This means that about 64% of the P in the water column should be absorbed per mile of flow through downstream wetlands and canals (see page 86, SFWMD 1989—this coefficient was used to calculate the allowable P values in the WOD Rule [Rule 40E-61, F.A.C.]. For example, if water is leaving a property at 400 ppb P, its concentration should drop to 144 ppb after one mile (400 ppb X 0.36 coefficient = 144 ppb), 52 ppb after 2 miles, and 19 ppb after 3 miles. However, for this coefficient to work, there must be no more P inflows down stream, the system must never become saturated with P, and stream flows and volumes must not be too fast for assimilation to occur. The first two conditions generally are not met in the watershed and the third often is not met.

Using assimilation coefficients, the SFWMD calculated that for lake inflows to meet the SWIM standard of 180 ppb, that dairies could shed water at 1200 ppb P, improved pastures could shed water at 350 ppb P, and native plant cover could shed water at 180 ppb P. Unfortunately, follow-up studies determined that much of the "assimilated" P had turned into muck on the bottom of the tributaries that is not static and in fact, flows toward the lake (especially during high flow events)(Steinman 1999). The 1997 SWIM Plan update estimates that about 800 tons P are lying on the bottom of the main tributaries and canals just upstream of Lake Okeechobee.

The SWIM goal of an average 180 ppb P in the tributaries was a highly enriched level. For comparison, Lake Apopka's 10-year average (1989-1999) of 184 ppb P was almost identical to the SWIM goal for the Kissimmee River (SFWMD 1997) of 180 ppb P. Goals of 1200 ppb P around dairies have contributed to Taylor Creek Nubbin Slough (S-191) readings averaging 610 ppb P between 1990 and 1994 (SFWMD 1997). Recognizing the high P loads in the tributaries and waterways, a recent dairy nutrient management plan (Soil and Water Engineering Technology, Inc. 2001) noted that "…these sloughs and wetlands have been significantly impacted with accumulated P over the years and therefore will likely become P sources for several years if inflow P concentrations are reduced…"

In a similar vein, an analysis covering the years 1985-1989 estimated that about 90% of the P that was imported into the basin stayed on the land, or at least, did not make it to the Lake (Boggess et al. 1995). This "legacy P" helps explain why the Buck Island Ranch, operated by the Archbold Biological Field Station, has pastures that 15 years after fertilization stopped still had P outflows ranging between 300-700 ppb P (P. Bohlen, Archbold, pers. comm.). At an annual TMDL inflow rate of 105 tons per year, the legacy P would be enough to meet the entire TMDL for the lake for the next 4,285 years (not including the "natural" P background that flows into the lake). Extrapolations such as these are subject to great inaccuracies, but they illustrate the enormity of the problem for the lake and its watershed. It also can be noted that the above extrapolation only uses P numbers from half the watershed (the P deposition in the northern half is not included).

The P loading to the watershed was re-examined in 2002 (Mock-Roos). This report examined the "Northern Lake Okeechobee Watershed," which is defined as areas north of Lake Okeechobee but not including the Kissimmee Chain of Lakes or the Lake Istokpoga watershed. This creates some confusion because these two areas are north of the "Northern Watershed." Additional

confusion arises because this assessment only covers about half the entire watershed; the Kissimmee Chain of Lakes is about 40% of the area and Istokpoga's watershed is about 10% of the area. Another P assessment was done for these watersheds (Mock-Roos 2003) and is discussed in Appendix B.

Mock Roos (2002) estimated that net imports of P into Lake Okeechobee's watershed had decreased by 28% from the previous assessment (Boggess et al. 1995). The update (Mock Roos 2002) estimated that 17% of the P imported to the basin was reaching Lake Okeechobee, a considerable increase over the 10% estimate from the previous 10-year period (Boggess et al. 1995). The percent of P retained by wetlands had decreased from 61% to 32% because the years of P loading had reduced the P assimilation capacity of the wetlands. As in Lake Okeechobee itself, the assumption that P assimilation would continue (or that saturation would not occur) in the watershed has proven incorrect. The final conclusion was that the most effective way to decrease P loading to the lake was decreasing net imports into the watershed.

Agriculture appears responsible for about 91% of the net of 1,717 metric tons of P that were estimated to be imported annually to the northern watershed (Mock Roos 2002)(Table 8). The largest 3 importers are truck and field crops (33%), improved pasture (32%), and dairies (27%). Although improved pasture is one of the largest total importers, it also is the largest land area in the watershed (42% of area) and has relatively low P import per acre. In contrast, dairies and crops make up only 3% of the watershed, but combine for 60% of the total P import. Range and forestry uses have native plant cover, and although they occupy a large area of the watershed, are generally considered to exporter more P out of the watershed in the form of products (timber, cattle) than they import into the watershed. Based on these numbers, it appears that P control strategies should prioritize working on high-P concentration areas such as dairies and crops, and protecting range and forest acres as much as possible.

Table 8. Estimated net import of P into the Northern Okeechobee Watershed from Table 12 of Mock Roos (2002). Some land uses appear to be net exporters (e.g., sod and forestry), and are subtracted from the total net estimate (1,717 tons net). Wetlands were listed as a separate land use category making up about 19% of the watershed, even when embedded in other land uses such as improved pastures, therefore "percent of land area" reported below is adjusted upward 19% from the Mock Roos (2002) estimate in "Exhibit 4."

Land use	Estimated net P import (metric tons)	Percent of total import	Percent of land area in watershed
Residential and golf courses	155	9	2
Improved pasture	558	32	42
Range and forest	-9.5	Na	25
Dairy	458	27	2
Truck and field crops	560	33	1
Citrus	184	11	6
Sod	-236	Na	1
Other land uses	~48	2	~21
Total	1717	100%	100%

In summary, the SWIM goal of 360 metric tons per year was too high for lake health. A large part of the reason it fails is because assimilation coefficients did not work as predicted. Further, P reduction efforts did not lower P levels even to this goal. Many tributaries remain polluted at or above 180 ppb P, which pollutes Lake Okeechobee. There continues to be a net addition of about 1,717 metric tons to the lower half of Okeechobee's watershed each year (Mock-Roos 2002). There is a new goal of 140 tons P per year total input to Lake Okeechobee, and the 4000 square-mile watershed is heavily loaded with legacy P. With the legacy P and continued additions, the P goal (TMDL) will be very challenging to meet.

Internal P Loading in the Lake

For the past 50 years or so, P inflows into Lake Okeechobee probably have been about five times greater than natural. Much of this phosphorus accumulated as a major part of a "mud" center that covers about 300 square miles, contains an estimated 200 million cubic meters of material, and an estimated 51,600 tons of P (Lake Okeechobee Sediment Management Team 2001) and now contains so much P that even if all P inflows were halted to the lake immediately, the lake's water would remain high in P for decades. P is constantly released from the sediments by diffusion, water chemistry changes, particles being stirred up by wind and waves, and even due to aquatic worms (oligocheates). This formerly mesotrophic (relatively low phosphorus levels) lake is showing signs of hyper-eutrophication.

Not only has the lake been receiving excess amounts of P, it also cannot flush itself of the mud center as it probably did historically. When the hurricane of 1928 swept across Lake Okeechobee with 100 mile per hour winds, it first pushed lake water northward through the town of Okeechobee. As it passed the lake, winds reversed and it pushed an estimated 12 foot storm surge over Belle Glade that moved some buildings more than a mile (Will 1978b, Mykle 2002). There are no quantitative measures of how much water left the lake, but it can be surmised that significant amounts of sediments were flushed during these events (Lodge 2005). Hurricanes are infrequent, but regular events. The soils of the southern rim of the lake have greater sand and mineral content than organic soils further south and away from the lake (Mayo 1940, Snyder 1994), which is consistent with a hypothesis of periodic "flushing" of Lake Okeechobee's sediments by hurricanes. Although the loss of human life was tragic, the storm events demonstrated the dynamic nature of Lake Okeechobee, and illustrated one way Lake Okeechobee maintained nutrient balance prior to construction of the Hoover Dike.

Other lines of evidence support a periodic flushing hypothesis. The mud center has been dated and appears to have been deposited mostly in the past 50 years (Brezonik and Engstrom 1998). This timing matches the intensified agricultural activities and the finishing of the Hoover Dike. Recently, an organic, mud accumulation in Fisheating Bay appeared to have been swept from the center during a storm (SFWMD 2001a). Further, during LOTAC's TMDL calculations for Lake Okeechobee various models were constructed to look at P inflows and outflows. In general, they predicted that if total future P inputs were about 140 tons, then outflows would eventually stabilize at about 70 tons, and the other 70 tons would remain in the lake. If the LOTAC inflow concentrations are similar to "natural inflow levels" (Fernald and Purdum 1998, Chapter 7), an estimated 420,000 tons of P should be in the sediments of the lake (70 tons per year for 6000

years). Because there is less P than this, flushing appears a valid hypothesis for P removal from the lake.

A final factor in evaluating internal loading in the lake is how P responds to other environmental variables, such as water levels and wind. Early hypotheses to understand changes in the water column P levels from year to year, and even day to day, often did not work very well (Canfield and Hoyer 1988). Hurricane Irene (in 1999) stirred the sediments and created higher P levels for several months (Havens et al. 2001), as did the hurricanes of 2004. However, even average wind conditions during winter (November to April) apparently stir the mud bottom more regularly and contribute to average higher P measurements during winter (Hanlon 1999). Higher water levels also are associated with higher average P levels due to several factors including: high water can eliminate submerged plants which creates a cycle of greater turbidity (the plants are not damping out waves), lack of P uptake (the plants are not growing); higher water may allow cooler water to collect near the bottom and not mix well with warmer water above it, which leads to depletion of oxygen near the bottom creating chemical conditions for P release from sediments; and, high water years also tend to be windy years, which may lead to further sediment movement and stirring by wave action (note this explanation conflicts with the temperature-stratification hypothesis above)(Havens 1997, Havens et al. 2003). Whatever the exact cause, when Lake Okeechobee is deeper, P levels often are greater.

A study was conducted to determine if the mud center could be removed, or otherwise neutralized, to help restore Lake Okeechobee's water quality (Blasland, Bouck and Lee, Inc. 2002). The study examined 36 potential alternatives to dealing with the sediment, and narrowed that list down to the 3 most promising: no in-lake action, chemical treatment to neutralize the P, and dredge the sediment.

No in-lake action: This option predicts that if the P concentration of Lake Okeechobee inflows could be reduced to 40 ppb P by the year 2015, then Lake Okeechobee's water column would return to about 40 ppb P within about 35 years (the year 2050). This prediction assumes: the P goal (TMDL) will be met by 2015, progressively lower P "mud" will cover the higher P mud underneath over time, and no hurricanes will significantly stir and re-shuffle the lake sediments during this period. Hurricanes such as Irene in 1999 stirred the mud enough to significantly raise water column sediment levels (Havens et al. 2001), and apparently would set back the 35-year recovery prediction.

Chemical treatment: Alum and sodium aluminate can bind with P, essentially neutralizing its effects on the ecosystem. This option would cost an estimated $500 million and take 3 years to complete. If started in 2012, P concentrations might be reduced by 90% by 2015. If inflows do not meet the 40 ppb P goal, then re-treatment would be needed approximately every 15 years. Again, substantial remixing of the sediments by hurricanes could negate the positive effects because the chemical likely would only neutralize surface sediments.

Dredging: A dredge was constructed and tested. It is estimated it would cost about $3 billion to dredge and dispose of the mud center. After dredging, a veneer of fine sediment likely would remain and could continue to release P into the water column, possibly resulting in little or no benefit to the lake.

The predictions from this study depend on many variables such as hurricane effects, when the TMDL will be reached, how much P exchange actually occurs between the sediments and water column, the depth of such exchange, if different parts of the sediment have greater or lesser exchange than assumed (BBL 2002). For now, further inquiry and testing of these assumptions seems warranted as Lake Okeechobee's recovery is clearly hindered by internal loading.

Symptoms of phosphorus enrichment

So much emphasis is placed on lowering P levels because of the profound damage it can do to Lake Okeechobee and other South Florida water bodies. Evidence of P over-enrichment now observed in Lake Okeechobee include algae blooms, a mud center, increased turbidity, drinking water problems, expansion of cattails, changes in invertebrate communities, possible effects on neo-tropical migrants, downstream water quality problems, and tourism impacts.

<u>Algal blooms</u>

Algae are ubiquitous in aquatic ecosystems and form a large part of the food chain. Most species, such as diatoms and green algae, are considered beneficial. However, as water bodies become eutrophic, many species of algae are replaced by less desirable species of cyanobacteria (often referred to as members of the algal community). Different combinations of P, N, light, turbidity, temperature, and other factors can create conditions suitable for many undesirable cyanobacteria (Steinman et al. 1997, Paerl et al. 2001). Lake Okeechobee presently has P levels above 100 ppb, making it ripe for algal blooms (Paerl et al. 2001), and indeed, blooms have been increasing (Havens et al. 1995a). These cyanobacteria produce toxins that make them unpalatable to primary consumers and therefore are a poor base for the aquatic food chain (Havens and East 1997). At high concentrations, these toxins have killed large animals, including livestock and humans (Paerl et al. 2001). As the cyanobacteria die, their decomposition can use all the oxygen in the water, killing aquatic organisms. Although the mud center keeps the water turbid enough to limit algae blooms in the lake's center, inshore areas, where most human use occurs, tend to have clearer water and more blooms (Walker and Havens 1995).

<u>Fish kills</u>

Fish kills have been a common event in the tributaries flowing into Lake Okeechobee (Don Fox, FWC, pers. comm.). For example, in 2001, grass carp in Harney Pond Canal and many species in Nubbin Slough, were killed during the summer. Although the water that caused the fish kills flows into Lake Okeechobee, the lake itself apparently has not suffered large kills related to water quality conditions. During the massive algae blooms of 1986-88 (153 square miles of bloom at the peak), fish apparently were able to evacuate bloom areas, while other aquatic life (e.g., snails) sometimes were killed, apparently by low oxygen levels and ammonia build-up (Maceina and Soballe 1989). As long as conditions remain suitable for algal blooms, fish kills remain a significant threat (SFWMD 1997). Finally, even at sublethal levels, nutrient enrichment affects ecological interactions through lakes, thereby changing fish species composition and decreasing species richness (Strickland and Grosse 2000, Ludsin et al. 2001).

Mud (organic flocculent) center

Lake Okeechobee has approximately 51,600 tons of P in a bottom layer of "mud," deposited mostly within the past 50 years (Brezonik and Engstrom 1998). This center contains an estimated 200 million cubic meters of material, covers some 300 square miles of bottom, and is formed in large part, from dead plant material (Blasland, Bouck, and Lee 2002). The flocculent nature of this material allows it to stir easily, cause turbidity, and raise P levels in the water of the lake. After Hurricane Irene passed in 1999, the stirred sediments contributed to P concentrations greater than 200 ppb in the lake with visibility of less than 0.5 meters, lasting for months (Havens et al. 2001). Even when hurricanes do not occur, the mud center releases so much P to the water column through chemical, physical (mostly waves), and biological (especially oligochaete worms) processes, that even if all P inflows were halted, the Lake would remain P enriched (Carrrick et al. 1994, Reddy et al. 1995b, Van Rees et al. 1996). The organic center also is causing a loss of clean-water benthic invertebrates which are being replaced by fewer species of pollution-tolerant invertebrates, apparently due to low oxygen conditions and physical changes in the sediments that exclude some species (Warren et al. 1995, Ali et al. 2003).

Increased turbidity

The organic center in the lake is often stirred by wind and waves, creating ongoing turbidity in the water column. Increased turbidity actually helps protect Lake Okeechobee from algal blooms because of light limitation (Phlips et al. 1997, Havens et al. 2003a). Similarly, turbidity probably helped prevent submerged plant recovery in the late 1990's when 50,000 acres of submerged plants were lost from the lake (Havens et al. 2001). Turbidity can contribute to problems in drinking water as well.

Drinking water

There are five public drinking water intakes in Lake Okeechobee. Small towns, such as Pahokee and South Bay have simple water treatment plants; they treat the water with chlorine and send it to consumers. Chlorine reacts with organic molecules to create a group of compounds called trihalomethanes (THMs, which include bromodichloromethane, dibromochloromethane, chloroform, and bromoform), which are suspected carinogens. Wind that stirs the mud bottom and backpumping from the EAA create high levels of organic material in the water column, resulting in drinking water violations. The EPA standard for THMs is 100 ppb. Samples taken by the Palm Beach County Health Department during August 2001 (while the SFWMD was conducting water-supply backpumping) detected THM concentrations in the drinking water of Pahokee between 800-950 ppb, and 1200-1300 ppb in South Bay. Staff at the Pahokee plant report that even when backpumping is not conducted, windy days can cause turbidity, which contributes to THM problems in the water.

Expansion of cattails and other invasive vegetation

Cattails are a native south Florida plant that has low abundance in the normal, low-nutrient conditions (Daoust and Childers 1999). Nutrient-rich water in the middle of Lake Okeechobee appears to be a factor in recent increases of cattails along the edge of the western marshes (Richardson et al. 1995, SFWMD 1997). Cattail expansion is a concern because solid stands of

cattails decrease both plant and animal diversity (Weller 1978). Torpedo grass and melaleuca are other species of great concern on Lake Okeechobee but the relationship to P enrichment is poorly understood (Richardson et al. 1995).

Tourism impacts

Nutrient enrichment can harm fish and wildlife populations, and water quality (smell, appearance), thereby harming tourism. Even in sub-lethal algal blooms, oxygen levels in the water can decrease such that fish will abandon the area (Furse et al. 1996).

Tourism is considered an "export market" by economists. Export markets are those that supply goods or services to groups outside a local economy and bring dollars into the local economy (Bell 1987). In other words, tourists come to Lake Okeechobee and leave their dollars here, making the economy larger. Bell (1987) estimated that Lake Okeechobee's recreational and commercial fishery has an estimated annual value greater than $100 million (in the 1980's). Lake restoration is important to the economy of this region.

Selected government actions to address P problem

Several government programs have been established to begin to address the P problem in Lake Okeechobee. These include:

The Rural Clean Water Program called for Best Management Practices (BMPs) to be used on agricultural lands in the Taylor Creek - Nubbin Slough (TCNS) basin (Stanley and Gunsalus 1991). This plan was one of the first efforts at nutrient control. These basins enter Lake Okeechobee through the structure "S-191" and received early attention because although they contributed 4% of Okeechobee's water inflow each year, they carried 27% of its P inflow (the highest ratio of any tributary). BMPs included such activities as fencing cattle away from streams and canals, water conservation and waste recycling, and improved fertilizer procedures. P readings in the watershed declined from an average of more than 1000 ppb P in the late 1970s, to around 500 ppb P by the late 1980s (Table 7.3.1, Stanely and Gunsalus 1991). P readings during the 1990s remained above 500 ppb P (FDEP 2000).

The Surface Water Improvement and Management (SWIM) Act was passed by the Florida Legislature in 1987. The SWIM Act had many parts (including the Dairy rule and the Works of the District Rule) and required the SFWMD to design and implement a program to protect the water quality of Lake Okeechobee. The SFWMD determined that about 361 tons of P should flow into Lake Okeechobee each year (based on the modified Vollenweider model)(Federico et al. 1981) and should be achieved by July 1, 1992. The 1992 deadline was not met and the goal of 361 tons (a 40% inflow reduction) remains unmet (SFWMD 1997). In-lake water column readings for phosphorus in the late 1990's were the highest ever (FDEP 2000). Updates to the SWIM plan (SFWMD 1993, 1997 and 2002b) included revisions to the methods and goals of Lake Okeechobee restoration.

The Dairy Rule, enacted in 1987 by the Florida Department of Environmental Regulation (now the Department of Environmental Protection), was a technology based rule and required dairies to implement Best Management Practices (BMPs). If dairies performed the required activities of

the BMPs, they would be "presumed to be in compliance" with applicable water quality standards, whether they met the actual numeric standard or not. Dairies constructed waste capture and treatment systems for runoff from their barn wastewater and concentrated holding areas, but not pastures or sprayfields. A major feature of the waste treatment process was application of the phosphorus-laden water on crop fields. The crops that were planted required such high P fertilization the dairies actually added P fertilizer to them and the areas are major sources of continuing P pollution.

Some dairies could not install waste treatment facilities, either for financial reasons, or because of space restrictions (lagoons require more property than the smaller dairies owned). Therefore the state initiated the Dairy Buy-Out Program in 1989 to remedy this situation. Florida bought the dairy operation from the owners, leaving them with the land to use for other purposes. This program resulted in the buy-out of 23 of the 52 dairies from the area. As of 1999, 25 dairies remained active in the Okeechobee watershed holding about 25,520 milking cows (down from 42,600 milking cows before the dairy programs began)(M. Meeker, FDEP, pers. comm.). Because the small dairies tended to sell, 48% of the dairies remain with 60% of the cows.

The goal for dairies was to drop their P outflows to an average of 1200 ppb P. This high number was calculated based on assimilation coefficients. From 1997-2001, at least 14 of the remaining dairies were above this level part or all of the time (SFWMD data). For comparison, the new TMDL goal for Lake Okeechobee inflows is about 60 ppb P. Although many dairies remain above the target level, they are "presumed to be in compliance."

The regulatory program called the Works of the District (WOD) was established by Rule 40E-61, of the Florida Administrative Code. This program sought to ensure that any connection to or use of a WOD project or land would be compatible with the SFWMD's ability to meet their water quality objectives (SFWMD 1997). This program used assimilation coefficients to set the standards of 350 ppb P runoff from improved pasture and 180 ppb P from native land cover. If a user could not meet the phosphorus requirements of the WOD program, they were required to take corrective actions.

In 2000, the Florida legislature passed CS\CS\HB 991, "The Lake Okeechobee Protection Act." The legislation required that a "Lake Okeechobee Protection Plan" be developed by Jan. 1, 2004 that spells out how to meet Lake Okeechobee's phosphorus goal (TMDL) by the year 2015. The legislation had many other facets, but the one of interest here is that all agriculture in the Lake Okeechobee basin must implement BMPs, it they cannot prove they meet water quality standards. If they do implement BMPs, they will be presumed to be in compliance. Therefore, all agricultural operations in the basin will be under a similar rule structure to the dairy rule, and the Rural Clean Water Act (TCNS), neither of which achieved the desired results.

While these programs have done some good, it is safe to say that all of the above-discussed programs combined have merely slowed the degeneration of Lake Okeechobee's condition. Recent inflows have averaged about 570 metric tons of P, which indicates a need to stop an additional 465 metric tons per year. The SWIM goal was to reduce P inflows by about 100 tons per year, and it failed. The new TMDL goal will indeed be a monumental undertaking.

<u>End result after these efforts</u>

After 30 years of programs, rules, legislation, and studies, Lake Okeechobee is still accumulating phosphorus. The year 2000 had the highest average P concentration recorded (SWWMD 2002b). Key factors relating to nutrient levels in Lake Okeechobee were summarized by the SFWMD in 1999:

(a) Phosphorus loads to the lake greatly exceed the total maximum load considered acceptable by the scientific community for sustaining a healthy ecosystem.
(b) The excessive phosphorus loads are attributable to human activities in the watershed, in particular agriculture.
(c) If the sources of these loads are controlled, residual phosphorus in the watershed still may considerably delay reductions in tributary loads.
(d) Substantial reductions in tributary loads are not projected to result in reductions of phosphorus in the lake for decades because of high internal loading from sediments.

Present programs and their contributions

The two main programs that will address Lake Okeechobee's P problem are the Everglades restoration plan (Lake Okeechobee Watershed [LOW] project) and the Lake Okeechobee Protection Plan (LOPP). The latter of these two was called for in the Lake Okeechobee Protection Act passed by the Florida legislature in the year 2000 (LOPA, Chapter 00-130, Laws of Florida). That act mandated that a Lake Okeechobee Protection Plan be written by January 1, 2004, that would outline a process to meet Lake Okeechobee's P goal by the year 2015.

These two plans work in concert with each other and of the two plans, the LOPP probably is most important in reaching Lake Okeechobee's phosphorus goals. It has the most comprehensive planning effort and covers Okeechobee's entire watershed (the LOW project leaves out the Kissimmee Chain of Lakes which is 40% of the watershed). The LOW project is designing a P control system that will provided additional and necessary P control after all the LOPP P-reduction activities are implemented.

The LOPP (SFWMD et al. 2004) used a baseline that estimated 433 metric tons of P flow into Lake Okeechobee each year (the baseline is the average from the years 1991-2000 and did not include basins south of the lake that presently contribute P to the lake but are scheduled to be diverted by the Everglades restoration). Of this, activities from the LOPP are projected to attain a reduction of 198 tons. Therefore, the LOW project needs to design a system that can gain a reduction of 130 tons, which would reach the phosphorus goal of 105 tons of inflow (i.e., 433 tons – 198 tons – 130 tons = 105 tons). The LOPP has many components including public works projects and private landowner projects, and is expected to yield more P reduction than the LOW project.

Best Management Practices

A large uncertainty with the LOPP is its strong reliance on "Best Management Practices" (BMPs) to gain P reductions. Landowners whose water does not meet numeric water quality standards must either get in compliance with the standards (which most cannot do because of the long history of P application), or implement BMPs. BMPs are a series of actions landowners can take (urban or agricultural) to reduce P outflow. Manuals are written for each type of land use and landowners, with guidance from agency staff, select actions from the manual suitable for their property and conditions. Once BMPs are implemented, the landowner is granted a presumption of compliance and is exempted from meeting numeric water quality standards.

The philosophy of BMPs is to have a cooperative and reasonable approach to working with landowners. This is partly due to the realization that P problems are so advanced on so many properties that immediate compliance is not feasible; a long-term approach will be needed. Agencies must be very aggressive in design and implementation of these programs to ensure their success.

Individual BMPs range from the simple, like placing a tarp under the fertilizer truck to contain spillage, to the complex, such as water treatment lagoons, chemical water treatment, or irrigation schemes based on soil tests or even satellite imagery. There are 18 BMPs described for Indian River Citrus, with 29 pages of narrative and references (Boman and Hebb 2000). The cow/calf BMPs have about 25 BMPs covering 18 pages (Florida Cattleman's Association 1999). BMPs are behavioral in nature and agencies have limited ability to observe compliance in day-to-day implementation.

BMPs explicitly state that the first priority is financial management, not P control. If any nutrient control practice is considered too costly, it is not done. While it makes sense not to drive people out of business with cost-prohibitive P control demands, this caveat creates a loophole that casts doubt on the ability of BMPs to meet environmental standards.

BMPs also allow people to continue a net import of P to their properties by adding fertilizer at "agronomic rates," which are the rates a crop is perceived to need. Unfortunately, agronomic rates are not designed to meet water quality standards and in many cases will violate them. For example, agronomic rates for row crops can be 30-50 pounds of P per acre, and two to three crops can be grown in a year. For reference, if every acre were to put its "proportional share" of P into Lake Okeechobee, each acre would shed only one-tenth pound per year. Runoff from farms adding 30 pounds of P per acre is likely to be in the range of 10 pounds per year, or about 100 times greater than desired.

Continued import of P into the watershed is of great concern (Table 9) because it exacerbates the saturation effects discussed earlier in this section, creating increasing P flows in the future. Because the LOPP based P control needs on a baseline of 1990s P levels, higher loads in the future would make the CERP and LOPP projects inadequate to protect Lake Okeechobee from excess P loading.

Table 9. Recent estimates of annual net import of P into the Lake Okeechobee watershed. These estimates are for the upstream part of the lake's watershed and do not include areas downstream of the lake (e.g., the Everglades Agricultural Area or Indian River Lagoon watershed).

Region	Net P import per year (metric tons)	% of Okeechobee watershed area	Source
"Northern Watershed"	1,717	~50	Mock Roos 2002
Kissimmee Chain of Lakes	3,256*	~40	Mock Roos 2003
Istokpoga watershed	664	~10	Mock Roos 2003
Watershed total	5,637	100	

* At least 1500 tons of this estimate are for human food, therefore much of this P is contained in municipal waste treatment activities and not released directly to the watershed.

The target in the present round of BMPs is a 25% reduction in P outflows, which for most properties will not meet water quality goals. For example, if improved pastures that have 350 ppb P runoff reduce that to 262 ppb P (25% reduction), they will remain well above Lake Okeechobee's P inflow goals (about 60 ppb P). There is a provision that if water quality problems persist after BMPs are implemented, further BMPs are to be implemented. Considering BMPs take about 10 years to reach full effectiveness (Bottcher and Harper 2003), this remedy will be slow. The large public works projects (e.g., filtration marshes) are being built to make up for much of these deficiencies.

The LOW project recognizes the uncertainties of BMP performance and has commissioned an external review of the likelihood that BMPs will work to expectations.

Comprehensive Everglades Restoration Plan (CERP)

The main components of CERP that will significantly affect Lake Okeechobee's nutrient problem are the LOW Project, Aquifer Storage and Recovery wells (ASR), the Indian River Lagoon Feasibility Study, the Lower West Coast Feasibility Study, and the EAA storage reservoirs.

An important goal of Everglades Restoration is to send more water from Lake Okeechobee to the Everglades when environmentally beneficial. Water entering the Everglades should have P concentrations no greater than 10 ppb (Scheidt 1999). If water enters the Everglades at greater concentrations, cattails invade large areas and other imbalances occur. Presently, Storm Water Treatment Areas (STAs) are the primary technology envisioned to clean water to the desired standards before entering the Everglades. A 5-year synopsis of STAs reports that average inflow concentrations were 114 ppb P, and outflow concentrations were 21 ppb (SFWMD 2000d). Considering that 21 ppb is twice as high as needed to restore the Everglades, and considering that Lake Okeechobee water usually ranges from 130 to 200 ppb, the high P levels in Lake Okeechobee's water column must be reduced. Even as new technologies come on line, lowering Lake Okeechobee's water column P will be important.

Lake Okeechobee Watershed Project

The most prominent feature of the CERP that will affect P loading to Lake Okeechobee is the LOW project. The CERP identified four main project features for the LOW project.

1. North of Lake Okeechobee Storage Reservoir. This reservoir was projected to need a 200,000 acre-foot capacity, cover 17,500 acres and have an adjacent 2,500-acre STA.
2. Taylor Creek/Nubbin Slough STA. This reservoir was projected to need 20,000 acre-foot capacity, cover about 5,000 acres and have an adjacent 5,000 acre STA.
3. Lake Okeechobee watershed water quality treatment facilities. This feature envisioned two STAs in two problem areas: a 1775-acre facility in the S-154 basin and a 2,600-acre facility in the S-65D sub-basin. Additionally, they planned to plug drainage ditches that can restore about 3,500 acres of wetlands in the watershed.
4. Lake Okeechobee tributary dredging. This project would dredge nutrient-rich mud from the bottom of 10 miles of major canals flowing into Lake Okeechobee. This one-time effort might remove 150 tons of P from Okeechobee's waterways.

As this project moves forward, there are several issues that the LOW must consider: meeting the TMDL, accounting for the entire watershed and incorporating natural storage.

Water Quality

After the CERP designed the above plans, two major things changed. The first was Lake Okeechobee's P goal was reduced from 360 metric tons per year to 140 tons per year, making the CERP design inadequate. The second change was passage of the Lake Okeechobee Protection Act in 2000, which gave another major program to help the CERP control P.

As of 2005, the LOW study team is designing alternatives. Challenges for the LOW project include:

1) The new P goal for the lake requires a new configuration of projects
2) The study area does not include the Kissimmee Chain of Lakes, which is 40% of the watershed; the LOW should directly link its hydrologic model to the Kissimmee Chain model being developed in 2005.
3) Continued addition of P to the watershed indicates present conditions could worsen (P saturation effects), therefore the plan must account for this.
4) STA technology remains uncertain because STAs can be damaged by P overloading or weather (hurricanes or droughts); STAs require large amounts of land and land prices have risen dramtically; and STAs require water during droughts.
5) Alternative P removal technologies must be continually explored. For example, "Hydromentia" is a concept that treats water by flowing it across algae mats and has shown promise, depending on conditions, to remove 10-50 times the amount of P per unit

area as STAs (Hydromentia 2005), at lower cost per pound (Sano et al. 2005), while using less space and water.

6) The original LOW project omitted natural storage from consideration.

<u>Natural Storage</u>

During plan formation for the Indian River Lagoon Feasibility Study, the study team constructed various models, including a watershed scale hydrologic model. This model was able to estimate water quality and timing differences with various hypothetical changes in reservoir size and placement, and with changing land use patterns (e.g., changes between hydrology of drained pastures vs. restored wetland areas). Of particular interest was the insertion of "water storage on semi-natural lands" as a model component. The study team concluded that if they restored wetlands in about 20% of the study area, they needed less reservoir and STA acres and many parts of the water control system worked "better." These "restored" wetlands created water quality benefits because wetlands absorb, or at least, detain nutrients. The longer the water remained in the wetlands, the more water that evaporated or percolated into groundwater, hence less that ran off (less runoff also equals less nutrient runoff). Being "natural," these wetlands capture water during the rainy season and slowly release it during the dry season, mimicking the natural water-timing cycles. These areas likely have lower long-term maintenance costs, have more predictable technology (no pumps or dikes to give out during a storm), spread storage over larger areas, help fulfill the environmental goals of the project, probably benefit aquifer recharge and raise regional water tables.

In the Indian River Lagoon Feasibility study, the restoration of about 1/5 of the area (~92,000 acres) decreases other storage needs by 30,000 acre-feet and prevents an estimated 9.5 tons of P per year from reaching the waterways. If similar relationships held for the Lake Okeechobee watershed, some 1000 square miles of habitat could be hydrologically restored, storing more than 200,000 acre-feet of water and reducing annual P loads by more than 60 tons per year. Obviously, the cost of this would exceed the present budget but funding could be supplemented through federal (e.g., the Farm Bill) or state (Rural and Family Lands Act) funding sources.

The original LOW project design did not contain natural storage but the study is investigating this option.

Conclusion

The LOW project must improve water quality and increase natural storage. The latter option could compensate for losses of habitat from the structural components (e.g., reservoirs), meet the CERP goals of increasing spatial extent of wetlands, habitat heterogeneity, and connectedness of habitats, and gain substantial water quality, water quantity and water timing benefits.

<u>Indian River Lagoon South (IRL-S) project</u>

The Recommended Plan for the IRL-S project predicts P inflow levels to Lake Okeechobee of about 17 metric tons per year. The Lake Okeechobee Protection Plan assumed all 105 tons of inflow would come from other regions; the 17 tons from this region, as of 2005, have not been accounted for. This problem could be addressed by building more STA capacity along C-44 near the lake. Assuming an STA at this location could remove about 1 ton of P per 150 acres (see

Lake Okeechobee Issue Team 1999, p. 17, for Fisheating Creek STA projections), it would take about an additional 1650 acres of STAs to reduce the lake load from 17 tons down to 6 tons P. 5 to 6 tons is a more reasonable target for this structure because it is likely to add 5-6% of Okeechobee's inflows. Another consideration is that the 2,300 acres STAs planned for the C-23/44 diversion might be more effective in this area than on Allapattah (see C-23/C-24 Diversion comments) and the IRL Plan could accordingly meet water quality goals at no extra cost.

EAA Storage Reservoirs

The goals of this project include reducing backpumping of water into Lake Okeechobee, supplying water to nearby STAs and WCAs, and ensuring flood protection and irrigation water for agriculture in the area. The Talisman property was purchased in 1999 at a cost of about $130 million. This 50,000-acre area has been envisioned as some combination of a storage reservoir (with a capacity of at least 360,000 acre-feet (USACE 1999a, page 9-9)), and an STA. More storage and treatment will be needed, but this one project has great potential to help Lake Okeechobee and the Everglades by storing and treating water pumped off farms south of the lake. This cleaned water then can be sent to benefit the Everglades, rather than being pumped back into Lake Okeechobee. For example, in 2001 325,000 acre-feet of water were backpumped into the lake adding an estimated 37.9 metric tons of P. Finally, considering that prolonged drawdowns are needed to recover submerged aquatic plants in the lake after high-water events, this reservoir also might be an integral part in storing agricultural irrigation water in preparation of drawdowns.

Sludge/septage issue

The Lake Okeechobee Protection Act requires further guidelines for applying sludge on land. "Sludge" (also known as biosolids) is the solid waste product from municipal wastewater treatment plants. An estimated 11,914 tons of sludge were applied in Okeechobee County in 1999, containing an estimated 275 tons of N and 133 tons of P (M. Meeker, FDEP, pers. comm.). Much of this sludge was imported from outside the Lake Okeechobee watershed, which increased basin loading. This was applied on only 2,324 acres, indicating that it was being "dumped," rather than applied for soil amendment purposes. FDACS, DEP and SFWMD must expedite new guidelines for applying all kinds of human and animal waste on the land to curtail a large and unnecessary sources of pollution.

Water level management: Lake Okeechobee regulation schedule

Better water level management in the lake is the single most important short-term measure that can be taken to reduce the P concentrations in Lake Okeechobee's water column. For a variety of reasons, open-water P concentrations tend to be lower when water levels are low than when they are high, particularly in the in-shore area (Havens 1997, Hanlon 1999, Havens et al. 2003).

As for the marshes, the lake gets more rain each year than evaporation, which means the water falling in the marshes must "flow" out. At lake levels less than 15 feet, the marsh water pushes toward the center of the lake, which makes most of the marsh full of "clean" rainwater, and keeps the nutrient-rich water out of the marshes. Water quality samples in the marsh zone after the drawdown of 2000 contained P levels less than 40 ppb in areas that months before, during

higher water, had P concentrations of 140 ppb or more (Havens et al. 2001). When the lake rises above 15 feet, wind can push nutrient-rich lake water deep into the marshes. Therefore, if the lake is maintained below 15 feet most of the time, about 20-25% of the lake (100,000 acre marsh) can have a "restored" water quality almost immediately. Lastly, shallower water facilitates growth of submerged plants that help attenuate P levels by reducing wave action and absorbing P (Havens et al. 2003).

Lake Okeechobee Structures Permit

The SFWMD must get water quality permits from the DEP to operate the various structures around Lake Okeechobee. The last permit expired in 1983 and although some correspondence occurred between the agencies, the permit has not been renewed as of 2004. This makes 20 years without a permit. The previous permit set an annual average goal of 360 metric tons of P (TMDL = 360 tons) entering Lake Okeechobee each year (SWIM 1997), but the new goal is 140 tons (FDEP 2000). SFWMD and DEP are required to renew the permit as part of the Lake Okeechobee Protection Plan, and the new water quality standards must be met by the year 2015.

Farm Bill

The Farm Bill passed in Congress in 2001 included increased funding and flexibility for Florida. A major component missing from the Lake Okeechobee Watershed Project of CERP is lack of wetland restoration. Farm Bill programs such as Wetland Reserve Program (WRP) and the Conservation Reserve Enhancement Program (CREP) can infuse millions into efforts to help landowners, especially ranches, comply with new regulations and restore the region. Additionally, cattle ranches are some of the lowest intensity agriculture and can have high value as wildlife habitat (Cox et al. 1994, Adams and Grambling 1998).

Summary of P problem as of 2004

As it now stands, Lake Okeechobee has enough P in its sediments and watershed to remain polluted for decades or perhaps centuries. The CERP is designing alternatives to stop about 130 tons of P from reaching the lake annually, based on the assumption that the Lake Okeechobee Protection Plan will stop about 198 tons. BMPs are a major feature of the LOPP, and have a P reduction goal of 25%, but are uncertain and may happen too late to stop P saturation in the major lakes of the watershed (see Appendix B for more information about P saturation of these lakes).

WATER QUALITY GOALS: PHOSPHORUS

Outcome: Restore water quality in Lake Okeechobee and its watershed by reducing water column phosphorus concentrations to a system-wide average of 40 ppb to promote a healthy ecosystem and reduce harmful discharges to downstream ecosystems.

Goals:

1. **Support phosphorus concentration goals of 40 parts per billion in Lake Okeechobee and its inflows.**

    A. **Support an annual loading of 140 metric tons phosphorus into Lake Okeechobee, estimated as 105 tons of inflow and 35 tons of rain and dust. (TMDL=140 tons)**

7. **Improve the CERP's Lake Okeechobee Watershed Project by designing and constructing a system that will achieve the above water quality goals.**

    A. **Consider Lake Okeechobee's entire drainage basin in the plan. Re-design reservoirs and stormwater treatment areas (and other technology such as algal turf scrubbers) to achieve water quality goals.**

    B. **Include a basin-wide wetland restoration component in the plan to improve water quality, increase regional storage, increase habitat, and assist landowners in meeting water quality goals.**

8. **Fully implement the Lake Okeechobee Protection Legislation (HB 991).**

    A. **Ensure the Lake Okeechobee Protection Plan fully addresses and offers solutions to the water quality problems.**

    B. **Ensure agricultural Best Management Practices control P to the maximum extent possible including balancing on-farm P budgets, and basin-wide P budgets.**

    C. **Continue examining strategies for dealing with Lake Okeechobee's internal sediment problem.**

9. **Keep Lake Okeechobee water levels in the 13.5 to 15.5 foot range, as allowed in WSE (lake water level schedule).**

NITROGEN

Introduction

About 78% of the earth's atmosphere is composed of nitrogen (N). Despite this abundance, N is a limiting nutrient in most ecosystems. This apparent contradiction lies in the fact that most atmospheric N is in a form that plants cannot use. The two main natural events that convert unusable atmospheric nitrogen to usable forms are lightening and nitrogen-fixing organisms, most of which are bacteria or algae that have the ability to take the main atmospheric form and convert it to biologically usable forms.

Human activities around the world have roughly doubled the amount of N that enters the biological processes of ecosystems each year, compared with pristine periods (Vitousek et al. 1997). Global effects of increased N include: increased global concentration of nitrous oxide (a greenhouse gas) in the atmosphere; accelerated loss of soil nutrients such as calcium and potassium; acidification of soils and water bodies; changes in plant systems that has accelerated the loss of biodiversity; and, long-term declines in ocean fisheries and coral reefs (Vitousek et al. 1997). Large increases in N accelerate growth of some plants and can cause great changes in ecosystem functioning. Effects of N enrichment on aquatic ecosystems include: increased mass of algae; changes in algae communities, often favoring noxious species; changes in invertebrate communities; changes in plant species and increases in undesirable plants; decrease in water clarity; taste, odor and water treatment problems; oxygen depletion; fish kills; reductions in desirable fish and increases in undesirable fish; and decreases in perceived esthetic value of water bodies (Carpenter et al. 1998). The single greatest contributor to increased N in most ecosystems is fertilizer use, with other factors including deforestation, fossil fuel burning, increased planting of nitrogen fixing crops, and oxidation of organic soils (Vitousek et al. 1997).

The aquatic ecosystem of Lake Okeechobee originally was considered P limited, meaning that the main factor limiting plant growth was insufficient P levels (Joyner 1971). During the 1970's Lake Okeechobee received N loads ranging from 8,000-14,000 tons of N annually, and during the same period water column N levels rose from an average concentration of about 1500 ppb N in the early 1970s, to about 2500 ppb N by 1980. Most of this N input was from the Everglades Agricultural Area and carried into Lake Okeechobee by backpumping (SFWMD 2002b). The reason large amounts of N come from the EAA is because these former soils of the Everglades are organic and decompose under current agricultural practices. The decomposition releases large amounts of N. Indeed, so much N is freed through soil loss that crops in the EAA do not need additional N fertilizer (Bottcher and Izuno 1994).

Like P, large amounts of N can be absorbed in ecosystems by plants and chemical interactions. However, ecosystems can become N saturated and once this happens, N runoff accelerates, even if the same amount is applied as before (Vitousek et al. 1997). Nitrogen differs from P in ecosystems in that it forms a greater variety of chemical compounds and, unlike P, it can enter and/or leave the system through conversion to a gaseous form (Carpenter et al. 1998).

Nitrogen standards for Lake Okeechobee were set in 1983 and supposed to be met by the time the permit expired in 1988. The 1983 permit had targets of a total of 2,949 tons of N from 14 major structures around the Lake. N inflows into the Lake have been greater than this (i.e., in

violation) every year since (SFWMD 2002b). As of 2004, the 16-year-old, 1988 Lake Okeechobee structures permit still has not been renewed (SFWMD must get a permit from DEP for nutrients flowing through their structures). In spite of the imbalances N can cause, nutrient control strategies for Lake Okeechobee recently have focused almost entirely on P. For example, the Lake Okeechobee Action Plan (Lake Okeechobee Issues Team 1999) has excellent discussion and recommendations for P, but no discussion for N.

Lake Okeechobee's nitrogen budget

From 1973 to 2000, an estimated average of 8,926 tons of N entered the lake each year, and 3,557 tons of N exited, creating a net deposition of 5,219 tons. Before water supply backpumping from the EAA was stopped in the early 1980's, about 10,000 to 13,000 tons N were entering Lake Okeechobee annually (SWIM 2002). Water column concentrations ranged from 1500-3000 ppb. A drop of annual N inflows after the early 1980s to a general range of 6,000 to 10,000 tons per year is attributed to decreased backpumping (James et al. 1995). Since the 1980's, the water column concentration of N has remained around 1500 ppb N (SWIM 2002).

It is difficult to determine what "pristine" levels of N in Lake Okeechobee might have been. Samples taken in the 1970's from lakes in the region recorded N levels ranging from 850 to 1400 ppb N (Table 10). Samples taken from relatively pristine areas of Okeechobee's watershed recorded N levels between 1300 and 1750 ppb (Table 11). Considering that after backpumping was curtailed, Lake Okeechobee N levels dropped to about 1500 ppb N and have remained relatively stable, N levels appear to be in a safe range. Further research is warranted to determine if this assumption is sound.

Table 10. Nitrogen levels in Lake Okeechobee and similar lakes in south Florida (1.0 mg/l equals1000 ppb). These levels are some of the earliest measurements available and may reflect close to natural levels.

Location	Year	TKN mg/l
Lake Okeechobee[1]	69-70	1.4
Lake Okeechobee[2]	1973	1.6
Lake Okeechobee[2]	1979	1.9
Lake Okeechobee[3]	1990s	1.5
Lake Istokpoga[4]	1974	1.00
Lake Arbuckle[4]	1974	0.85
Lake Kissimmee[4]	73-74	1.26
DEP standard	1999	0.90

1 Joyner 1971
2 Federico et al. 1981
3 SWIM 2002
4 Milleson 1978

Table 11. Nitrogen levels from relatively pristine locations in Lake Okeechobee's watershed (1000 ppb = 1.0 mg/l).

Location	Year	N mg/l
Bay Hammock Slough[1]	73-78	1.39
Starvation Slough[1]	73-78	1.57
Pine Island Slough[1]	73-78	1.30
Tick Island Slough[1]	73-78	1.27
Ice Cream Slough[1]	73-78	1.20
Armstrong Slough[2] (station 1)	79-80	1.59
Armstrong Slough[2] (station 2 fertilized)	79-80	5.66
Armstrong Slough[2] (station 3)	79-80	1.60
Kissimmee Prairie Sanctuary[3]	97-98	1.75

1 Federico 1982
2 Goldstein and Ulevich 1981. Station 2 was fertilized during the sampling period, temporarily raising its N levels
3 Kozusko 1999

Past actions to address the N problem

The levels of N in Lake Okeechobee during the 1970s appeared to be increasing. Much of the N that was entering the lake was coming from the EAA, where organic soils release large amounts of N as they decompose. The water from the EAA was being pumped into Lake Okeechobee (which is sending the water upstream) to increase the lake's storage volume, which increases water supply.

A lawsuit, filed by the Florida Wildlife Federation, National Wildlife Federation, Friends of the Everglades and the Coral Gables Women's Club, over EAA water that was being backpumped into Lake Okeechobee was settled in 1979. The resulting management agreement is called the Interim Action Plan (IAP) and still controls this practice. Water cannot be pumped into Lake Okeechobee from the EAA for the purpose of filling the lake and increasing water supplies (water-supply backpumping). However, when the canals south of the lake become so full during wet periods that they risk overflowing, excess water can be pumped into the lake for flood protection (flood-control backpumping). The IAP reduced N flows from these structures by an estimated 90% and N levels in the lake dropped to the present levels, averaging about 1500 ppb. These levels are considered acceptable for now (SFWMD 2002b), but are slightly higher than the goal of 1,200 ppb N, identified in the Lake Okeechobee Conceptual Model (Havens 2004).

Backpumping for water supply has occurred four times since then, associated with dry periods in 1981-82, 1985, 1989, and 2001. Droughts are a natural event and important in ecosystem function. Water management during droughts should function to help protect Lake Okeechobee from getting too low, hence "needing" backpumping.

Dairies and sludge applications are other significant sources of N in the Okeechobee watershed. The Dairy Rule is discussed in more detail in the P section, but most of the P control measures, especially holding more water and containing cattle waste, yield significant N control as well (Stanley and Gunsalus 1991). An estimated 11,914 tons of sludge was applied in Okeechobee

County in 1999, containing an estimated 275 tons of N, and 133 tons of P (M. Meeker, FDEP, pers. comm.). Large chicken farms near Indiantown transported nitrogen-rich chicken manure into Okeechobee's watershed through 2001, and no agency was actively monitoring the program. A partial moratorium on sludge application was called in 2001 and BMPs for sludge application for agriculture were in development by the Florida Department of Agriculture and Consumer Services (FDACS).

Summary of N problem as of 2005

Lake Okeechobee has averaged about 1500 ppb N for more than a decade. This level is somewhat greater than the 1200 ppb N goal expressed in the Lake Okeechobee Conceptual Model. However, 1500 ppb N is similar to measurements taken in parts of the watershed that are considered relatively pristine. Therefore, while continued monitoring of N is essential to prevent problems, focusing most efforts on P control is warranted. The recommendations to control P in the previous section (implement BMPs that reduce application and hold water, and construct STAs or other water treatment technologies) will help control N levels in the future. The CERP also should be designed to stop all backpumping to Lake Okeechobee from the EAA.

WATER QUALITY GOALS: NITROGEN

Outcome: Maintain nitrogen concentrations in the water column of less than 1500 ppb while attaining an N:P ratio of 30:1 or greater.

Goals:

Return Lake Okeechobee to a N limited system by attaining N:P ratios of at least 30:1.

Obtain a water column concentration of 1,200 ppb N.

Chapter 4

Nuisance and Exotic Species

Photo: SFWMD

NUISANCE AND EXOTIC SPECIES

INTRODUCTION

Human activity is moving species around the world at unprecedented rates. Whether plant or animal, species arriving in new regions often become very important in ecosystem interactions in their new environment, often at the expense of the native organisms. Animal invaders can cause problems through predation, grazing, competition and/or habitat alteration, while plant invaders can alter fire regimes, nutrient movement, hydrology, energy budgets, greatly diminish abundance or survival of native plants, block navigation and even enhance flooding (Mack et al. 2000). Both plant and animal invaders may, under some circumstances, hybridize with closely related native species. Hybridization not only threatens the genetic integrity of the native species, but also can change a species' characteristics. Two different species of salt cedar trees (Tamarix spp.) introduced to the western United States appear to have hybridized and created an even more invasive tree than either of the parent stock (Raloff 2003). Disease organisms and parasites can be invaders as well. Indeed, many of the principle pests on agriculture crops in temperate regions (most of North America) are exotic (Mack et al. 2000). In Florida, all of these effects seem to have occurred.

Human activity also can change the abundance and distribution of native organisms, allowing them to become "nuisance" species. Perhaps the best example of this in South Florida is the spread of cattail. Cattail is a native Florida plant, but does not thrive in the low-nutrient ecosystems of South Florida (Daoust and Childers 1999). With the phosphorus (P) enrichment of Lake Okeechobee, a broad band of cattail has covered the edge of the western marshes (Richardson et al. 1995) in areas that formerly were dominated by sawgrass (Pesnell and Brown 1977). Cattail replacement decreases both plant and animal diversity (Weller 1978, SFWMD 2003a), therefore it is considered a nuisance species.

In a summary of exotic (also termed "non-indigenous") plants and animals inhabiting Florida, the USACE (1999a) reported totals of approximately 1200 plant species, 1000 invertebrate species, and almost 200 vertebrate species. Many of these exotic species seem to have little ecological impact, yet others have spread rapidly and altered entire ecosystems (Austin 1978; Simberloff et al. 1997). The Florida Exotic Pest Plant Council (FLEPPC) categorizes exotic plants based on their invasiveness. Category I species represent the greatest threats and include, "invasive exotics that are altering native plant communities by displacing native species, changing community structures or ecological functions, or hybridizing with natives." Category II species include "invasive exotics that have increased in abundance or frequency but have not yet altered Florida plant communities to the extent shown by Category I species" (FLEPPC 2001).

Approximately 50 species of exotic plants have been observed on Lake Okeechobee (Bradley et al. 1997; SFWMD 2003a). Twenty-one of these species are listed as Category I (Table 12). Ten of the Category I species at Lake Okeechobee are widely distributed (found on >100 acres), including seven species that occur within natural habitats. These seven species are Brazilian pepper (*Schinus terebinthifolius*), hydrilla (*Hydrilla verticillata*), melaleuca (*Melaleuca quinquenervia*), torpedo grass (*Panicum repens*), water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*), and wild taro (*Colocasia esculenta*). Australian pine (*Casuarina spp.*) and Napier grass (*Pennisetum purpureum*) are widely distributed but have not been found in

natural areas. The eleven remaining Category I species have limited distributions (found on <100 acres). Opportunistic observations identified four additional Category I species: Chinese tallow (*Sapium sebiferum*), climbing fern (*Lygodium sp.*), hygro (*Hygrophila polysperma*), and strawberry guava (*Psidium cattleianum*); only a few individuals of these species were observed.

Table 12. Category I invasive exotic plants found at Lake Okeechobee.

Scientific Name	Common Name	In Natural Areas
Species with wide distribution (>100 acres)		
Casuarina equisetifolia	Australian pine	No
Casuarina glauca	suckering Australian pine	No
Colocasia esculenta	wild taro	Yes
Eichhornia crassipes	water hyacinth	Yes
Hydrilla verticillata	hydrilla	Yes
Melaleuca quinquenervia	melaleuca, cajeput, paper bark tree, tea tree	Yes
Panicum repens	torpedo grass	Yes
Pennisetum purpureum	Napier grass	No
Pistia stratiotes	water lettuce	Yes
Schinus terebinthifolius	Brazilian pepper	Yes
Species with limited distribution (<100 acres)		
Abrus precatorius	rosary pea	No
Bischofia javanica	bischofia	No
Cestrum diurnum	day jessamine	No
Cupaniopsis anacardioides	carrotwood	No
Eugenia uniflora	Surinam cherry	Yes
Ficus microcarpa	laurel fig	No
Hymenachne amplexicaulis	West Indian marsh grass	No Data
Psidium guajava	guava	Yes
Senna pendula var. glabrata	climbing cassia, Christmas senna	No
Syzygium cumini	jambolan, Java plum	No
Urochloa mutica	pará grass	No Data

Seven exotic species found at Lake Okeechobee are listed as category II species by the FLEPPC (Table 13). Two of these species, alligator weed (*Alternanthera philoxeroides*), and castor bean (*Ricinus communis*), are widely distributed and occur within natural areas. The remaining twenty-two exotic species found at Lake Okeechobee are not listed by the FLEPPC and few are widely distributed or found within natural areas. Many of these species persist from previous cultivation on islands within the lake. Opportunistic observations have identified one additional non-listed species, millet (*Echinochloa sp.*).

Table 13. Category II invasive exotic plants found at Lake Okeechobee.

Scientific Name	Common Name	Natural Areas
Species with wide distribution (>100 acres)		
Alternanthera philoxeroides	alligator weed	Yes
Ricinus communis	castor bean	Yes
Species with limited distribution (<100 acres)		
Cyperus involucratus	umbrella plant	No Data
Ficus altissima	false banyan	No
Myriophyllum spicatum	Eurasian water-milfoil	No Data
Pteris vittata	Chinese brake fern	No
Solanum torvum	susumber, turkey berry	Yes

In general, the spread of invasive or nuisance plant species within Lake Okeechobee appears to have been aided by elevated nutrient levels and unnatural water level management (Milleson 1987, LOLZTG 1988, Richarson et al. 1995, Daost and Childers 1999). Torpedo grass now covers about 18,000 acres of Okeechobee marsh (28 square miles) and is the plant of most concern. Other plants of concern include melaleuca, Brazilian pepper, hydrilla, water hyacinth, water lettuce, and cattail. Exotic plant control is a multi-agency effort with major contributions from SFWMD, USACE, FDEP, FWC, DOF, and others depending on the species and location. Total expenditures on exotic plant control (not including cattail) in FY 2002 were $4.8 million (SFWMD 2003a).

MAJOR EXOTIC AND NUISANCE PLANTS

Torpedo grass

Torpedo grass was introduced in the lower Kissimmee River basin during the 1920s and has been used for grazing purposes throughout South Florida (SFWMD 1997). By 1998, torpedo grass had displaced more than 17,000 acres of native plant habitat within the marsh (Smith et al. 1998). Torpedo grass can form such thick stands that there literally is little room for wildlife use. Water under torpedo grass stands tends to have little oxygen, severely limiting aquatic organisms and truncating the base of the food chain.

SFWMD (2001) research on torpedo grass control shows the most promising method appears to be burning the grass during the dry season followed by the application of herbicide four to six weeks later when new growth appears. About 9,600 acres were treated using this method between June 2000 and June 2002 (SFWMD 2003a). In a 500-acre area treated east of Moore Haven, 90% of the torpedo grass was still under control after 2 years and the treated area contained a mixture of spikerush, fragrant water lily and open water (Chuck Hanlon, pers. comm.). Effective burning requires water levels to drop to at least 13 feet and that condition did not occur during the dry season (winter) of 2002-03 or 2003-04. Although promising, the burning followed by herbicide application remains in the experimental stage.

Herbicide treatment also is very expensive and until these techniques are more predictable, trying to treat all the torpedo grass acreage would be a risky investment. Therefore, while control research continues, the agencies are focusing efforts on controlling further spread of torpedo grass. Moonshine Bay has high quality spike rush habitat (excellent Snail Kite habitat) and the SFWMD treated new patches of invading torpedo grass totaling about 3,800 acres in 2002. Once effective techniques are developed, major efforts should be funded to eradicate torpedo grass from the Indian Prairie areas (especially between Buckhead Ridge and Indian Prairie Canals).

Melaleuca

Melaleuca was planted around Lake Okeechobee during the 1930s and 1940s by the Corps to protect the levee system from wind and wave erosion. By 1996, these plantings formed thick monocultures of approximately 3,000 acres. The trees also spread lakeward and surveys indicated that melaleuca inhabited over a quarter of the 100,000-acre marsh zone (SFWMD 1997). Melaleuca is one of the most problematic exotic species in Florida because of its tremendous reproductive, invasive, and survival capabilities (Bodle et al. 1994). Melaleuca is adapted to fires, an integral component of Florida ecology, which promotes desiccation of seed capsules and the release of seeds (Woodall 1981). Within a few months of fire and germination, melaleuca can withstand total immersion in water for up to six months (Meskimen, 1962). Melaleuca are an ecological problem for the lake because they displace native plants and replace open marsh with "forested" habitat, 30 to 65 ft tall. Melaleuca invasion decreases plant community diversity and decreases the quality of habitat for marsh-dependent wildlife (Shaw and Jacobs 1996). In 1993, a multi-agency group, including Audubon, formed a "Melaleuca Advisory Committee" to unify agency efforts to control melaleuca on Lake Okeechobee (SFWMD 1997). By 2002, every tree on the lake was treated with a combination of mechanical and herbicidal methods. Continued maintenance is required to kill new growth and plants that survived earlier treatments (SFWMD 2003a).

Water Hyacinth and Water Lettuce

Water hyacinth and water lettuce are two exotic species of floating plants subject to ongoing control programs. These rapidly growing plants once covered thousands of acres of open water and marsh areas within Lake Okeechobee until management efforts started in the 1970s. Thick concentrations of floating plants can block navigation, clog water control structures, prevent light from reaching submerged aquatic vegetation, and decrease oxygen in the water column.

The current control strategy on Lake Okeechobee is to rely mostly on herbicides to limit floating plant coverage to less than 1% of the lake's surface. In some areas, such as around municipal water intakes, mechanical harvesters are used. Harvesters appear not to create water quality impacts (mostly related to turbidity) beyond the local area of work (Alam et al. 1996), however, this method is too expensive and slow to use over the entire lake. The underlying philosophy of herbicide control is to maintain very low coverage of plants. These plants spread so rapidly, that if they are not maintained at very low levels, huge acres of infestations will develop and require more herbicide use in the long term. This program tends to be controversial because of public wariness of herbicide use, unsightliness of dying plants, possible fish kills due to decomposing plants, and impacts to non-target species (e.g., the plants float into stands of bulrush and it is difficult to spray one without the other).

Although mistakes are sometimes made, control crews have improved their techniques and lessened damage and problems. The alternative would be to allow more acres of floating plants, which would be a worse and more expensive problem, in the long run.

Hydrilla

Hydrilla is a submergent plant species first found in Florida in 1960. Hydrilla became prevalent in Lake Okeechobee in the 1980s. Currently, hydrilla is a major component of Lake Okeechobee's submergent plant communities that used to be dominated by native species such as eelgrass (*Vallisneria americana*) and peppergrass (*Potamogeton illinoensis*). Hydrilla can provide good habitat for waterfowl, waterbirds and fish. However, it covers native plant communities, impedes navigation, and impairs water control structures (Langeland 1996). Because of its invasive nature and many negative impacts, hydrilla is less desirable than native species that provide the same benefits. Hydrilla coverage on Lake Okeechobee appears limited by high water levels and wave action, and it almost disappeared during the high water period in the late 1990s (Havens et al. 2001). Presently, no comprehensive programs exist for control of hydrilla in Lake Okeechobee, instead the plant is either removed mechanically or treated with herbicide when it encroaches upon access areas and impedes navigation (SFWMD 1997).

Brazilian pepper

Brazilian pepper is present in many of the better-drained areas of Lake Okeechobee, including tree islands, canals, and levees, but cannot invade wetter regions of the lake. It can form dense stands that almost completely displace native vegetation (Ewel et al. 1982). Unfortunately, the herbicides that are most effective on Brazilian pepper are difficult to use on Lake Okeechobee because they are not safe for use in an aquatic environment. During low water levels in 2000 however, the agencies were able to treat 735 acres in various areas throughout the lake (SFWMD 2001b). Follow-up treatments are planned on treated areas as well as targeting specific stands.

Australian pine

Australian pine (*C. equisetifolia*) and suckering Australian pine (*C. glauca*) are both short hydroperiod species that form dense stands. *C. glauca* is more tolerant of inundation (SFWMD 1997) and may pose a threat to the tree islands and short hydroperiod portions of the marsh in Lake Okeechobee. Australian pines form dense stands and produce thick beds of leaf-litter that reduce or eliminate the presence of other species (Rockwood et al. 1990). As melaleuca is removed from the lake's perimeter, Australian pine should be controlled as well.

Wild taro

Wild taro was introduced to Florida by the U.S. Department of Agriculture as a crop plant. It can form dense clusters along shorelines, displacing native vegetation (Langeland 1996). Wild taro is not targeted by any control programs for Lake Okeechobee even though it is a Category I species with an estimated distribution between 1,000 to 10,000 acres (Bradley et al. 1997).

Cattail

Cattail is not an exotic species, but is considered a nuisance species in South Florida due to its recent spread throughout many wetland habitats, including the marsh zone of Lake Okeechobee (Richardson et al. 1995). Increased phosphorus levels and high water levels are believed to contribute to their rapid proliferation. After the drought of 2001, cattail invaded areas of Bay Bottom, west of King's Bar and Cody's Cove, and near the Monkey Box. The SFWMD successfully treated about 2000 acres in these three areas to keep the cattail from becoming established in these sensitive areas. The large band of cattail along the outer marsh remains and may not be worth controlling until Lake water quality improves.

MAJOR EXOTIC AND NUISANCE ANIMALS

Exotic and nuisance animals have great mobility and are often difficult to detect, thus are difficult to control. Most of the species listed below do not have control programs; instead agencies focus on monitoring population trends.

Feral pigs

Feral pigs are present along elevated areas such as dikes and levees, and can venture into the marshes during low water. These popular game animals can be very harmful because they: eat native plants and animals (including eggs from bird or reptile nests), root through soil thereby altering plant community structure and succession patterns (possibly allowing exotics to invade), and can spread diseases such as brucelosis and pseudorabies to animals and humans. Because pigs are generally limited to the perimeter of the lake, allowing hunters to harvest unlimited numbers of pigs throughout the year may be sufficient control.

Exotic fish

Lake Okeechobee has at least 16 species of exotic fish (Table 14). As with most of the exotic animals listed in this section, the effects of these exotics are poorly known, and control programs do not exist. Some species appear to have been carelessly released by people who had them as pets (Padilla and Williams 2004). Notable species include the blue tilapia (*Oreochromis aureus*) and the armored catfish (*Pterygplichthys multiradiatus*), both of which feed, root and nest in the bottom, and can destroy vegetation and compete with native fish (SFWMD 2002c). The catfish also can be a significant predator at high densities.

Exotic clams

The Asiatic clam (*Corbicula fluminea* or *manilensis*) is extremely abundant in Lake Okeechobee. These clams were first detected in Florida in the 1960s and now are found throughout the state. There is no efficient method to control these clams. Over time, the Asiatic clam can accumulate so many dead shells in the substrate that some native species that are adapted to soft bottoms can have trouble burrowing (SFWMD 2002c). Possible benefits of the Asiatic clam include being a food item for shell crackers, and perhaps the flocks of lesser scaup that winter in the middle of the Lake.

Table 14. Exotic fish species known from lake Okeechobee and the Kissimmee River as of January 2003. Data courtesy of Don Fox, FWC, Okeechobee.

Common Name	Species Name
Blue tilapia	*Oreochromis aurus*
Peacock bass	*Cichla ocellaris*
Callichthyid catfish	*Hoplosternum littorale*
Common carp	*Cyprinus carpio*
Convict cichlid	*Cichlasoma nigrofasciatum*
Grass carp	*Ctenopharyngodon idella*
Green sunfish	*Lepomis cyanellus*
Jack Dempsey	*Cichlasoma octofasciatum*
Jewelfish	*Hemichromis bimaculatus*
Sailfin Catfish	*Liposarcus multiradiatus*
Mayan cichlid	*Cichlasoma urophthalmus*
Oscar	A*stronotus ocellatus*
Pacu	*Colossoma spp.*
Spotted tilapia	*Tilapia mariae*
Suckermouth catfish	*Hypostomus plecostomus*
Walking catfish	*Clarias batrachus*

Spiney water flea

Spiney water flea (*Daphnia lumholtzii*) is a crustacean and not a true flea. Water fleas are small and swim in the water column as members of the plankton community. The SFWMD is sampling for these organisms at 5 locations in the lake. Effects are unknown but of concern because of their location at the base of the food chain (i.e., they could eat desirable organisms, or form a poor food source for higher organisms).

Exotic apple snails

An exotic apple snail (*Pomacea bridgesi*) inhabits many Florida waters, though its status in Lake Okeechobee is uncertain. It grows to a larger size than the native apple snail and may displace the natives. Anecdotal information indicates snail kites may not be able to feed on these larger snails. Because of this threat, monitoring for this species should be performed routinely to detect invasions as early as possible.

Mallards

Mallard ducks (*Anas platyrhynchos*) are relatively common winter migrants to Florida, but did not historically breed here (Kahl and Maehr 1990, Gray 1993). Mallards are a favorite bird for releases in parks and ponds and domestic varieties have established breeding populations throughout Florida and on and around Lake Okeechobee. Unfortunately, feral Mallards (the term "feral" refers to domestic animals living in the wild) are so closely related to Mottled Ducks that they interbreed, threatening the genetic integrity of Florida's Mottled Duck population

(Mazourek and Gray 1994). Indeed, hybridization with Mallards is probably the single greatest threat to the long-term persistence of Mottled Ducks (Moorman and Gray 1994). Although Florida Administrative Code 39-4.005 effectively bans the release of Mallards due to disease risks (Hill 1994), most people are unaware that releasing mallards is against the law, and that they threaten our native Mottled Duck populations. FWC recently enacted rules that limit Mallard releases from game farms and that restrict Mallard sales (http://myfwc.com/commission/2004/feb/68A-4-0052.pdf). FWC also has a permitting program that can allow control of feral Mallards during the summer, when migrant Mallards are not present (http://www.wildflorida.org/mallard). FWC also is working to raise public awareness of this problem.

AUDUBON RECOMMENDATIONS

The key to controlling the invasive plants of Lake Okeechobee is the development and refinement of a comprehensive management program. An exotic species control program was prepared (SFWMD 2003a) as called for in the Lake Okeechobee Protection Program. Two species that deserve priority attention at present are torpedo grass and melaleuca, but the management program should consider all plants listed as Category I by the FLEPPC. The program should strive for the complete elimination of each species; this would keep populations at a minimum and decrease long-term costs.

Below is a list of components considered necessary to create a successful program. Commendably, the Lake Okeechobee Exotic Species Plan appears to contain all these components. The largest limitation at this point is resources; the exotic control teams need more support if they are to be successful.

Components for success

1. comprehensive scope
2. adequate and consistent funding
3. integrated approach to management
4. research on invasion biology
5. agency coordination and integration with existing management programs
6. education

1. Comprehensive scope

   A successful invasive species management program must consider how management decisions will affect all of Lake Okeechobee's invasive species. Experience shows that individual species respond differently to the same management practice. Conditions that affect several species (e.g., fire regime and water levels) must be factored for their net effect on all invasive species. This strategy can help prevent management practices from solving one problem while creating another.

2. Proper and consistent funding

Once a management program is developed, proper funding is necessary to make it successful. For individual species, the initial investment should be the most substantial since it is beneficial to decrease the species population as quickly as possible. An aggressive strategy will provide the most environmental benefit and decrease long-term maintenance costs (herbicide use, equipment, and labor). For example, in 1985, hydrilla management in Florida's public waterways required $2.5 million. However, funding did not keep pace with the expansion of hydrilla, and by 1995 an estimated $14 million was needed to manage hydrilla - unfortunately only $5 million was appropriated (Simberloff et al. 1987). Invasive species populations continue to grow and become more expensive to manage each year that funding is insufficient. Additionally, eradication may become impossible as populations increase and spread to new areas or develop resistance to herbicides.

3. Integrated approach to management

   There are three common methods for controlling the expansion of invasive species. Mechanical removal is the most direct method, yet it is very time consuming and expensive. Herbicide use is the most efficient method, but herbicides can only be used on certain species under specific conditions. Biological controls are available for several species, but few achieve enough success to preclude the used of additional methods (Center et al. 1997). Since each method has advantages and disadvantages, an integrated approach combining all available methods is necessary for successful control of invasive species. Application of these methods should be integrated with management practices (water levels, fire regime) in order to maximize their effectiveness. Successful integration requires research projects like the SFWMD investigation of hydroperiod effects on torpedo grass management (SFWMD 2003a). Integration of control methodology and lake management practices should be investigated for all Category I invasive plants at Lake Okeechobee.

4. Research on invasion biology

   Research programs should continue to explore the impact of invasive species in Lake Okeechobee and the factors that contribute to their spread. Since many species are already known to have deleterious impacts (e.g., Category I invasive plants), most research will focus on understanding the biological characteristics that contribute to their spread. For poorly known species, like the exotic animals at Lake Okeechobee, research is needed to determine their impacts on the lake. Also, ongoing monitoring should evaluate populations of exotic species present on the lake but not yet determined to be invasive. Monitoring these species (or eliminating them) could be of immense benefit since many species persist in low numbers before becoming pervasive (Gordon and Thomas 1997).

5. Agency coordination and integration with existing management programs

   Many agencies are involved in invasive species management at Lake Okeechobee. As agencies develop an exotic species control program, the responsibilities of each agency involved should be formally expressed, including responsibilities, goals, and funding requirements. Additionally, existing management programs target several species in and around Lake Okeechobee (melaleuca, water lettuce, water hyacinth, hydrilla, and Brazilian

pepper). Lake Okeechobee's program should integrate the management activities of existing programs to maximize results and minimize redundancy.

6. Education

Education is critical to help local landowners and recreational users understand how they can help prevent the spread of invasive species at Lake Okeechobee. Private lands may harbor invasive species and provide a continuous source for the recolonization of public lands, negating the effects of management programs. Landowners should be informed about the problematic species and encouraged to maintain their property free of invasive species. Recreational users should be informed about invasive species and instructed in safe-use practices, such as removing aquatic plants from boats when entering and leaving waterways as well as removing seeds from clothing.

EXOTIC AND NUISANCE SPECIES GOALS

Outcome: Eliminate all harmful nuisance and exotic plants and animals from Lake Okeechobee and surrounding areas in order to allow all parts of the ecosystem to function without impairment.

Goals:

1. Identify nuisance and exotic species that have the greatest amount of impact in Lake Okeechobee.

A. Generate accurate maps of the distribution and rate of spread of exotic and nuisance species.

B. Conduct ongoing research and monitoring on the effects of exotic and nuisance species. These data will be critical in determining which species are most important to target.

2. Continue research on control of exotic species to improve cost effectiveness of control measures.

3. Ensure control programs encompass areas outside of Lake Okeechobee that could be sources of species invasions.

4. Focus current efforts on:

A. A follow-up treatment of Melaleuca

B. Continued research on torpedo grass control with an ongoing program to prevent its spread.

C. Ongoing maintenance control of water hyacinth and water lettuce with a goal of obtaining initial control and maintaining minimal acreage.

D. Active patrolling for, and eradication of, Old World Climbing Fern.

5. Continue public education and outreach efforts on effects of nuisance and exotic species, identification of nuisance and exotic species, and effective control methods for exotic species.

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Glossary of Terms, Acronyms, and Abbreviations

Acre: a square of land with sides of 209 feet and totaling 43,560 square feet (english measure). Abbreviated “ac”

Acre-foot: the amount of water that would cover one acre (43,560 square feet) one foot deep. It equals 326,000 gallons of water. Abbreviated “ac-ft”

ASR: “Aquifer Storage and Recovery” a plan to inject water from the surface into deep aquifers and recover it during dry periods.

Assimilation co-efficient: a number used in equations that estimates how much of a nutrient (e.g., P) gets absorbed (assimilated) by a wetland, stream or lake.

Backpumping: the practice of pumping water from the EAA, northward, into Lake Okeechobee. It is called backpumping because the natural water direction would be toward the south. This water carries nutrients and contaminants that otherwise would not be placed in Okeechobee.

Benthic invertebrate: benthic means bottom-dwelling, invertebrates are animals without backbones including organisms such as insects, snails, crawdads, worms, and clams.

BMP: “Best Management Practices,” typically thought of for agricultural operations but also applicable to urban areas. BMPs are a series of activities that are recommended to improve efficiency, environmental protection and also protect profitability.

CERP: Comprehensive Everglades Restoration Project.

cfs: “cubic feet per second” a measure of water flow. One cfs of flow equals about 2 acre-feet, or 650,000 gallons, per day.

Chironomid: a type of fly whose larvae live in the water and transforms into a non-biting, mosquito-like adult fly. Chironomids are an important food source, especially during blooms that release billions at a time. These tend to decrease with pollution.

EAA: “Everglades Agricultural Area” about 700,000 acres (280,000 ha) of farmland south of Lake Okeechobee and north of the WCAs.

EPA: “Environmental Protection Agency” a federal agency that is a counterpart to the State’s DEP.

Eutrophic: nutrient rich, in limnology, usually refers to water bodies with phosphorus concentrations above 20 parts per billion

Exotic species: any organism, plant or animal, that is not native to the area, which has been introduced by human activities

FDACS: “Florida Department of Agriculture and Consumer Services”

FDEP: “Florida Department of Environmental Protection”

Flood control backpumping: backpumping conducted only when canals in the EAA region are full enough to risk overflowing and flooding

Governing Board: nine citizens appointed by the Governor who serve 4-year terms and oversee the activities of the SFWMD.

HB 991: “Lake Okeechobee Protection Plan” legislation passed in 2000 designed to help restore Okeechobee and its watershed.

Hectare: an area of 100 meters on each side and total area of 10,000 square meters. Also equal to about 2.5 acres. Abbreviated “ha”

IAP: "Interim Action Plan” a plan adopted in 1979 allowing backpumping into Lake Okeechobee only to control flooding but not to augment water supply

Internal loading: the process of nutrients (e.g., P) in a water body recycling from the sediments and plant communities to such an extent that the water body becomes its own “source” of P loads.

IRL: “Indian River Lagoon,” references to the IRL are to the southern part only (St. Lucie County and southward)

IRL Feasibility Study: the IRL component of CERP for the southern IRL.

Lake Okeechobee Protection Act: (HB 991), legislation passed in 2000 designed to help restore Okeechobee and its watershed.

Lake Okeechobee Protection Plan (LOPP): The plan to meet Lake Okeechobee’s phosphorus goal by 2015, which was developed by mandate from the Lake Okeechobee Protection Act.

Lake Okeechobee Service Area (LOSA): The areas around Lake Okeechobee that receive water supply from the Lake, including agricultural areas on all sides, urban areas, the estuaries and Everglades.

LEC: “Lower East Coast” the region south of Lake Okeechobee, including the EAA and extending to Florida Bay and as far east as Palm Beach.

Littoral zone: in Lake Okeechobee, generally considered the areas where rooted plants grow—the marshes.

LOTAC: “Lake Okeechobee Technical Advisory Committee” a panel of experts brought together to examine problems in the Lake; three LOTACs have been formed (1986, 1990, and 2000) to address P loading issues.

LOW project: “Lake Okeechobee Watershed Project” the Lake Okeechobee watershed component of CERP.

Mesotrophic: medium nutrients, usually refers to water bodies with phosphorus concentrations between 10 and 20 parts per billion

MFL: “Minimum Flows and Levels” For lakes, this is the water level below which withdrawing more water would cause harm lasting several years.

Nuisance species: any organism, plant or animal that is native to a region, but due to human activities, creates problems. For example, cattail is native to Florida but the introduction of phosphorus has helped it spread rapidly, covering plant communities that formerly were there.

Oligochaete: an aquatic worm that lives on the bottom (benthic) and is adapted to polluted water. These pump P back into the water column and often are called sludge worms.

Oligotrophic: nutrient poor, usually with phosphorus concentrations less than 10 parts per billion (also see mesotrophic and eutrophic)

P: “phosphorus” in this document P refers to total phosphorus, often written elsewhere as “TP” which stands for total phosphorus

ppb: parts per billion, also known as micrograms per liter

ppm: parts per million, also known as milligrams per liter

ppt: parts per thousand

RaSTA: “Reservoir-assisted stormwater treatment area” this structure has a holding reservoir next to an STA and is operated by holding water until the STA has time to receive and treat it.

Regulation Schedule: a plan for water level management in water bodies. Usually expressed as a graph with dates across the bottom and water levels on the side

Regulatory release: water releases from Lake Okeechobee designed to lower water levels and help prevent flooding (i.e., dumping water to keep the lake from getting too deep)

Restudy: “Central and Southern Florida Project Comprehensive Review Study” this study documented conditions in the greater Everglades ecosystem and recommended to Congress a conceptual plan for Everglades restoration, which led to the CERP.

SAV: “Submerged aquatic vegetation” rooted plants that grow underwater, to the surface of the water, such as hydrilla, pepper grass, or eel grass.

SFWMD: “South Florida Water Management District”

SSM: “supply-side management” For Okeechobee, this is the water management plan during drought conditions, otherwise known as a water rationing plan for the Lake’s water.

STA: “stormwater treatment area” otherwise known as “filter marshes,” these constructed areas use aquatic vegetation to filter nutrients from the water.

SWIM: “Surface Water Improvement Act” a statewide program designed to address water quality issues in Florida. The Lake Okeechobee SWIM plan (1989) recommended an annual inflow of P into the Lake of an average of 397 tons.

TCNS: “Taylor Creek/Nubbin Slough” watersheds.

THMs: “trihalomethanes” a group of cancer-causing chemicals that form after chlorine treatment is used on water with a high organic content. The towns of South Bay and Pahokee have chlorine treatment facilities and have problems with THMs periodically.

TMDL: “Total Maximum Daily Load” the amount of a pollutant that can enter a waterway per year without causing undue harm.

Ton: an English tons is 2000 pounds while a metric ton is 2200 pounds, or 10% larger (actually, a metric ton is 1000 kilograms and at 2.2 pounds per kilogram, equals 2200 pounds)

USACE: “United States Army Corps of Engineers”

Water supply backpumping: backpumping done from EAA region canals intended to fill Lake Okeechobee and increase water supplies. The Interim Action Plan stopped this practice.

Water supply release: water releases from Lake Okeechobee to supply a users needs (either irrigation or water utility) or to supply an environmental need (e.g., keep salt intrusion from harming the Caloosahatchee Estuary)

WCAs: “Water Conservation Areas” historic Everglades habitat that lies north of Everglades National Park and south of the EAA. These areas were diked for water supply protection but cannot meet current demand.

WOD: “Works of the District” a map of the various waterways, streams, canals and properties that make up the main drainage areas going into Lake Okeechobee.

WRAC: “Water Resources Advisory Commission” comprised of stakeholders from south Florida and agencies, this commission serves in an advisory role to the SFWMD Governing Board

WSE: “Water Supply and Environment” the water level management plan for Lake Okeechobee which tends to keep water from exceeding 17 feet and allows it to drop as low as 13.5, during normal periods.

Appendix A

Kissimmee River Restoration

Photo: Paul Gray

APPENDIX A. KISSIMMEE RIVER RESTORATION

INTRODUCTION

Once completed, the Kissimmee River Restoration will be the largest river restoration project in the history of the world. In a now famous example of a misguided project, the Kissimmee River floodplain had a massive channel dug through its center between 1962 and 1971. The effects of the channelization to the floodplain's environment were predictably devastating and calls to restore the river were sounded even before the project was complete (Marshall et al. 1972). The 1971 Governor's Conference on Water Management in South Florida produced a consensus that river restoration should be investigated. In 1976, the Florida Legislature passed the Kissimmee River Restoration Act that established a process to examine whether restoration was possible, and if so, to start the process of restoration.

The Kissimmee River restoration preceded the Comprehensive Everglades Restoration Plan (CERP), and therefore is not part of CERP. The Lake Okeechobee Watershed component of CERP assumes the River is restored, an assumption that has not been fulfilled yet. Because the Kissimmee River provides about one half of Lake Okeechobee's annual inflow, it is critical that the hydrological patterns and the water quality of the river are appropriate for the lake's health.

It has been suggested that the Kissimmee River restoration project might serve as an example of how CERP goals can be fulfilled. The project design was built and verified in a systematic, scientific manner. The process was publicly vetted and stakeholders throughout the basin provided input. Unfortunately, the project has fallen behind schedule and now must compete, during financially austere times, with other expensive projects. Another concern is that the project lacks a water quality component and a hydrologically-restored Kissimmee River could end up polluted. These problems can be corrected, however.

PAST ACTIONS THAT AFFECTED THE KISSIMMEE RIVER

Channelization

The Kissimmee River flows from Lake Kissimmee southward to Lake Okeechobee. Although the distance between the 2 lakes is about 50 miles (83 km), the main river channel originally meandered across its 1-3 mile-wide (2-5 km) floodplain for about 100 miles (166 km) to connect the lakes. The river was exceptionally winding. One report says the first steamboat up the river was the *Bertha Lee* in 1883, which made the trip from Fort Myers to Kissimmee in 52 days (Will 1965). Apparently some river bends were too short for the boat and considerable "shaving" of the banks was required in places. A federal channel for navigation was authorized in 1902 between Fort Bassinger and the town of Kissimmee (USACE 1991).

The Kissimmee River basin is the largest watershed flowing into Lake Okeechobee and supplies about half the lake's water flow (SWIM 2002b). The Kissimmee Chain of Lakes includes a basin of about 1,633 square miles that supplies Lake Kissimmee with water.

The water leaves Lake Kissimmee to the Kissimmee River, which has an additional basin of about 758 square miles (USACE 1991). The Lake Istokpoga basin (609 square miles) formerly contributed flow to the lower part of the Kissimmee River through Istokpoga Creek, but the Istokpoga Canal now has a structure on it that is largely inoperable, stopping almost all flow. This structure is to be replaced and flow might be restored to some extent as part of the restoration.

Water levels in the region were higher historically than they are today. The Kissimmee Chain of Lakes would rise to levels 3-5 feet (1-1.7 m) deeper than they do presently (USACE 2002a). Indeed, early settlers living between Lake Kissimmee and Lake Istokpoga considered themselves as living on the "Kissimmee Island," because when water levels were high, they were surrounded by water on all sides; the Kissimmee (lake and river) on the east, Istokpoga and its creek on the south, Arbuckle Creek and Lake to the west and Lakes Weohyakapka, Rosalie and Tiger to the north (Lewis 1986). The Blue Jordan Swamp connected Lakes Arbuckle and Weohyakapka. This regional abundance of water kept the Kissimmee River and its floodplain wetter than it is in today's altered landscape.

The Kissimmee River was unique among North American river systems in that not only did the main channel flow, but also the adjacent floodplains were inundated most of the time (Koebel 1995). Prior to channelization, about 94% of the floodplain was wet more than 50% of the time (Toth 1990) and 77% of the floodplain was wet about 70% of the time (Toth et al. 1998). In 11 of 25 years of pre-channelization records, 80% of the floodplain was wet the entire year and 100% of the floodplain was wet for at least two consecutive years three separate times (Toth 1990). Conversely, 84% of the floodplain went dry for five months during three separate drought events.

The floodplain wetlands occupied about 45,000 acres (18,000 ha). Floodplain depths were more than three feet (1 m) in the middle but most areas averaged from about 1-2 feet (0.3 to 0.7 m). These conditions formed diverse wetland plant communities (Toth 1990), which in turn supported diverse invertebrate communities (Vannote 1971), fish communities (Trexler 1995), and wetland bird communities (Perrin et al. 1981, 1982).

Two deadly hurricanes on Lake Okeechobee during the 1920s and several exceptionally wet hurricanes that flooded much of Central Florida during the 1940s fueled calls for increased drainage (Florida Cattlemen's Association 1999, USACE 1991, Koebel 1995). In response, the Central and Southern Flood Control Project outlined a plan to channelize the Kissimmee River for increased flood protection (USACE 1991). In theory, the large central channel could convey excess water to Lake Okeechobee where it could be controlled.

The effects of the channelization were severe to the floodplain environment. The main canal, named C-38, is 30 feet (9 m) deep and 110 yards (100 m) wide; at least three times the width and depth of the natural river channel. About 30,000 to 35,000 acres of wetlands were drained, covered with canal spoil, or converted into canal (USACE 1991). With the wetlands gone, winter waterfowl use dropped 92% (Perrin et al. 1982) and

wading bird use dropped drastically, except for Cattle Egret (Toland 1990), Bald Eagles declined 74%, and fish spawning and foraging habitat was lost and no longer supported the famous bass fishery (Trexler 1995).

The canal itself was sectioned into a series of five pools (termed A, B, C, D, and E from north to south) that were created by five water control structures (named A through E). These pools are more similar to lake habitat than river habitat in that water does not flow, they are very deep and oxygen levels often are low. Fish communities now have a larger percent of fish that are tolerant of low oxygen levels (such as gar and bowfin) and have fewer sunfish such as bass and crappie. The invertebrate species in the canal are more similar to those found in lakes than in large rivers (Toth 1993).

Restoration plans and tests

Many scenarios were proposed to restore the river and floodplain, each with specific trade-offs and uncertainties. Flood control and navigation had to be maintained in all scenarios. The Kissimmee Chain of Lakes, which furnished much of the river's flow, had lower water levels than in historic times and regulation schedules that did not release water in a pattern the restored river would need. Much of the watershed had been drained since the 1960s, further altering hydrology. Many people had moved onto the floodplain and might have to be displaced. Also, development in the area might have affected water quality. Finally, it was not certain that wetlands and wildlife would respond to hydrological restoration.

A Feasibility Study was conducted from 1978-1985 to investigate these uncertainties. This study concluded that simply trying to manage water levels better with the present structures could not improve conditions much; the effects of the canal were too great. Completely filling in the C-38 canal was not feasible, but filling strategic areas might be. In the end, six plans were advanced for further consideration (Koebel 1995). They were to investigate:

1. partial backfilling of the C-38 canal, focusing on the central area,
2. construction of flow-through marshes throughout floodplain,
3. modification of control structures to increase water levels enough to flood the floodplain,
4. creation of wetlands through separate actions including flow-through marshes, tributary impoundments, and pool stage manipulations,
5. restoration of Paradise Run (the southern-most part of the river near Lake Okeechobee), and
6. the use of Best Management Practices to improve water quality and restore wetlands.

In 1984, a little more than a dozen years after the river channelization was completed, three weirs were placed in the C-38 canal in Pool B (often called the Pool B demonstration project) to test whether re-flooding the floodplain would restore its ecological values or create sedimentation problems, and to examine engineering questions about feasibility and flooding issues (Loftin et al. 1990). These structures

blocked all canal flow except through their central navigation opening, which is about 6 feet (2 m) deep and 40 feet (12 m) wide. Water releases from Lake Kissimmee were managed to mimic more natural patterns.

The demonstration project was successful in showing that the biological communities would respond to hydrological restoration and sedimentation would not be a problem. During periods of high flow, the weirs diverted up to 60% of the C-38 flow into the river floodplain (Toth et al. 1993) and diverted smaller amounts during periods of low flow. The positive response of the floodplain ecosystem to the redirected water was rapid. Wetland plant communities replaced upland plant communities (Toth 1990), riverine invertebrates replaced lake-like invertebrates (in only 40 days in some cases) (Toth 1993), twenty-five fish species were found in the reflooded areas compared with only 16 species in downstream unrestored areas (Wullschleger et al. 1990), and the restored area in Pool B had greater numbers and species diversity of waterfowl and wading birds than in un-restored areas (except Paradise Run which retains wetland habitat)(Toland 1990).

A large-scale model of the Kissimmee River and its floodplain was constructed at the University of California, Berkeley. Experiments using this model helped predict flow and sediment movement characteristics of a restored river (Shen et al. 1994). This and other inquiries indicated that a refilled canal would not suffer excessive erosion. They also concluded that if the canal were plugged in only a few places, instead of completely filled, the remaining canal would cause high velocities in remnant river channels, rapid recession of water from the floodplain and inadequate floodplain inundation (Loftin et al. 1990, Shen et al. 1994).

A "test fill" of the C-38 was conducted in 1994 where about 330 yards (300 m) of the canal was filled with spoil. The primary goals were to evaluate fill consolidation and to test construction techniques (Koebel 1995). The filling was successful and had minimal erosion, as predicted in earlier studies.

Using scientific techniques to evaluate and understand each step of the process helped develop a well-conceived project. The cooperating agencies in the Kissimmee River Restoration project deserve credit for using science to evaluate alternatives and make decisions based upon sound knowledge. This model should be followed by future restoration projects.

PRESENT PROGRAMS AND THEIR CONTRIBUTION

The river restoration has two main components: filling in the C-38 canal ("backfilling”), and changing the water level management in the Kissimmee Chain of Lakes to facilitate delivering natural water flow patterns to the river. Due to many constraints, backfilling will only occur in about 40% of the C-38 canal (22 miles of the 56 mile canal). This will restore about 26,500 acres (10,600 ha) of floodplain wetlands and about 43 miles (70 km) of meandering river channel. An often-overlooked part of the restoration project, that will create large environmental and recreational benefits is the Headwaters Revitalization project. This project will raise seasonal water levels around Lakes Kissimmee,

Hatchinehaw, and Cypress by about 1.5 feet, which will re-flood and restore about 30,000 acres (12,000 ha) of lake marsh.

Backfilling

The filling of about 22 miles (35 km) of the C-38 canal is divided into a land acquisition phase and 4 main construction phases. All the land in the floodplain must be acquired by the SFWMD. In January 2003, Phase I backfilling was completed in Pool C, with about 7.5 miles of canal filled. This also involved demolishing the Pool B structure, re-carving certain portions of the river channel in areas that were under the spoil pile or in the former canal, and removing many smaller canals and earth works in the floodplain. About 11,000 acres of floodplain have been re-flooded and recovery is progressing very well.

Phases II and III will fill the C-38 in Pool D. Numerous smaller ditches and works in the floodplain must be leveled or removed, some structures must be modified, some levees rebuilt, and the Pool C structure will be removed. Highway 98 and its bridge in the floodplain were raised in 2003 to allow the braided river to pass under it. The 4th and final Phase of backfilling will involve the canal in Pool B. All of these phases are behind schedule due to land acquisition and modeling delays (Table A-1). These delays have changed the final completion date from 2010 to 2012.

Headwaters Revitalization Project

To ensure adequate amounts of water will be available to mimic natural flows to the restored river, Lakes Kissimmee, Hatchineha, and Cypress will be allowed to attain water levels about 1.5 feet deeper than today's levels. These higher water levels are closer to historic high-water levels in these lakes and will increase storage to allow more natural flow patterns in the river. As of 2004, about 5,000 acres (2000 ha) of land along the shorelines of these lakes remained to be acquired. Land acquisition for this project is scheduled for completion in 2005.

Structural changes in the area also must be completed. The canals between Lakes Kissimmee, Hatchineha and Cypress must be widened to allow adequate water movement when needed. The Kissimmee to Hatchineha canal-widening project was delayed because of technical problems working in the soils. The S-65 structure, which releases water out of Lake Kissimmee, also had to be enlarged.

Table A-1. As of January 2003, most of the land required for the project has been acquired.

Site	Total acreage needed	Acres purchased	Acres to be purchased
Upper Basin	35,000	30,000	5,000
Lower Basin	75,000	60,000	15,000
Total	110,000	90,000	20,000

note: acres are approximate for planning purposes.

Paradise Run

The restoration of Paradise Run is a project that was frequently discussed but ultimately dropped from present plans (Koebel 1995). Paradise Run is the lowest stretch of the Kissimmee River where it flows into Lake Okeechobee (near Buckhead Ridge). The ecological value of this are was so significant that the C-38 was built along the eastern edge of the floodplain to reduce impacts. This left much of Paradise Run largely intact, although disconnected from river flows.

During the Pool B demonstration project, more wading birds, including 4 Species of Special Concern (Little Blue Heron, Tri-colored Heron, Snowy Egret and White Ibis), were found on Paradise Run than were found anywhere else along the river, including the restored areas of Pool D (Toland 1990). The close proximity of Paradise Run to Lake Okeechobee makes it of special importance to wading birds from the lake's rookeries (Smith et al. 1995b). Additionally, 65% of all the ducks in the Kissimmee River were found in Paradise Run (Toland 1990). Unfortunately, the lack of water flow caused deterioration of fish habitat and species diversity dropped from 39 species in 1957, to 9 and 17 species found in 1980 and 1987, respectively (Davis et al. 1990). These declines included a drop in percent of game fish from 43% of all fish in 1957, to 28% in 1987 (Davis et al. 1990).

Various proposals were made to restore Paradise Run and the SFWMD purchased about 1,406 acres (560 ha) of the total 4,265 acres (1,700 ha) needed for completion. These acres are called Mims Island and constitute the marsh on the eastern side of the old river channel. Additional purchases of at least 2,859 acres (1,144 ha) are needed to complete land acquisition for this project.

Paradise Run could be a very successful project because, not only are most of its wetlands and river channel intact, but its upstream end is only about 0.5 miles (1 km) from the Pool E structure. The water upstream of the Pool E structure is maintained at about 21 feet (6.4 m), and the elevation of the northern end of Paradise Run is about 16 feet, which yields a 5-foot difference. Water deliveries could be made largely through gravity flow (Allen et al. 1981), making it cost effective to re-hydrate the floodplain.

Paradise Run should be restored due to its demonstrated value as river habitat, its proximity to Lake Okeechobee (making both systems more whole), its apparent cost effectiveness, and its recreation potential (right next to large boat ramps and camp grounds on the Lake).

KISSIMMEE RIVER RESTORATION GOALS

Outcome: **Restore the hydrology and water quality of the Kissimmee River that will restore plant and animal populations and provide water to Lake Okeechobee at the right times and with appropriate water quality.**

Goals:

1. **Support the present plans of 1) altering the hydrology of the Kissimmee Chain of Lakes to store more water (and improve the health of the lakes themselves) and 2) fill 22 miles of the C-38 canal between Pools B and D and restore river features in this area as needed.**

2. **Refine Kissimmee Chain of Lakes regulation schedules to provide healthy hydrological patterns to the river at all times and prevent periodic hydrologic interruptions similar to that experienced with the Lake Tohopekaliga extreme drawdown in 2004.**

3. **Develop a water quality component that will provide clean water flowing into and out of the river.**

4. **Restore Paradise Run as part of the project.**

5. **Support completion of the Long Term Management Plan for the Kissimmee Chain of Lakes.**

Appendix B

Management Needs of the Kissimmee Chain of Lakes and Lake Istokpoga

Photo: Paul Gray

APPENDIX B. MANAGEMENT NEEDS OF THE KISSIMMEE CHAIN OF LAKES AND LAKE ISTOKPOGA

INTRODUCTION

The Kissimmee Chain of Lakes watershed covers an area of about 1,633 square miles, and the Lake Istokpoga watershed covers about 609 square miles. These basins form the headwaters of Lake Okeechobee's two largest watersheds, and make up about half of Okeechobee's natural watershed area. Although the water and nutrients from these watersheds flow to Lake Okeechobee, these areas were not explicitly considered in the Lake Okeechobee Surface Water Improvement Plan (SWIM), the SFWMD's Works of the District Program, or the Everglades restoration's Lake Okeechobee Watershed Project. The Lake Okeechobee Protection Act, passed by the legislature in 2000, considers these two watersheds, but does not grant them the same level of planning or protection as regions closer to Lake Okeechobee. There are other programs intended to enhance or protect parts of these watersheds, but those programs are not comprehensive in scope. To address these shortcomings, the Everglades restoration team decided to include the Lake Istokpoga watershed in the Lake Okeechobee watershed project, and the SFWMD has taken the lead on developing a "Long Term Management Plan" for the Kissimmee Chain of Lakes.

The Kissimmee Chain of Lakes (also called the Upper Chain of Lakes) form the headwaters of the greater Everglades ecosystem and is named for its myriad lakes (about 176 square miles of lakes with 26 lakes greater than one square mile in area), many connected in sequence. The region's waters were historically connected by broad waterways, streams, or sloughs that flowed during the wet season, and stopped flow during some dry seasons (Koebel 1995). Lake Kissimmee is considered the downstream end of the Kissimmee Chain region; hence the Kissimmee Chain also can be viewed as Lake Kissimmee's watershed. The construction of the Central and South Flood Control project (C&SF) in the 1960's included many canals and structures that allowed greater water level control in these lakes and allowed humans to fundamentally change flow patterns throughout the region (Table 1-B).

The lakes in these regions have many similarities to Lake Okeechobee. They tend to be shallow, have extensive perimeter marshes and submerged plant beds (including *Hydrilla* infestation problems), have naturally low nutrient levels (mesotrophic), and are subject to the same wet-dry season water level patterns. Lake Kissimmee is Florida's third largest lake at about 35,000 acres, with a maximum depth of about 20 feet. Lake Istokpoga is Florida's fifth largest lake at 27,500 acres and a maximum depth of about 10 feet. Like Okeechobee, water is released through gates on human-imposed schedules.

Water levels in the lakes formerly varied by as much as 10 feet between drought and flood years and by 2-5 feet during average years. After the 1960s, this variation was reduced to about 1-3 feet, depending on the lake. This reduction in water level fluctuation has harmed the marshes of the lakes and lead to the use of periodic extreme drawdown projects to try to rejuvenate the lakes. Although these occasional projects help some

aspects of the lake ecosystems, they cannot replace the chronic ecosystem problems that continually restricted water levels create.

Not only have water level patterns changed, these formerly low-nutrient lakes are becoming nutrient enriched from human activities. Lake Tohopekaliga received human sewage until the mid-1980s (USACE 2002a). Modern agricultural practices have encouraged the extensive use of phosphorus fertilizer, which enters waterways in large quantities (Boggess et al. 1995). Growing urban areas contribute large amounts of pollution as well (Mock-Roos 2003). Lakes that in pristine conditions probably had phosphorus levels in the range of 30-49 parts per billion (ppb) now have levels considerably greater, resulting in water quality conditions for the Kissimmee Chain of Lakes that now are rated fair to poor (McDiffett 1981, Livingston et al. 1998). Average phosphorus concentration of water flowing out of Lake Kissimmee increased from 38 pbb between 1990-94 to 84 ppb between 1995-2000 (SFWMD 2002b). It has been estimated that four of the major lakes in the Kissimmee Chain (Kissimmee, Hatchineha, Cypress, and Tohopekaliga) will be saturated with phosphorus by about the year 2014 (White et al. 2003).

Lake Istokpoga's watershed is a different drainage basin than the Kissimmee Chain of Lakes, but is affected by the same issues of stabilized water levels and nutrient enrichment. For example, in 2000, the Florida Fish and Wildlife Conservation Commission conducted an extreme drawdown and muck removal project on Istokpoga that cost about 2.7 million dollars and scraped about 1,325 acres ($2000/acre) of marsh, filling about 20 acres of marsh area with spoil piles. However, the water management pattern that originally created the problem remains in place, facilitating the return of the same problem plants. The FFWCC actively sprays the re-growing plants, leaving much of the marsh zone devoid of any plant life at all. Similar to Lake Kissimmee, Lake Istokpoga's phosphorus outflows increased dramatically during the 1990s, going from an average of about 7 tons per year between 1990-94 to an average of about 23 tons per year between 1995-99 (SFWMD 2002). Lake Istokpoga is projected to become phosphorus saturated by about the year 2019 (White et al. 2003).

Table B-1. Estimated historic water level fluctuations and present water regulation schedules from selected Upper Chain lakes (from USACE 2002a).

Lake	Maximum High (Level MSL)	Maximum Low (Level MSL)	Range (feet)	Present high (Level MSL)	Present Low (Level MSL)	Range (feet)
Tohopekaliga	59.4	48.93	10.47	55	52	3
Cypress	56.8	?	?	52.5	49	3.5
Hatchineha	55.0	47.29	7.71	52.5	49	3.5
Kissimmee	56.6	44.2	12.4	52.5	49	3.5
Istokpoga	42.4	35.4	7	39.5	38.25	2

GENERAL EFFECTS OF RESTRICTED WATER LEVEL FLUCTUATIONS ON PLANT COMMUNITIES

Historically, water levels in most of the larger lakes fluctuated as much as 10 feet over long-term climate cycles and 2-5 feet annually (Champeau et al. 2000, USACE 2002a).

During these periods of wide water level fluctuations, the Kissimmee Chain of Lakes and Lake Istokpoga reportedly had sandy bottoms and diverse plant communities (Sincock et al. 1957, Champeau et al. 2000, USACE 2002a). Present management is designed to keep most of these lakes within a one to three foot fluctuation range (Table 1-B).

Distribution and species composition of wetland plant communities is influenced by many factors including hydrology, slope, nutrients, substrate type, exposure to wave action or current, competition for resources, and herbivory. Of these, the single most important factor usually is considered water level fluctuation (Gosselink and Turner 1978, Weller 1978, Mitsch and Gosselink 1986, Keddy and Fraser 2000). When water levels are not allowed to fluctuate in historic (natural) patterns, seed germination, decomposition, plant growth, community succession, fire pattern, and animal use patterns, all are altered.

Keddy and Fraser (2000) suggest that lake marshes reach their greatest plant species diversity when exhibiting varying within-year and between-year water level fluctuations (assuming moderate fluctuations). The C&SF system has allowed such a high degree of control over water levels in these lakes that there is minimal variation in water levels over multi-year cycles, and little variation from year to year. Consistent with this theory, the loss of diversity in water level patterns created a concomitant loss of diversity in vegetation communities. Plant response in these regulated lakes has tended toward dominance by a small number of long-hydroperiod plant species in near-shore (1-3 foot deep) areas, and short-hydroperiod plant communities virtually disappearing (Champeau et al. 2000, USACE 2002a). Species that tend to increase in abundance above historic levels include pickerelweed, cattail, burhead sedge (*Scirpus cubensis*), and water primrose. These plant communities often form interwoven mats of roots that hold plants together and also are referred to as “tussocks.” Sincock et al. (1957) sampled plants before these lakes were regulated and recorded a progression of more than 50 different species of plants from the shoreline to deeper water in Lake Tohopekaliga, a much more diverse situation than found today. The short-hydroperiod species that grew in higher elevations have largely disappeared in the present lakes.

Another result of restricted water level fluctuation is accumulation of organic material in the tussocks that fills the water column and replaces sand-bottomed marshy areas, with deep, mucky material (Champeau et al. 2000, USACE 2002a). Organic material accumulates because decomposition is inefficient in areas that rarely, or never, dry and partly decomposed material eventually fills the water body with peat (Reddy and Patrick 1983, Kushlan 1990). The organic soils of the Everglades were formed in this manner (Snyder 1994), as were organic soils south of Lake Istokpoga and in various areas around the Chain of Lakes. The tussocks that are forming in these Lakes now essentially are in a successional "peat forming" mode that has been artificially enhanced because water levels do not drop low enough, for long enough, to allow decomposition to keep up with production (USACE 2002a).

Accumulated organic material also binds nutrients in the peat matrix, making those nutrients unavailable to living plants (Gosselink and Turner 1978). The benefits of

extreme drawdowns result partly because decomposition is allowed once the wetland dries down (air (oxygen) surrounds the dead plants), and nutrients are released from dead plant tissues. When the wetland re-floods, a burst of productivity occurs partly because plants can use the newly available nutrients (Kadlec 1962, Kushlan 1990). Sometimes, wetlands burn when dry, which also helps release nutrients back to the ecosystem, which then increases plant growth and plant nutrient content (Smith and Kadlec 1985, Wade et al. 1980). Restricted water levels tend to prevent these ecosystem processes, although anthropogenic nutrient enrichment may be compensating for some of the nutrient binding.

Tussocks cover areas that other communities formerly occupied. Most wetland plants sustain themselves over the long term through their seeds, which germinate under differing conditions, depending on hydrologic cycles (Van der Valk 1981). One group of plants called "moist soil" plants needs mudflats to germinate (Goodwin 1979, Fredrickson and Taylor 1982). In Florida, this plant zone is also often referred to as a wet prairie zone and characterized by a variety of grasses, sedges, smartweeds, St. John's worts, and other plants, and often hosts the greatest plant diversity in wet systems (Winchester et al. 1985, Kushlan 1990, Kirkman et al. 1998). This plant zone tends to produce desirable seeds for waterfowl and other seed-eating birds (Goodwin 1979, Fredrickson and Taylor 1982, Olinde et al. 1985). If mudflats do not occur, moist soil plants can virtually disappear from lakes (Sincock and Powell 1957, Milleson 1987, LOLZTG 1988), as they appear to have done on most of these lakes (Champeau et al. 2000, USACE 2002a). Other common wetland plants such as cattails and submerged species can germinate in shallow water but not deeper water (Meeks 1969, Van der Valk and Davis 1978, Keddy and Ellis 1985). Not only are seeds germinating when water is low, decomposition of organic material is releasing nutrients for growth. The loss of natural fluctuations has impeded these processes and short-hydroperiod plants, in particular, are severely inhibited from growing in these lakes.

GENERAL EFFECTS OF RESTRICTED WATER LEVEL FLUCTUATIONS AND TUSSOCK FORMATION ON ANIMAL COMMUNITIES

Some reports state that tussocks have little fish or wildlife value (USACE 2002a). Further investigations indicate tussock communities have value for many kinds of wildlife including myriad species of small fish, amphibians, and reptiles, and furnish Sandhill Crane and Snail Kite nesting habitat (Kitchens et al. 2002b).

Fish

The influence of stabilized water levels and tussock formation on fish populations is unclear. When they physically fill the water column, tussocks can exclude fish. However, a study on the Lake Kissimmee drawdown detected no significant differences in overall bass populations before versus after the drawdown (Allen et al 2003).

The most fished-for species in the Upper Chain of Lakes are sunfish (Centrarchidae) including black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), and redear sunfish (*Lepomis microlophus*), as well as largemouth bass (*Micropterus salmoides*). These fish tend to nest in relatively shallow areas in or near the marsh zone.

Tussocks have been implicated in excluding these game fish from suitable spawning areas (USACE 2002a), but because bass can spawn on sand, mud, cobble, vegetation, and roots, in water up to 25 feet deep (Stuber et al. 1982b), the relatively small area of tussock coverage on these lakes should not be an impediment. Similarly, bluegill can spawn in water up to 10 feet deep on “almost any substrate,” although sand or fine gravel is preferred (Stuber et al. 1982a). Crappie also can nest in deeper water, and on a variety of substrates (Pflieger 1975, Edwards et al. 1982), therefore tussocks would not appear to impede breeding. Early conclusions that tussocks do not contain small sunfish (Allen and Tugend 2002) might be flawed because the authors used rotenone to kill the fish and collected specimens for about 2 hours afterward. However, sunfish do not readily float after death, therefore likely were under-sampled (Kitchens et al. 2002b). Kitchens et al. (2002b) used activity traps and found many fish in the tussocks, of which 78% were sunfish.

After hatching, sunfish fry tend to migrate to open water areas as part of a lake's plankton communities, living on the productivity of the plankton food chain, not on inshore (i.e., tussock-zone) communities (Pflieger 1975, Bull et al. 1995). When grown, bass live in open water or marsh fringes mostly eating smaller fish, but supplemented by a great variety of other aquatic organisms (Pflieger 1975). Adult black crappie tend to live in near-shore open water, eating insect larvae and small fish, particularly threadfin shad, which in-turn, feed primarily in deeper water habitats on plankton and benthic invertebrates (Williamson and Nelson 1985, Bull et al. 1995, Fry et al. 1999). Adult bluegill tend to stay inshore in marsh zones and eat a wide variety of small prey including insects, shrimp, snails, and small fish (Furse and Fox 1994). Redear sunfish feed predominantly on snails and clams (Pflieger 1975) but also eat a large number of insect larvae from bottom sediments in open water, as do black crappie (Bull et al 1995). Considering that tussocks hold many species of fish and other forage, and that many sport fish also rely on plankton and benthic food resources, tussocks may have a beneficial impact on fishery productivity.

Wading birds

Wading birds are considered good indicators of ecosystem health because many processes must be functioning before wading birds become abundant (Weller 1995). Restricted water level fluctuations on the Kissimmee Chain of Lakes and Istokpoga create problems for wading bird nesting. The small wading birds (e.g., White Ibis, Little Blue Heron, Snowy Egret, Tricolored Heron; all are Species of Special Concern) need about three months to complete a nesting cycle (roughly one month for feeding/courtship/nest building, a month for egg-laying and incubation and a month for fledging nestlings (DeAngelis et al. 2002)). They also need declining water levels, with declines of about 6 inches during April and May (David 1994b, Fredrick and Collopy 1989). Present water regulation schedules do not provide the 3-month window needed for breeding or expose large enough areas for optimal foraging. The result is there do not appear to be as many wading bird rookeries in the Kissimmee Chain as one might expect in a region with so many lakes and marshes (see Runde et al. 1991). In spite of its water management problems, Lake Istokpoga has one of the "Top 100" wading bird rookeries in Florida (Runde et al. 1991)(Table 2-B), hosting thousands of breeding birds, although

most are Cattle Egrets (P. Gray, unpub. data). Although this indicates birds are able to forage off the lake, providing high quality foraging habitat with-in lake should be a goal.

Waterfowl

Waterfowl use these lakes for breeding, molting, feeding and loafing. Resident Mottled Ducks utilize the lakes for brood-rearing and molting, with broods preferring shallow water and mudflats and molting birds seeking flooded, vegetated, cover during the day and shallow marshes during the night, which can include tussock communities (Moorman and Gray 1993). Florida is the southern terminus of the Atlantic Flyway in North America, therefore of value to hundreds of thousands of waterfowl from Canada and the United States (Sincock 1957, Bellrose 1976). Migrant dabbling ducks feed heavily in moist soil plant communities because of their great seed production (Goodwin 1979, Frederickson and Taylor 1982) and prefer water that is less than 12 inches deep for feeding (White and James 1978, Johnson and Montalbano 1984). For dabbling ducks, rising or falling water levels can make new feeding areas available. Spring drawdowns allow the germination of moist soils plants on the exposed mudflats (Sincock et al. 1957, Goodwin 1979). In addition to the dabblers, diving ducks such as the Ring-necked Duck, Lesser Scaup, and Canvasback utilize submerged plants that are found in deeper water, but that require periodic shallow water periods to germinate (Sincock et al. 1957, Van der Valk and Davis 1978). Lake Istokpoga is famous for wintering Canvasbacks although their numbers dropped from an average of about 2,900 per year between 1972-1992, to an average of about 260 between 1993-2002 (FWC, unpub. data). Stabilized water levels on these lakes have reduced waterfowl-friendly plants and reduced feeding opportunities.

Table B-2. Approximate number of nesting pairs of wading birds in Lake Istokpoga (not including Cattle Egrets) as determined by annual counts. Most abundant species are in parentheses.

Year	Bumblebee Island	Big Island
1970's	200-300	1000
Species	(Great Egrets)	(White Ibis)
1988	vacant (one count)	250-500
Species		(large waders)
1993	132	200
Species	(Great Egrets)	(mixed species)
1996	222	705
Species	(Great Egrets, Anhinga)	(White Ibis)
1997	21	vacant (one count)
Species	(Great Egrets)	
1997	152	5000
Species	(Great Egrets)	(White Ibis, Great Egrets)
2005*	600	1500
Species	(Great Egret, White Ibis)	(80% Cattle Egret plus 7other species)

*Unpub. Data; Audubon, SFWMD, FWC

Snail Kites

The Kissimmee Chain of Lakes is one of the major Snail Kite breeding areas in Florida (Dreitz et al. 2001a, Bennetts et al. 2002). Although a relatively small fraction of the total population usually breeds on these lakes, during the drought of 2001, when the Everglades were largely dry, 48 of 49 total nests located statewide were on the Kissimmee Chain of Lakes (Martin et al. 2003). Tussock formation reduces apple snail density, therefore can affect Snail Kites by excluding their food. However, bulldozing not only removes tussocks, but also removes plant communities conducive to snail use. Snail population recovery after drawdowns and scraping appears to take several years (Snail Kite Issue Team 2004).

EXTREME DRAWDOWNS AND MECHANICAL AND CHEMICAL TREATMENTS

To address the myriad problems created by water level management, the Florida Fish and Wildlife Conservation Commission has conducted several "extreme drawdowns" to rejuvenate target lakes (Table 3-B). Early drawdowns simply lowered the target lake for a period of time (simulating a drought). More recent projects have included bulldozing plants and organic material from dried areas. Some of the material is carried out of the lakebed, but some spoil is dumped in the lake itself, filling parts of the littoral zone. Herbicide treatments continue for years after the drawdown to impede plant re-establishment. The increased activity has increased the costs of these projects dramatically (Table 3-B).

During the 1971 drawdown of Lake Tohopekaliga, where no bulldozing was done, organic sediment was reduced by 50-80% and desirable vegetation increased 16% (Wegener and Williams 1974 in USACE 2002a, p. 26). After the 1979 drawdown on the same lake, harvestable largemouth bass increased about 400%. After the 1987 Lake Tohopekaliga drawdown, standing crop of fish increased 74% and largemouth bass increased about 320% in biomass. The 1987 project was the first to utilize bulldozing (615 acres), yet appears to have yielded similar benefits to the previous "simple" drawdowns. Most projects, whether they utilized bulldozing or not, have attained increases of harvest-size game fish 2-3 years after the drawdown, followed by a decline in subsequent years (USACE 2002a).

Drawdowns last one year and benefits are short-term. After the 1996 drawdown on Lake Kissimmee, no significant difference was detected in the bass fishery before or after the drawdown (Allen et al. 2003). Similarly, "Three years post drawdown on Lake Tohopekaliga, the vegetation communities in the scraped areas reverted to dense aquatic vegetation returning to pre-drawdown densities" (USACE 2002a, p. 35). In response, "Combinations of chemical and mechanical treatments to reduce biomass and control re-growth were also being tried." In reference to ongoing management of scraped areas, the Lake Tohopekaliga EIS states (Section 3.2.5.3), "The FWC has also funded, in conjunction with DEP, the thinning and management of cattails, smartweed and pickerelweed stands on scraped areas to create a more diverse native plant community." Section 3.2.5.4 of the Lake Tohopekaliga EIS (USACE 2002a) discusses the problem of

undesirable plants colonizing the scraped areas and plans to put them on a regular maintenance schedule, utilizing methods described above. It appears that desirable plant communities usually do not return and although a considerable amount of time, money, and herbicide is used to inhibit "undesirable" plants, there remains limited ability to encourage "desirable" communities without changing water level management.

It is not surprising that diverse, healthy plant communities do not readily colonize scraped areas. Not only is a substantial part of the seed bank removed with the organic material, but more importantly, the hydroperiod that encouraged undesirable plants to proliferate is re-established immediately after scraping. Many moist soil plants will not grow unless their seeds are annually exposed on mudflats; this does not happen with current regulation schedules. Dabbling ducks still do not find moist soil plant seeds to feed on. Tussock-forming plants re-establish and are not inhibited by low water. Organic material builds up without exposure to burning or decomposition. Wading birds, that depend on annual water-level decreases for breeding, still do not have suitable water patterns in any year. In short, ecological processes are not restored and the community remains impaired.

Additional concerns about the recent lake restoration projects include costs and collateral harm from the projects. Bulldozing can cost more than $2000/acre (Table 3-B). Research on Lake Tohopekaliga by the University of Florida before the planned drawdown concluded the tussocks have more habitat value and hold many more species of animals than earlier investigations had detected (or surveyed). Notably, there are many more sunfish in the tussock zones than previously reported (Kitchens et al. 2002b). The University of Florida (Kitchens et al. 2002b) noted that if there was removal of all of Lake Tohopekaliga's littoral zone, "the effects of muck removal at that scale may be more detrimental to the littoral communities than good."

This study team also counted more than 200 Florida Sandhill Crane nest structures in the habitats that were eliminated in the project (Kitchens et al. 2002b). These habitats will remain unsuitable for Cranes because of herbicide treatments. Florida Sandhill Cranes are listed by the FWC as "Threatened" (Wood 1996), yet that Agency's project is systematically eliminating their nests from these lakes. Drawdown projects also label many native plants as "undesirable" and target them for elimination, including willow trees that could hold wading bird and kite nests, and smartweed, which is considered a desirable waterfowl food (Goodwin 1979, Olinde et al. 1985, USACE 2002). Further, there is concern that follow-up herbicide spraying can affect Snail Kite nesting as well, by direct disturbance to the nests, and indirect affects on plants that apple snails utilize (Kitchens et al. 2002b).

The project on Lake Istokpoga filled an estimated 70 acres of wetlands, and the project on Lake Tohopekaliga filled 150 additional acres of wetlands (Table 3-B). The spoil piles can be colonized by exotic species but managers have no apparent plant management plan ready. Spoil piles near Lake Kissimmee State Park were removed because of their undesirable appearance and potential for invasion by exotic species.

Extreme drawdowns also can strongly affect downstream ecosystems. In spring of 2003, the Lake Tohopekaliga extreme drawdown had to be postponed because heavy rains in December throughout the Okeechobee watershed and Kissimmee Valley filled Lake Okeechobee and the Kissimmee Chain lakes above their regulation depths. In order to proceed with the extreme drawdown schedule, the volume of water that would have to be released would be enough to raise Lake Okeechobee about 7 inches (in a 6 week period). Lake Okeechobee already was more than 18 inches above its regulation schedule and the additional water likely would have triggered harmful Lake Okeechobee releases to the estuaries. Therefore, to protect Lake Okeechobee and the estuaries from additional harm, the agencies postponed the project.

In the winter of 2003-04, Lake Okeechobee remained so deep that in December, the SFWMD and Corps officially deviated from the regulation schedule to lower it, with a stated goal to get to 15 feet as soon as possible (SFWMD 2003b, 15 feet was considered the level at which harm from deep water would cease). Unfortunately, the Lake Tohopekaliga drawdown started while Lake Okeechobee remained above 15 feet, and ultimately added enough water to keep Okeechobee in a harmful state (above 15 feet) for about an extra month. This occurred while Okeechobee was making extra releases to the estuaries. In response to these conflicts, the Indian Riverkeeper filed a preliminary injunction against the Corps (as project supervisors) in federal court (Case No, 03-81 003-CTV-Middlebrooks/Johnson), challenging the adequacy of the Environmental Impact Statement upon which it was based. Although Judge Middlebrooks found that additional harm would occur to downstream systems from the project, he ruled that the Corps' omission of examining downstream impacts during wet periods was not sufficient grounds to overturn the entire Environmental Impact Statement. The project proceeded and Okeechobee did not reach the 15-foot mark until March 22, 2004, after the drawdown releases stopped.

The SFWMD arranged to store the "extra" water dumped from Lake Tohopekaliga itself, in locations other than Lake Okeechobee, but that amount was a fraction of the total released, and storing it did not prevent additional harm to Okeechobee. The problem was not the small amount of extra water from the Lake Tohopekaliga drawdown, but rather the much greater amount of water from Lakes Kissimmee, Cypress, and Hatchineha, that had to be drained first, and that could not be stored. The Lake Tohopekaliga project worked directly against the goals of the deviation for Lake Okeechobee and prolonged the harm to the lake.

The most direct harm from the Tohopekaliga drawdown was to the Kissimmee River Restoration project. The drawdown required dewatering the Kissimmee Chain by mid-March, and after that, the restored section of the Kissimmee River dropped into a 1-in-10 year drought. There was no water left in the Kissimmee Chain to supply a proper hydrology to the river restoration, and hydrologic goals could not be met. Through August 2004 the river remained in this drawdown-induced drought. No wading birds attempted to nest along the river in 2004. The Tohopekaliga EIS (USACE 2002a) also predicted that the Kissimmee River Restoration would experience another 1-in-10 year drought in 2004-05 because the refill deficit in the Kissimmee Chain was enough to

require an above-average rainfall year to refill the lakes, plus have enough water to supply the needs of the river. The hurricanes of 2004 provided enough rain to avoid another year of drought; if they had not, the Lake Tohopekaliga drawdown had the potential to create 2 years of artificial droughts and delay ecosystem recovery (an estimated 15,000 acres of restored and enhanced habitat, which is at least 4 times the area scraped on Lake Tohopekaliga).

One benefit from drawdowns and bulldozing is it increases recreational access to former tussock communities. Boaters, wading fishermen, and others enjoy this access. Also, homeowners on some of the lakes enjoy viewing the lake without plants. Although these are not biological goals, they are reasons some people support drawdown projects.

GENERAL GOALS FOR WATER LEVEL MANAGEMENT

Hydrology is perhaps the single most important influence on wetland plant communities. Management of the Kissimmee Chain of Lakes and Istokpoga has changed the characteristics of at least three ecologically important hydrological patterns: range, duration and timing:

1) Range: the multi-year range of fluctuation formerly was about 7 to 10 feet (depending on the lake), and the average annual range of fluctuation was about 2-5 feet, both have been reduced to about 1-3 feet at present,
2) Duration: the annual dry-down period (dry season recession) now occurs over about 3 months, rather than the historic pattern of about 7 months. Duration of "high water" events has been reduced to zero (i.e., the lakes cannot rise to former high water levels because of human structures near them), and
3) Timing: temporal pattern of low and high water periods has been altered in that water tends to be held lower than natural during the wet season (to maintain storage capacity in case of a storm event) and higher than natural during the dry season (to maintain water for human use if needed).

The guiding principle in the Kissimmee Chain of Lakes Long Term Management Plan and the Lake Istokpoga part of the Everglades restoration projects should be restoring these hydropattern characteristics as well as possible.

Table B-3. Major enhancement projects on the Kissimmee Chain of Lakes and other lakes in the Okeechobee watershed. Data courtesy of FWC biologists Martin Mann and Beachum Furse, and USACE 2002a. Lake Okeechobee data taken from projections in original Project Proposal.

Lake	Year	Contract cost in dollars	Cubic yards of material removed	Approx. acres scraped	Approx. acres exposed	Approx. acres of in-lake disposal
Tohopekaliga	1971	0	0	0	10,500	0
Tohopekaliga	1979	0	0	0	10,500	0
Tohopekaliga	1987	446,705	215,598	615	10,500	0
East Lake	1990	650,000	399,321	461	3,000	0

Tohopekaliga						
Jackson	1994-97	631,655	451,000	222	250	2.5
Kissimmee	1977	0	0	0	13,000	0
Kissimmee	1996	3,036,773	1,393,015	974	13,000	6
Cypress	1997-98		97,100			~6
Alligator Chain	2000	1,088,712	904,910	562	4,455	5
Istokpoga	2001	2,740,321	2,372,000	1325		~70
Okeechobee	2001	~500,000	~600,000	~200	na	20
Tohopekaliga	2001	6-10 million	6,700,000	2,844	10,500	151

NUTRIENT CONCERNS AND PROGRAMS

Lake Istokpoga and the Kissimmee Chain of Lakes are receiving increased nutrient loads due to human activities, and these nutrients will affect the health of the lakes no matter how well water levels can be managed. With nutrient enrichment there tend to be an increase in dominance by problem plant species (and loss of plant biodiversity), and accelerated plant growth, which leads to accelerated muck accumulation, either in tussocks or as mud in deeper zones.

White et al. (2003) estimated that Lakes Kissimmee and Tohopekaliga would be phosphorus saturated in10 years, Lake Cypress in 11 years, Lake Hatchineha in 9 years, and Lake Istokpoga in about 15 years (i.e., by about 2014-2019). The Lake Okeechobee Protection Plan (LOPP) is the only plan to date (2004) addressing phosphorus in these regions through the implementation of P Best Management Practices (page C-23). The Plan (SFWMD et al. 2004, page 7) notes that,

> "…at this time only typical cost-share BMPs will be considered for these [Istokpoga and KCOL] basins. More information is needed to determine if larger regional public works are needed for restoration in these areas. It must be noted that Lake Istokpoga and Lake Kissimmee provide a buffering effect through their assimilation of phosphorus, thus masking the impacts of upstream phosphorus reduction measures. However, this buffering ability will not continue indefinitely. Studies of sediment cores in the lakes indicate that current assimilative capacity will continue for approximately 10 years under existing conditions (White, Belmont, Reddy, and Martin 2003). The effects of implementing P reduction programs upstream of these lakes will extend the ability of the lakes to assimilate P into the future and not create additional P loads to Lake Okeechobee. Based on this information, a recommendation has been included in the LOPP to start implementation of cost-share BMP programs in the Lake Istokpoga and Lake Kissimmee watersheds in 2009."

This paragraph reveals that the phosphorus control in the Lake Okeechobee Protection Plan is not designed to protect any of these lakes from phosphorus saturation, and recognizes that these lakes are on a path toward saturation. If Best Management Practices

are enacted, as envisioned above, the time to P saturation is postponed only by about 2-5 years (White et al. 2003).

If and when these lake become saturated with P, the effects likely will be increased algae blooms, possible periodic fish kills, accelerated organic material accumulation, increased turbidity due to algae blooms and sediment re-suspension, changes in benthic (bottom-dwelling) organisms, increased coverage by cattail and other problem plant species, and increased phosphorus outflows. The problems with tussock-type communities are strongly linked to nutrients as well. Fertilized shorelines tend toward plant communities with fewer species, with greater biomass (i.e., tussocks), whereas low-nutrient areas tend toward higher species diversity and lower biomass (Keddy and Fraser 2000).

Most algae species, such as diatoms and green algae, are considered beneficial. However, when P concentrations in the water rise above about 50-60 parts per billion (ppb, also referred to as micrograms per liter), as appears to be happening in Istokpoga and many lakes of the Kissimmee Chain, algae blooms tend to increase dramatically (Walker and Havens 1995). In theory, because of their position in the food web, more algae can translate to more fish (Bachmann et al. 1996). However, strong blooms can have high enough concentrations of algae that when they die, their decomposition depletes oxygen from the water, and releases ammonia and other decomposition byproducts, killing aquatic organisms, including fish. Further, algae blooms occurring during high P concentrations also tend to have more cyanobacteria (blue-green algae) in them. Not all cyanobacteria are considered harmful, but species such as *Anabaena*, *Microcystis*, and *Cylindrospermopsis* that thrive in elevated P concentrations in south Florida lakes produce toxins that occasionally kill larger animals, including livestock and humans (Smith et al. 1995b, Paerl et al. 2001). These toxins are part of a survival strategy to make them unpalatable to predators. This unpalatability also makes them a poor base for the aquatic food chain. Allowing the proliferation of undesirable algae species, can lead to toxins in the water, water turbidity, low oxygen levels in the water column, noxious odors, fish kills, and increased accumulation of organic "muck" (dead algae) on the bottom.

To understand the extent of this threat, the Lake Okeechobee Protection Act mandated that a phosphorus study be conducted for the Istokpoga and the Kissimmee Chain of Lakes watersheds for the years 1995-2001 (Mock-Roos 2003). This report estimated that net import of P into the Istokpoga watershed was 664 tons per year. The greatest importers were improved pasture (246 tons), truck crops (269 tons), and residential areas (246 tons)(Mock-Roos 2003). These imports translate into runoff and recent P inflows into the north end of Lake Istokpoga from Arbuckle Creek have been in a general range of 50-150 ppb between 1998-2000. As a result, P concentrations in the northern end of the Lake tend to be about 16 ppb higher than P concentrations on the southern end of the Lake (Walker and Havens 2003). An analysis of inflow and outflows from Istokpoga concluded the lake is absorbing large amounts of P each year (Walker and Havens 2003). The study by White et al. (2003) actually measured P absorbing capacity of sediments in Lake Istokpoga, and extrapolated the total absorptive capacity for the whole lake, and then compared it with inflow levels. From that, the 15-years to saturation estimate (about 2018) was derived.

Once saturation occurs, more P would flow toward Lake Okeechobee and recovery efforts could take decades. Lake Istokpoga's watershed occupies about 10% of Lake Okeechobee's watershed, therefore it could be estimated this watershed should shed about 10% of Okeechobee's P goal, which would be about 10 tons. Present P imports of 664 tons promise to continue the loading to Istokpoga and are a threat to Lake Okeechobee.

The Mock-Roos (2003) report estimated that the annual net import of P to the Kissimmee Chain of Lakes watershed during the 1995 to 2001 time period was about 3,256 tons per year. This estimate includes P import related to theme parks and tourism and for the 43 million people that visit each year; some 1,072 tons P is brought in. Some of this is contained in sewage treatment facilities and is not a direct threat to the watershed. Urban and residential areas also imported large amounts of P totaling an estimated 961 tons. Much of this also is contained in sewage treatment facilities (including septic systems), but some of this is fertilizer for landscaping directly enters the watershed. The remainder of P import, which is mostly related to agriculture, is about 1,223 tons.

Because this watershed forms about 40% of Okeechobee's watershed, a phosphorus outflow goal from Lake Kissimmee should be close to 40 tons (i.e., 40% of the 105 ton inflow goal for Lake Okeechobee). Therefore, the total of 3,256 tons represents a threat to Lake Okeechobee, not to mention the Kissimmee River, first recipient of this water. The Mock-Roos (2003) report, discussing the numerous lakes in the region and the continued phosphorus import, noted that, "…these large water bodies assimilate and retain the phosphorus, resulting in significant storage of P in the lakes that could potentially become a source of P in the future" (page ES-11). To address this threat, Mock Roos (2003) recommended, "Reduce phosphorus imports to the greatest extent possible" (page ES-12).

Although desirable outflows from the Kissimmee Chain and Lake Istokpoga might be close to 40 and 10 tons respectively, the annual P outflow from Lake's Kissimmee and Istokpoga averaged 100 and 23 tons P, respectively, between 1995 and 2000 (SFWMD 2002b). These numbers reflected more than a 2-fold increase over the average in the previous 5-year period (possible signs of a saturation effect). Although this total of 123 tons P is more than Lake Okeechobee's entire 105 ton P inflow goal, the Everglades restoration Lake Okeechobee Watershed project does not specifically address phosphorus issues in the Kissimmee Chain. While it is possible to build filter marshes (STAs) next to Lake Okeechobee to improve the quality of water entering the Lake itself, such a strategy would allow Istokpoga, the Kissimmee Chain and the rest of the watershed to remain polluted.

Similarly, the Kissimmee River Restoration will cost about 500 million dollars to restore an appropriate hydrology, but has no water quality component. The Kissimmee River is receiving polluted water (50-100 tons of P per year) at present with no definite plan to correct that problem. Further, as the River itself becomes P saturated, it will shed progressively more P and become detrimental to Lake Okeechobee and Everglades

restoration goals (Marshall et al. 1972). Allowing the Kissimmee Chain of Lakes and Kissimmee River watersheds to function as treatment lagoons would be poor planning and poor policy.

Lastly, the Lake Okeechobee Watershed project is building a system that will protect Lake Okeechobee from P loads equal to the period of record, 1990-2000. With continuing addition of P to the watershed and a prediction that many of the large lakes will be P saturated soon, it is likely that P levels flowing toward the lake will increase in the future. A system designed to meet conditions in the 1990s is unlikely to remain adequate for very long. Failure to address P problems in the watershed of the Kissimmee Chain and Istokpoga will harm these lakes, harm Okeechobee, and generally jeopardize Everglades restoration success.

General Goals
Nutrient runoff problems can take years to correct. Considering these lakes may be P saturated within 15 years, that there is a large, continuing, addition of P to these watersheds each year, and there is no plan in place to fully address these problems, it appears these lakes have a challenging future. Lake Okeechobee's water column phosphorus goal of 40 ppb was based on lake health (FDEP 2000); the goals for the Kissimmee Chain of Lakes and Lake Istokpoga should be at least this low.

EXOTIC PLANT MANAGEMENT

As with Lake Okeechobee, many exotic aquatic plants infest these lakes and warrant control. Strategies in general should be similar to those for Lake Okeechobee, keeping coverage as low as possible. This section will focus on hydrilla because it is particularly problematic to these lakes.

Hydrilla management
The Kissimmee Chain of Lakes and Lake Istokpoga have some of the worst infestation problems from *Hydrilla verticillata* (hydrilla) in Florida. Hydrilla comes from Africa, can grow in lower light conditions than most native plants, hence can grow in deeper water (up to 50 feet in springs)(Tarver et al. 1986). Therefore, hydrilla can grow in almost all parts these lakes, and completely cover their surface. Dense hydrilla impedes navigation, changes water chemistry, displaces native plants, and is a threat to break loose during storms and clog water control structures.

Hydrilla was first detected on Lake Istokpoga in 1979, but did not reach problem proportions until the late 1980s, when it infested about 20,000 acres of the 27,000-acre lake (O'Dell et al 1995). By that time it had formed a dense surface-mat that impeded navigation and impacted almost all water-related functions of the lake. Once hydrilla establishes tubers in the sediments, they can sprout and reach the surface in one growing season even after lying dormant for as many as seven years (J. Schardt, FDEP, pers. comm.). Therefore, if not successfully managed, hydrilla has the potential to re-infest nearly 95% of the surface area of Lake Istokpoga in as little as one year from the billions of tubers present in the sediments."

In 1992 and 1993, about 125,000 triploid grass carp (about 12 inches in length) were released in Lake Istokpoga to control hydrilla but that effort was unsuccessful (Alam et al. 1995). Presently, hydrilla is treated mostly with chemicals. Floridone is most commonly used, and is a slow-acting herbicide that interferes with hydrilla's ability to produce chlorophyll. The plants die over a period of several months, reducing the risk that many dying plants could deplete oxygen and cause fish kills. To be effective, lethal levels of floridone must stay in contact with hydrilla for 75-90 days. To allow continuous contact, and to save money by treating a smaller area of a lake, floridone application usually is scheduled late in the dry season after the lake is drawn down to reduce volume. Hydrilla is vulnerable this time of year, and being the dry season, herbicide loss with lake outflows can be minimized. Unfortunately, hydrilla in Florida appears to be becoming resistant to floridone.

Another herbicide works on hydrilla but has limitations. Endothall is a fast-acting contact herbicide. Because it can kill large amounts of plants quickly, areas of no more than a few hundred acres are controlled at any one time to prevent widespread oxygen depletion during plant decomposition. Endothall also does not appear to control hydrilla for as long a period of time as floridone, lasting a few to several months rather than the 18-24 months expected of floridone. Management with endothall usually is focused on areas around the flood control structures, boat trails, and in hydrilla that has high (>10ppb) floridone tolerance (J. Schardt, FDEP, pers. comm.).

Hydrilla reaches such great biomass in lakes that it greatly affects nutrient levels. Dense stands of submerged plants (dense was defined as covering more than about 30-50% of the surface) in Florida lakes can sequester enough phosphorus to lower chlorophyll concentrations (i.e., lower algae numbers) in the water column (Canfield et al. 1984). After hydrilla treatment on Lake Istokpoga, significant increases of phosphorus levels in the water column and algae blooms were detected likely linked to decomposition of hydrilla (O'Dell et al. 1995). If rain events create the need for large water releases during treatment periods, large amounts of phosphorus could be exported downstream.

The future of hydrilla control is in question. By the time present chemicals have lost effectiveness, desirable alternatives may not be available. Grass carp eat hydrilla, but eat native plants as well, which can be a problem. Drawing lakes low to allow herbicide treatments and holding them low for long periods disrupts their hydrology. Yet, unfettered growth of hydrilla would restrict human use of these lakes and disrupt the ecosystems profoundly.

AUDUBON RECOMMENDATIONS

Water Levels

The Kissimmee Chain of Lakes Long Term Management Plan should be used to determine the best probable regulation schedules for these lakes and lead to a design process that can meet those needs. The Lake Istokpoga part of the Everglades restoration plan should be used to determine the best probable regulation schedule for the lake and design a system that meets those needs. These schedules should be viewed as hypotheses for optimal lake management and plant community response should be formally

monitored over time. As results are collected, they can be used to modify (adaptive management) the schedules to meet restoration goals.

The guiding principle of water regulation schedules for these lakes should include water level fluctuations that mimic natural patterns as much as possible. In theory, water level management (and nutrient control) that mimics natural ecosystem patterns will restore healthy plant and animal communities and allow for the management of species that are poorly understood, but that are adapted to Florida conditions. If these patterns are restored, the need for drastic, costly, and perpetual mechanical and/or chemical treatments in these lakes can be reduced or eliminated.

Historic fluctuations will never return to these lakes. Homes are built along many shores, precluding the possibility of fully restoring historic high water levels. People use some of the lakes for irrigation or other water supply, which might restrict lowering some lakes to some extent. Lake Istokpoga is especially constrained by projected water supply shortages in its watershed (SFWMD 2000a). Drainage throughout the watersheds moves runoff water to the lakes sooner, and in larger volumes, than historically occurred. Conversely, dry season water tables, and stream flows are lower, due to increased drainage. Nutrients from urban and agricultural activities have fertilized the lakes.

Because of irreversible changes in the region, the question of management switches from "what is natural" to "how close to natural is possible?" Keddy and Fraser’s (2000) suggested that lake marshes reach their greatest plant species diversity when exhibiting both within-year and between-year water level fluctuations. Alternating high and low water levels stress every plant and help prevent dominance by a few, entrenched, species. In theory, water pattern diversity occasionally meets the needs of all species, at least some of the time. Today, with the high water level stressor limited by human property, the remaining stressor will be the low water level. Lowest permissible levels will depend partly on water supply needs for humans and downstream ecosystems, especially the restored Kissimmee River. It may be more important than ever to allow frequent low levels in these lakes as part of their annual cycle.

Lake Istokpoga is typical of the challenge of re-establishing natural patterns. It formerly had a 7-foot multi-year range of fluctuation and averaged 3.27 feet per year (between 1936 and 1963, when water control was initiated). Houses now preclude the lake from rising the top 3 feet that it formerly reached, precluding restoration of the entire natural range. Therefore the “remaining” annual range possible, without dropping the lake to lower levels then in the past, is 4 feet. However, dropping Lake Istokpoga always raises water shortage concerns. An examination of Istokpoga's water management suggested that a large reservoir between Lake Istokpoga and Lake Okeechobee could give managers the ability to lower Lake Istokpoga while saving the water in the reservoir to meet irrigation needs in the region (Loftin et al. 1993). A landowner in the area recently proposed installing a Stormwater Treatment Area (STA) of about 6,000 acres (2,400 ha), indicating a willingness to talk about using this parcel. Projects upstream of Istokpoga also should store water to ensure better winter flows. It appears that the average historic fluctuation likely can be reached in a managed system, but less opportunity will exist for

between-year fluctuations. How much this limitation impedes restoration ability is uncertain.

Lake Kissimmee reportedly fluctuated as much as 6-7 feet in some years, and as much as 12.4 feet between flood highs and drought lows. It presently fluctuates 3.5 feet. To ensure adequate water supply for the restored Kissimmee River, about 17,000 acres of land is scheduled for acquisition around the shorelines of Lake's Kissimmee, Hatchineha and Cypress. This land can be flooded to allow the lakes to hold an estimated 100,000 extra acre-feet of water (Koebel 1995). To allow the storage, the regulation schedules for these lakes will be adjusted to rise 1.5 feet higher than before, changing Lake Kissimmee's annual fluctuation range from 3.5 feet to 5 feet. For the health of Lake Kissimmee, the plans to increase water level fluctuation will be an improvement, but remains about half the historic level, and further opportunities for increased variability should be investigated.

One way to assess the relative amount of drawdown benefits is to examine the lake's contours. About 2500 acres of bottom are exposed on Lake Kissimmee per 6 inches of water level drop between 52.5 to 49 feet. However, as the lake drops six more inches, from 49 to 48.5 feet, only 500 acres of bottom are exposed (USACE 2002, p. 31) and if it drops 6 more inches from 48.5, only 100 more acres become exposed. By matching how long each of these elevations are flooded in various water management scenarios, predictions can be made as to what plant communities will grow, and in what proportions. Similarly, the recent location of tussocks can be identified (areas that are wet >75% of the time) and their likelihood of persisting under various management schemes evaluated. It will be important to treat proposed regulation schedules as experiments, with monitoring programs to determine if they meet goals.

Even with increased storage capacity in the Kissimmee Chain from the Kissimmee River project, there remains a concern that there may not be adequate water to keep the restored Kissimmee River floodplain as wet as desired (SFWMD 1991). Were it determined that lakes in the Kissimmee Chain can be drawn lower each year, then more water might be available for the Kissimmee River. A re-analysis of Lake Kissimmee's needs should explore not only potential benefits to the lakes by lowering their regulation schedule, but also the extra water that might be available for the Kissimmee River.

Lastly, in spite of 30 years of “lake restoration” projects, costing tens of millions of dollars, no projects have tried to experiment with water level fluctuations to improve plant community structure. Scientists still have no data on what plant communities alternative water level patterns would create. Proposed regulation schedules must be implemented experimentally to test hypotheses in a systematic manner, that can be incorporated in future management decisions. Spending money to address tussock formation (a symptom) without investigating the root of the problem (water level problems) has been an unsuccessful policy.

Audubon recommends implementation of regulation schedules with these guiding principles:

1. Provide for annual fluctuations that mimic historic fluctuations as much as possible,
2. Provide for multi-year fluctuations as much as possible (e.g., go lower during droughts),
3. Provide fluctuations tailored for each lake, or group of lakes,
4. Improve the hydrology of the Kissimmee River,
5. Initiate experiments with water levels to fine tune water management decisions,
6. Implement adaptive management, and
7. Prevent filling of wetlands with dredged material scraped from accumulated peat deposits in each lake.

Nutrients

The Kissimmee Chain of Lakes Long Term Management Plan must identify the nature and extent of the phosphorus problem in the region to enable active solutions to be designed. The Lake Okeechobee Protection Plan will not protect these lakes because the BMPs that are proposed will not be finished in time, and if they were, might only reduce phosphorus inflows by about 25% (Bottcher and Harper 2003), delaying saturation by 2-5 years (White et al. 2003). Excessive phosphorus loading must be stopped, not reduced.

Lake Istokpoga's nutrient problems must be addressed in the Everglades restoration plans. Failure to do so will harm Lake Istokpoga, and Lake Okeechobee by eventually overwhelming the nutrient control facilities built in the watershed.

Because Best Management Practices will not solve the phosphorus problem, other measures must be enacted including:

1. Best Management Practices for urban and agricultural areas must be accelerated (i.e., starting in 2009 is too late)
2. Formal efforts must be made to stop the net import of phosphorus for all land uses into the watersheds.
3. Public works, including Storm Treatment Areas (STAs = filter marshes), chemical treatment, composting facilities, and the like must be explored for installation throughout the watersheds.
4. Land acquisition must be initiated to allow placement of facilities identified in #2, and to allow as much wetland restoration as possible in the watershed. This act will also benefit storage and habitat needs and enhance recreation.
5. A water quality component must be added to the Kissimmee River Restoration.
6. The entire Lake Okeechobee watershed, including the Chain of Lakes and the Kissimmee River floodplain must be analyzed in a comprehensive and integrated manner. Such comprehensive planning must include downstream effects from Okeechobee releases.

Exotic species

Due to the serious nature of the hydrilla problem and the increasing resistance to known effective herbicides, improvement of hydrilla control techniques must remain a high priority for managing agencies.

Outcome: Establish water management protocols that create healthy littoral zones in these lakes and implement programs that will achieve and sustain average in-lake phosphorus concentrations of 40 ppb phosphorus.

Goals:

1. **Install regulation schedules on the Kissimmee Chain of Lakes and Lake Istokpoga that mimic more natural water level patterns including regular drawdowns during the spring.**

   A. **Complete a comprehensive Kissimmee Chain of Lakes Long Term Management Plan.**

   B. **Improve the hydrology of the restored Kissimmee River through improved modeling and management of the Kissimmee Chain of Lakes.**

   C. **Complete the Lake Istokpoga Regulation Schedule Study as part of the Lake Okeechobee Watershed Project (within CERP).**

2. **Implement measures to achieve 40 ppb phosphorus concentrations, or less, in the water columns of these lakes.**

   A. **Continue identifying sources and concentrations of phosphorus throughout these watersheds.**

   B. **Identify and design public works projects (such as Stormwater Treatment Areas) in locations where water quality improvements are most needed.**

   C. **Aggressively implement BMPs for all agricultural and urban areas to control phosphorus.**