Chapter 10: Lake Okeechobee Protection Program – State of the Lake and Watershed

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SUMMARY

Lake Okeechobee, the largest lake in the southeastern United States, is shallow, frequently turbid, eutrophic, and a central component of the hydrology and environment of South Florida. The lake is used for water supply and flood control for surrounding areas, including agricultural land and downstream estuarine ecosystems. Lake Okeechobee is home to migratory water fowl, wading birds, and the federally endangered Everglade snail kite (*Rostrhamus sociabilis plumbeus*). The lake is also a multimillion-dollar recreational and commercial fishery. This chapter of the *2011 South Florida Environmental Report* (SFER) – *Volume I* provides the Water Year 2010 (WY2010) (May 1, 2009–April 30, 2010) status of major issues affecting Lake Okeechobee's water quality and ecology, and ongoing projects to address those issues under the Northern Everglades and Estuaries Protection Program (NEEPP) [Section 373.4595, Florida Statutes (F.S.)].

Lake Okeechobee has been subject to three long-term stresses: (1) excessive phosphorus loads, (2) extreme water-level fluctuations, and (3) rapid spread of exotic and nuisance plants in the littoral zone. The South Florida Water Management District (District or SFWMD), Florida Department of Environmental Protection (FDEP), Florida Department of Agriculture and Consumer Services (FDACS), U.S. Army Corps of Engineers, and Florida Fish and Wildlife Conservation Commission (FWC) are working cooperatively to address these interconnected issues in order to rehabilitate the lake and enhance the ecosystem services that it provides, while maintaining other project purposes such as water supply and flood control.

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Despite a long history of regulatory and voluntary incentive-based programs to control phosphorus inputs into Lake Okeechobee, loads to the lake did not decline substantially during the 1990s. Consequently, the lake continues to become more eutrophic with blooms of noxious blue-green algae (cyanobacteria), loss of benthic invertebrate diversity, and spread of cattail (*Typha* spp.) in shoreline areas. In 2000, the Florida legislature passed the Lake Okeechobee Protection Act (LOPA), which requires state water quality standards to be achieved no later than January 1, 2015 (Section 373.4595, F.S.). LOPA also requires the coordinating agencies — SFWMD, FDACS, and FDEP — to work together to address total phosphorus (TP) loading and exotic species control. LOPA was subsumed in 2007 by NEEPP (Section 373.4595, F.S.).

WATERSHED UPDATES

The Lake Okeechobee Watershed Protection Program is being implemented as part of NEEPP, which promotes a comprehensive, interconnected watershed approach to protecting the lake and its downstream (Caloosahatchee and St. Lucie) estuaries. These programs address pollutant loading reductions, natural hydrology restoration, and applicable state water quality standards compliance. The watershed protection program is a cooperative effort between the District, the FDEP, and the FDACS and includes seven elements: (1) Lake Okeechobee Watershed Protection Plan (LOWPP), (2) Lake Okeechobee Watershed Construction Project Phase I Plan and Phase II Technical Plan (P2TP), (3) Watershed Phosphorus Control Program, (4) Lake Okeechobee Watershed Research and Water Quality Monitoring Program, (5) Lake Okeechobee Exotic Species Control Program to protect native flora and fauna in the region (see Chapter 9 and Appendix 9-1 of this volume), (6) Internal Phosphorus Management Program to examine the feasibility of removing or treating internal phosphorus loading in the lake, and (7) submission of an annual progress report, a requirement this chapter fulfills.

Major developments and accomplishments under the Lake Okeechobee Watershed Protection Program during WY2010 include the following:

- NEEPP requires that the LOWPP be updated every three years. Plan update efforts were started in early 2010.
- Numerous efforts have begun under the P2TP, including: (1) the Chemical Treatment Pilot Project Phase II study to conduct an implementation cost and site selection analysis for phosphorus removal technologies and (2) Hybrid Wetland Treatment Technology, which represents a combination of chemical and wetland treatment technologies to remove phosphorus at sub-basin and farm scales; (3) construction of Phase I of the Lakeside Ranch Stormwater Treatment Area, which is planned to remove phosphorus from stormwater runoff in the Taylor Creek/Nubbin Slough Basin before it enters Lake Okeechobee; (4) the Fisheating Creek Feasibility Study to identify potential locations for phosphorus removal and water storage; and (5) the Watershed Assessment Model documentation and application project.
- TP load to the lake from all drainage basins and atmospheric deposition was 478 metric tons (mt) in WY2010. Fisheating Creek, the C-41 basin, Lower Kissimmee Basin, and Taylor Creek/Nubbin Slough contributed the largest TP loads while discharges from the L-59W, S-154, C-40, and C-41 basins had the highest TP concentrations. The most recent five-year average (WY2006–WY2010) was 496 mt, which exceeds the Total Maximum Daily Load (TMDL, 140 mt) by 356 mt.
- Total nitrogen (TN) load to the lake from all drainage basins and atmospheric deposition was 6,325 mt in WY2010. The Upper Kissimmee and Lake Istokpoga

sub-watersheds contributed the largest TN loads while discharges from the East Shore Drainage District, S-3, and S-2 basins had the highest TN concentrations.

- FDACS-sponsored Best Management Practice (BMP) demonstration and evaluation projects are ongoing at representative sites for all agricultural land uses in the watershed, including dairy, beef, citrus, and vegetable production. The TP load reduction to Lake Okeechobee from these typical cost-share BMP projects is estimated to be 19 mt.
- The monitoring and evaluation of District-sponsored projects to demonstrate water quality improvement continued through WY2010. The TP load reduction from these projects is estimated to be 27 mt.
- Research and assessment activities conducted during WY2010 included (1) the conclusion of the Taylor Creek Algal Turf Scrubber® facility study, (2) MIKE SHE/MIKE 11 model application in the S-191 basin, (3) nutrient budget analysis, (4) the continued operation and evaluation of four Hybrid Wetland Treatment Technology projects, (5) Watershed Assessment Model documentation and validation, (6) Northern Everglades Chemical Treatment Pilot Project, (7) permeable reactive barrier technology, (8) ranchland BMP research, and (9) wetland BMP research.

Average water clarity in the nearshore region from May through September of WY2006–WY2010 increased, with the Secchi disk being visible on the bottom of the water column in 48 percent of the observations. This increase in water clarity can be attributed to increased submerged aquatic vegetation (SAV) abundance in the nearshore region that reduces sediment resuspension. Nearshore TP declined in WY2010 to 57 parts per billion (ppb), reducing the nearshore five-year average slightly from 119 ppb in WY2009 to 104 ppb in WY2010. Reduced nearshore TP during WY2010 is also likely a result of the increased SAV abundance.

The flow of water to Lake Okeechobee was 2.4 million acre-feet (ac-ft) or about 2,960 million cubic meters (m^3) in WY2010, which is similar to the baseline average (calendar years 1991–2005) of 2.5 million ac-ft or about 3,083 million m^3. Lake stage at the beginning of WY2010 was at 11.1 feet National Geodetic Vertical Datum 1929 (ft NGVD) or 3.4 m and increased over time to 15.1 ft NGVD (4.6 m) by April 30, 2010. Water levels gradually increased over the wet season as inflow increased, and then remained around 13.4 ft NGVD (4 m) until March 2010 when greater inflow resulted in higher stage. To offset this increase, pulse releases of water were discharged to the Caloosahatchee River in March and April 2010. Detailed information on the hydrology of the SFWMD during WY2010 is presented in Chapter 2 of this volume.

ECOLOGY

SAV communities on Lake Okeechobee reached abundances similar to those before the 2004 and 2005 hurricanes. Coverage of SAV in August 2009 was 46,418 acres compared with 35,834 acres in August 2008. The amount of coverage by vascular aquatic plants increased to 30,171 acres in August 2009 compared with 7,319 acres in August 2008. The total SAV coverage and coverage by vascular plants exceeded the in-lake goals of 40,000 and 20,000 acres, respectively. The major SAV species were the non-vascular macroalga muskgrass (*Chara* sp.), eelgrass (*Vallisneria americana*), coontail (*Ceratophyllum* sp.), the exotic *Hydrilla verticillata*, and pondweed (*Potamogeton illinoensis*). Decreases in the coverage of the invasive exotic torpedograss (*Panicum repens*) during this period are attributed to continued herbicide treatments. Native plants have started to grow and wading birds are foraging in many of the areas formerly overrun by torpedograss. Herbicide applications have also been effective at controlling the spread of the recently discovered invasive exotic, South American watergrass (*Luziola subintegra*), in Fisheating Bay.

Faunal communities have recovered more slowly following the recent hurricanes and drought. Benthic invertebrates measured from 2005–2008 were recovering fastest in the sand and peat substrate zones and slowest in the central mud zone of the lake (see 2010 SFER – Volume I, Chapter 10). Annual electrofishing and trawl sampling data show an increase in abundance of important prey fish species since 2005. The largemouth bass (*Micropterus salmoides*) population is recovering more quickly than the black crappie (*Pomoxis nigromaculatus*). The latter may be lagging because forage (rotifers and invertebrates) have not recovered. Both redear sunfish (*Lepomis microlophus*) and bluegills (*L. macrochirus*) had recovered strongly as of the 2008 survey.

Herpetofauna (amphibians and reptiles) are an important component of wetland food webs but, with the exception of the alligator (*Alligator mississippiensis*), populations have not been well inventoried or monitored in the Lake Okeechobee littoral zone. Consequently, there is currently no information on how these species respond to changes in lake stage, extreme water level events, and disturbances like tropical weather systems or marsh habitat management practices. A study was begun in April 2010 along three transects that start at the base of the Herbert Hoover Dike and end near open water of the lake to survey the fauna with a number methods. Preliminary details of the herpetofauna study and a report on the status of alligators in the lake are included in the *Lake Monitoring and Research* section of this chapter.

An initiative continued during WY2010 to determine if the Florida apple snail (*Pomacea paludosa*), a key species in the lake's food web, raised in captivity could be released in the wild to augment the recovery of natural populations. Snails raised in tanks were marked and released in two areas of Eagle Bay marsh, a wetland next to Lake Okeechobee. Analysis of data from these experiments show some promise, but a rapid increase in water levels prevented the recapture of enough snails to indicate success.

A similar stocking experiment was conducted to determine if largemouth bass could be successfully stocked in the lake. Few marked bass or their progeny, as determined from genetic markers, were recaptured from stocked sites.

IN-LAKE MANAGEMENT

Low water levels in 2007 provided a management opportunity to effectively scrape muck sediments from several nearshore regions of the lake (James and Zhang, 2008). The pre–post comparison at one site, Harney Pond East, illustrates a common pattern reported for other scraped sites. Prior to scraping, cattail (*Typha* spp.) was the most abundant emergent plant followed by American cupscale (*Sacciolepis striata*) and other grasses (8 acres). Two years after scraping, the dominant plants were native spikerush (*Eleocharis cellulosa*) and smartweed (*Polygonum hydropiperoides*).

A second sediment management project was conducted in 2008 on a 40-acre site located adjacent to Indian Prairie canal in the lake's northwest littoral zone. The purpose of this project was to evaluate the effectiveness of tilling the surface organic layer into the underlying sand substrate as a mechanism for reducing the surficial total and extractable phosphorus levels and reducing internal phosphorus loading (Zhang et al., 2009). As lake waters quickly rose to average conditions in August 2008, further muck removal plans were put on hold pending a return to lower water levels. Two years prior to tilling (pre-drought), cattail was the dominant plant species and covered most of the management area. As a result of the drought, the prominent vegetation in the site vicinity was herbaceous ground cover — primarily smartweed (*Polygonum hydropiperoides*), with low-density patches of macrophytes such as cattail and bulrush (*Scirpus* *californicus*), and shrubs such as willow (*Salix* sp.) and primrose willow (*Ludwigia* sp.). In 2010, two years after tilling, the area was much wetter with the prominent species being the desirable floatingheart (*Nymphoides* spp.) or water lily (*Nymphaea*) species and emergent bulrush as well. Cattail coverage was low.

Fish and wildlife habitat improved following both scraping and tilling. The quantified changes in landscape coverage were, in part, the result of management activity. Hydrologic conditions also influenced plant community composition and distribution. The evaluation of temporal landscape changes in these and other management areas will continue to determine the long-term effects of these sediment management practices on the lake's fauna and flora.

LAKE ISTOKPOGA

The distribution and areal coverage of SAV in Lake Istokpoga was evaluated during spring 2009. The most common SAV were the exotic hydrilla (*Hydrilla verticillata*) and the native eelgrass (*Vallisneria americana*). Hydrilla was found in 66 percent of the vegetative sites while eelgrass was observed in 53 percent of the sites. Most recently, 1,200 acres of hydrilla were treated, primarily in the northern and northeastern regions of the lake, in November 2009; 644 acres were treated near the central and southern islands and along the southern and southwestern shore in April 2010. Lake sediment samples were evaluated and consisted mostly of sand (52 percent) and mud (47 percent).

INTRODUCTION

Lake Okeechobee (located at 27^o N latitude and 81^o W longitude) is a central part of the South Florida watershed and the U.S. Army Corps of Engineers (USACE) regional flood control project. The lake has a surface area of 445,559 acres (ac) [1,803 square kilometers (km^2)], and is extremely shallow, with a mean depth of 8.9 feet (ft) [2.7 meters (m)] and maximal depth of 18 ft (5.5 m) (James et al., 1995). Average volume is approximately 3.9 million acre-feet [(4,810 million cubic meters (m^3)], with a turnover time (based on surface outflows) of 3.2 years (James et al., 1995).

Lake Okeechobee receives water from a 5,400-square-mile (sq mi) (14,000 km^2) watershed that includes the Kissimmee Chain of Lakes, the Kissimmee River, Lake Istokpoga, Fisheating Creek, and other drainage basins (**Figure 10-1**). Lake waters flow south, to the Everglades Protection Area east to the St. Lucie River (C-44 canal), and west to the Caloosahatchee River (C-43 canal). More information about the Kissimmee Chain of Lakes and the Kissimmee River can be found in Chapter 11 of this volume. Information on the St. Lucie and Caloosahatchee rivers can be found in Chapter 12 of this volume. Nutrient source control efforts for these watersheds are described within Chapter 4 of this volume. Additional information on exotic species status in South Florida is presented in Chapter 9 of this volume.

Lake Okeechobee serves many roles: (1) it provides water supply to urban areas, agriculture, and downstream estuarine ecosystems; (2) supports a multimillion-dollar sport fishery (Furse and Fox, 1994), commercial fishery, and various recreational activities; and (3) provides habitat for migratory waterfowl, wading birds, alligators (*Alligator mississippiensis*), and the Everglade snail kite (*Rostrhamus sociabilis plumbeus*) (Aumen, 1995). The lake is also used for flood control during the wet season (June–October) and water supply during the dry season (November–May). The lake faces three major environmental challenges: (1) excessive total phosphorus (TP) loads, (2) extreme water-level fluctuations, and (3) the rapid spread of exotic and nuisance plants.

This chapter updates the discussion of lake and watershed conditions presented in Chapter 10 of the *2010 South Florida Environmental Report* (SFER) – *Volume I* focusing on water quality, water levels, and aquatic vegetation. Results of recently completed research projects are presented, as well as the status for ongoing watershed and in-lake management projects.

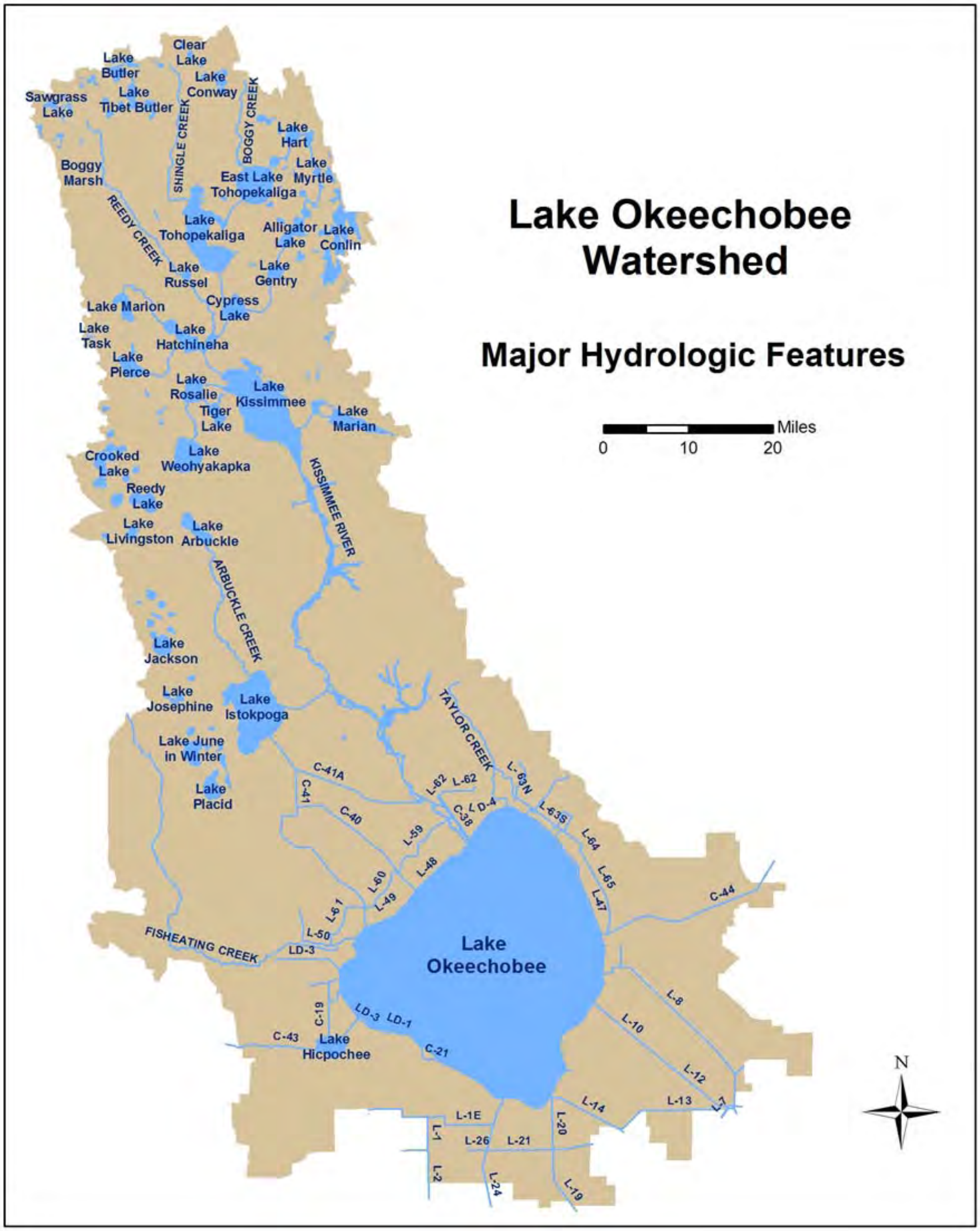


Figure 10-1. Major hydrologic features of the Lake Okeechobee Watershed (L = levee, C = canal).

OVERVIEW OF THE LAKE OKEECHOBEE WATERSHED PROTECTION PROGRAM

The Lake Okeechobee Protection Act (LOPA) [Section 373.4595, Florida Statutes (F.S.)] was passed by the 2000 Florida legislature to establish a restoration and protection program for the lake. This program addresses the reduction of TP loading to the lake from both internal and external sources. In 2007, the legislature amended LOPA to include the protection of the Caloosahatchee and St. Lucie River watersheds. Section 373.4595, F.S., now known as the Northern Everglades and Estuaries Protection Program (NEEPP), promotes a comprehensive, interconnected watershed approach to protecting these water bodies (SFWMD et al., 2008). NEEPP contains the Lake Okeechobee Watershed Protection Program (formerly the Lake Okeechobee Protection Program) and the Caloosahatchee and St. Lucie River Watershed Protection Program. These programs address the reduction of pollutant loadings, restoration of natural hydrology, and compliance with applicable state water quality standards. Details on river watershed protection program elements are presented in Chapters 4, 7, and 12 of this volume.

The SFWMD, in cooperation with the Florida Department of Environmental Protection (FDEP) and Florida Department of Agriculture and Consumer Services (FDACS), developed the Lake Okeechobee Protection Plan (LOPP), which was submitted to the Florida legislature on January 1, 2004 (SFWMD et al., 2004). The LOPP was considered the best available technologically achievable plan designed to achieve water quality goals, particularly for phosphorus, in Lake Okeechobee and its downstream receiving waters by 2015. The Lake Okeechobee Protection Act (Section 373.4595, F.S.) requires that the protection plan, now entitled the Lake Okeechobee Watershed Protection Plan (LOWPP), be reevaluated every three years to determine if further TP load reductions are needed to achieve the Total Maximum Daily Load (TMDL) target of 140 metric tons (mt) established for Lake Okeechobee (FDEP, 2001). A three-year reevaluation report was submitted to the legislature in March 2007 (SFWMD et al., 2007). The Lake Okeechobee Watershed Construction Project (LOWCP) Phase II Technical Plan (P2TP) was submitted to the Florida legislature in February 2008 as required by NEEPP (SFWMD et al., 2008) and is currently being implemented. The P2TP identifies construction projects and on-site measures that prevent or reduce pollution at the source, such as agricultural and urban Best Management Practices (BMPs), needed to achieve the TMDL for TP established for Lake Okeechobee. In addition, the P2TP includes other projects for increasing water storage north of Lake Okeechobee to achieve healthier lake levels and reduce harmful discharges to the Caloosahatchee and St. Lucie river estuaries. A diagram illustrating the relationship among the protection programs, the associated elements, and the projects is shown in **Figure 10-2**.

As specified by NEEPP, elements of the Lake Okeechobee Watershed Protection Program include: (1) LOWPP, (2) Lake Okeechobee Watershed Construction Project Phase I and P2TP, (3) Lake Okeechobee Watershed Phosphorus Control Program, (4) Lake Okeechobee Watershed Research and Water Quality Monitoring Program, (5) Lake Okeechobee Exotic Species Control Program, (6) Lake Okeechobee Internal Phosphorus Management Program, and (7) annual progress report. Currently, the District, with the Coordinating Agencies (FDEP, FDACS, and others), is updating the LOWPP with input from stakeholders. The protection plan is required to be submitted to the legislature in spring 2011. The annual progress report requirement is fulfilled by this chapter and Volume III, Appendix 4-1. More details on exotics in the SFWMD and certain source control programs for surrounding watersheds are presented in Chapters 9 and 4 of this volume, respectively.

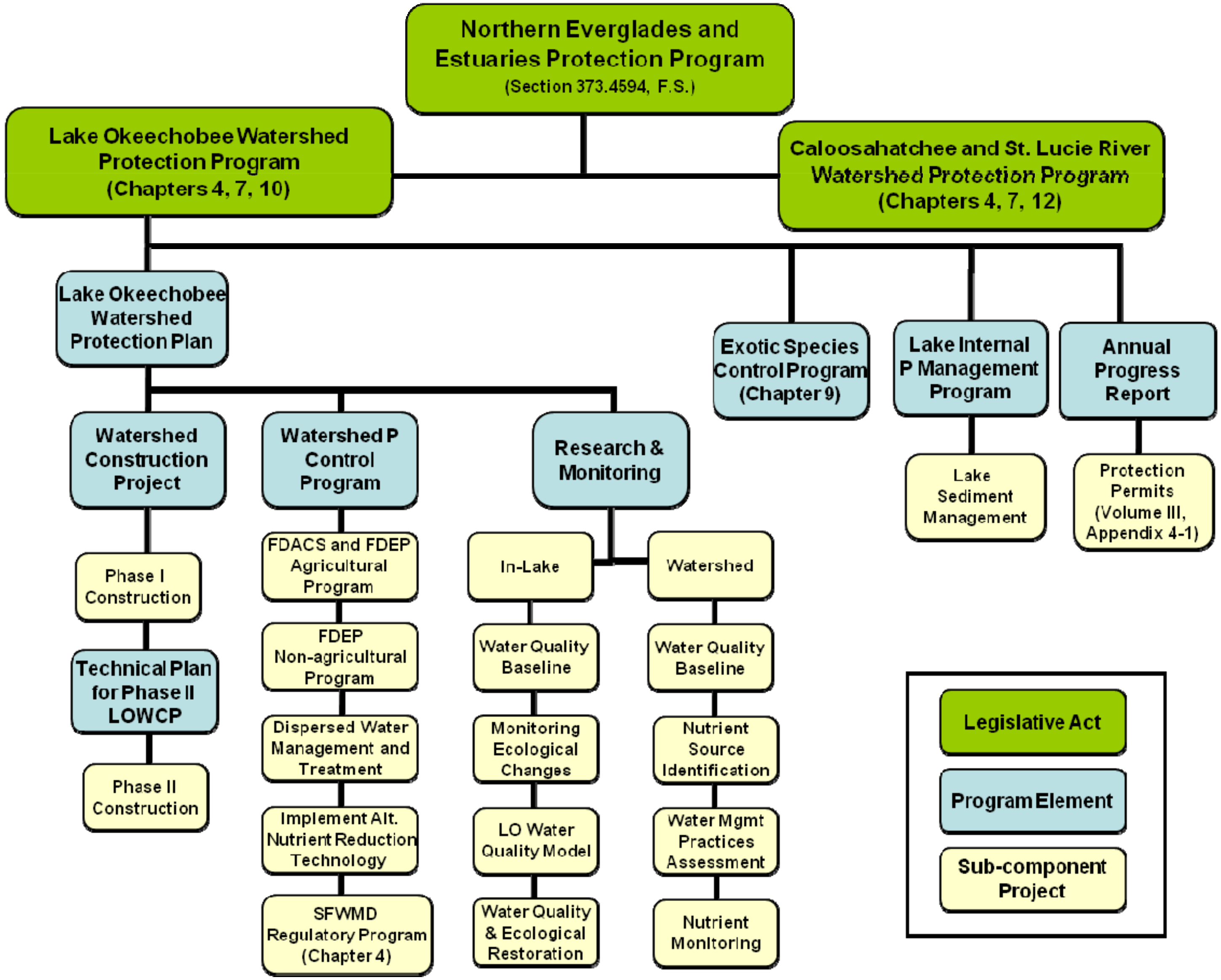


Figure 10-2. The Northern Everglades and Estuaries Protection Program structure, detailing the Lake Okeechobee Watershed Protection Program's elements and projects. Note: P – phosphorus.

WATERSHED CONSTRUCTION PROJECT

Phase I

The Lake Okeechobee Watershed Construction Project (LOWCP) is being implemented in two phases. Phase I projects, constructed in the four priority basins, include two pilot Stormwater Treatment Areas (STAs) and a sediment removal pilot project. The sediment removal pilot project was completed in 2004, but no significant removal of particulate phosphorus was observed.

The Taylor Creek STA is one of the two pilot-scale STAs being implemented north of the lake (**Figure 10-3**). The U.S. Army Corps of Engineers (USACE) is the federal sponsor of the project and is responsible for the activities performed under the original permit issued to them on September 15, 2003, for the construction and preliminary operations of the STA. The District is the local project sponsor and is responsible for operation and maintenance of the facility as a contractor to the USACE until the project is transferred over to the District as provided in the Project Cooperation Agreement.

Constructed in April 2006, the Taylor Creek STA is a long, narrow enclosure located about 2 miles north of the city of Okeechobee in central Okeechobee County. It is bordered on the east by U.S. Highway 441 and by Taylor Creek on the west. The STA is approximately 142 acres with an effective treatment area of 118 acres. It is divided into two cells in series and is expected to treat about 10 percent of the water flow in Taylor Creek. The expected annual average TP removal performance of the Taylor Creek Pilot STA was estimated at 2.08 metric tons per year (mt/yr) (Stanley Consultants, Inc., 2003).

Flow-through operations at Taylor Creek STA commenced on June 26, 2008. The facility continued to operate in discharge mode until February 24, 2009, when pumping and discharge activities were suspended after a failure of the culvert at the outfall structure was detected. From June 2008 to February 23, 2009, the system removed 1.35 mt of phosphorus from the Taylor Creek drainage basin. Repairs were completed on August 23, 2010. Following a demonstration of compliance with pre-discharge requirements as laid out in Taylor Creek Permit No. 0194485-007-GL, flow-through operations were resumed on September 8, 2010.

Figure 10-3. Taylor Creek Stormwater Treatment Area (STA) (photo by the SFWMD).

The Nubbin Slough STA is the larger of the two pilot STAs being implemented north of the lake. It is located approximately 6.5 miles southeast of the city of Okeechobee, adjacent to Nubbin Slough, immediately north of State Road 710 and just east of the bridge that spans Nubbin Slough. This two-celled STA is approximately 809 acres with an effective treatment area of 773 acres. The projected long-term average phosphorus reduction within the STA was estimated at over 5 mt/yr or about 85 percent of the phosphorus load of Nubbin Slough at the project location (Stanley Consultants, Inc., 2003).

Construction of the Nubbin Slough STA was completed in September 2006; however, operations have not been initiated due to a series of mechanical problems uncovered during pump tests. Repairs at Nubbin Slough were completed in June 2010; however, initial operational testing and monitoring did not begin because sedimentation at the bay around the inflow structure prevented remote operation. Manual operation is possible if a significant rain event occurs in the area during WY2011. A concern is that the Nubbin Slough Basin may not produce a sufficient amount of runoff in a year with average rainfall to supply the STA for full-time operation (Stanley Consultants, Inc., 2003). The USACE and the SFWMD are currently exploring ideas on providing additional water to the STA.

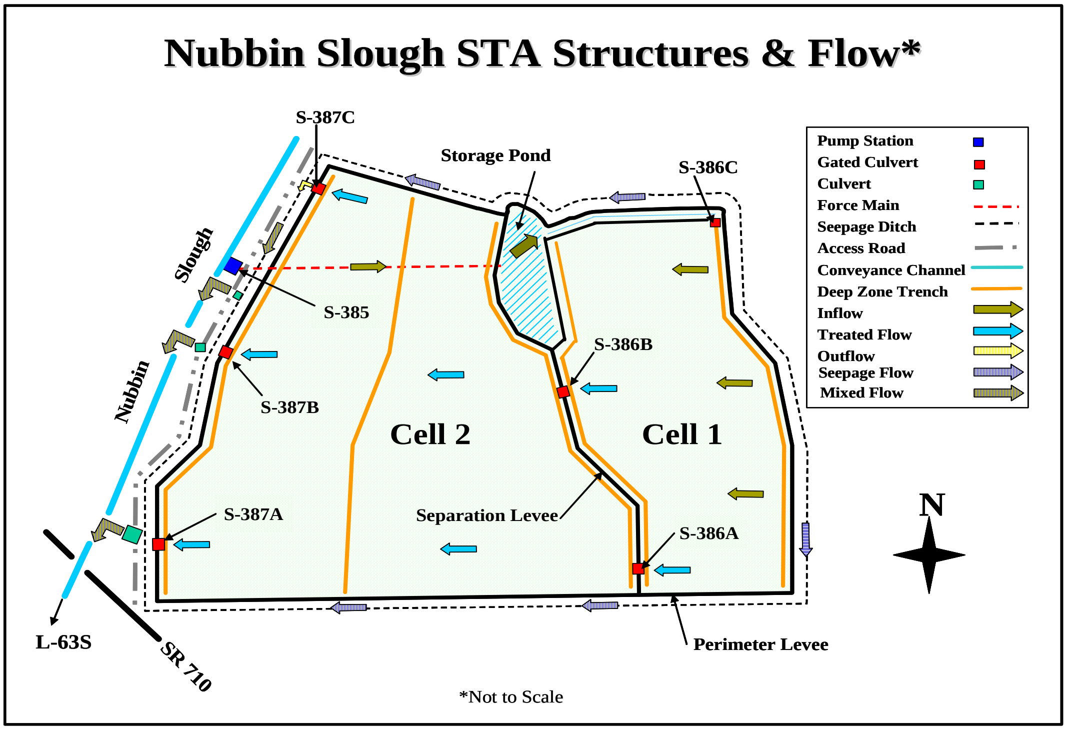


Figure 10-4. Nubbin Slough STA, detailing anticipated flow direction and structure locations.

Phase II Technical Plan

NEEPP required the development of a detailed technical plan to include measures for the improvement of Lake Okeechobee and downstream receiving estuaries. The P2TP was developed by the District in coordination with the FDEP and FDACS and with extensive input from stakeholders and submitted to the legislature on February 1, 2008 (SFWMD et al., 2008). The P2TP outlines the steps expected to reduce pollution and improve storage in the Lake Okeechobee Watershed (LOW) as necessary to achieve water quality standards in the LOW and Lake Okeechobee. Other projects for increasing water storage north of Lake Okeechobee to achieve healthier lake levels and reduce harmful discharges to the Caloosahatchee and St Lucie estuaries are also included. Major components of the P2TP include:

1. Implementing BMPs on more than 1.7 million acres of farm and urban lands
2. Adopting new regulations that will reduce the impacts of development on water quality and flow
3. Building treatment wetlands to clean water flowing into the lake
4. Using other nutrient control technologies to reduce phosphorus loads from the watershed
5. Creating between 900,000 and 1.3 million ac-ft of water storage north of the lake through a combination of aboveground reservoirs, underground storage, and alternative water storage projects on public and private lands

The LOWPP is updated every three years as required by NEEPP. The next plan update will include the results of several studies and will be submitted to the legislature in 2011.

Since the delivery of the P2TP to the Florida legislature in February 2008, numerous efforts identified in the process development and engineering component have begun. These include (1) implementation of the Northern Everglades Chemical Treatment Pilot Project, (2) construction and operation of several Hybrid Wetland Treatment Technology (HWTT) Projects, (3) construction of the Lakeside Ranch STA, (4) implementation of the Fisheating Creek (FEC) Feasibility Study, and (5) the development of the Watershed Assessment Model (WAM). The technical plan and its appendices are available at www.sfwmd.gov/northerneverglades.

Northern Everglades Chemical Treatment Pilot Project

The Northern Everglades Chemical Treatment Pilot Project is designed to further investigate the field-scale chemical treatment technologies that have been tested to reduce TP loads in stormwater runoff and to identify feasibility of large-scale implementation of such technologies in the LOW and St. Lucie and Caloosahatchee river watersheds. Existing information suggests that such technologies may be a cost-effective way to control phosphorus that discharges from these watersheds. The first phase of the study, which examined chemical treatment effects through an STA, was completed in July 2009 and concluded that various technologies may be viable and effective options for reducing phosphorus loads. Detailed analyses and conclusions are available in the final report at http://stormwater.ucf.edu/chemicaltreatment/Report%20July%206%20updated%20August%203.pdf.

During Phase II of the Northern Everglades Chemical Treatment Pilot Project, the District conducted an implementation costs and site selection analysis completed in WY2011. This analysis of chemical treatment at various spatial scales in the Northern Everglades is expected to be discussed in the 2012 SFER. The HWTT, which is one of the technologies under evaluation, represents a combination of chemical and wetland treatment technologies. Projects are being initiated as a joint effort between the District and the FDACS in the St. Lucie and Lake Okeechobee watersheds. The HWTT studies are further described in the *Watershed Research, Assessment and Monitoring* section of this chapter.

Lakeside Ranch Stormwater Treatment Area

The Lakeside Ranch STA is in the Taylor Creek/Nubbin Slough Sub-watershed, one of the nutrient hot spots in the LOW. This project is being expedited under NEEPP and involves construction of a 2,700-acre STA adjacent to Lake Okeechobee in western Martin County (**Figure 10-5**). The STA is expected to provide up to 19 mt of phosphorus reduction annually. Reducing phosphorus from this area is expected to help improve Lake Okeechobee's water quality. The STA is also capable of recirculating water from the lake, which may provide potential for internal phosphorus removal. This effort is anticipated to be one component of the Tentatively Selected Plan chosen for the Lake Okeechobee Watershed Comprehensive Everglades Restoration Plan (CERP) project (see www.evergladesplan.org). The Lakeside Ranch STA Project is designed in two phases:

- **Phase 1: STA – North, S-650 Pump Station, and Canal Improvements.** A 250 cubic feet per second (cfs) inflow pump station is under construction, along with canal improvements along the L-63 and L-64 levees and a northern STA (925 acres). Existing state appropriations are being used for Phase I.
- **Phase 2: STA – South and S-191A Pump Station.** Includes construction of a southern STA (1,050 acres), a new pump station at structure S-191, and a discharge canal. Phase II implementation will be subject to future funding.

The construction of the Phase I (North) STA has achieved several milestones with an investment of $4.2 million in construction to date, including: (1) constructed 4.5 miles of canals and seepage ditches, (2) built 3 miles of levees, (3) planted 25 acres of sod on the levees, (4) cleared 500 acres of land, (5) constructed five control structures, and (6) hauled 600,000 cubic yards (30,000 dump trucks full) of material.

Figure 10-5. Location and layout of Lakeside Ranch Stormwater Treatment Area (STA).

Construction for the Phase I (north) STA and the S-650 pump station (Phase 1) is expected to be completed in January 2012 and February 2012, respectively. Final design of Phase 2 (south) STA was scheduled for completion in December 2010. The final design submittal for the S-191A pump station (Phase 2) is expected to be completed in March 2011.

Fisheating Creek Feasibility Study

The objective of the Fisheating Creek (FEC) Feasibility Study is to identify alternative sites that meet storage and water quality goals for the FEC Sub-watershed. Of the nine sub-watersheds in the P2TP study area, the FEC Sub-watershed is one of the major sources of phosphorus loading to Lake Okeechobee at a rate of 59 mt/yr from 1991–2005. Fisheating Creek drains into Lake Okeechobee from the west and is the only tributary with an uncontrolled discharge to the lake (i.e., there are no structures on FEC directly controlling discharge to the lake). The study consists of two phases: Phase I included an investigation of available information for the FEC Sub-watershed and the development of a detailed work plan for Phase II. Phase II is currently under way and includes formulation and evaluation of alternatives for achieving storage and phosphorus reduction goals in the FEC Sub-watershed, and compilation of results into a feasibility report. A preferred plan for the FEC Sub-watershed will also be identified from the evaluated alternatives and described in the feasibility report. The feasibility report will also provide an initial cost estimate for land acquisition, design, and construction of each alternative site or combination of sites to achieve the storage and water quality goals. The feasibility study is expected to be completed by mid-2011.

Other efforts include development of new assessment tools to evaluate the effectiveness of various phosphorus control programs on load reductions to the lake. The Lake Okeechobee Watershed Assessment Model (WAM) was developed to meet this purpose. In April 2009, a panel of five experts completed a peer review of WAM (Graham et al., 2009) and made several major recommendations including one to rewrite the technical manual to provide the level of detail and clarity needed to support the model and its applications. The model documentation project designed to achieve this recommendation is described in the *Watershed Research and Assessment* section of this chapter.

WATERSHED PHOSPHORUS CONTROL PROGRAM

The Lake Okeechobee Watershed Phosphorus Control Program is designed to be a multifaceted approach that includes (1) continued implementation of regulatory and voluntary agricultural and non-agricultural BMPs, (2) development and implementation of improved BMPs, (3) improvement and restoration of hydrologic function of natural and managed systems, and (4) utilization of alternative technologies for nutrient reduction. In February 2001, the SFWMD, FDEP, and FDACS entered into an interagency agreement to address how to cooperatively implement this program and coordinate with existing regulatory programs, including the Lake Okeechobee Works of the District (LOWOD) Permitting Program [Chapter 40E-61 Florida Administrative Code (F.A.C.)], FDEP Dairy Rule (Chapter 62-670.500, F.A.C.), and Everglades Forever Act [Section 373.4592(13), F.S.]. Under the NEEPP legislation, the FDACS is charged with implementing an incentive-based BMP program on all agricultural lands within the LOW. The FDEP is responsible for developing non-agricultural, non-point source BMPs. The District is responsible for the implementation of TP-reduction projects and large-scale regional projects, and enforcing existing regulations as defined within Chapter 40E-61, F.A.C. An overview of the various watershed phosphorus control projects is in the *Watershed Status and Management* section of this chapter. More details about the District’s source control program are presented in Chapter 4 of this volume.

RESEARCH AND WATER QUALITY MONITORING PROGRAM

A research and water-quality monitoring program was developed by the District in cooperation with other coordinating agencies, to (1) collect data to establish long-term water-quality trends in the LOW, (2) develop a water quality model for the lake, (3) continue to identify and quantify phosphorus sources, (4) assess water management practices within the watershed, (5) evaluate the feasibility of alternative nutrient removal technologies, and (6) assess the relationship between water volumes and timing from the watershed, water level changes in the lake, and the timing and volume of water delivered to the estuaries. The last component was documented in the P2TP. The update for other components is described in the *Watershed Research, Assessment and Monitoring* section of this chapter.

EXOTIC VEGETATION CONTROL

Each year the District aggressively treats exotic vegetation in Lake Okeechobee. This is done to protect threatened native habitat and to restore areas of the marsh that have been impacted by exotic species. The herbicides imazapyr and glyphosate, which are registered for use in aquatic environments by the Federal government and have low toxicity to non-plant organisms, are used to maintain exotics at low levels. As a result, the marsh landscape has been altered by vegetation management activity.

One particular species, torpedograss (*Panicum repens*), exists in dense monocultures and has covered tens of thousands of acres in the upper elevation regions of the marsh. During periods of low lake stage, prescribed burns were set to remove most of the aboveground biomass and stress underground rhizomes. New plants that emerged rapidly from thick underground rhizomes were then treated with herbicides while they were small (20–30 cm) and actively growing. With this management approach, very little dead biomass remains after treatment. Dierberg (1992) indicated that the decomposition of such emergent vegetation would not add much phosphorus to the open water column.

More than 10,000 acres of torpedograss were treated with this method from 2004–2006, and more than 20,000 acres of torpedograss were treated from 2007–2009. Historic treatment efficacy has varied, but the level of control remains high in many areas several years after treatment. Without these treatments, dense monocultures would remain in the upper elevation regions of the marsh. Although torpedograss is still present in many areas, its coverage has declined dramatically. Native plant communities have colonized some of the treated sites and monthly wading bird surveys conducted in 2010 have documented thousands of birds foraging in shallow open water areas previously affected by torpedograss (see the *Emergent Aquatic Vegetation* section of this chapter). More information regarding the status of exotic species in the SFWMD is presented in Chapter 9 and Appendix 9-1 of this volume. Additional exotic vegetation treatments are noted throughout this chapter under area-specific sections.

INTERNAL PHOSPHORUS MANAGEMENT PROGRAM

Phosphorus-rich sediments have been accumulating in Lake Okeechobee for several decades. The current volume of these phosphorus-rich sediments in the lake is estimated at 260 million cubic yards or 199 million m^3. Phosphorus loads from these sediments to the water column will delay the response of the lake to significant reductions in external phosphorus loads as NEEPP-sponsored projects and others are completed within the LOW.

The LOPA required a study to examine the engineering, ecological, and economic feasibility of managing these sediments (Blasland, Bouck and Lee, Inc., 2003). It was determined that any management strategy would be temporary unless the external loads were reduced to meet the Lake Okeechobee phosphorus TMDL. Both sediment removal by lake-wide dredging and chemical treatment with aluminum sulfate or similar compound were evaluated and deemed not cost effective. However, water quality model results also suggest that once the TMDL is met, the water quality in-lake goal of 40 ppb — as established by the TMDL and described by Havens and James (1997) and Havens and Walker (2002) — will take decades to achieve.

To evaluate the effectiveness of chemical compounds on reducing phosphorus release from Lake Okeechobee mud sediments, laboratory studies were completed in 2008 using four chemical compounds [alum (aluminum sulfate), calcium hydroxide ($CaOH_2$), calcium carbonate ($CaCO_3$), and ferric chloride ($FeCL_3$)] at four concentrations each (Golder Associates, Inc., 2008). Ferric chloride at a concentration of 50 milligrams per liter (mg/L) or parts per million (ppm) was the most effective, followed by alum at 30 mg/L and 40 mg/L. At these concentrations, TP and soluble reactive phosphorus (SRP) release were reduced by 50 percent or greater within one to two days compared with untreated sediment cores. These reductions were observed both in cores where the sediment was periodically resuspended and in those in which the sediments were undisturbed. TP and SRP concentrations in the water above the sediments were generally between 20 and 100 micrograms per liter (µg/L) or parts per billion (ppb) depending on the treatment (undisturbed or resuspended) and day. Toxicity tests of ferric chloride and alum on larval bluegill sunfish (*Lepomis macrochirus*) survival found no larval mortality at any concentrations. Further larger-scale field tests using both of these chemicals and others containing organic polymer compounds have been recommended.

Since the 2003 study, a number of factors have emerged which warrant revisiting its conclusions and recommendations. First, there may be an unwillingness to wait decades for restored water quality conditions in the lake. Additionally, even if the phosphorus eventually leached from the sediments, the sediments themselves will still be present, leading to continuing turbidity and light-penetration issues for submerged plants in the lake as well as potential impacts to downstream receiving bodies. Finally, there is also recognition that additional improvements to the quality of water entering the Everglades downstream of the Everglades Agricultural Area (EAA) will also be very difficult to achieve without improving the quality of the water from Lake Okeechobee.

Further evaluation of new technologies and approaches are planned. As a matter of process, a new study would begin by reviewing the recommendations from the 2003 effort. The new study would reevaluate the previous recommendations and the current probable costs for implementation of any of those recommendations. New concepts and technologies would be evaluated and then compared against those from the previous report. Finally, new recommendations would be made for implementation.

ANNUAL PROGRESS REPORT

The SFWMD is required to submit an annual progress report to the Florida legislature. This chapter constitutes the 11th annual report to the legislature summarizing the hydrology, water quality, and aquatic habitat conditions of the lake and its watershed based on the results of research and water quality monitoring, and the status of the LOWCP. In addition, state funding appropriations and expenditures for the Lake Okeechobee Watershed Protection Program during Fiscal Year 2010 (FY2010) (October 1, 2009–September 30, 2010) are also included at the end of this chapter.

WATERSHED STATUS AND MANAGEMENT

WATERSHED STATUS

The LOW comprises roughly 3.445 million acres [14,000 square kilometers (km^2)], extending from Central Florida to agricultural and urban areas in South Florida that spread out from the lake on the south, east, and west (**Figure 10-6**). The watershed is further divided into nine sub-watersheds and 61 drainage basins (**Figure 10-6**). A drainage basin is an area of land where water from rainfall drains downhill into a body of water, such as a river or a lake. A sub-watershed contains one or more drainage basins and is grouped based on the geographical location and nutrient discharge conditions. The most recent land use data were obtained in 2006 with some minor updates in 2008 as part of the WAM Enhancement and Application Project (SWET, 2009) (**Figure 10-7**). The update included the addition of abandoned dairies, corrections made to the low density residential category in the S-133 basin, and changes to a large area in C-44 from reservoir to agriculture because the anticipated STAs there have not yet been built.

The nutrient levels in surface water runoff are directly related to land use and land management practices within the watershed (Hiscock et al., 2003; Zhang et al., 2002). The LOW is dominated by (1) agricultural land uses (51.2 percent), including improved pasture for beef cattle grazing (19.7 percent) and unimproved pasture/rangeland (9.4 percent) located north of the lake; (2) sugarcane production (11.6 percent) located south of the lake within the EAA; (3) citrus groves (7.1 percent) located primarily within the eastern portion of the watershed and Lake Istokpoga basin; (4) with sod farming, row crops, dairies, and other areas together making up the remaining (3.4 percent) of agricultural land uses (**Table 10-1**). The second-largest category is natural areas (36.9 percent), consisting of barren land, upland forests, and water and wetlands, the majority of which lie within the Upper Kissimmee and Lake Istokpoga drainage basins (**Figure 10-6** and **Table 10-1**). The SFWMD uses the Florida Land Use, Cover and Forms Classification System to define land use types. The SFWMD's minimum mapping unit standards for land cover and land use are 5 acres for upland and 2 acres for wetlands. For example, a wetland area less than 2 acres and located within pastures will be included in the pasture total.

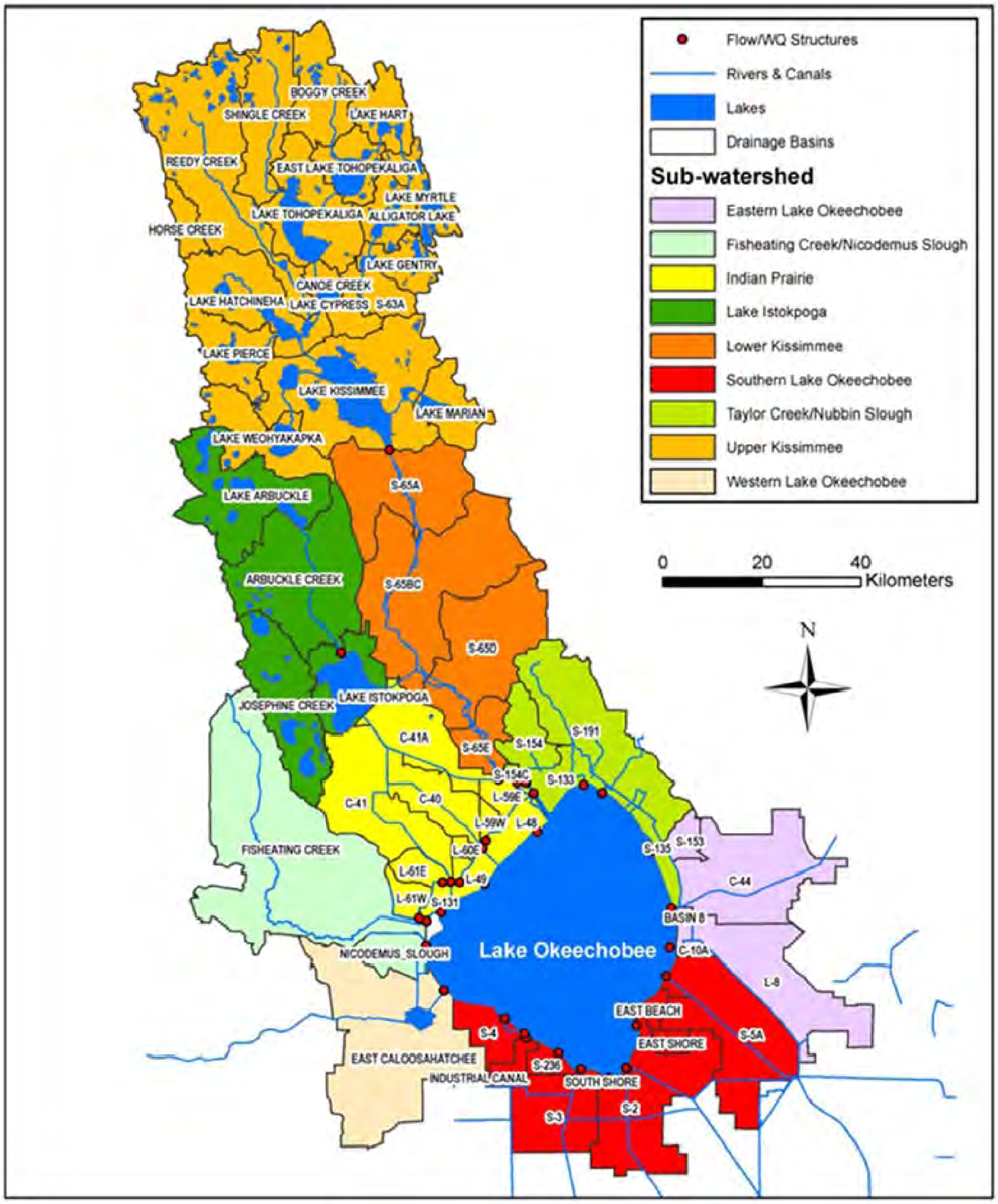


Figure 10-6. The Lake Okeechobee Watershed detailing sub-watershed and structure locations where TP loads were determined from tributary basins that drain into Lake Okeechobee (red dots).

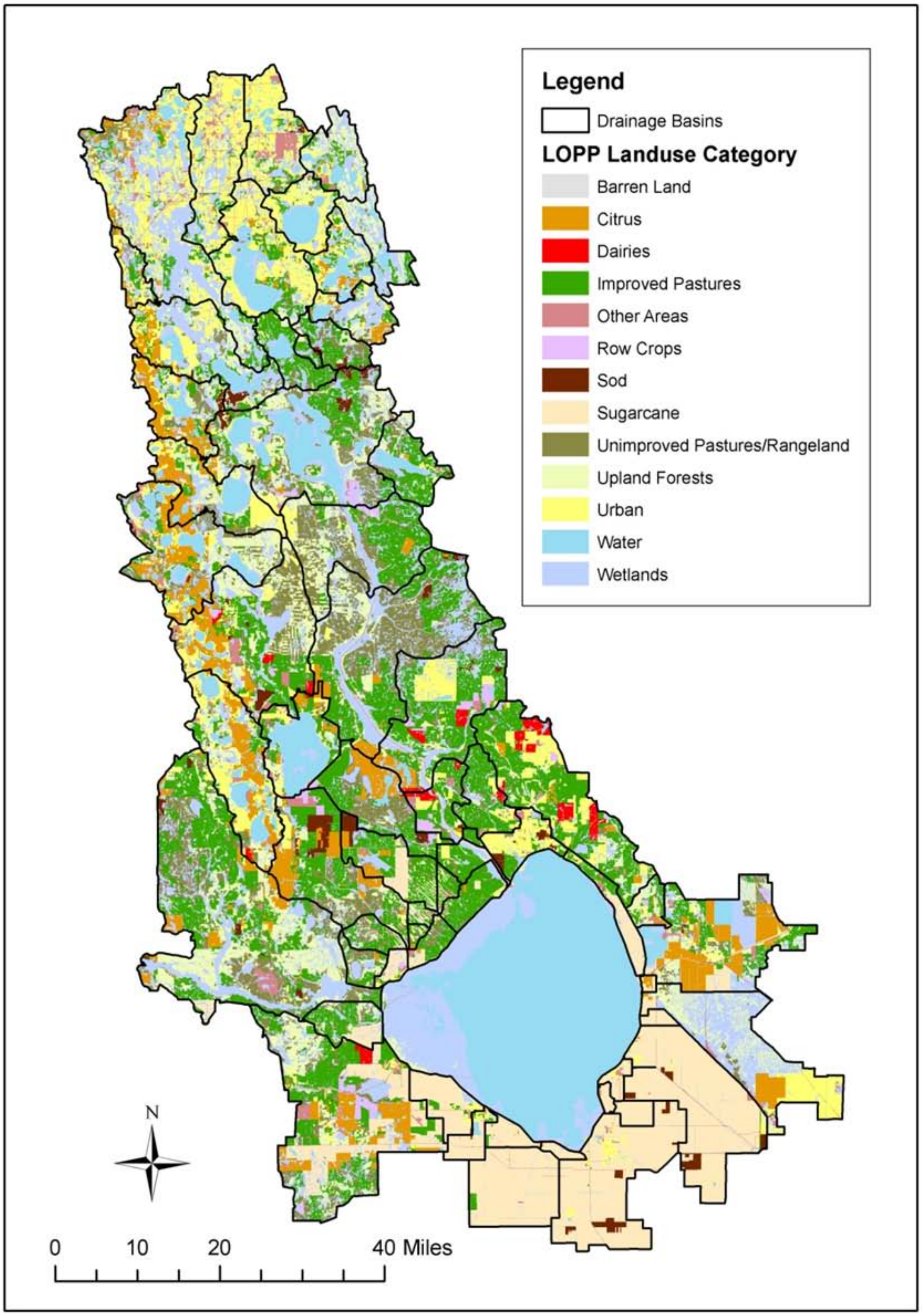


Figure 10-7. Land use distribution in the Lake Okeechobee Watershed.

Table 10-1. Land use data for the Lake Okeechobee Watershed.

Land Use	Area (acres) 2008	Percent
Barren Land	41,318	1.2%
Citrus	245,790	7.1%
Dairies	23,361	0.7%
Improved Pastures	676,991	19.7%
Other Areas	30,935	0.9%
Row Crops	23,238	0.7%
Sod	38,425	1.1%
Sugarcane	399,213	11.6%
Unimproved Pastures/Rangeland	325,064	9.4%
Upland Forests	392,200	11.4%
Urban	410,397	11.9%
Water Bodies	219,847	6.4%
Wetlands	615,081	17.9%
Total Acreage	**3,441,861**	100.0%

Surface water flow, TP loads, and total nitrogen (TN) loads to the lake for WY2010 were calculated for the major drainage basins (**Tables 10-2** and **10-3**). These calculations include discharges from lakes Istokpoga and Kissimmee. These lakes are the outfalls of sub-watersheds that collect water flow and nutrient loads from the smaller drainage basins that surround them (**Figure 10-6**). Data are based on monitoring stations where flow is continuously monitored and TP and TN samples collected on a bi-weekly basis or monthly basis when flow is present. During WY2010, the TP load to the lake from all drainage basins and atmospheric deposition (estimated as 35 mt – FDEP, 2001) was 478 mt (**Table 10-2**). The largest surface water inflow came from the Upper Kissimmee Sub-watershed (above structure S-65), followed by the Fisheating Creek basin and the Lake Istokpoga Sub-watershed. The Upper Kissimmee Sub-watershed covers about 30 percent of the drainage area in the LOW, and contributed about 54 percent of total inflow and 24 percent of total TP load during WY2010 (**Table 10-2**). The Fisheating Creek basin comprises 9 percent of the drainage area in the LOW, and contributed about 8 percent of total inflow and 17 percent of total TP load during WY2010. The Lake Istokpoga Sub-watershed has 11 percent of the drainage area in the LOW, and discharged 8 percent of total inflow and 5 percent of total TP load in WY2010. The highest TP concentration came from the L-59W drainage basin (884 ppb), followed by the S-154 (626 ppb), C-40 (512 ppb), C-41 (495 ppb), and Taylor Creek/Nubbin Slough (469 ppb) drainage basins. Even though many TP reduction projects have been implemented in these basins, more TP reduction measures will need to be implemented. (See Chapter 11 of this volume for a discussion of phosphorus in the Kissimmee Basin.)

During WY2010, the TN load to the lake from all drainage basins and atmospheric deposition (estimated as 1,233 mt – James et al., 2005) was 6,325 mt (**Table 10-3**). The highest TN load came from the Upper Kissimmee Sub-watershed, followed by the Lake Istokpoga Sub-watershed and Fisheating Creek Basin. In terms of TN concentration, the East Shore Drainage District Basin had the highest value (8.67 ppm), followed by the S-2 (8.33 ppm) and S-3 (8.05 ppm) basins.

Phosphorus loading rates into Lake Okeechobee have varied over time as a result of a combination of climatic conditions, land use changes, and changes in water management conditions (**Table 10-4**). From WY1981–WY2010, the highest loading rate was 1,189 mt in WY1983, followed by 960 mt in WY2005, and 913 mt in WY1998. The highest five-year average load was 715 mt during the WY2002–WY2006 period of record. The most recent five-year average load was 496 mt (WY2006–WY2010), which exceed the TMDL by 356 mt (**Table 10-4**) and was a decrease from 572 mt during the previous five-year period (WY2005–WY2009). This decrease is attributable to substantially higher discharges to the lake in WY2005 (960 mt). The WY2005–WY2009 average includes two of the consecutive wettest years on record (WY2005 and WY2006) that demonstrated the impacts of four hurricanes and two subsequent dry years (WY2007 and WY2008). These extremes confirm the rationale for the TMDL being based on a five-year average that can account for these variations in water flow and related nutrient loads.

Table 10-2. Water Year 2010 (WY2010) (May 1, 2009–April 30, 2010) surface water inflows, total phosphorus (TP) loads, and TP concentrations from the drainage basins in the Lake Okeechobee Watershed.

Source	Area		Discharge		TP Load		Average TP Conc.
	(acres)	(%)	(ac-ft)	(%)	(mt)	(%)	(ppb)
715 Farms (Culv 12A)	3,302	0.1	-	-	0	-	NA
C-40 basin (S-72) – S-68	43,965	1.3	12,671	0.5	8.0	1.8	512
C-41 basin (S-71) – S-68	94,655	2.8	76,272	3.2	46.6	10.5	495
C-41A basin (S-84) – S-68	58,488	1.7	79,587	3.3	14.5	3.3	148
S-308C (St. Lucie – C-44)	129,430	3.8	51,013	2.1	10.6	2.4	168
East Beach DD (Culv 10)	6,624	0.2	367	0.0	0.1	0.0	114
East Shore DD (Culv 12)	8,416	0.2	1,617	0.1	0.3	0.1	171
Fisheating Creek at Lakeport[a]	297,817	8.7	189,418	7.9	74.4	16.8	319
Industrial Canal	13,024	0.4	33,315	1.4	5.6	1.3	136
L-48 basin (S-127 total)	20,774	0.6	12,111	0.5	3.3	0.7	219
L-49 basin (S-129 total)	12,093	0.4	20,679	0.9	2.2	0.5	85
L-59E basin (G-33+G-34)	14,409	0.4	26,605	1.1	6.8	1.5	207
L-59W basin (G-74)	6,440	0.2	23,291	1.0	25.4	5.7	884
L-60E basin (G-75)	5,038	0.1	5,467	0.2	2.1	0.5	312
L-60W basin (G-76)	3,271	0.1	3,782	0.2	0.9	0.2	186
L-61E basin	14,286	0.4	NA		NA		NA
Taylor Creek/Nubbin Slough (S-191)	120,754	3.5	52,897	2.2	30.6	6.9	469
S-131 basin[a]	7,164	0.2	5,457	0.2	0.7	0.2	100
S-133 basin	25,660	0.7	3,459	0.1	1.0	0.2	245
S-135 basin	18,088	0.5	10,613	0.4	0.6	0.1	46
S-154 basin	31,619	0.9	13,118	0.5	10.1	2.3	626
S-154C basin	2,179	0.1	2,390	0.1	1.7	0.4	561
S-2 basin	106,372	3.1	10,509	0.4	2.9	0.7	223
S-3 basin	62,946	1.8	6,572	0.3	1.1	0.3	139
S-4 basin	26,389	0.8	37,715	1.6	10.5	2.4	226
Lower Kissimmee Sub-watershed (S65E-S65)	425,196	12.4	102,783	4.3	31.9	7.2	252
South FL Conservancy DD (S-236)	11,028	0.3	862	0.0	0.1	0.0	101
South Shore/South Bay DD (Culv 4A)	4,134	0.1	289	0.0	0.0	0.0	67
Nicodemus Slough Basin (Culv 5)	25,641	0.7	3,131	0.1	0.4	0.1	106
Upper Kissimmee Sub-watershed (S-65)	1,021,674	29.7	1,307,559	54.4	109.4	24.7	68
Lake Istokpoga Sub-watershed (S-68)	392,147	11.4	180,344	7.5	22.4	5.1	101
S-5A basin (S-352 WPB Canal)	119,443	3.5	-	-	0	-	NA
East Caloosahatchee Basin (S-77)	200,993	5.8	10,312	0.4	2.2	0.5	171
L-8 basin (Culv 10A)	108,402	3.1	38,032	1.6	6.3	1.4	135
Culvert 5A	NA		82,985	3.5	10.3		101
Totals from LOW	**3,441,861**	100.0	**2,405,223**	100.0	**443**	97.7	149
Atmospheric Deposition					35		
Total Loads to Lake Okeechobee					**478**		

[a] The drainage area includes the L-61W basin
NA – Not Available

Table 10-3. WY2010 surface water inflows, total nitrogen (TN) loads, and TN concentrations from the drainage basins in the Lake Okeechobee Watershed.

Source	Area		Discharge		TN Load		Average TN Conc.
	(acres)	(%)	(ac-ft)	(%)	(mt)	(%)	(ppm)
715 Farms (Culv 12A)	3,302	0.1	-	-	0	-	NA
C-40 basin (S-72) – S-68	43,965	1.3	12,671	0.5	39.6	0.8	2.54
C-41 basin (S-71) – S-68	94,655	2.8	76,272	3.2	254.8	5.0	2.72
C-41A basin (S-84) – S-68	58,488	1.7	79,587	3.3	153.9	3.0	1.57
S-308C (St. Lucie – C-44)	129,430	3.8	51,013	2.1	102.7	2.0	1.63
East Beach DD (Culv 10)	6,624	0.2	367	0.0	0.8	0.0	1.75
East Shore DD (Culv 12)	8,416	0.2	1,617	0.1	17.3	0.3	8.67
Fisheating Creek at Lakeport[a]	297,817	8.7	189,418	7.9	433.6	8.5	1.86
Industrial Canal	13,024	0.4	33,315	1.4	124.4	2.4	3.03
L-48 basin (S-127 total)	20,774	0.6	12,111	0.5	34.0	0.7	2.28
L-49 basin (S-129 total)	12,093	0.4	20,679	0.9	46.8	0.9	1.83
L-59E basin (G-33+G-34)	14,409	0.4	26,605	1.1	88.9	1.7	2.15
L-59W basin (G-74)	6,440	0.2	23,291	1.0	90.1	1.8	3.14
L-60E basin (G-75)	5,038	0.1	5,467	0.2	14.8	0.3	2.19
L-60W basin (G-76)	3,271	0.1	3,782	0.2	9.5	0.2	2.04
L-61E basin	14,286	0.4	NA		NA		NA
Taylor Creek/Nubbin Slough (S-191)	120,754	3.5	52,897	2.2	131.2	2.6	2.01
S-131 basin[a]	7,164	0.2	5,457	0.2	10.3	0.2	1.54
S-133 basin	25,660	0.7	3,459	0.1	6.2	0.1	1.45
S-135 basin	18,088	0.5	10,613	0.4	19.1	0.4	1.46
S-154 basin	31,619	0.9	13,118	0.5	37.6	0.7	2.33
S-154C basin	2,179	0.1	2,390	0.1	5.8	0.1	1.97
S-2 basin	106,372	3.1	10,509	0.4	108.0	2.1	8.33
S-3 basin	62,946	1.8	6,572	0.3	65.3	1.3	8.05
S-4 basin	26,389	0.8	37,715	1.6	160.0	3.1	3.44
Lower Kissimmee Sub-watershed (S65E-S65)	425,196	12.4	102,783	4.3	181.1	3.6	1.33
South FL Conservancy DD (S-236)	11,028	0.3	862	0.0	2.6	0.1	2.42
South Shore/South Bay DD (Culv 4A)	4,134	0.1	289	0.0	1.0	0.0	2.86
Nicodemus Slough Basin (Culv 5)	25,641	0.7	3,131	0.1	8.1	0.2	2.09
Upper Kissimmee Sub-watershed (S-65)	1,021,674	29.7	1,307,559	54.4	2126.8	41.8	1.32
Lake Istokpoga Sub-watershed (S-68)	392,147	11.4	180,344	7.5	483.1	9.5	2.17
S-5A basin (S-352 WPB Canal)	119,443	3.5	-	-	0	-	NA
East Caloosahatchee Basin (S-77)	200,993	5.8	10,312	0.4	23.5	0.5	1.85
L-8 basin (Culv 10A)	108,402	3.1	38,032	1.6	117.1	2.3	2.50
Culvert 5A	NA		82,985		193.5		1.89
Totals from LOW	**3,441,861**	100.0	**2,405,223**	96.5	**5,092**	96.2	1.72
Atmospheric Deposition[b]					1,233		
Total Loads to Lake Okeechobee					**6,325**		

[a] The drainage area includes the L-61W basin
[b] From James et al. (2005)
NA – Not Available

Table 10-4. Annual TP loads to Lake Okeechobee (WY1981–WY2010).

WATER YEAR May–April	Measured Load[a] (mt)	Long-term Load (five-year moving average)[a] (mt)	Long-term over-target Load (five-year moving average)[a/b] (mt)
1981	151	NA	NA
1982	440	NA	NA
1983	1,189	NA	NA
1984	369	NA	NA
1985	500	530	390
1986	421	584	444
1987	562	608	468
1988	488	468	328
1989	229	440	300
1990	365	413	273
1991	401	409	269
1992	408	378	238
1993	519	385	245
1994	180	375	235
1995	617	425	285
1996	644	474	334
1997	167	425	285
1998	913	504	364
1999	312	531	391
2000	685	544	404
2001	134	442	302
2002	624	533	393
2003	639	479	339
2004	553	527	387
2005	960	582	442
2006	795	715	575
2007	203	630	490
2008	246	551	411
2009	656	572	432
2010	478	496	356

NA – Not available
[a] Includes an atmospheric load of 35 metric tons per year based on the Lake Okeechobee Total Maximum Daily Load (FDEP, 2001).
[b] Target is the Lake Okeechobee Total Maximum Daily Load of 140 metric tons compared to a five-year moving average.

WATERSHED MANAGEMENT

The Lake Okeechobee Watershed Phosphorus Control Program includes (1) continued implementation of existing regulations and voluntary agricultural and non-agricultural BMPs, (2) development and implementation of improved BMPs, (3) improvement and restoration of hydrologic function of natural and managed systems, and (4) use of alternative technologies for nutrient reduction. The strategies for reducing the phosphorus loading from the watershed and the implementation schedule were described in the Lake Okeechobee Protection Plan update (SFWMD et al., 2007), as well as the P2TP (SFWMD et al., 2008). Those phosphorus reduction strategies, the lead agency responsible for implementing these strategies, and the anticipated phosphorus load reduction upon full implementation of the protection plan are being updated and are expected to be documented in the 2011 LOWPP.

FDACS Agricultural Programs

NEEPP requires that FDACS, in consultation with the FDEP, SFWMD, and affected parties, develop BMPs and assist agricultural landowners with their implementation to achieve necessary phosphorus load reductions to Lake Okeechobee. In response to this directive, the FDACS adopted Chapter 5M-3, F.A.C. The purpose of this code is to affect pollutant reduction through the implementation of non-regulatory and incentive-based programs. Where water quality problems are detected for agricultural non-point sources despite the appropriate implementation of adopted BMPs, the FDACS, in consultation with the other coordinating agencies and affected parties, institutes a reevaluation of the BMPs and makes appropriate changes to the rule adopting those BMPs. In addition to the presumption of compliance with state water quality standards, participants in the FDACS BMP program are eligible to participate in cost-share programs that provide monetary assistance with the implementation of BMPs. These provisions are meant to provide an incentive for owners or operators of agricultural non-point sources to participate in the implementation of BMPs and improve water quality in the long term.

A critical component in the success of the agricultural BMP program is the collection and analysis of data to determine whether the BMPs are working as anticipated. The interagency team plans to continue funding on-farm BMP demonstration projects at representative sites that, over time, will provide both effectiveness data and insight into what new or modified practices may be necessary to reach the phosphorus reduction goals required to achieve lake and tributary restoration. These BMP demonstration and evaluation projects are ongoing at representative sites for all agricultural land uses in the watershed including dairies, beef cattle, citrus, and vegetable production. This effort incorporates regional and sub-regional water quality monitoring in collaboration with the SFWMD and the U.S. Geological Survey (USGS), which can help identify where to focus on plan development and implementation and BMP-effectiveness studies. More information about the FDACS agricultural program can be found in Chapter 4 of this volume.

The TP load reduction to Lake Okeechobee from typical BMPs implemented/planned through June 2010 is estimated to be 15 mt (**Table 10-5**). This reduction reflects special BMP projects in the FDACS' typical cost-share BMP program. An additional approximately 4 mt reduction is estimated as a result of either owner-implemented or typical cost-share BMPs implemented on cow/calf operations throughout the watershed.

Table 10-5. TP load reduction projects implemented or planned by the Florida Department of Agriculture and Consumer Services (FDACS) under typical cost-share Best Management Practice (BMP) programs.

Basin	Project Category	Project Site	Estimated Annual Phosphorus Reduction to Lake Okeechobee (mt)	Construction Status
S-154	Dairy Hurricane Upgrade	Milking R	0.63	Complete
S-191		Larson 5	0.93	Complete
S-191		McArthur 1 and 3	0.4	Complete
S-65E		Butler Oaks	0.28	Complete
Arbuckle Creek		Wabasso Dairy	To be determined	Complete
S-65E	Dairy Stormwater Management System	B-4	3.08	Complete
S-65E		Butler Oaks	4.45	Complete
S-65D	Tailwater Recovery Project	Joe Hall	0.36	Complete
S-191	Dairy Composting Project	McArthur 1 and 3	2.74	Complete
S-65E		Butler Oaks	1.91	Complete
C-41A	Citrus Variable Rate Fertilizer Technology	Lykes Brothers	0.2	Complete
S-65D and S-65E	Alternative Water Supply Project*	Haynes Williams	0.16	Complete
		David Williams	0.16	Complete
S-191	Florida Ranchlands Environmental Services	Williamson Cattle Company	0.09	Complete
Total	**Total Estimated Phosphorus Reduction (mt)**		**15.39**	

*Cost-share with the SFWMD

FDEP Agricultural Programs

The FDEP permits and inspects active dairies and other Concentrated Animal Feeding Operations (CAFOs) within the Lake Okeechobee Watershed via the Clean Water Act's National Pollutant Discharge Elimination System (NPDES) permits. CAFOs are facilities where large numbers of poultry, swine, cattle, or other livestock are confined within a much smaller area than traditional pasture operations. The FDEP currently regulates 23 facilities in the watershed and permits are issued under Chapter 62-670, F.A.C. These permitted facilities are frequently inspected, and farm managers are educated regarding methods to prevent environmental impacts that could result from improper management of wastes. Manure and wastewater from these facilities have the potential to contribute pollutants including nitrogen, phosphorus, organic matter, sediments, pathogens, and heavy metals to the environment. The dairies permitted in the watershed reuse their wastewater to irrigate and fertilize crops to avoid off-site discharges.

Domestic wastewater residuals, also known as sewage sludge or biosolids, are the treated solids from a municipal wastewater treatment facility. In Florida, approximately 83 percent of residuals generated are beneficially used. Approximately 66 percent are land-applied as Class B residuals, primarily through surface application to pastures. The spreading of Class B biosolids regulated by the FDEP is anticipated to cease by the end of 2012 in the LOW and the St. Lucie and Caloosahatchee river watersheds because of the difficulty of demonstrating compliance with the nutrient balance demonstration required by Section 373.4595, F.S. Class AA biosolids distributed and marketed as a fertilizer product are currently exempted from the nutrient balance demonstration of the statute and are regulated by the FDACS. Regulations require residuals to be applied at an agronomic rate to minimize or prevent nitrogen leaching. Application rates are based on the nutrient content of the residuals and the needs of the crops. Florida also requires phosphorus to be considered in certain geographic areas, including the LOW.

The FDEP amendments to Chapter 62-640, F.A.C., to improve site accountability and management to address growing public concerns about the use of biosolids/wastewater residuals were adopted on May 20, 2010.

FDEP Non-Agricultural Programs

The acres of urban land that drain to Lake Okeechobee are minimal compared to the vast acres of agricultural land that drain into the lake. As a result, the percentage of the total nutrient load flowing into Lake Okeechobee from urban areas is relatively small (11 percent) when compared to the contribution from agricultural lands (77 percent). However, the higher per-acre nutrient contribution from urban areas prompts the FDEP and stakeholders to continue to evaluate and implement alternative strategies to further reduce nutrient loads flowing from urban areas into Lake Okeechobee. The largest contributors of TP loading from non-agricultural areas to the lake are nonpoint source nutrients that enter the watershed, including sheetflow runoff from residential lawns, (e.g., fertilizers and pet wastes) and effluent from septic tanks.

The FDEP uses regulatory and incentive methods to enhance and protect the LOW and provides grant funds for municipalities and others to construct projects that treat stormwater before it enters surface waters. The two primary regulatory programs that address urban point-source stormwater and nonpoint source inflows to the Lake Okeechobee tributaries are the NPDES Stormwater Permitting Program and the Submerged Lands and Environmental Resources Program, respectively. The FDEP also issues other permits for restoration activities in the watershed as well as NPDES permits for wastewater. In addition to these permitting activities, the FDEP is responsible for numerous other programs and activities that are designed to improve water quality in the LOW as well as throughout the state (e.g., rulemaking efforts pertaining to the statewide stormwater rule and numeric nutrient criteria). Another key responsibility of the FDEP is to administer the TMDL Program for the U.S. Environmental Protection Agency. The national TMDL Program is a surface water assessment and restoration program intended to bring all states' surface water bodies into compliance with respective water quality standards. Lake Okeechobee and its tributaries have TMDLs established for TP. Once a TMDL is established, a Basin Management Action Plan (BMAP) may be created to direct restoration efforts to meet the TMDL. BMAPs identify and describe various projects, programs, and activities planned to reduce pollutant loading, restore beneficial uses, and meet water quality standards. Currently, the LOWPP fulfills the role of a BMAP for Lake Okeechobee and its tributaries. A more in-depth discussion of these activities is presented in Chapter 4 of this volume.

SFWMD Phosphorus Control Programs

State funding has been provided under the LOWPP for the construction of more than 30 TP reduction projects located mainly in the four priority basins (**Figure 10-8**). These BMP implementation projects continued to provide TP load reductions to the lake during WY2010. Average annual TP load reduction from all implemented and competed projects is estimated at 27 mt. All these projects have some level of performance monitoring to validate the effectiveness of these technologies in reducing TP loads.

Phosphorus Source Control Grant Program

The Lake Okeechobee Phosphorus Source Control Grant Program was to fund the early implementation of projects that have the potential for reducing phosphorus exports to Lake Okeechobee from the watershed. The program originally consisted of 13 projects with a total cost of $7.5 million. The funded projects began in 2001 and varied in size and complexity. Grant recipients included landowners, public facilities, and private corporations. Currently, the program includes nine operational projects with an estimated TP load reduction of 17.5 mt (**Table 10-6**).

Isolated Wetland Restoration Program

Historically, isolated wetlands covered a considerable area of the four priority basins within the LOW (**Figure 10-8**). These wetlands captured stormwater runoff and retained phosphorus. Many of these wetlands were drained to increase the amount of land in agricultural production, which increased phosphorus discharge. Conceptually, the isolated wetlands program was intended to enhance and restore wetlands, reduce TP discharge and attenuate peak stormwater runoff by increasing regional water storage. A phosphorus reduction of 20 percent or greater was expected. As more wetlands are restored, it has been suggested that phosphorus loads to the lake should decrease while regional water storage in the watershed should increase (SFWMD, 2004).

The load reduction estimates from the four projects under this program were obtained from the design report or feasibility studies and the reductions were mainly due to flow volume reductions (**Table 10-6**). The isolated wetland restoration effort has also taken place at sites located at Lamb Island Dairy, Lofton Ranch, and Smith Okeechobee Farms. However, the Lamb Island Dairy site is categorized under Former Dairy Remediation and the last two are grouped under the Phosphorus Source Control Grant Program.

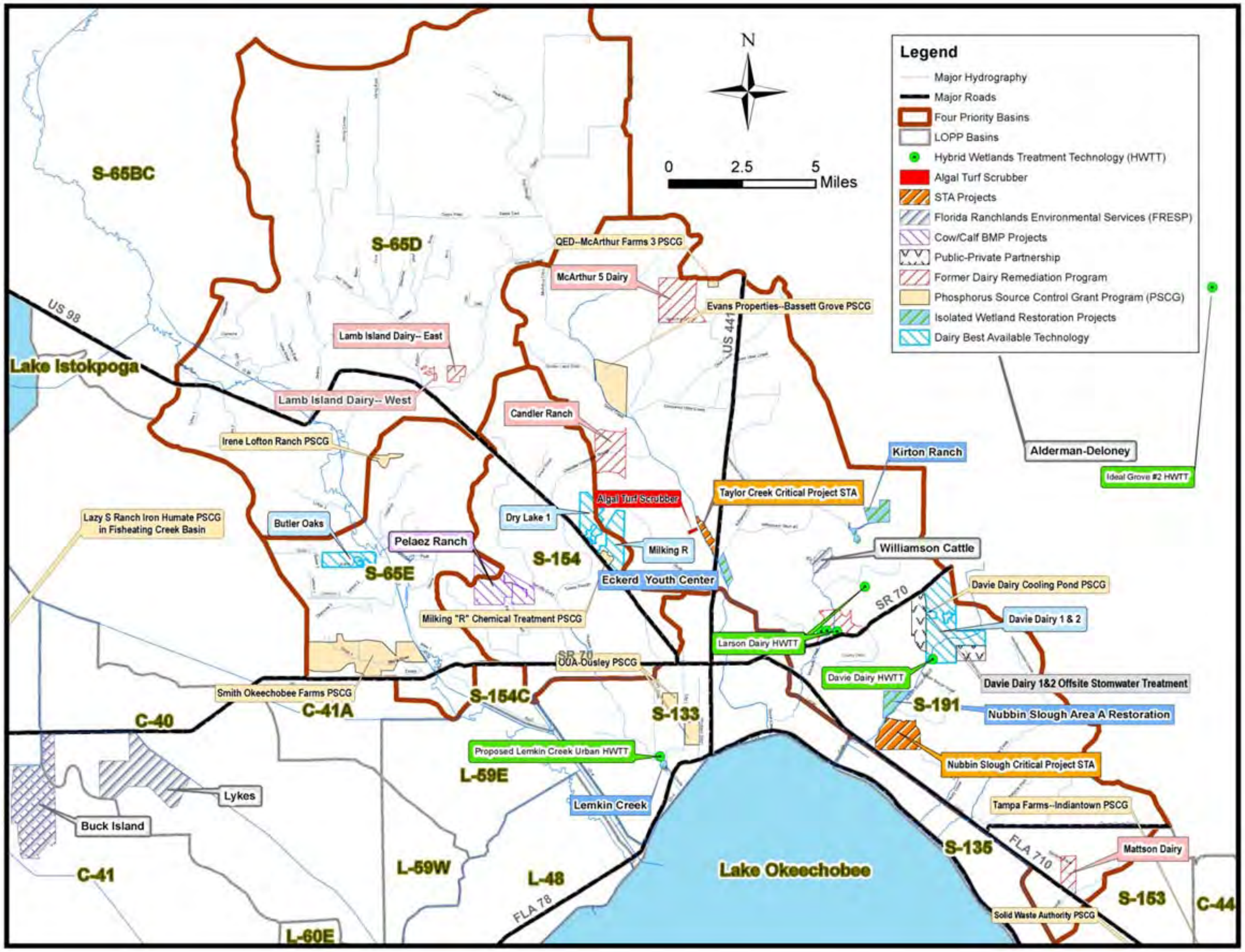


Figure 10-8. South Florida Water Management District (SFWMD or District) project locations under the Lake Okeechobee Watershed phosphorus control program.

Table 10-6. Summary of projects implemented and completed under the District's Lake Okeechobee Watershed phosphorus control programs.

Project Category	Project Site	Basin	Estimated Annual TP Load Reduction (mt)	Construction Status
Phosphorus Source Control Grant Program	Tampa Farms – Indiantown	S-154	7.67	Complete
	QED – McArthur Farms 3	S-191	6.02	Complete
	Davie-Dairy Cooling Pond	S-191	0.39	Complete
	Evans Properties – Bassett Grove	S-191	0.13	Complete
	OUA-Ousley	S-133	0.22	Complete
	Smith Okeechobee Farms	S-65E	0.59	Complete
	Lofton Ranch	S-65E	0.04	Complete
	Solid Waste Authority	S-65D & E	2.32	Complete
	Lazy S Ranch Iron Humate	Fisheating Creek	0.11	Complete
Isolated Wetland Restoration Project	Kirton Ranch	S-191	0.81	Complete
	Nubbin Slough Area A Restoration	S-191	0.39	Complete
	Eckerd Youth Center	S-191	0.40	Complete
	Lemkin Creek	S-133	0.12	Complete
Former Dairy Remediation	Mattson	S-191	0.37	Complete
	McArthur 5	S-191	1.05	Complete
	Candler	S-191	0.06	Complete
	Lamb Island	S-65D	2.34	Complete
Dairy Best Available Technology	Milking "R"	S-154	1.60	Complete
	Butler Oaks	S-65E	1.62	Complete
	Davie Dairy 1 and 2	S-191	0.10	Complete
Public-Private Partnership	Davie Dairy 1 and 2 Offsite Stormwater Treatment	S-191	0.09	Complete
Florida Ranchlands Environmental Services Project (FRESP)	Lykes Brothers	C-40	0.20	Complete
	Buck Island Ranch*	C-41	0.37	Complete
	Williamson Cattle Company**	S-191	0.09***	Complete
	Alderman-Deloney Ranch (not in the Lake Okeechobee Watershed)	C-25	0.08***	Complete
	C.M. Payne & Son	Fisheating Creek	TBD	Complete
	Lightsey Cattle Company	Fisheating Creek	TBD	Complete
	Syfrett Ranch West	C-41A	TBD	Complete
	Rafter T Ranch	Arbuckle Creek	TBD	Complete
TP load reduction for Watershed Phosphorus Control Program in metric tons (mt)			**27.00 mt**	

*Cost-share with FDACS
Also included in **Table 10-5
***Not included in the total reduction estimate

The configuration of each of these wetlands was unique since they were designed to fit the hydrology and topography of their respective sites. They cover a range of community types: forested cypress wetland (Eckerd Youth), mixed forest and open marsh (Lamb Island West and Kirton Ranch), and open marsh (Lemkin Creek, Lofton Ranch, and Smith Okeechobee). Except for Eckerd Youth, which relies on a pump to move water through the wetland during the wet season, all the other projects rely on passive flow through a variety of types of water control structures. All but Lemkin Creek, which currently receives low-phosphorus (approximately 20–40 ppb) inflow water from its associated Hybrid Wetland Treatment Technology (HWTT) pilot project, receive inflow water in the 150–1,000 ppb TP range.

In general, the quantity of monitoring data (e.g., water quality, flow, actual storage volumes, vegetation composition, and wildlife utilization) for all of the wetland projects is very sparse and was mostly limited to event monitoring during the initial year of the project. Monitoring was limited due to budgetary constraints. Based on the available data it appears that all of these created or restored wetlands were net exporters of phosphorus during the periods that they were monitored. To date, there is insufficient data to evaluate actual storage, potential improvements in habitat quality, or wildlife utilization.

The apparent net positive phosphorus balance of these wetlands is not surprising given that nearly all of the available water quality monitoring data were collected during the time that the wetlands might have been expected to be discharging accumulated legacy phosphorus from prior uses (Kadlec and Knight, 1996). These areas were likely transitioning from their one vegetation community to another, with a wetter, successional state probably resulting in the large-scale death and decay of the pre-restoration plant community. The literature suggests that Cypress wetlands like Eckerd Youth may be effective nutrient sinks for nitrogen and phosphorus (Dierberg and Brezonik, 1986), but information gained through the operation of STAs indicates that for open marsh wetlands characterized by alternating wetting and drying — similar to most of the isolated wetland projects — phosphorus retention may be poor due to oxidative processes that release phosphorus during dry periods which is then flushed from the system upon rehydration (SFWMD, 2008; SFWMD, 2010). In addition, the management plan for at least one isolated wetland in the group (Kirton Ranch) allows grazing of cattle within the conservation easement during the dry season (Birkett Environmental Services, Inc., 2004), which may lead to the deposition of additional phosphorus and to soil disturbance, both of which may contribute to increased export of phosphorus during periods of hydration and net positive flow.

A plan was recommended for ongoing monitoring of these systems to obtain additional information regarding their function as improved habitat, and in some cases, from the perspective of actual water storage capability. The plan recommended that additional monitoring be conducted for the Eckerd Youth, Lemkin Creek, Kirton Ranch, and Lamb Island West wetlands. Eckerd Youth is of interest because it is the only cypress wetland in the group and because it had a detailed initial vegetation survey which facilitates identifying changes resulting from rehydration. Lemkin Creek is of interest because of its association with the HWTT project and resulting low-phosphorus inflows. Lemkin Creek also has a long hydroperiod which favors phosphorus retention and functions as a trap for aluminum escaping the downstream end of the HWTT pilot. Kirton Ranch and Lamb Island West were recommended for further monitoring because of their size and because both had good pre-construction vegetation surveys. The dearth of available information on Smith Okeechobee (coupled with restricted access) and the reported poor hydraulic performance of Lofton Ranch make these two projects less amenable to continued tracking efforts.

Former Dairy Remediation

This remediation project of former dairies was initiated by the SFWMD to reduce stormwater TP load from these properties by implementing one or more remedial alternatives identified in the Agriculture Nutrient Management Assessment (AGNMA) developed to minimize phosphorus discharges from these sites. Three privately owned former dairies (Mattson, McArthur 5, and Candler), and one District-owned property (Lamb Island East and West), which are currently cow/calf operations, were selected for this project. Based on AGNMA recommendations, the following remediation practices were implemented to minimize phosphorus discharges from the properties: (1) runoff retention from old high-intensive areas (HIAs), (2) amendment of high-phosphorus soils, (3) rehydration of on-site wetlands, and (4) reduction of stormwater flow off-site via minor impoundments. The implementation of the different remedial management practices was completed from calendar years 2004–2008. Water quality monitoring for TP concentration reductions during flow events was conducted for one year following construction completion, but, because of drought, limited data have been collected from each site. The TP load reduction from this program is estimated to be 3.8 mt (**Table 10-7**).

***Candler Ranch Dairy*.** For Candler Ranch, an estimated 10 inches per year (in/yr) runoff with an average phosphorus concentration of 0.726 milligrams per liter (mg/L) was used to calculate the discharge load as the average annual basis. This phosphorus concentration value was obtained based on the 157 samples collected from 1992–2003 and two samples collected in 2009. It was assumed that phosphorus loading from the rest of the property is less significant. Due to extreme drought conditions, no discharges from the property were recorded during the monitoring period (HSA Engineers & Scientists, 2009), which resulted in a 100 percent load reduction. Candler Ranch also reported that approximately 4 million gallons of surface water were treated in a second-stage waste pond, resulting in the inactivation of 204 pounds (lbs) of phosphorus. Aluminum sulfate treatment and backfilling of the first and second waste holding ponds also inactivated approximately 447 lbs of phosphorus in the waste organic solids. In addition, the replanting of waste pond areas and the replacement of all existing cattle crossing culverts and risers over Chandler Hammock Slough increased runoff retention and reduced flooding on the farm (HSA Engineers & Scientists, 2009).

Lamb Island East and West Dairy. The Lamb Island site had only four discharge events from the property during the monitoring period. Based on pre-load condition estimates, 5,142 lbs of phosphorus (99.5 percent retention) were retained within the property (HSA Engineers & Scientists, 2006).

Mattson Dairy. A water and mass balance model was developed using 13 years of daily rainfall from the area for the Mattson Dairy (Royal Consulting Services, 2007). This approach was used because drought conditions had resulted in no discharges from the site during the monitoring period.

McArthur 5 Dairy. For the McArthur 5 site, an estimated 10 in/yr runoff with an average phosphorus concentration of 0.79 ppm was used to estimate the average annual discharge load. No discharge flows from the property were recorded during the monitoring period (Professional Service Industries, Inc., 2009), which also resulted in a 100 percent load reduction.

Regional drought conditions during the implementation of remediation practices on some of these projects influenced the total phosphorus load retention calculated during the monitoring periods. However, post-BMP monitoring at historic long-term monitoring sites has shown a reduction in phosphorus concentrations when compared to the pre-BMP period.

Table 10-7. Summary of former dairy remediation projects implemented under the District's watershed phosphorus source control programs.

Project Site	Phosphorus Inactivated in Waste Pond Water (lbs)	Phosphorus Inactivated in Waste pond Solids (lbs)	Estimated Annual Phosphorus Load From Surface Runoff (lbs)	Estimated Annual Reduction due to Water Retention (lbs)	Estimated Phosphorus Reduction due to Water Retention (%)
Candler	204	447	137	137	100
Lamb Island	299	17,010	5,165	5,142	100
Mattson	-	-	1,269	805	64
McArthur 5	-	14,076	2,307	2,307	100

Dairy Best Available Technology Projects

After a thorough evaluation of alternatives by an interagency project team, edge-of-farm stormwater treatment was selected for implementation on three dairy properties in the LOW under the Dairy Best Available Technology (BAT) Project. This type of projects consists of (1) capturing stormwater runoff (especially from all of the high-nutrient pasture areas), (2) reusing the runoff on-site in current operations if possible, and (3) if off-site discharge is necessary, chemically treating the stormwater prior to its release. Three dairy BAT projects are fully constructed, and performance monitoring was initiated in May 2004. A fourth BAT site, the Milking "R" Dairy was completed in December 2005. The performance monitoring and evaluation phase was completed in June 2008. The annual TP load reductions ranged from 0.19–1.62 mt (SWET, 2008). Butler Oaks, Dry Lake, and the Davie Dairy use retention and reuse followed by chemical treatment to achieve reduction rates ranging from 66–100 percent. Drought conditions contributed to the high phosphorus load reduction rates via solely retention/reuse during WY2007 and WY2008. For example, for Milking "R" Dairy, no off-site outflow occurred, so the phosphorus load reduction rate via retention was 100 percent. During the design phase, a 15 percent phosphorus reduction rate was assumed for this method. Of note, the Dry Lake Dairy was converted to Hudson Lakes Ranchettes, a project that was expected to include an urban stormwater treatment system to provide additional load reductions due to the termination of the on-site chemical treatment system. The land-use conversion was partially completed and the dairy BAT project was terminated.

Davie Dairy is the participant of both the dairy BAT and the Public-Private Partnership programs. The TP load reduction from the dairy averaged 0.19 mt per year during the 2004–2008 (**Table 10-6**). Based on the drainage area, the load reduction from Davie Dairy BAT is estimated to be 0.10 mt per year (9 percent) and the remaining 0.09 mt is attributed to the Public-Private Partnership Program. The Davie Dairy flow-through system proved technically challenging with frequent equipment failures and inefficient chemical flocculation. This system has been retrofitted with HWTT. The load reduction rate for Davie Dairy was increased from 9 to 70 percent (Watershed Technologies, LLC, 2010).

Florida Ranchlands Environmental Services Project

The Florida Ranchlands Environmental Services Project (FRESP) is finalizing the design of a pay-for-performance program in which ranchers in the Northern Everglades sell environmental services of water retention and TP load reduction to agencies of the state and other willing buyers. These ranches can bring services online quickly as compared to other options and are planned to complement public investment in regional water storage and water treatment facilities. The sale of the services could provide additional income opportunities for ranchers that face low profit margins and could provide an incentive against selling land for land uses that could further aggravate excess water flow, poor water quality, and habitat problems. FRESP, as a pilot program, is being implemented through collaboration among the World Wildlife Fund, participating ranchers, Natural Resources Conservation Service, the FDACS, District, and FDEP. Technical support is being provided by scientists from the MacArthur Agro-Ecology Research Center and University of Florida. Funding from federal, state, and private sources exceeds $6 million for Phase One (pilot, 2006–2011). Expected outcomes of the FRESP pilot phase include the development of cost-effective, credible procedures for documenting environmental services from ranchlands, identification of roles and responsibilities for implementing a Payment for Environmental Services program on a wider scale, and agreement between buyers and sellers on contracting and pricing of environmental services.

All eight of the FRESP water management projects are designed, constructed, and being monitored to capture hydrological and chemical data (**Table 10-6**). Note that Alderman-Deloney Ranch is located in the C-25 basin which is not part of the Lake Okeechobee Watershed. Data collection started in 2007 on four of the ranches and is planned to continue on all eight through the end of the pilot project in 2011. Projects include rehydrating drained wetlands, water table management, and pumping water from a nearby off-site canal through the existing ranch and then letting the treated water gravity-flow back into the canal. The eight ranchland water management projects occupy approximately 8,500 acres, not including drainage acres. A planning level estimate of the static water-retention capacity of the eight projects is 8,260 ac-ft (10.2 million m^3) of water for a single storm event with the average storage depth of 0.98 ft (0.3 m). Under FRESP, a simple model is being developed to improve water retention estimates by providing rainfall inputs at a given site.

WATERSHED RESEARCH, ASSESSMENT AND MONITORING

RESEARCH AND ASSESSMENT

The SFWMD, in cooperation with the FDACS, FDEP, University of Florida Institute of Food and Agricultural Sciences (UF/IFAS), and other agencies and interested parties, has implemented a comprehensive research and assessment program for the LOW. Research and assessment projects are assessed and prioritized each year by an interagency team to ensure that key issues and information needs are being addressed. The Northern Everglades Interagency Team now includes participants from local governments in the Northern Everglades Planning Area, which includes the Upper Kissimmee Basin and the Caloosahatchee and St. Lucie estuary watersheds. The work of this group is an integral component of the overall restoration program.

Research, demonstration, and assessment projects under way or completed in WY2010 are summarized in **Table 10-8**. Among the 11 projects listed in **Table 10-8**, five projects (two completed and three ongoing) are highlighted in detail in this section. More information on the other projects may be found on the District's web site at www.sfwmd.gov/okeechobee.

Taylor Creek Algal Turf Scrubber® Nutrient Recovery Facility

This is a scaled-up demonstration of a proprietary water treatment technology that uses algae to remove pollutants from impaired waters. The process design for this facility was based upon the successful implementation of a single Algal Turf Scrubber® (ATS™) treatment system in the S-154 basin. The facility was projected to remove 4,000 lbs of phosphorus per year. However, water quality-based TP removal during the three-year operational period (January 2007–January 2010) was only 236 lbs (or 78.6 lbs/year), less than 2 percent of the projected performance.

Initial evaluations revealed no substantial evidence related to physical operational and design issues or analytical/sampling error. There were also no discernible impacts from growth factor deficiencies, grazing, external nutrient sources, or excessive evapotranspiration. However, formal toxicity testing using the Environmental Protection Agency's Toxicity Identification Evaluations (TIE) procedure applied to green algae found toxicity in the Taylor Creek source water, which was concentrated within the associated foam. Gas chromatography and mass spectrometry analyses showed comparatively large spikes which resembled signatures associated with organic solvent type compounds like dipropylene glycol – a common surfactant/adjuvant and solvent used in agriculture. Complementary to efforts associated with the identification of the toxin(s), several investigations related to the attenuation or elimination of deleterious impacts of the toxin(s) were conducted. Positive results were obtained from the use of a water hyacinth scrubber, constructed wetland, and aluminum sulfate precipitation. However, the foam fractionation, used to concentrate the suspected toxins in the source waters so that studies could be made, was shown to be ineffective. The project concluded on May 31, 2010, without success.

Table 10-8. Status of Lake Okeechobee Watershed research, demonstration, and assessment projects during WY2010.

PROJECT NAME (INVESTIGATOR)	MAJOR OBJECTIVES	STATUS
Taylor Creek Algal Turf Scrubber® Nutrient Recovery Facility (HydroMentia, Inc., under contract to SFWMD)	The design for the 15 million gallons per day facility in Taylor Creek was based on the results obtained from a pilot investigation of the single Algal Turf Scrubber® (ATS™) treatment system in the S-154 basin. The facility contained 3.6 acres of effective treatment area on a 70-acre parcel owned by the District in the S-191 basin. The facility was expected to remove 1.81 metric tons (mt) of total phosphorus (TP) per year, but water quality data demonstrated only minimal phosphorus removal of 0.05 mt per year. Algae-toxic agents in Taylor Creek surface water have been identified as a possible cause for the underperformance of the ATS™ system. The project concluded on May 31, 2010.	Complete
Mike SHE/Mike 11 Application in the S-191 Basin (SFWMD)	The objective of this study was to develop a model to quantify the long-term hydraulic capacity for different water management projects. These include retention/detention ponds, stormwater treatment areas (STAs), and Dairy Best Available Technologies (BATs). The model has been calibrated and validated to observed data. To date the model has simulated alternatives that include the Taylor Creek STA and Davie Dairy BAT.	Complete
Nutrient Budget Analysis for the Lake Okeechobee Watershed (HDR Team, under contract to SFWMD and other state agencies)	The overall objective of this study is to determine the relative contribution and sources of TP and total nitrogen (TN) from identifiable sources and land uses. Specific tasks are to (1) obtain the TP and TN import and export data and develop the gross import, gross export, and net import coefficients (the import or export amount per unit area) by land use; (2) upgrade the graphical user interface to view input data including farms, drainage basins, hydrographic features, land uses, soil types, and nutrient (TP and TN) budget results using Esri's™ ArcGIS; (3) perform a mass balance analysis of TP and TN for each land use and contrast the results with the 2002 study. Obtain the baseline data for TN at different spatial levels; and (4) obtain the relationships between net nutrient (TP and TN) imports and basin characteristics (land use type, soil type, stream type, etc.) for each basin. The first three tasks have been completed and the final project report was completed in October 2010, with results slated for inclusion in the 2012 SFER.	Ongoing
Watershed Assessment Model Documentation and Validation (Soil and Water Engineering Technology, Inc., under contract to SFWMD and other state agencies)	In April 2009, a panel of five experts completed a peer-review of the Watershed Assessment Model (WAM) and gave seven major recommendations in a final report. The overall objective of this project for WY2011 is to address all major recommendations by the panel, except recommendations #2 (sensitivity analysis) and #5 (uncertainty analysis). The sensitivity and uncertainty analyses will be completed if funding is available. It is also recognized that the completion of detailed documentation is necessary for future work to address these two recommendations. WY2011 efforts are geared toward improving documentation of the model, ensuring that scientifically sound calibration and validation procedures are followed using established and objective goodness-of-fit measures, and testing the model. This project is scheduled for completion in April 2011.	Ongoing
Lake Istokpoga Environmental Evaluation and Vegetation Mapping (SFMWD)	Geographical Information Systems (GIS)-based vegetation maps are used by resource managers to monitor and evaluate the quality of fish and wildlife habitat in Lake Istokpoga. Temporal changes in the marsh landscape that occur in response to hydrologic conditions and management activity (exotic species control) can effectively be evaluated using vegetation maps as can the success of efforts to enhance wildlife habitat through various activities such as tree-planting projects. A detailed vegetation distribution map was constructed for the nearshore emergent plant communities in Lake Istokpoga in 2008 and a 2009 map is near completion. Lake sediment samples were collected and consist mostly of sand (52 percent) and mud (47 percent).	Ongoing

Table 10-8. Continued.

PROJECT NAME (INVESTIGATOR)	MAJOR OBJECTIVES	STATUS
Hybrid Wetland Treatment Technology (Watershed Technologies, LLC, under contract to SFWMD and other state agencies)	This project involves the design, deployment, and monitoring of Hybrid Wetland Treatment Technology (HWTT) facilities in the St. Lucie and Lake Okeechobee watersheds. The HWTT technology combines attributes of treatment wetlands and chemical treatment systems. In 2008, four HWTT systems were constructed and operational and optimization efforts were initiated. Three of the HWTT facilities – the 0.7-acre Ideal 2 Grove system, the 1.7-acre Nubbin Slough system, and the 1.4-acre Mosquito Creek system are continuous-flow systems (subject to water flow availability), while the fourth is situated adjacent to a dairy lagoon and is used for batch treatment of the high-strength waters. Two additional systems were constructed on Wolff Ditch and Lemkin Creek and began operations in late 2009. These systems show promising results with TP concentration reductions ranging from 87–95 percent. Five systems (dairy lagoon system discontinued) are being operated for phosphorus load reduction and evaluated for cost effectiveness through March 2011. An additional system is anticipated to be constructed and begin operations at the District's Taylor Creek/Grassy Island property during WY2011.	Ongoing
Wetland Soils Nutrient Criteria Development and Evaluation of "Safe" Soil Phosphorus Storage Capacity (UF/IFAS)	The overall objective of this project is to identify routine soil tests that can be used as indicators of phosphorus release from the soil to the water column in wetland soils across wetland locations and types. The first task involves synthesis of all relevant data available on wetland soils within the Lake Okeechobee Watershed to identify critical gaps in the dataset. A protocol for field soil sampling, laboratory analysis, and statistical interpretation of data will be developed. The validity of numeric phosphorus criteria and "safe" phosphorus levels in wetland soils will be evaluated on 200 samples from the watershed and other wetland sites in South Florida. The final report of the project will include the accuracy of numeric phosphorus criteria that could be used for predicting phosphorus release in wetland soils. Results for this project are anticipated in WY2011.	Ongoing
Permeable Reactive Barrier Technology (PRBs) (UF/IFAS)	This project will evaluate the incorporation of water treatment residuals or similar materials capable of interception and long-term sequestration of phosphorus into permeable reactive barriers (PRBs) in the Lake Okeechobee Basin before phosphorus enters the water conveyances into the lake. The project objectives are to (1) assess the feasibility of significantly reducing phosphorus loads to Lake Okeechobee using PRB technology; (2) test suitable materials for PRB construction and design for locations appropriate for the basin in the laboratory; and (3) install a pilot-scale PRB in the basin. A systematic evaluation of numerous soil amendments using standard protocols was conducted to provide directly comparable results upon which to judge amendment effectiveness. The protocols included standard total elemental analysis of each amendment, short-term laboratory equilibrations, small column leaching studies, and simulated rainfall studies. Amendments included water treatment residuals (Fe-, Al-, and Ca-based), industrial by-products produced or marketed in Florida (slag, silica-rich, and humate materials), and agricultural amendments (lime and gypsum). The assessment, completed in December 2009, identified two amendments worthy of field investigation. Task two was completed in September 2010; the funding for task three is uncertain.	Ongoing

Table 10-8. Continued.

PROJECT NAME (INVESTIGATOR)	MAJOR OBJECTIVES	STATUS
Ranchland BMP Research (UF/IFAS)	Limited data exist on the effectiveness of ranchland BMPs (e.g., water retention in wetland and pasture). The goal of the project is to evaluate the cow/calf BMPs (cattle fencing and wetland/pasture water retention) regarding water storage and flows, phosphorus loads, and economic feasibility. Specific objectives include (1) design a hydrologic and water quality monitoring network for testing the BMPs at a cow/calf ranch in the Lake Okeechobee Watershed; (2) collect and analyze the long-term baseline and post-BMP hydrologic and water quality data (surface and ground waters); (3) use the monitoring data to evaluate the selected hydrologic and water quality models for their efficacy in simulating the BMP effects; (4) use the models to refine the BMPs for optimizing ranch-scale water and phosphorus retention; and (5) disseminate the project results to ranchers and state and federal agencies. The water retention BMP is being evaluated at two BMP sites. Results from the water retention BMP are important for the basinwide implementation of ranchland water storage projects in the watershed. This project is scheduled to continue through June 2011.	Ongoing
Protocol Development to Evaluate the Effect of Water Table Management on Phosphorus Release to Drainage Water (UF/IFAS)	A thorough understanding of potential phosphorus release from soils is critical for the successful implementation of water table management. A protocol for evaluating soils applied with dairy- and beef-waste derived and inorganic fertilizers has been developed through this project. The protocol uses three easily determined parameters: Mehlich 1-phosphorus, iron, and aluminum. With the possible introduction of a new phosphorus risk assessment tool on a national scale (see http://wmc.ar.nrcs.usda.gov/partnerships/MSRB/NationalTools.html), this project aims at developing criteria for water table management (and other BMP implementations). The protocol will be updated to Mehlich 3 when parameters become available. Mehlich 3 is being implemented in Florida because of the pH of local soils. The new criterion for phosphorus risk assessment needs to be extended to wetland soils to account for additional phosphorus storage in association with organic matter above and beyond the mineral fraction. This project is scheduled to continue through June 2011.	Ongoing
Wetland BMP Research (UF/IFAS)	Long-term monitoring is required to determine the effect of restoration on the phosphorus-assimilation capacity of isolated wetlands. There is a time lag between hydrological restoration (when wetland water levels are permanently increased) and when wetland components (vegetation) respond to these new water level regimes. The study objectives are to (1) demonstrate and determine the efficacy of isolated wetlands located in land areas used for dairy and cow/calf operations on phosphorus assimilation and storage, (2) determine the effect of hydrological restoration on water storage and flow paths, (3) determine (if any) the change in phosphorus storage in wetland and surrounding upland soils and vegetation as a result of restoring hydrology, (4) determine the composition and stability of soil phosphorus (non-reactive phosphorus) under a range of hydrologic conditions, and (5) validate hydrologic and phosphorus models for adaptation to the Lake Okeechobee Watershed and use these models to simulate phosphorus retention capacity. Results of this study are expected to quantify how hydrology, nutrient cycling dynamics, and cattle affect retention and stability of phosphorus in isolated wetlands. These measurements will be extrapolated to basinwide to assess phosphorus retention by isolated wetlands. The project started in 2003 and is scheduled to run through calendar year 2011.	Ongoing

MIKE SHE/MIKE 11 Model Applications in the S-191 Basin

The S-191 basin is located northeast of Lake Okeechobee. It comprises 3.5 percent of the watershed, but discharges about 12 percent of the total load to the lake (**Table 10-2**). Extensive nonstructural and structural BMPs have been implemented in this basin to reduce TP loads (**Figure 10-8**). Davie Dairy BAT and Taylor Creek STA are two of the structural BMP projects. Taylor Creek STA reduces phosphorus loads to the lake through detention, plant growth, and soil sorption. Davie Dairy BAT project reduces phosphorus loads to the lake through detention and chemical treatment. However, due to limited data collected after the construction was completed, the TP reduction under different hydrologic conditions over a longer period is unknown. A better understanding of the project's long-term performance will benefit future BMP implementation decision making and funding allocation. The objective of this study was to develop a MIKE SHE/MIKE 11 coupled model to simulate the daily flow rate and long-term treatment volume under different hydrological (base and structural BMPs) and meteorological conditions for the S-191 basin. The MIKE SHE/MIKE 11 coupled model was selected for this study because it can simulate the dynamic exchanges between the overland flow plain, groundwater aquifer, and river system.

This study developed, calibrated, and validated a MIKE SHE/MIKE 11 coupled model for this basin. The simulated flow at structure S-191 compared favorably with measured values for calibration and validation time periods. Simulated groundwater levels for calibration were reasonably consistent with the measured groundwater levels. The calibrated and validated model simulated the long-term treatment performance of these two structural BMP projects using the observed hydrology from 1994 through 2009. The simulated annual runoffs at both projects' outflow points match the available monitoring data well. For the Taylor Creek STA project, the simulated annual inflow to the system was 11,190 ac-ft and the outflow from the system was 10,454 ac-ft. The inflow flow-weighted mean (FWM) TP concentration, as measured from July through December 2008 was 494 ppb and the outflow FWM TP concentration was 335 ppb (USACE, 2009). Based on this STA performance, the long-term annual average inflow TP load into the STA was 6.8 mt and the outflow TP load was 4.3 mt. The annual load reduction was 2.5 mt, or 36 percent of the load to the STA. The load reduction estimation is consistent with the design rate of 2.08 mt on an average annual basis. For the Davie Dairy BATs Project, the simulated annual inflow to the system was 1,398 ac-ft and the outflow from the system was 1,271 ac-ft. The measured average inflow TP concentration was 836 ppb and the design treatment efficiency was 78 percent for TP concentration reduction (ERD, 2003). Based on the designed treatment efficiency, a reduction of 1.1 mt may be achieved.

This model can be used as a management tool to estimate daily flow rate and long-term annual runoff volume at different structural BMP projects inflow and outflow points. Further, the simulated long-term daily runoff data can be used to estimate the TP load reduction combined with the available water quality monitoring data or linked to other water quality models. The projects that can be simulated by this model tool include detention/retention ponds, STA, and Dairy BAT projects. This model can also estimate the daily flow at tributaries and farm levels through minor modification to internal model specification and combination with structure dimensions and stream survey data. The application of the coupled MIKE SHE/MIKE 11 modeling system to the S-191 basin demonstrated its potential to represent complex hydrological systems and other structural BMP projects found in the LOW.

Nutrient Budget Analysis – Phosphorus Imports and Exports

The nutrient budget analysis included a detailed material budget of both TP and TN imports and exports in the Lake Okeechobee Watershed (HDR Team, 2010). This budget analysis utilized current land use data, and more recent rainfall and runoff phosphorus values. It integrated all imports including fertilizer, feed, and animals, and exports including nutrient loads in surface water runoff, milk, harvested crops, and animals for the entire LOW. Based on data collected from 2009, approximately 6,088 mt of phosphorus was imported into the Lake Okeechobee Watershed annually for anthropogenic land use activities; 5,047 mt of the total net phosphorus imported was stored on-site in upland soils (HDR Team, 2010). The net import of nitrogen from anthropogenic land use activities was 42,513 mt (HDR Team, 2010).

The current phosphorus budget results by land use were compared to the previous data (Mock Roos Team, 2002; Mock Roos Team, 2003; Hiscock et al., 2003; Zhang and Donovan, 2004; Zhang et al., 2004). The net phosphorus import decreased by 25 percent from the previous budget, from 8,085 mt to 6,088 mt. This is primarily due to changes in phosphorus import from three land uses: truck crop, sugarcane, and improved pasture (**Table 10-9**).

Table 10-9. Comparison of phosphorus budget analyses in metric tons (mt).

Land Use	2002–2003 Phosphorus (P) Budget Analysis				Current Phosphorus Budget Analysis			
	Area (acre)	Percent	Net P Import (mt)	Percent	Area (acre)	Percent	Net P Import (mt)	Percent
Barren Land	64,092	1.9%	-	0.0%	41,318	1.2%	-	0.0%
Citrus	250,755	7.3%	285	3.5%	245,790	7.1%	1,274	20.9%
Dairies	28,256	0.8%	504	6.2%	23,361	0.7%	470	7.7%
Improved Pastures	714,245	20.8%	1,672	20.7%	676,991	19.7%	1,916	31.5%
Other Areas	52,853	1.5%	434	5.4%	30,935	0.9%	170	2.8%
Row Crops	22,699	0.7%	1,845	22.8%	23,238	0.7%	309	5.1%
Sod	32,823	1.0%	(493)	-6.1%	38,425	1.1%	(256)	-4.2%
Sugarcane	399,836	11.6%	1,562	19.3%	399,213	11.6%	543	8.9%
Unimproved Pastures/Rangeland	337,385	9.8%	2	0.0%	325,064	9.4%	(84)	-1.4%
Upland Forests	416,214	12.1%	(14)	-0.2%	392,200	11.4%	(36)	-0.6%
Urban	281,633	8.2%	2,288	28.3%	410,397	11.9%	1,783	29.3%
Water Bodies	226,650	6.6%	-	0.0%	219,847	6.4%	-	0.0%
Wetlands	614,701	17.9%	-	0.0%	615,081	17.9%	-	0.0%
Total Acreage	**3,442,141**	**100.0%**	**8,085**	**100.0%**	**3,441,861**	**100.0%**	**6,088**	**100.0%**

The net phosphorus imports for improved pasture were increased by 15 percent. This is primarily due to the land application of residuals, which were not included previously. If residuals were removed from the budget, there would be a 22 percent decrease in improved pasture, which suggests that the effort by the coordinating agencies and local ranchers to reduce the use of phosphorus in feed and fertilizers appear to be successful. Other factors, such as changes in land application rates of fertilizers and changes in farm types from pasture to sod may also be influencing the results. Other significant reductions occurred in truck crops and sugarcane. The reduction in truck crops may be attributable to the economy. The change in sugarcane, however, may reflect a more accurate calculation of imports and exports, which were compared to fertilizer sales and crop reports. By contrast, the net import of phosphorus for citrus increased. This is due primarily to changed coefficients in the Lake Istokpoga and Upper Kissimmee basins where citrus was previously calculated as a net phosphorus exporter (as opposed to an importer as calculated previously in the other regions). Citrus was found to be a net phosphorus importer in all of the regions with fertilizer rates in the mid-range of UF/IFAS recommendations.

Overall, urban land uses (12 percent of the watershed) represent 33.5 percent of the total net phosphorus import. This warrants further study of ways to reduce nutrient imports onto these land uses. An offsetting factor, however, is that most urban land uses are in the Upper Kissimmee region, which includes an extensive lake system that provides a significant amount of nutrient retention. This retention, though, could also begin adversely affecting the lakes' chemistry and eventually result in increased nutrient discharges to the Kissimmee River and Lake Okeechobee.

Hybrid Wetland Treatment Technology

The Hybrid Wetland Treatment Technology (HWTT) studies represent a combination of wetland and chemical treatment approaches in a wetland (**Figure 10-9**). Chemical coagulants are added, either continuously or intermittently, to the front end of the treatment system, which contains one or more deep zones to capture the resulting floc material. A fundamental concept of HWTT is that the floc resulting from coagulant addition generally remains active and has the capability of additional phosphorus sorption. Both passive and active reuse of floc material is practiced in HWTT. Passive reuse refers to the settling of active flocs of plant roots and stems, where it can contact additional untreated aliquots of water. Active reuse refers to the mechanical resuspension of previously settled floc. The HWTT system was developed as an approach that attempts to maximize nutrient removal per unit of chemical coagulant use, typically by incorporating novel design and multiple operational strategies. In addition to passive and active recycling/reuse of chemical flocs, optimization approaches include the sequencing and configuring of the wetland unit processes to provide desirable nitrogen and phosphorus species transformations. The operational desirability and cost-effectiveness of the various strategies were under evaluation at the time this report was written.

During WY2008, four HWTT systems were constructed and operational and optimization efforts were initiated. Three of the HWTT facilities — the 0.7-acre Ideal 2 Grove system, the 1.7-acre Nubbin Slough system, and the 1.4-acre Mosquito Creek system — are continuous-flow systems (subject to water flow availability), while the fourth is situated adjacent to a dairy lagoon and is used for batch treatment of high-strength waters. The dairy lagoon system was discontinued at the end of WY2009 since adequate data had been obtained. Two HWTT facilities (Lemkin/FDOT and Wolff Creek systems) were constructed and brought online during WY2010 and an additional site at Grassy Island is planned for completion when the extended permitting process is completed. Effective performance of the HWTT technology is demonstrated by the change in TP concentrations from inflow and outflow during the study period (Watershed Technologies, LLC, 2010). TP FWM concentration reductions ranged from 93–82 percent, with the exception of a 70 percent decrease at Nubbin Slough which had a TP FWM concentration of 905 ppb (**Figure 10-10**).

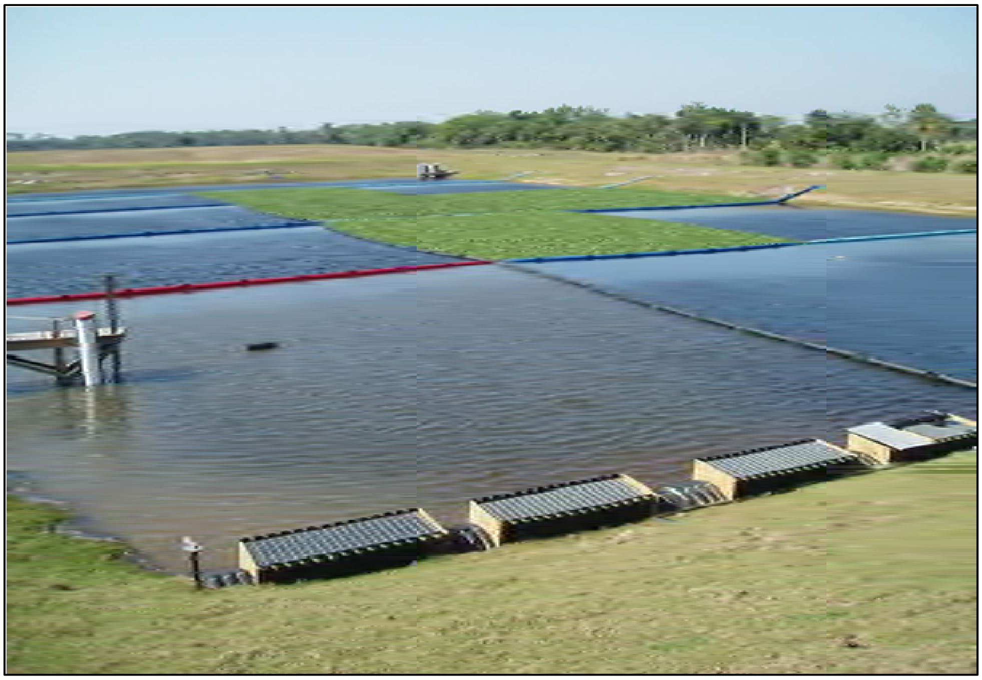


Figure 10-9. The Nubbin Slough Hybrid Wetland Treatment Technology (HWTT) facility with the mixing chamber and inflow manifold in the foreground, and the outflow riser at the upper right (photo by the SFWMD).

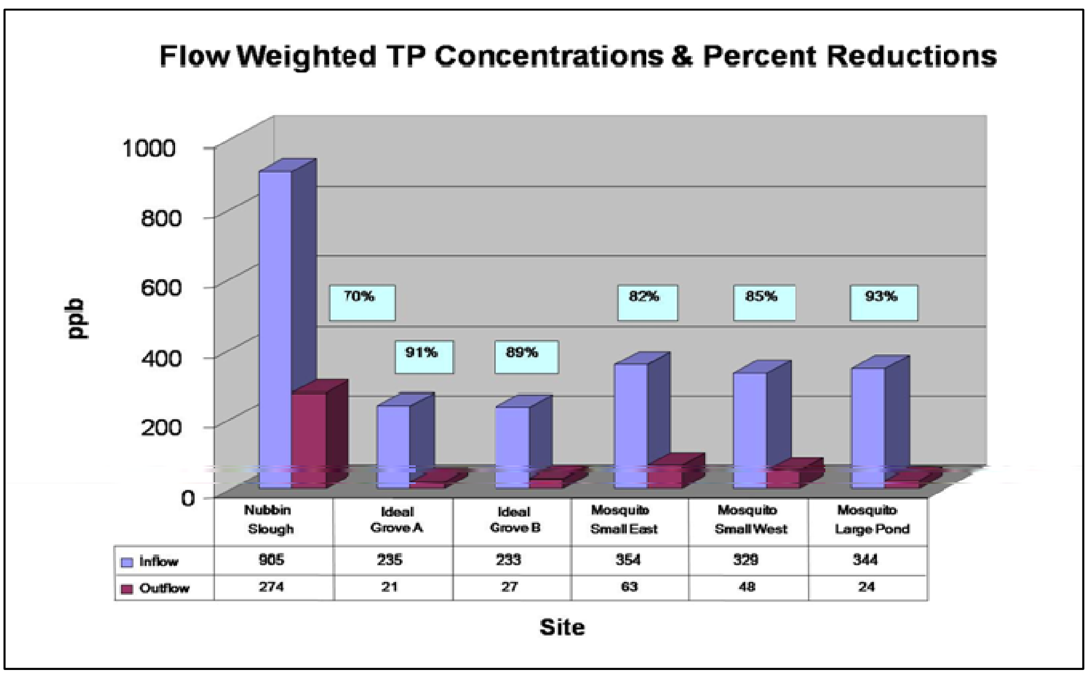


Figure 10-10. TP concentration reductions by the HWTT facility from November 2009 through November 2010.

Ranchland BMP Research

This project evaluated the effectiveness of the cow/calf BMPs that appear most promising for ranches in the LOW, and to assess the change in nutrient loads to surface waters and groundwater (Shukla et al., 2009). The BMPs included (1) ditch fencing and culvert crossing to keep cattle out of waterways and (2) wetland water retention to increase the storage of water and nutrients on ranches. The two BMPs were implemented at a commercial cow/calf ranch in Okeechobee (**Figure 10-11**). For the ditch-fencing BMP, a fence was installed along both sides of a 170-m section of the ranch's main drainage ditch and a culvert crossing was built to allow cattle access over the ditch. The wetland BMP consisted of riser board structures at the outlets of two wetlands (wetlands 1 and 4). Boards could be added to meet desired water retention levels. The effectiveness of these BMPs was evaluated by comparing TP and TN discharge and concentrations between pre- and post-BMP periods.

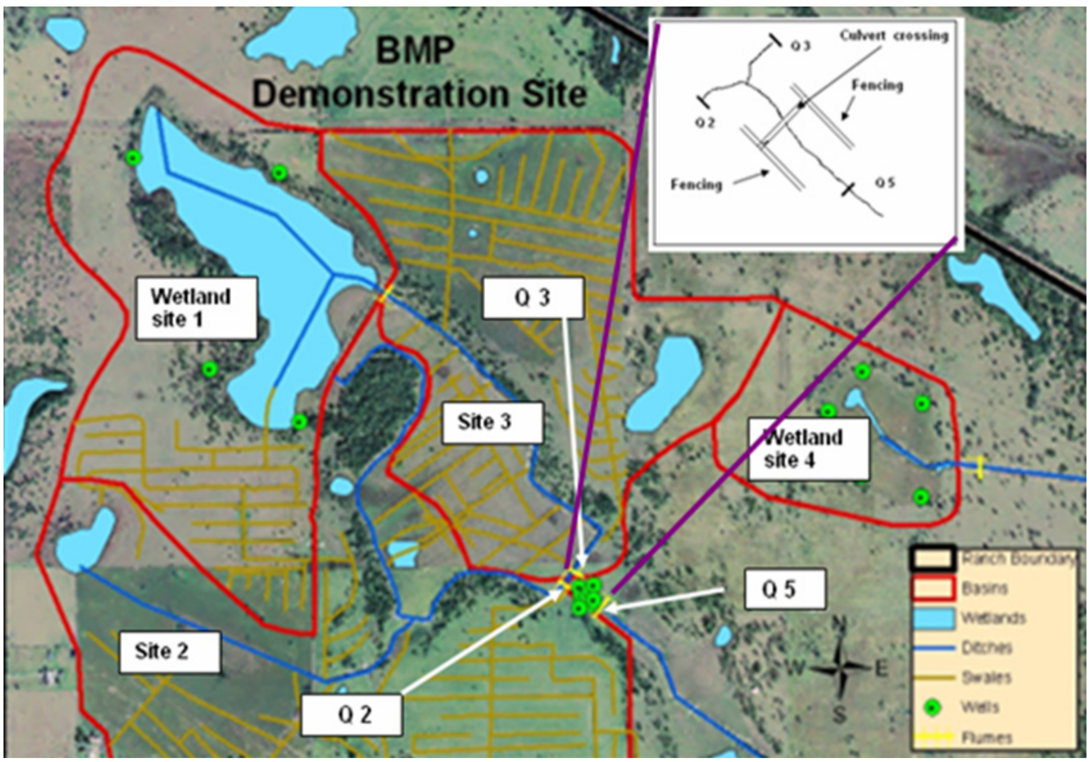


Figure 10-11. The BMP demonstration sites at a beef cattle ranch in the Lake Okeechobee Watershed.

Ditch Fencing and Culvert Crossing

The wet season (June–October) of 2005 was the pre-BMP period and the wet seasons of 2006–2008 were the post-BMP periods (post-BMP1, post-BMP2, and post-BMP3 periods, respectively). During the pre-BMP period (2005), downstream TP loads were 123 kg higher than the upstream TP loads, indicating phosphorus addition at the fencing site. In the post-BMP1 and 3 periods, downstream TP loads were 17 and 88 kg lower than the upstream TP loads indicating reduction/retention of TP in the ditch section. Downstream TP loads were 35 percent higher than the upstream loads in the pre-BMP period and 32 and 11 percent lower during post-BMP1 and 3, respectively. TN load reduction was also measured at the post-BMP1 and 3 periods. Post-BMP2 (2007) was an exception. Unusually dry conditions during 2007 resulted in the addition of nitrogen and phosphorus at the BMP site, which was likely due to the mineralization of resident phosphorus and nitrogen from soil and aquatic vegetation in the 170-m ditch section. Averaging all three BMP periods resulted in a net reduction in nitrogen and phosphorus. Average upstream and downstream TP loads were 295 and 264 kg, respectively (a 10 percent reduction). Average upstream (675 kg) and downstream (601 kg) TN loads showed an 11 percent reduction of nitrogen at the BMP site.

Wetland Water Retention

The effectiveness of this BMP at wetland 1 was evaluated using two years of pre-BMP (June 2005–May 2006, pre-BMP1; and June 2006–May 2007, pre-BMP2) and two years of post-BMP (June 2007–May 2008, post-BMP1; and June 2008–May 2009, post-BMP2) data. For wetland 4, one pre-BMP period was monitored (June 2005–May 2006) and three post-BMP periods were monitored (June 1, 2006–May 2007, June 2, 2007–May 2008, and June 3, 2008–May 2009).

At wetland 1, the TN and TP loads for post-BMP1 were less than those during the two pre-BMP periods. However, the reductions could not be attributed entirely to the BMP since record drought conditions resulted in low flow volume during post-BMP1 (June 2007–May 2008). These drought conditions most likely allowed an increase of mineralization of organic soil and plant material. Several consecutive rainfall events in July 2008 and Tropical Storm Fay in August 2008 resulted in large flows and phosphorus loads from the wetland. For post-BMP2 (June 2008–May 2009), TN and TP loads were almost double those of pre-BMP1. The average TN (304 kg) and TP (93 kg) loads for the two post-BMP periods were higher than the average TN (161 kg) and TP (47 kg) loads for the two pre-BMP periods. Because of the large rainfall variability, long-term data will be needed to evaluate this BMP at wetland 1.

For wetland 4, individual TN and TP loads during the three post-BMP periods were less than those during the pre-BMP period. Due to relatively low rainfall during post-BMP1 and post-BMP2, both flow volume and nutrient loads were less than those observed during the pre-BMP period. In contrast, the pre-BMP and post-BMP3 periods had similar rainfall and flow volumes allowing for a better comparison than the other two post-BMP periods. The post-BMP3 loads of nitrogen and phosphorus were lower than pre-BMP loads, indicating that this approach may have reduced both the flow volume and the TN and TP loadings.

TN and TP loads from the two wetlands were averaged together for pre- and post-BMP periods. Overall there was a 16 percent reduction in TN loads (pre-BMP, 214 kg; post-BMP, 180 kg) and 23 percent reduction in TP loadings (pre-BMP, 92 kg; post-BMP, 71 kg). However, due to large variability in pre- and post-BMP flow and rainfall, these results are not conclusive. This BMP affects flow as well as nutrient dynamics. Furthermore, wetland water retention changes the subsurface movement of water and nutrients. Collection of long-term flow and nutrient data is critical for evaluating this BMP. Monitoring and data collection are ongoing.

WATER QUALITY MONITORING IN THE WATERSHED

A comprehensive research and assessment program for water quality in the watershed is conducted by the SFWMD, in cooperation with the FDEP, FDACS, and USGS. The SFWMD monitors the inflows to Lake Okeechobee at the District-operated control structures and maintains an extensive water quality monitoring network in the Lake Okeechobee Watershed. This comprehensive monitoring program consists of several projects based on geographic location or basin hydrology (**Figure 10-12**). This network is continually reviewed for efficiency and to ensure all data objectives associated with the numerous legislatively mandated and permit required monitoring within the watershed are being met. The District's current monitoring network functions to collect data from three hydrologic levels within the LOWPP area through the use of several projects level initiatives:

1. Overall basin level monitoring for flow, TP, TN, and other parameters at 35 control structures discharging directly to Lake Okeechobee (loading stations).
2. Sub-basin or tributary monitoring at 35 stations for both TP and TN concentrations (ambient monitoring Taylor Creek/Nubbin Slough and Kissimmee basins), as well as 16 flow proportional tributary stations that provide real-time nutrient loadings in locations key to understanding nutrient transport and to evaluating trends over time as restoration projects come online within the Lake Okeechobee drainage basins (USGS loading stations); the upstream monitoring at LOWA monitoring network sites which are used as part of the Lake Okeechobee Watershed Regulatory Phosphorus Source Control Program.
3. Parcel or farm-level monitoring at 16 dairy stations for TP concentrations (see Chapter 4 of this volume).

The five-year average TP and TN data collected from ambient and USGS stations from WY2006–WY2010 are presented in **Table 10-10**. The District only calculates a TN value if both nitrate + nitrite (NO_x) and total Kjeldahl nitrogen (TKN) are listed. Several very high concentrations of TN were detected, but since these were paired with elevated levels of TP during times of increased flow, the values were deemed to be reasonable for the drainage areas and, therefore, included in the calculations.

Table 10-10. TP and TN data collected from the ambient and U.S. Geological Survey networks in the Lake Okeechobee Watershed from WY2006–WY2010.

BASIN	TOTAL PHOSPHORUS				TOTAL NITROGEN			
	Mean (ppb)	Median (ppb)	Standard Deviation	Number of Samples	Mean (ppb)	Median (ppb)	Standard Deviation	Number of Samples
C-41	242	160	210	135	2,286	1,959	1,113	139
C-41A	82	79	32	143	1,703	1,770	461	137
S-65A	77	68	42	235	1,340	1,240	388	232
S-65BC	92	77	46	223	1,343	1,240	331	223
S-65D	217	160	167	567	1,663	1,586	565	538
S-65E	424	253	464	141	2,217	2,089	780	145
Fisheating Creek	243	199	192	318	2,467	2,062	1,252	288
Lake Istokpoga	104	80	67	171	1,463	1,462	351	168
S-154	552	426	451	201	2,205	2,186	774	196
S-191	409	338	367	1,490	2,118	1,932	1,356	1,424

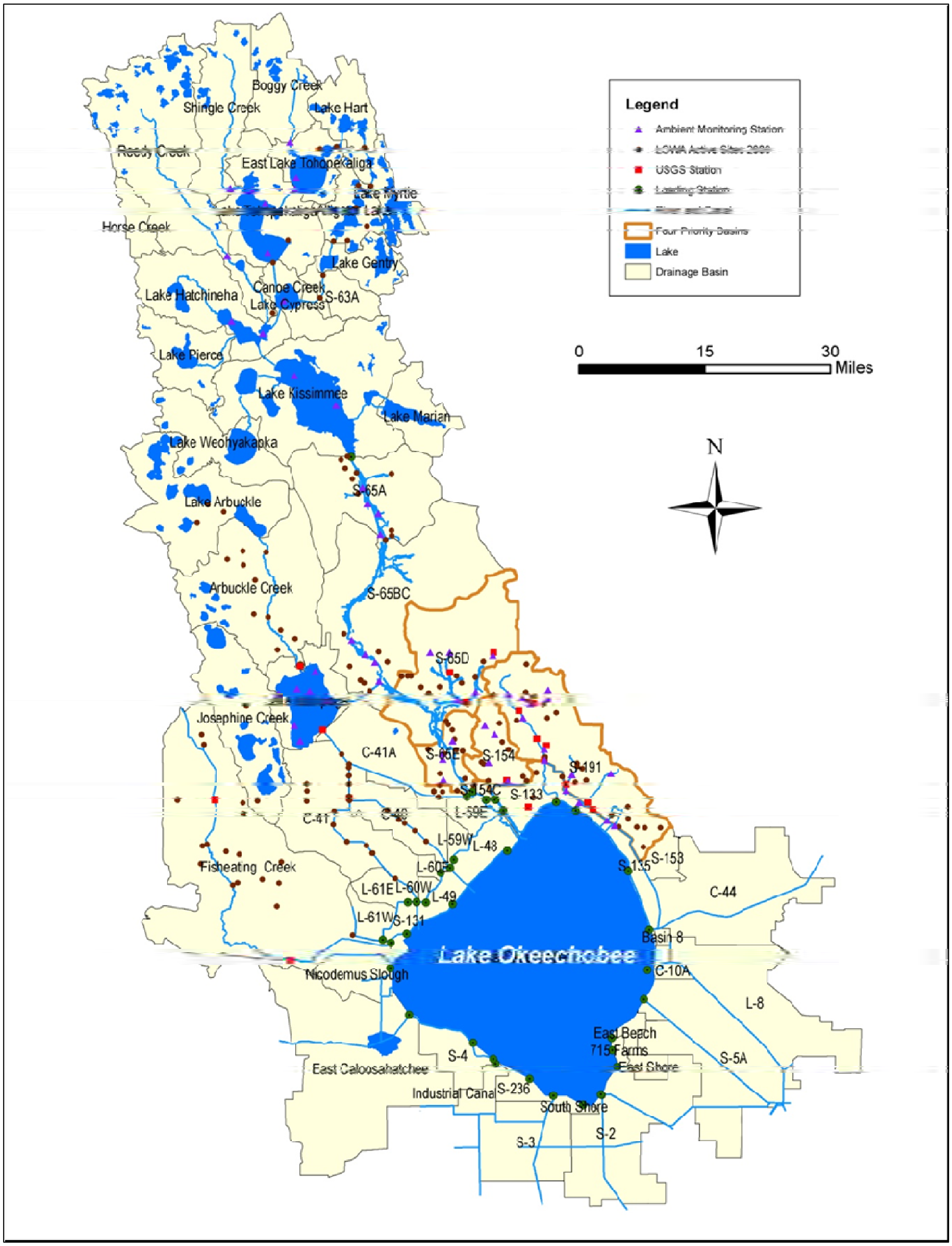


Figure 10-12. Locations of WY2010 sampling stations under various monitoring programs in the Lake Okeechobee Watershed.

Tributary Phosphorus Loading Trends

A Seasonal Kendall Tau test was used to determine statistical significance of mean monthly trends in flow, TP load, and FWM TP concentration during the period of record (POR) calendar years 2001–2009 for the nine sub-watersheds in the LOW (see **Figure 10-6**). The Seasonal Kendall Tau is a non-parametric test frequently used to detect trends for water quality time-series data. It is a rank-order statistic that can be applied to time-series data exhibiting seasonal cycles, missing and censored data, and indications of non-normality (Yu and Zou, 1993). When data are collected over time, significant autocorrelation may exist between data values. The Seasonal Kendall Tau provides an adjusted p-value for data that exhibit a significant level of dependence (Reckhow et al., 1992). For the purpose of determining statistical significance, an alpha (α) level of 0.05 was selected. Results indicating a statistically significant increase or decrease in flow, TP load, and TP concentration were present at the sub-watershed level.

Each sub-watershed consists of one or more drainage basins that ultimately flow into the lake through designated water control structures (**Figure 10-6**). The Seasonal Kendall Tau test requires monthly data inputs to determine an annual slope statistic (trend). Two sub-watersheds (Lower Kissimmee and Indian Prairie) included in this analysis do not have well-defined groundwater drainage boundaries and can be influenced over shorter data intervals (i.e., monthly) by seepage through structures and groundwater interactions. The program normally used to calculate annual loads for these two sub-watersheds involves subtracting out upstream sub-basins to get a more reliable overall annual flow value. Since this method could not be employed for this analysis when computing the monthly basin-level flow and TP load using structure measurements in these two sub-watersheds, monthly data represented by the S-65E structure for the Lower Kissimmee and S-70, S-71, and S-84 for Indian Prairie, respectively, were used. The Western Lake Okeechobee Sub-watershed is represented by inflows through the S-77 structure located at the interface of the Caloosahatchee River with Lake Okeechobee. This structure normally allows for flows out of the lake and only during periods of extreme drought or extreme, isolated rainfall events within the Caloosahatchee Basin (and the lake is at a low stage), does flow usually enter the lake through this structure. This infrequent level of flow to the lake was not sufficient to get mean monthly values to calculate a trend for the POR. (Annual loadings are presented for this sub-watershed in Chapter 4 of this volume.) The Western Lake Okeechobee Sub-watershed has therefore been excluded from the discussion.

The data for the POR were analyzed to determine trends for the following three parameters: flow (ac-ft), TP load (mt) and FWM TP concentration (µg/L) (**Table 10-11**). The monthly values, 12-month moving averages, and the Seasonal Kendall trend lines are presented in **Figures 10-13** through **10-15**. While the presence of significant trends (+ or -) provides the most valuable management tool for determining how a sub-watershed is reacting to regulatory or restoration measures, other statistics represented in **Table 10-11** can be used to predict likely trends and help focus resources on the most efficient ways to achieve water quality improvements for the LOW. For instance, the Sen slope indicates the change in annual concentration for a constituent which, taken into consideration with the p-value, can indicate if a sub-watershed is more likely to continue to follow its current direction in the next few years and if these changes will be significant. Sub-watersheds with highly negative or positive slopes where p-values are close to 0.05, though not showing a statistically significant trend, could still be targeted for in-depth investigations to help evaluate success stories or identify areas where more intense nutrient control measures need to be implemented.

A total of three of the eight sub-watersheds analyzed revealed significant trends for at least one parameter (**Table 10-11**). The Taylor Creek/Nubbin Slough Sub-watershed showed a decreasing trend in flow and for TP loads. A closer look at the other statistics relating to this sub-watershed reveals that the Sen slope for TP concentration (-6.00) shows negatively trending values even though they are not statistically significant. This may be a reflection of the sub-watershed having the largest BMP implementation rate so far and the completion of many TP source control projects.

The Lake Istokpoga Sub-watershed exhibited significant decreasing trends for flow and TP load (**Table 10-13**, **Figure 10-14**, and **Figure 10-15**). However, TP concentrations had a positive Sen slope (**Table 10-11**). The Indian Prairie Sub-watershed displayed a significant decreasing trend for flow. Again, a positive Sen slope for TP concentrations was found. For the remaining five sub-watersheds, no significant trends were found for the three parameters. Concentrations for TP at two sub-watersheds (Fisheating Creek and Eastern Lake Okeechobee) showed a negative Sen slope.

Although BMPs have been initiated to a certain degree, there is still a large percentage of the watershed that needs dedicated resources in order to realize the full level of BMP implementation needed for nutrient reductions. The high levels of legacy phosphorus in the soils play a role in the delayed response of the watershed to show TP concentration reductions. In summary, more aggressive nutrient control measures still need to be implemented in all the surrounding basins that discharge to the lake in order to reach the lake’s TMDL goal of 140 mt of phosphorus per year (FDEP, 2001). In order to assess the success or deficiencies of restoration efforts in the LOW, continued evaluation of these sub-watersheds for statistically significant trends is critical. Statistical evaluations need many continuous years of data to determine long-term trends. The highly variable nature of the data from these sub-watersheds — and the influence of storm events on those data — make continuous evaluations a critical management tool. Evaluations that show no significant trends over several years can also be useful in helping to determine if the system has stabilized and what measures need to be taken if the stabilized state is still not meeting target water quality goals.

Table 10-11. Seasonal Kendall Tau trend analyses of flow and TP (bold, italic fonts indicate significant changes).

Sub-Watershed	Parameter (unit)	Number of Samples (Total / NA / Zero Values)[2]	Kendall's Tau	Sen Slope	Intercept	p-Value	Significant Trend
Upper Kissimmee (S-65)	Flow (ac-ft)	108 / 0 / 12	-0.081	-1,526	43,108	0.67	No
	TP (mt)	108 / 0 / 12	-0.060	-0.10	4.29	0.45	No
	TP FWM concentration (µg/L)	108 / 12 / 0	0.106	1.00	71.5	0.22	No
Lower Kissimmee (S-65E)	Flow (ac-ft)	108 / 0 / 10	-0.120	-5,554	81,473	0.52	No
	TP (mt)	108 / 0 / 10	-0.130	-0.48	7.58	0.46	No
	TP FWM concentration (µg/L)	108 / 10 / 0	0.039	0.42	67.9	0.73	No
Lake Istokpoga (S-68)	***Flow (ac-ft)***	***108 / 0 / 8***	***-0.266***	***-1,972***	***23,658***	***<0.001***	***Yes***
	TP (mt)	***108 / 0 / 8***	***-0.188***	***-0.11***	***1.77***	***0.02***	***Yes***
	TP FWM concentration (µg/L)	108 / 8 / 0	0.046	0.75	70.3	0.59	No
Indian Prairie[1]	***Flow (ac-ft)***	***108 / 0 / 1***	***-0.194***	***-1,357***	***25,717***	***0.01***	***Yes***
	TP (mt)	108 / 0 / 1	-0.148	-0.14	3.71	0.06	No
	TP FWM concentration (µg/L)	108 / 1 / 0	0.127	4.25	150	0.11	No
Fisheating Creek	Flow (ac-ft)	108 / 0 / 0	-0.139	-531	11,901	0.08	No
	TP (mt)	108 / 0 / 0	-0.100	-0.065	1.72	0.21	No
	TP FWM concentration (µg/L)	108 / 0 / 0	-0.118	-3.63	149	0.13	No
Taylor Creek/Nubbin Slough	***Flow (ac-ft)***	***108 / 0 / 17***	***-0.197***	***-282***	***4,184***	***0.01***	***Yes***
	TP (mt)	***108 / 0 / 17***	***-0.222***	***-0.11***	***1.47***	***0.004***	***Yes***
	TP FWM concentration (µg/L)	108 / 17 / 0	-0.117	-6.00	379	0.23	No
Southern Lake Okeechobee	Flow (ac-ft)	108 / 0 / 3	-0.241	-271	3,955	0.07	No
	TP (mt)	108 / 0 / 3	-0.162	-0.04	0.62	0.18	No
	TP FWM concentration (µg/L)	108 / 3 / 0	0.208	7.49	120	0.17	No
Eastern Lake Okeechobee (S-308C)	Flow (ac-ft)	108 / 0 / 20	0.132	93.9	1,304	0.47	No
	TP (mt)	108 / 0 / 20	0.086	0.01	0.26	0.63	No
	TP FWM concentration (µg/L)	108 / 20 / 0	-0.131	-8.00	213	0.37	No
Western Lake Okeechobee	Flow (ac-ft)	108 / 0 / 80	Insufficient data to perform trend analysis				
	TP (mt)	108 / 0 / 80					
	TP FWM concentration (µg/L)	108 / 80 / 0					

[1] Structures used to calculated Indian Prairie sub-watershed flows, loads and flow-weighted means: L-59W, L-60E, L-60W, S-127, S-129, S-131, L-59E, S-71, S-72, and S-84

[2] NA - not available due to zero values of flow and load

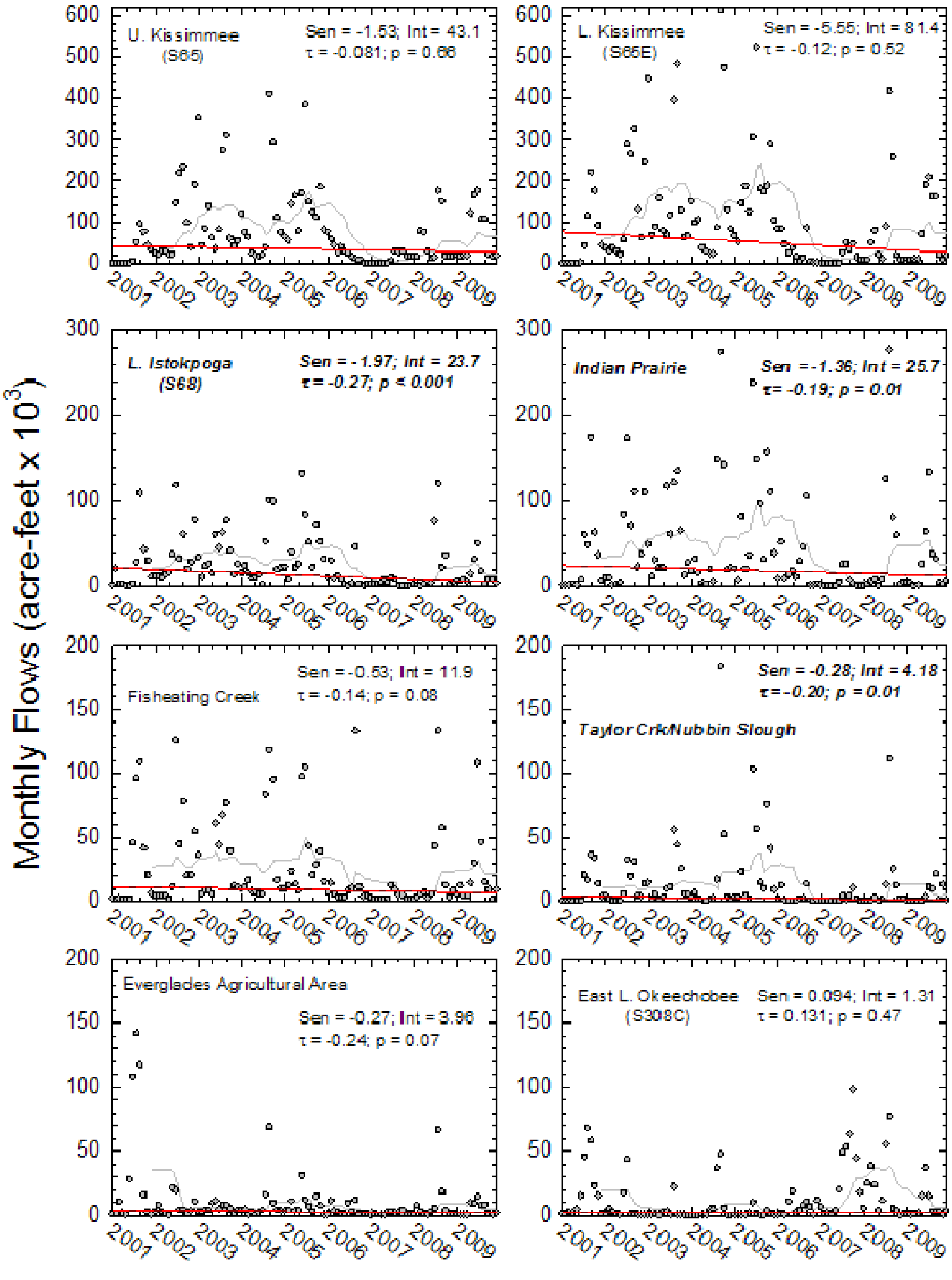


Figure 10-13. Monthly sub-watershed flows for the period of record (POR) January 2001 through December 2009. Gray dots represent monthly values, gray line presents 12-month moving average, and red line represents Seasonal Kendall Tau trend line. Bolded and italicized results indicate statistically significant changes.

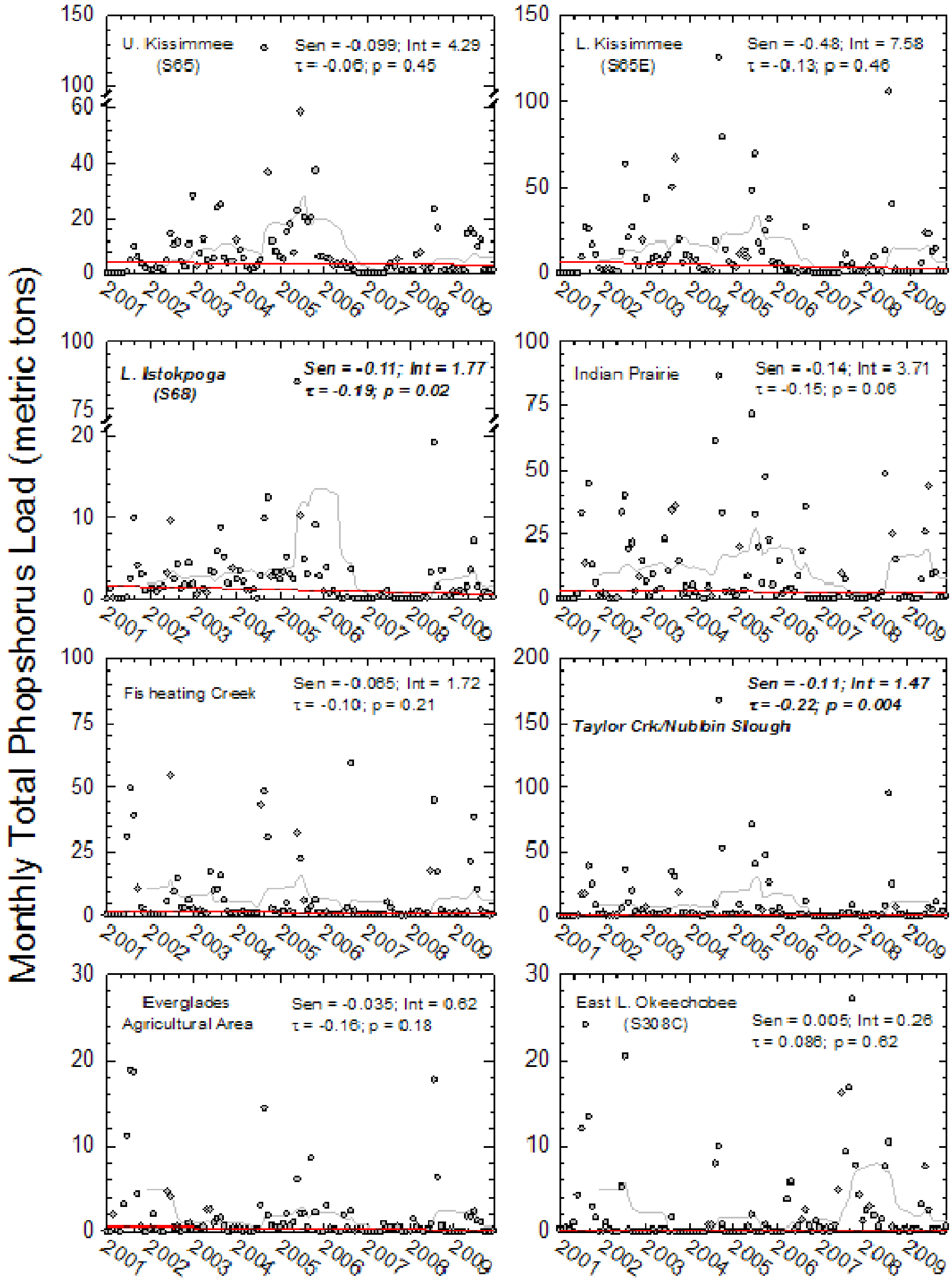


Figure 10-14. Monthly sub-watershed TP loads for the 2001–2009 POR. Gray dots represent monthly values, gray line presents 12-month moving average, and red line represents Seasonal Kendall Tau trend line. Bolded and italicized results indicate statistically significant changes.

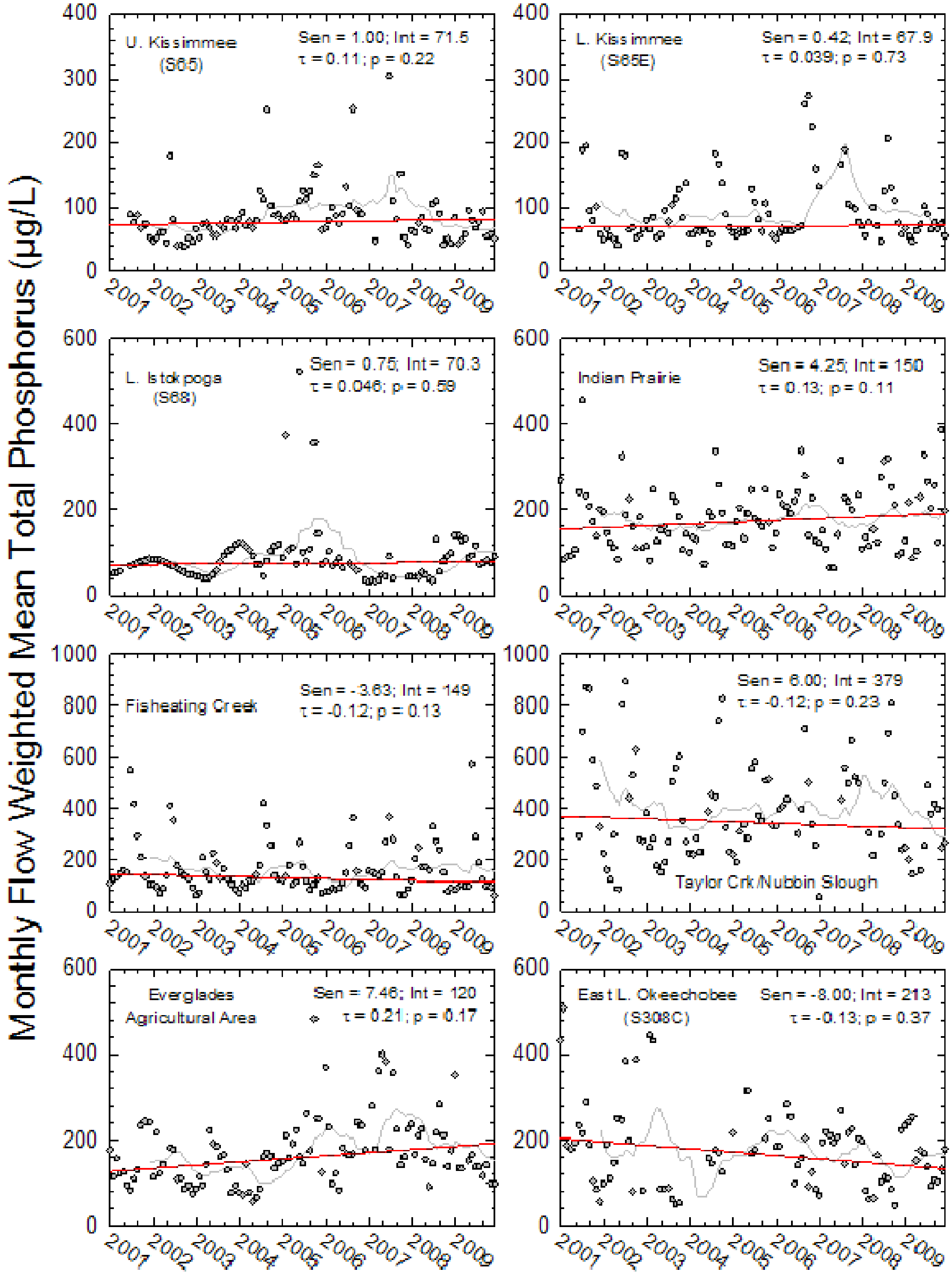


Figure 10-15. Monthly sub-watershed TP FWM concentrations for the POR from January 2001 through December 2009. Gray dots represent monthly values, gray line presents 12-month moving average, and red line represents Seasonal Kendall Tau trend line. Bolded and italicized results indicate significant changes.

LAKE STATUS

PERFORMANCE MEASURES

Measurements of TP, chlorophyll *a*, phytoplankton, submerged aquatic vegetation (SAV), and water levels have been adopted as quantitative performance measures for the lake (Section 373.4595, F.S.). These measures describe the status of the ecosystem and its responses to implemented restoration programs. Measures are five-year averages, which ensure consistency with TMDL reporting, reduce year-to-year variation due to climate and hydrology, and improve understanding of underlying trends. These values are compared to quantitative restoration goals (**Table 10-12**). The TP load is the only goal that is to be met by a set date, 2015, as specified in FDEP (2001). The Lake Okeechobee Protection Program Report provides a technical foundation for these restoration goals (SFWMD et al., 2004). The WY2010 averaged observations document water quality and lake level conditions.

Of the 11 performance measures given as current five-year (WY2006–WY2010) averages, two met their goal: the diatom-to-cyanobacteria ratio was 3.6 and algal bloom conditions were found in only 4.3 percent of the samples (**Table 10-12**). Lowered algal blooms could be attributed primarily to the increased turbidity and reduced light climate of water since the hurricanes of 2004 and 2005 (James et al., 2008). In contrast to the five-year average, algal blooms were found in 11 percent of the samples in WY2010, which may reflect reduced turbidity and improved light climate for the water year.

The WY2006–WY2010 TP load was 496 mt/yr, which is a decrease from 578 mt for the previous five-year period of WY2005–WY2009 (**Table 10-12**). The current five-year average is lower because the high loads from WY2005 (967 mt, **Table 10-13**), which resulted from the hurricanes of that year, are no longer included (see the *Nutrient Budgets* section of this chapter). The current five-year average is three-and-a-half times higher than the 140 mt/year TMDL considered necessary to achieve the in-lake TP goal of 40 ppb.

The TN load averaged 6,128 mt/yr for the WY2006–WY2010 period, while the WY2010 load was 6,325 mt/yr, similar to the previous water year. There is no in-lake goal for TN; however, a tributary TMDL for nitrogen has been proposed (USEPA, 2008).

The concentrations of nutrients in the lake have continued to decline, as have the ratios of these nutrients. Both TP and TN declined from 162 ppb and 1.76 ppm, respectively, in WY2009 to 118 ppb and 1.48 ppm, respectively, in WY2010. The larger decline in TP (27 percent) relative to TN (15 percent) led to an increase of the TN-to-TP ratio (by weight) from 12:1 in WY2009 to 12.5:1 in WY2010. The five-year average of water year ratios also increased from the WY2005–WY2009 period of 10:1 to the current five-year period of 10.7:1.

Nearshore TP decreased from 97 ppb in WY2009 to 57 ppb in WY2010, resulting in a decrease of the five-year average from 119 ppb (WY2005–WY2009) to 104 ppb (WY2006–WY2010). This decrease may partially be attributed to increased SAV that has absorbed the nutrients and reduced the resuspension of sediments.

Water clarity in the nearshore region during the annual wet season (June–October) periods for WY2006–WY2010 increased, with the Secchi disk being visible on the bottom of the water column in 48 percent of the observations (**Table 10-12**). In WY2010, over 67 percent of the Secchi disk measurements were visible on the bottom of the water column. This was likely a result of reduced resuspended sediments because of an increase in SAV coverage in WY2010.

SAV increased to the second-largest abundance (46,418 acres) recorded from August mapping surveys conducted annually since 2000. In 2009, the vascular plant coverage increased to 30,171 acres. Both the total SAV and vascular SAV abundances exceeded the annual goals for SAV abundance. Overall, these performance measures indicate that the lake environment improved in WY2010.

Table 10-12. Summary of Lake Okeechobee rehabilitation performance measures, rehabilitation program goals, and lake conditions. Unless otherwise indicated, conditions for WY2010 are listed with five-year annual averages (WY2006–WY2010), as specified in the Restoration Assessment Plan of the Lake Okeechobee Protection Program.

Performance Measure	Goal	Five-Year Average	WY2010
Total Phosphorus (TP) load	140 mt/yr (to be met by 2015)	496 mt/yr	478 mt/yr
Nitrogen load	N/A	5,477 mt/yr	6,347 mt/yr
Pelagic TP	40 ppb	172 ppb	118 ppb
Pelagic TN	N/A	1.62 ppm	1.48 ppm
Pelagic SRP	N/A	60 ppb	42 ppb
Pelagic DIN	N/A	263 ppb	201 ppb
Pelagic TN:TP[a]	> 22:1	10.7:1	12.5:1
Pelagic DIN:SRP[a]	> 10:1	4.4:1	5.2:1
Plankton nutrient limitation	Phosphorus >Nitrogen	Nitrogen >>> Phosphorus	Nitrogen >>> Phosphorus
Diatoms:cyanobacteria ratio[b]	> 1.5	3.6	N/A
Algal bloom frequency	< 5% of pelagic chlorophyll *a* exceeding 40 µg/L	4.3%	11.0%
Water clarity	Secchi disk visible on Lake bottom at all nearshore SAV sampling locations from May–Sep	41.0%	53.0%
Nearshore TP	Below 40 ppb	104 ppb	57 ppb
Submerged aquatic vegetation (SAV) [c]	Total SAV > 40,000 acres	24,854 acres total	46,418 ac total
	Vascular SAV > 20,000 acres	9,821 acres vascular	30,171 acres vascular
Extremes in low lake stage (current water year)	Maintain stages above 10 ft	N/A	Goal attained
Extremes in high lake stage (current water year)	Maintain stages below 17 ft; stage not exceeding 15 ft for more than 4 months	N/A	Goal attained
Spring recession (January to June 2007)	Stage recession from near 15.5 ft in January to near 12.5 ft in June	N/A	Goal not attained

[a] By weight
[b] Mean values from June 2004 to April 2009
[c] Mean yearly acreages (from August 2005–2009 maps)
N/A – Evaluated for current water year only
SRP – soluble reactive phosphorus; DIN – dissolved inorganic nitrogen

HYDROLOGY

Flows to Lake Okeechobee have varied tremendously in the past 10 years; from highs of over 3 million ac-ft from WY2003–WY2006 to flows of less than 1 million ac-ft in 2001, 2007, and 2008 (**Figure 10-16**). In WY2010, the flow was over 2.4 million ac-ft or 2,960 million m^3. For all years, flows are primarily from the north with a majority discharging to the lake through the S-65E structure (the Kissimmee River) (see Chapters 2 and 11 of this volume for details on the hydrology of South Florida and the Kissimmee Basin, respectively). Fisheating Creek (FEC) is also a major contributor of flow to the lake. Flow has been measured on this creek at Palmdale since the early 1970s (DBKEY 15627, Lat. 26557, Long. 811853). In May 1997, the USGS began monitoring flow downstream near Lakeport (DBKEY WHO36, Lat. 265744, Long. 810705). The average flow at Lakeport is 44 percent higher than at Palmdale. Using Lakeport instead of Palmdale measurements increases the total estimated flow to Lake Okeechobee by 3 percent. Because water quality data also are obtained at Lakeport, loads from FEC now have been based on this flow since WY2001. As a result, load estimates are also increased by about 3 percent.

Regulatory releases of water from the lake occur primarily through S-77 to the Caloosahatchee River and S-308C to the St. Lucie River (**Figure 10-17**; see also Chapter 12 of this volume). Flow is also sent to the south for irrigation in the Everglades Agricultural Area (EAA) and as backup water supply to the Lower East Coast. During the drought of 2007–2008, flow to the south was the major discharge from the lake. Regulatory releases remained low in 2009 and 2010 as water levels in the lake remained low (**Figure 10-18**). Beginning in May 2008, changes were made to the stage regulation schedule used to manage regulatory releases from the lake (USACE, 2007). This new schedule includes plans to deal with drought as well as high rainfall and water flow events (USACE, 2008). These plans are designed to maintain water levels from 12.5 through 15.5 ft NGVD.

In May 2009, water levels were below the water supply-side management schedule (**Figure 10-18**). Water levels then increased, reaching near average values (14.5 ft NGVD) by October 2009. The increase is attributed to the gradual increase of inflow over the first few months of the water year (**Figure 10-19**). Higher inflows in the summer wet season were followed by low flows from October through January during the winter dry season. Inflows increased again from February through April 2010.

For WY2010, discharges to the south (EAA) were highest in May, November, and October. A number of separate base-flow releases were implemented in November 2009 and January and February 2010 to maintain chloride concentrations in the Caloosahatchee Estuary at nominal levels. Regulatory pulse releases were begun in March 2010 and continued through April with only 12 days without flow. These releases were to offset the higher March and April 2010 inflows to the lake in an effort to maintain lower water levels at the start of the wet season (**Figure 10-18**).

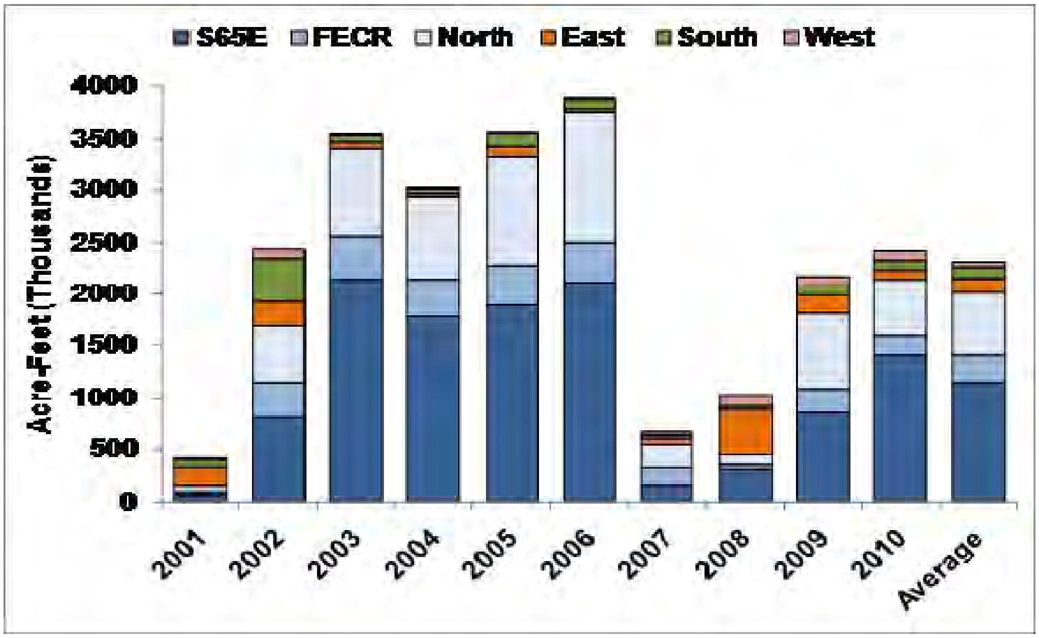


Figure 10-16. Lake Okeechobee inflow measurements in the past 10 water years. S-65E – Kissimmee River, FEC - Fisheating Creek, North – other northern inflows, East – S-308 and L-8, South – Everglades Agricultural Area (EAA), West – S-77 and Culvert 5.

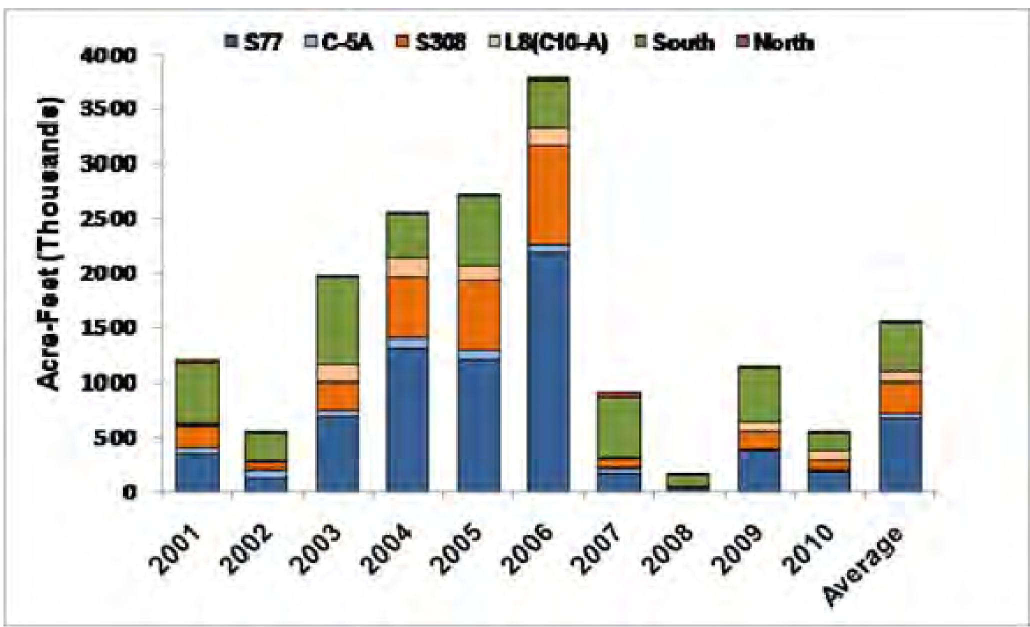


Figure 10-17. Lake Okeechobee discharge measurements in the past 10 water years. S77 – Caloosahatchee, C-5A – Culvert 5A, S308 – St. Lucie, L8 – L8 canal, South – EAA discharges, North – Indian Prairie.

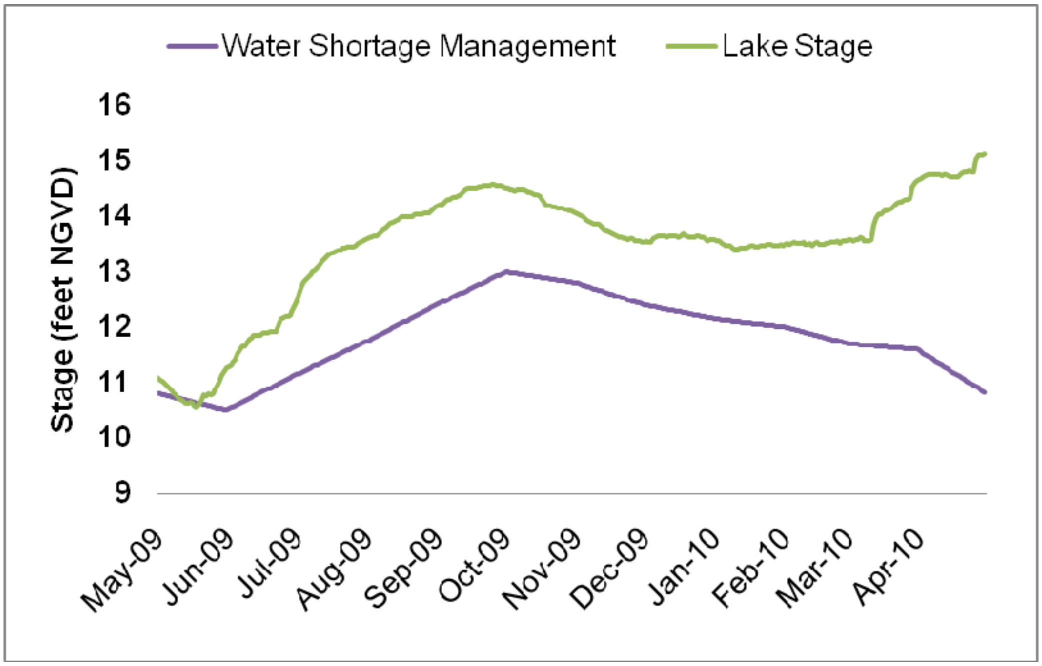


Figure 10-18. Lake Okeechobee stage (green) and supply-side management trigger line (purple) for WY2010.

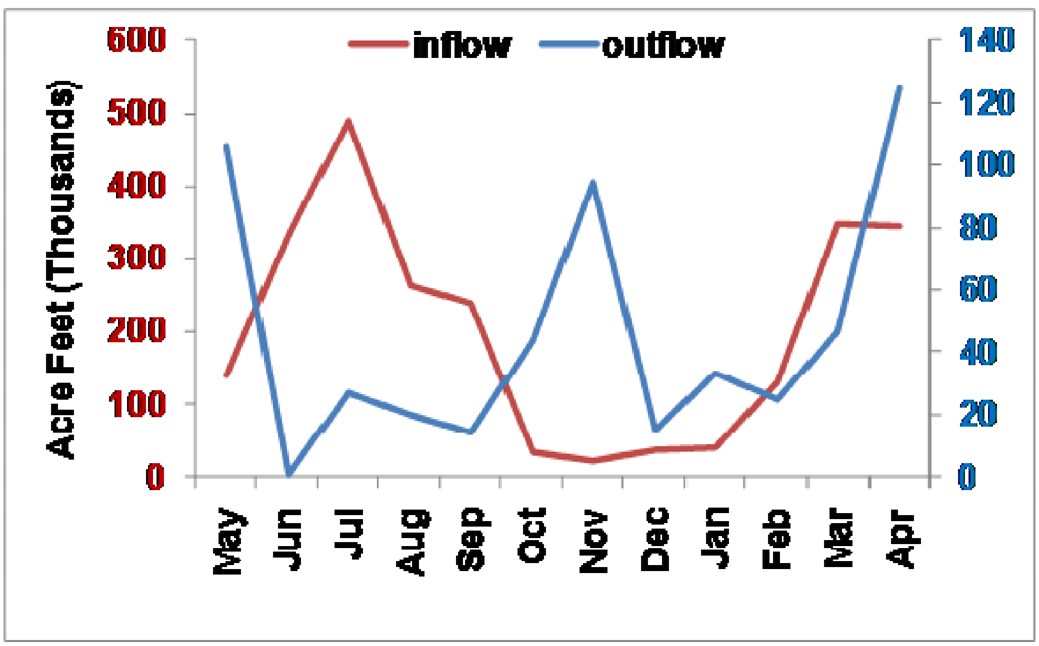


Figure 10-19. Surface water inflow and outflow for Lake Okeechobee in WY2010.

NUTRIENT BUDGETS

TP loads to the lake from tributaries and atmospheric deposition (estimated as 35 mt/yr by the FDEP, 2001) totaled 478 mt in WY2010 (**Table 10-13** and **Figure 10-20**). This was a decrease from the previous year and was primarily due to reduced inflow concentration (**Figure 10-21**). Mean lake TP mass in WY2010 also was less than the previous water year due to lower water column concentrations (**Table 10-13** and **Figure 10-21**). Net change in lake content was positive and was attributed to the increase of water volume over the course of WY2010 (**Figure 10-18**). Loads out of the lake were less than WY2009 as discharge was less (**Figure 10-17**). The net load (inputs minus outputs) in WY2010 was similar to WY2009 (**Table 10-13**). However, the sediment accumulation was lower as more of the net load accumulated in the water column. The lower sediment accumulation resulted in a lower net sedimentation coefficient (sediment accumulation/mean lake TP mass).

Phosphorus concentrations in the lake water column have declined each year after reaching a maximum yearly average value of 233 ppb in 2005 (**Figure 10-21**). In WY2010, the average value was down to 120 ppb, similar to pre-hurricane values (before WY2005). This drop in TP concentrations can be attributed to increased SAV abundance, reduced inflow TP concentration, improved light conditions, and reduced suspended solids as sediments have reconsolidated.

The net sedimentation coefficient, σ_y (per year), of the phosphorus budget is the amount of TP that accumulates in the sediment per year divided by the average lake water TP mass (**Table 10-13** and **Figure 10-22**). A low σ_y indicates that the lake absorbs less excess TP loads from the watershed. For WY2010, the σ_y value was 0.22 per year (**Table 10-13**), which is below the 10-year average value of 0.44 per year. The WY2010 value is similar to values estimated in recent years and indicates low absorption of phosphorus by sediments. Over the past four decades σ_y declined from around 2.5 in the 1970s to below 1 in the 1990s (**Figure 10-22**; James et al., 1995; Janus et al., 1990; Havens and James, 2005).

Table 10-13. Phosphorus budget (mt) Lake Okeechobee for the most recent 10 water years.

Water Year	Mean Lake TP Mass	Net Change in Lake Content[a]	Load (mt) In[b]	Load (mt) Out	Net (mt) Load[c]	Sediment Accumulation[d]	Net Sedimentation Coefficient (σ_y)
2001	383	-320	131	206	-75	245	0.64
2002	425	264	635	81	554	291	0.68
2003	594	143	655	317	338	195	0.33
2004	578	113	558	302	256	143	0.25
2005	1,108	270	967	582	384	114	0.10
2006	1,104	-194	825	798	27	221	0.20
2007	593	-269	243	176	67	336	0.57
2008	462	132	249	26	223	91	0.20
2009	602	-276	685	242	443	720	1.20
2010	490	291	478	77	401	110	0.22
Average	**634**	**15**	**543**	**281**	**262**	**247**	**0.44**

[a] Net change from the start (May 1) through the end (April 30) of each water year
[b] Includes 35 mt/yr to account for atmospheric deposition (FDEP, 2001)
[c] Difference between load in and load out
[d] Difference between net change in lake content and net load (positive value is accumulation in sediments)

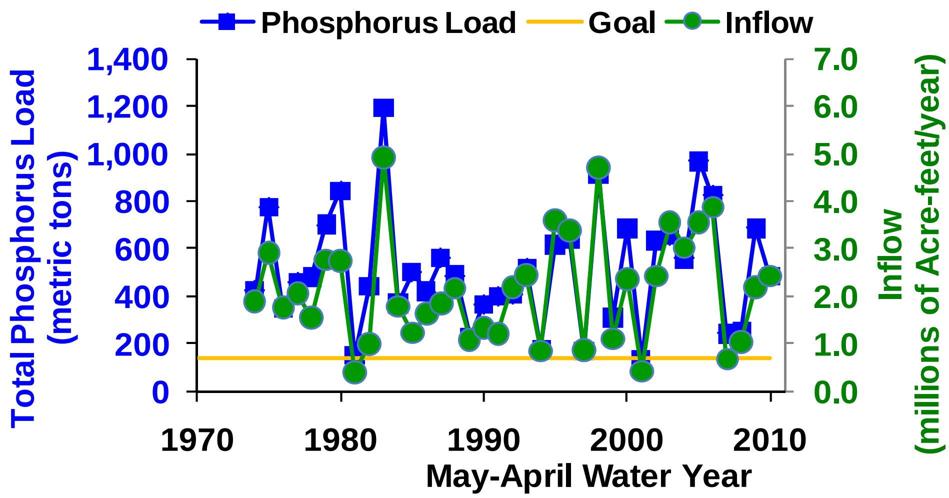


Figure 10-20. Timelines of water year phosphorus load and inflow entering Lake Okeechobee from its tributaries calculated from the phosphorus budget of the lake.

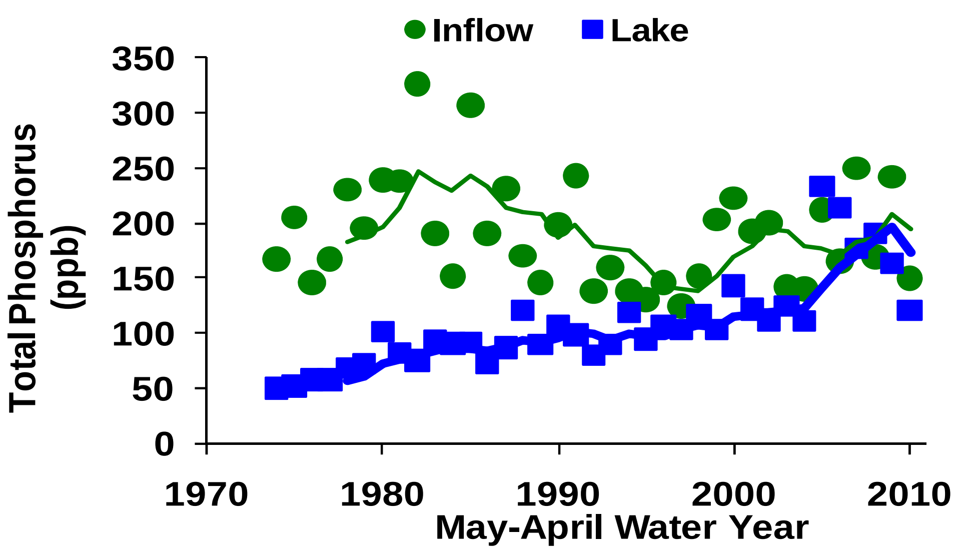


Figure 10-21. Timelines of inflow and lake average TP concentrations (five-year moving average trend lines calculated from the phosphorus budget of Lake Okeechobee).

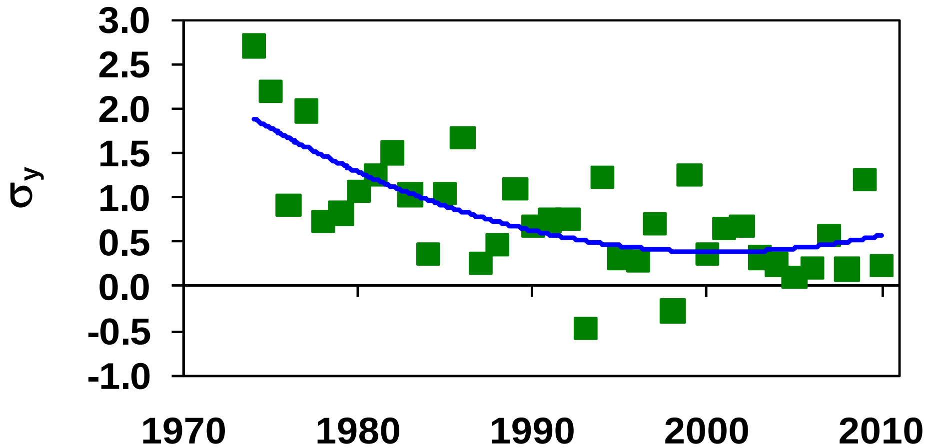


Figure 10-22. Timeline in water years of the net sedimentation coefficient (σ_y) calculated from the WY2009 phosphorus budget of Lake Okeechobee. (Trend line is a second-order polynomial.)

Loads of nitrogen to the lake are approximately tenfold greater than phosphorus (**Table 10-14**). Annual loads also are closely related to the hydrology of the lake, fluctuating between 2,500 and 14,000 mt/year (**Figure 10-23**). Discharge loads from the lake are approximately half of the inflow loads (**Table 10-14**). Despite this difference between loads into and out of the lake, concentrations of nitrogen in the lake have been relatively stable since the 1980s (**Figure 10-24**). Inflow concentrations tend to be higher than either in-lake or outflow concentrations while outflow concentrations tend to be slightly higher than in-lake concentrations. This is probably a result of the intra-annual variability of nitrogen in the lake, with higher levels in winter than in summer (Maceina and Soballe, 1990), and increased discharge of water in the late winter and spring.

Table 10-14. Nitrogen budget (mt) for Lake Okeechobee for the most recent 10 water years.

May 1–April 30 Water Year	Mean Lake TN Mass	Net Change in Lake Content[a]	Load (mt) In[b]	Load (mt) Out	Net (mt) Load[c]	Lake Adsorption[d]	Net Adsorption Coefficient (σ_y)
2001	5,114	-3,173	2,509	3,296	-787	2,386	0.47
2002	5,921	2,643	7,826	1,213	6,613	3,970	0.67
2003	7,630	1,426	8,279	4,165	4,115	2,689	0.35
2004	6,924	-208	6,526	4,642	1,884	2,092	0.30
2005	10,023	2,588	8,775	6,609	2,166	-422	-0.04
2006	9,389	-2,692	7,992	8,048	-56	2,636	0.28
2007	4,873	-3,460	2,965	2,023	942	4,402	0.90
2008	3,772	2,128	3,393	392	3,001	873	0.23
2009	6,566	-1,075	6,689	2,841	3,848	4,923	0.75
2010	6,659	2,735	6,325	1,106	5,219	2,484	0.37
Average	**6,687**	**91**	**6,128**	**3,434**	**2,694**	**2,603**	**0.43**

[a] Net change from the start (May 1) through the end (April 30) of each water year
[b] Includes 1,233 mt/yr to account for atmospheric deposition (James et al., 2005)
[c] Difference between load in and load out

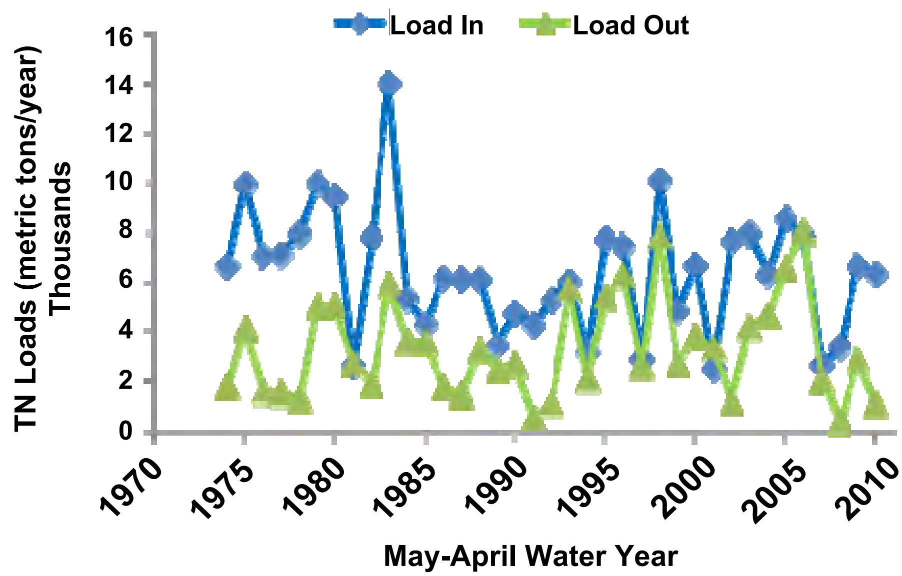


Figure 10-23. Timeline of water year inflow and outflow nitrogen load to and from Lake Okeechobee calculated from the nitrogen budget of the lake.

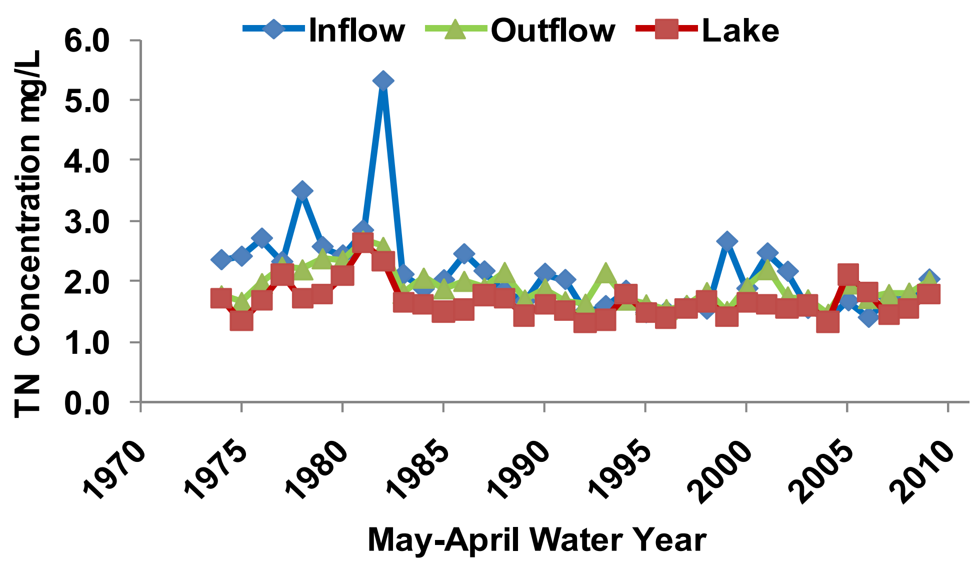


Figure 10-24. Timelines of inflow, outflow, and lake average TN concentrations calculated from the nitrogen budget of Lake Okeechobee.

PESTICIDES

Pesticide information on Lake Okeechobee can be found in quarterly reports on the District's website at www.sfwmd.gov (see the *Library and Multimedia* tab). Current water year data are included in Volume III, Appendix 4-1.

LAKE MONITORING AND RESEARCH

SUBMERGED AQUATIC VEGETATION

Monitoring

SAV abundance is a key indicator of the lake's overall ecological health. SAV biomass is measured monthly at stations located along 16 fixed transects encompassing the lake's north, south and west shoreline. This covers a region where SAV beds historically have occurred. Triplicate samples are collected at sites along each transect, starting at the shoreline and progressing lake-ward until a site is reached with no plants. Plants are sampled using a tool constructed of two standard garden rakes bolted together at the midpoint to create a tong-like device. The degree of opening is constrained by placing a chain between the two handles, such that three replicate samplings with the device removes ~1 square meter (m^2) of bottom cover. The harvested material is sorted by species, stripped of epiphyton, dried, weighed, and dry mass [grams dry weight per m^2 (g dry wt/m^2)] is calculated for each site. Values from all sites that were visited (including zeros) are averaged together to obtain the monthly average biomass estimate. Biomass estimates show that SAV in Lake Okeechobee continues to recover from hurricanes that occurred in 2004 and 2005, the drought that lasted from WY2007–WY2009, and the suddenly increased lake level caused by Tropical Storm Fay (McCormick et al., 2010). As lake levels returned to near-average conditions in 2009 (**Figure 10-18**), SAV biomass gradually increased from less than 5 g dry wt/m^2 before January 2009 to a peak of 50.61 g dry wt/m^2 in October 2009 (**Figure 10-25**).

Areal coverage of SAV is measured each year in August. This coverage increased to 46,418 acres [18,785 hectares (ha)], close to the 2004 pre-hurricane levels (**Figure 10-26**). Much of the initial increase was due to the growth of muskgrass (*Chara* sp.), a non-vascular macroalga with a competitive advantage under low light conditions. Moderate to dense beds of vascular species, including eelgrass (*Vallisneria americana*), coontail (*Ceratophyllum* sp.), southern naiad (*Najas guadalupensis*), and the exotic hydrilla (*Hydrilla verticillata*), currently dominate the northern and western shorelines (**Figure 10-27**). These vascular species provide better foraging areas and protection for young fish than do non-vascular species. The vascular plants account for almost 65 percent of the total SAV (**Figure 10-28**). The current SAV coverage meets the restoration goal of > 40,000 acres of total SAV with at least half being comprised of vascular species (**Table 10-12**).

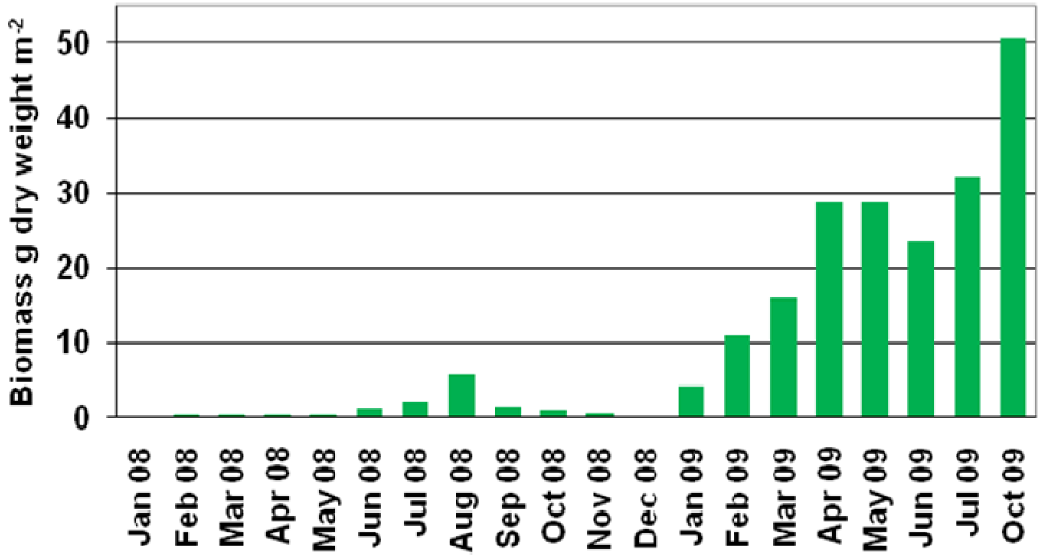


Figure 10-25. Monthly average submerged aquatic vegetation (SAV) biomass from transect sampling from 2008–2009.

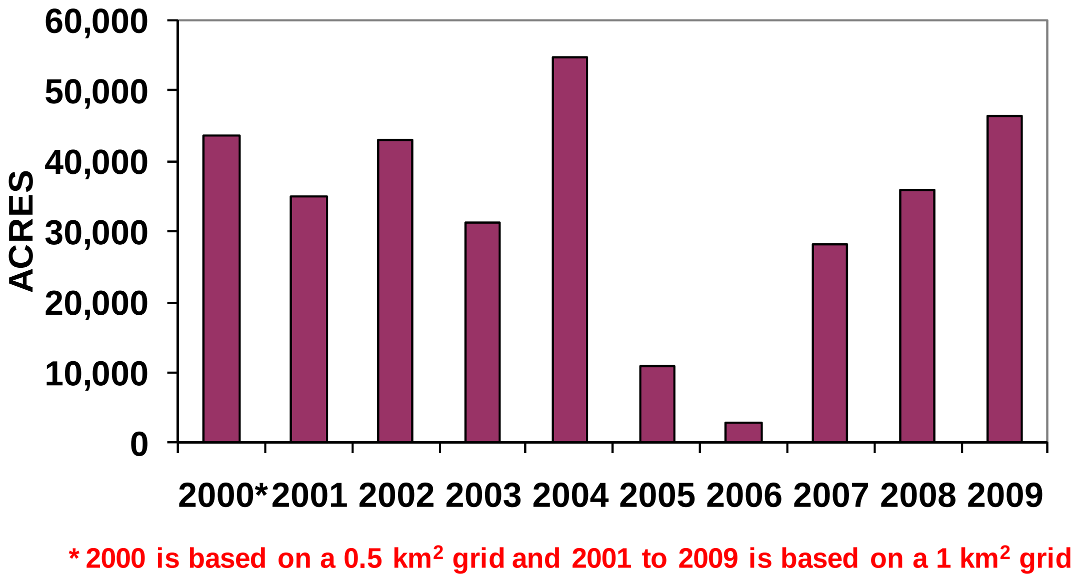


Figure 10-26. Acres of total of SAV (vascular and non-vascular species) measured from the annual August SAV mapping results from 2000–2009.

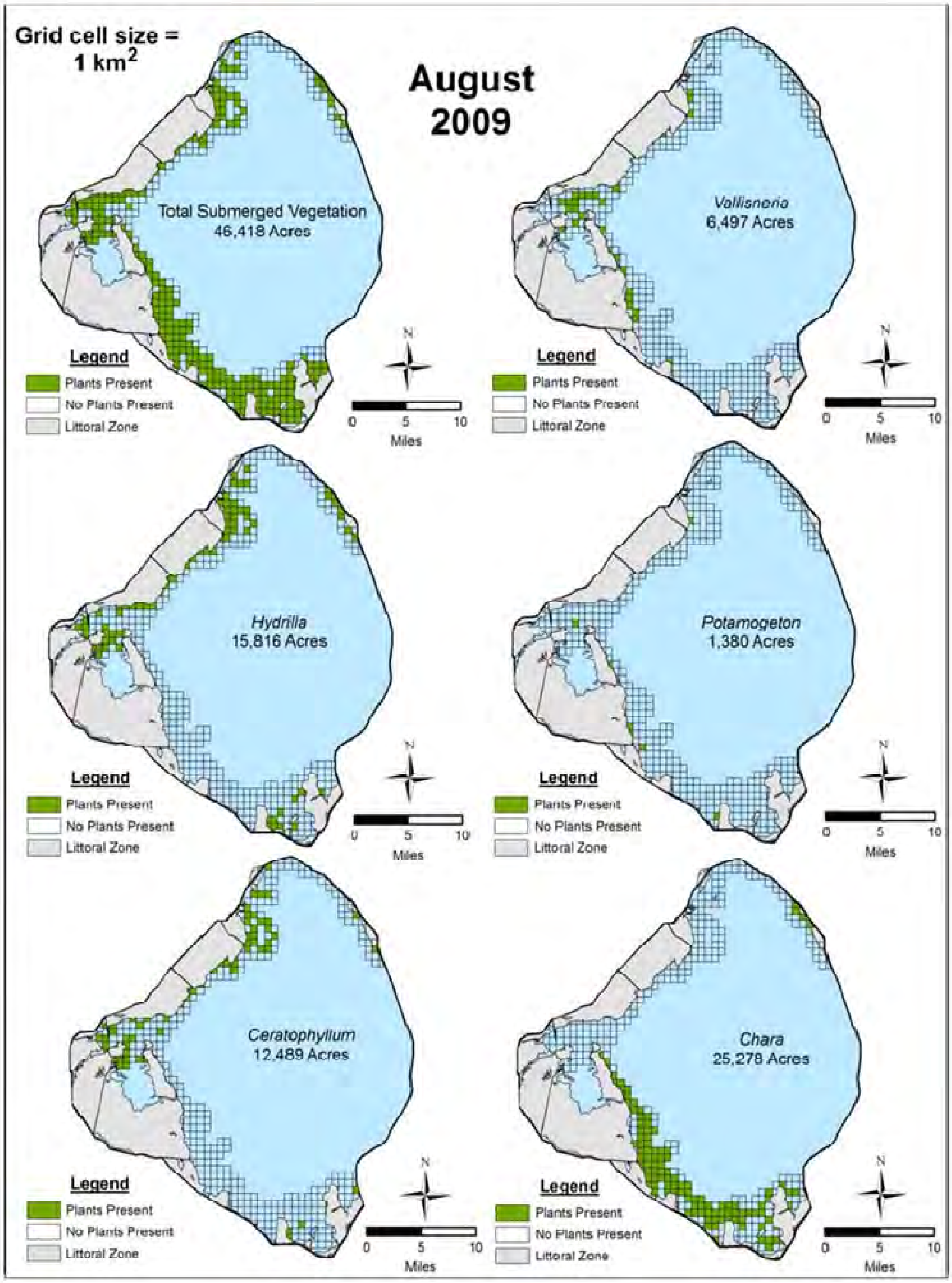


Figure 10-27. Annual SAV mapping results for 2009.

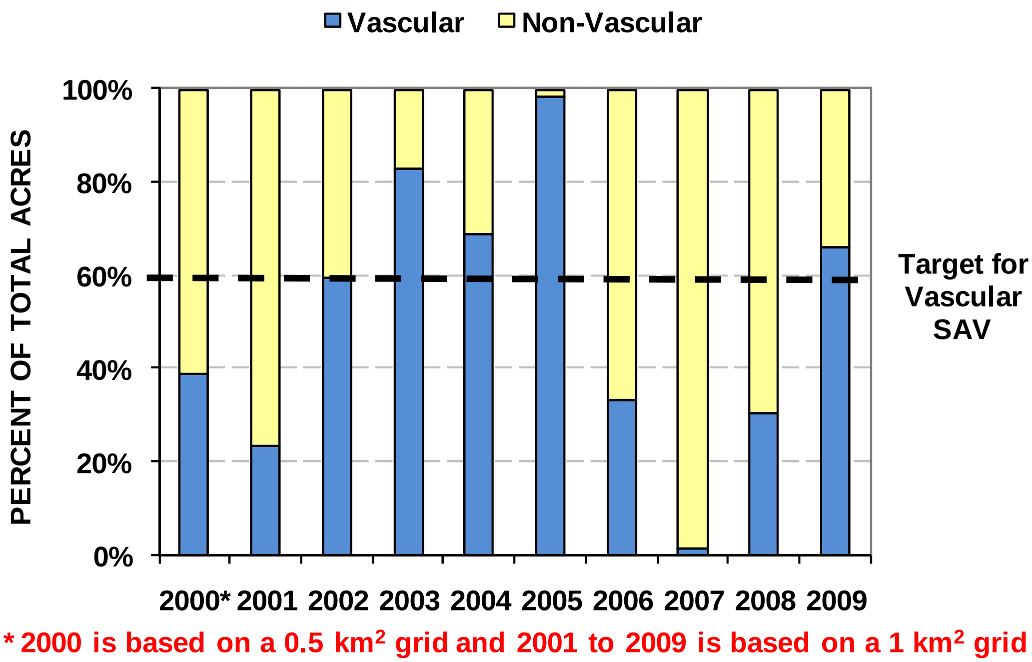


Figure 10-28. Percent of acres of vascular and non-vascular SAV determined from annual mapping results.

Research

Two short-term pilot experiments on SAV were conducted at the District's mesocosm facility at Port Mayaca Lock and Dam from April through October 2009. These experiments were devised to support future experiments that will look at the effect of water depth and light conditions on SAV growth. Such information can be used to support management decisions on water level regulations to improve the overall health of the lake.

Plants were grown at ambient temperatures and light in peat sediment cores that were obtained from Lake Okeechobee. The plants were incubated in large, 7,700 liter (L) circular outdoor tanks 3.6 m in diameter and 0.91 m deep. Water was continuously added at a slow rate.

The objective of the first experiment was to determine if mixed soils, which provide a homogeneous experimental media, produce a different result from unmixed soils, which represent conditions found in the field. Roots of eelgrass plants grown in unmixed peat were significantly shorter than the roots of plants grown in mixed peat (**Figure 10-29**). This suggests experiments using undisturbed peat cores are more representative of field conditions than if the material is mixed.

The objective of the second experiment was to determine if *Chara* could be grown from thalli, which are more easily handled and available than oocytes, providing a useful stock of experimental plants. Given sufficient light, *Chara* grew so luxuriantly that it overgrew the perimeter of its culture containers, eventually establishing throughout the mesocosm (**Figure 10-30**).

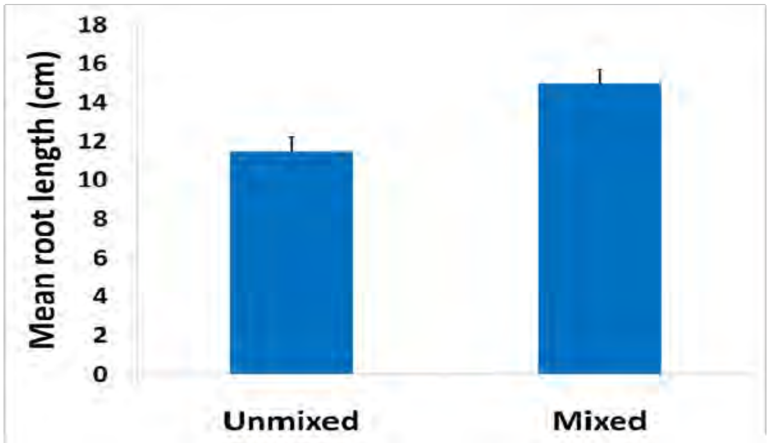


Figure 10-29. Mean root length of eelgrass (*Vallisneria americana*) plants grown in mixed and unmixed peat cores. Lengths are significantly different ($p < 0.05$).

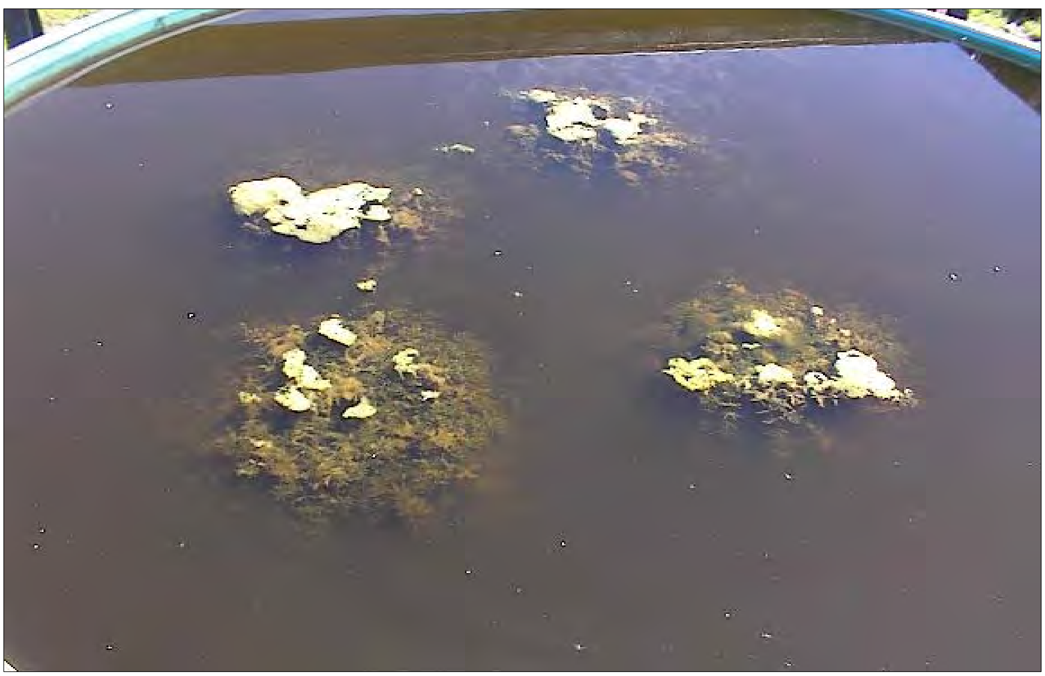


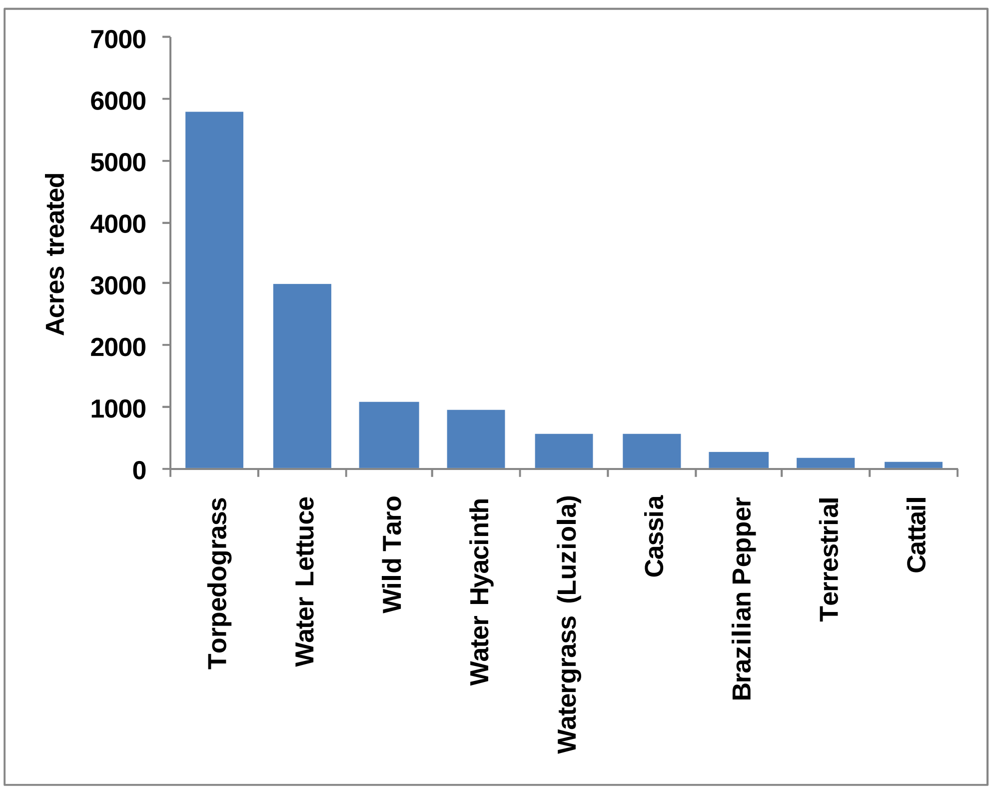
Figure 10-30. Growth experiments of *Chara* grown in mesocosms from thalli (photo by the SFWMD).

EMERGENT AQUATIC VEGETATION

Exotic Species

For the LOW, exotic species activities include identifying exotic and invasive plants and animals, managing existing invasions, developing and implementing measures to protect native species, and monitoring some animal species to assess possible future invasions.

Each year the District aggressively treats exotic vegetation in the Lake Okeechobee marsh to protect and restore native habitat. As a result, the marsh landscape has been altered. Over 12,000 acres of marsh were treated, primarily for torpedograss (*Panicum repens*) and water hyacinth (*Eichhornia crassipes*), in 2009 (**Figure 10-31**). More than 10,000 acres of torpedograss were treated from 2004–2006, and more than 14,000 acres were treated from 2007–2008. Historic treatment efficacy has varied, but the level of torpedograss control remains high in many areas several years after treatment (**Figure 10-32**). Without these treatments, dense monocultures of torpedograss covering tens of thousands of acres would be common in the upper elevation regions of the marsh. Although torpedograss is still present in many areas, its coverage has decreased substantially. Native plant communities have colonized some of the treated sites and monthly wading bird surveys conducted in 2010 documented thousands of birds foraging in shallow open water areas previously overgrown with torpedograss (**Figure 10-33**).



Note: Water lettuce (*Pistia stratiotes*), wild taro (*Colocasia esculenta*), Brazilian pepper (*Schinus terebinthifolius*).

Figure 10-31. Acres of exotic plants treated in Lake Okeechobee in 2009.

Figure 10-32. Long-term control of torpedograss (*Panicum repens*) (open water) seen in winter 2010 at a site north of Indian Prairie Canal that was treated in 2008. The brown vegetation is mostly dormant torpedograss (photo by the SFWMD).

Figure 10-33. Wading birds foraging in a shallow open water site located near an area previously impacted by torpedograss (photo by the SFWMD).

The floating exotic plants water hyacinth and water lettuce (*Pistia stratiotes*) continue to pose significant ecological harm to the marsh. During the summer and fall 2009, more than 11,000 acres of water hyacinth and 4,000 acres of water lettuce were treated. Because dense mats of water hyacinth often were entangled in bulrush (*Scirpus californicus*), the treatments caused significant non-target damage to bulrush (**Figure 10-34**). Much of the damage to bulrush appears to be short-term as the plants have shown signs of recovery.

Figure 10-34. Treated water hyacinth in foreground and non-target damage caused to emergent bulrush (*Scirpus californicus*) (November 2009) (photo by the SFWMD).

Periphyton

Periphyton is an important food source for herbivorous macroinvertebrates and fish in Lake Okeechobee (Havens et al., 1996b; Steinman et al., 1997; Carrick and Steinman, 2001). In the nearshore region of the lake, periphyton also may compete with phytoplankton for nutrients, when periphyton biomass is high, indirectly limiting phytoplankton growth (Phlips et al., 1993; Havens et al., 1996b; Rodusky et al., 2001).

The current periphyton monitoring program on Lake Okeechobee started in August 2002. Methods and sampling sites were reported in McCormick et al. (2010) and Rodusky (2010). The objective of this study was to examine periphyton biovolume, biomass, community structure, and nutrient storage dynamics under highly variable lake conditions that occurred during the study period. Periphyton abundance (as both biovolume and biomass) and nutrient storage were hypothesized to be inversely associated with water level and positively associated with the amount of available colonizable substrate. This hypothesis was tested by monitoring periphyton abundance, taxonomic composition, and nitrogen, phosphorus, and total carbon storage in periphyton on host plant and sediment substrates in the nearshore region of the lake. Analyses were conducted to better understand how these abiotic and biotic factors influenced primary production rates of periphyton and associated nutrient storage capacity in this lake.

Communities sampled included periphyton growing on SAV and emergent plant stems (epiphytes) and periphyton growing on the bottom sediments (epipelon). In 2007 and 2008, very little SAV substrate was available for periphyton due to drought conditions (McCormick et al., 2010). Additionally, epipelon sampling sites were moved lakeward because of low water levels. As water levels increased, some of the original sites were reinundated and sampling was renewed. As the coverage of the host plants rebounded, epiphyte sampling was resumed for *Chara* (south region), eelgrass (north and west regions), and cattail (all regions) in fall 2008, bulrush (north and west regions) in spring 2009, *Hydrilla* (north region) in fall 2009, and bulrush (south) in spring 2010.

Periphyton biomass from 2002–2006 was lower than observed in earlier studies. This has been attributed to a combination of prolonged high lake stage during the late 1990s, drought in 2000, two hurricanes in 2004 and one in 2005, all of which dramatically reduced emergent vegetation and vascular SAV host substrate coverage (Rodusky, 2010). Due to the number of sites added upon the recommencement of monitoring in 2007, a direct comparison of periphyton from the two sampling periods (2002–2006 and 2007–2009) is not possible. Nevertheless, general trends can be examined, and the fall data is the most directly comparable. Epipelic data in 2007 was only collected in the fall, and was not included in this analysis.

For the epiphyte host substrates present during most of these years, bulrush and eelgrass in the northern and western region and *Chara* in the southern region, the mean epiphyte biomass was either the same or higher during 2008 and 2009 as it was during 2003 and 2004 (**Figures 10-35** and **10-36**). There were neither epiphyte data for *Chara* in fall 2004 nor bulrush for fall 2008 because of seasonal senescence of host plants or a delay in recovery of host plants after the hurricanes in 2004 and 2005.

Epipelic mean biomass was highest in the south [62 milligrams per square centimeter (mg/cm^2)] and west (438 mg/cm^2) regions during 2009 and highest in the north (496 mg/cm^2) during 2005 (**Figure 10-37**). Mean biomass was lowest in all three regions during 2003, ranging between 7 mg/cm^2 (south) and 61 mg/cm^2 (north).

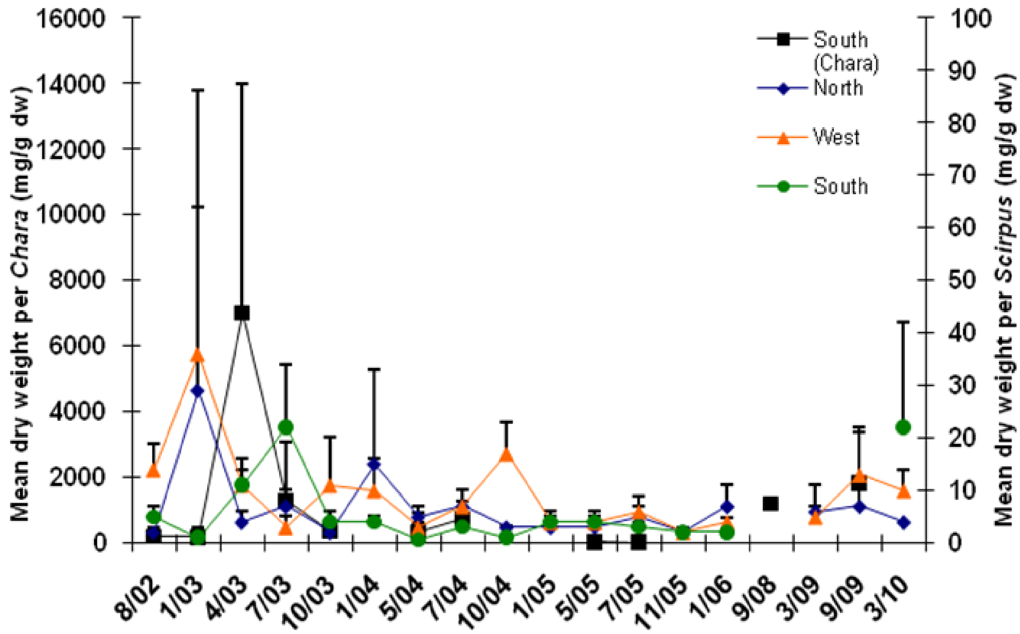


Figure 10-35. Nearshore *Chara* and bulrush epiphytic mean abundances [+1 standard deviation (SD)] in Lake Okeechobee as milligrams per gram (mg/g) host dry weight.

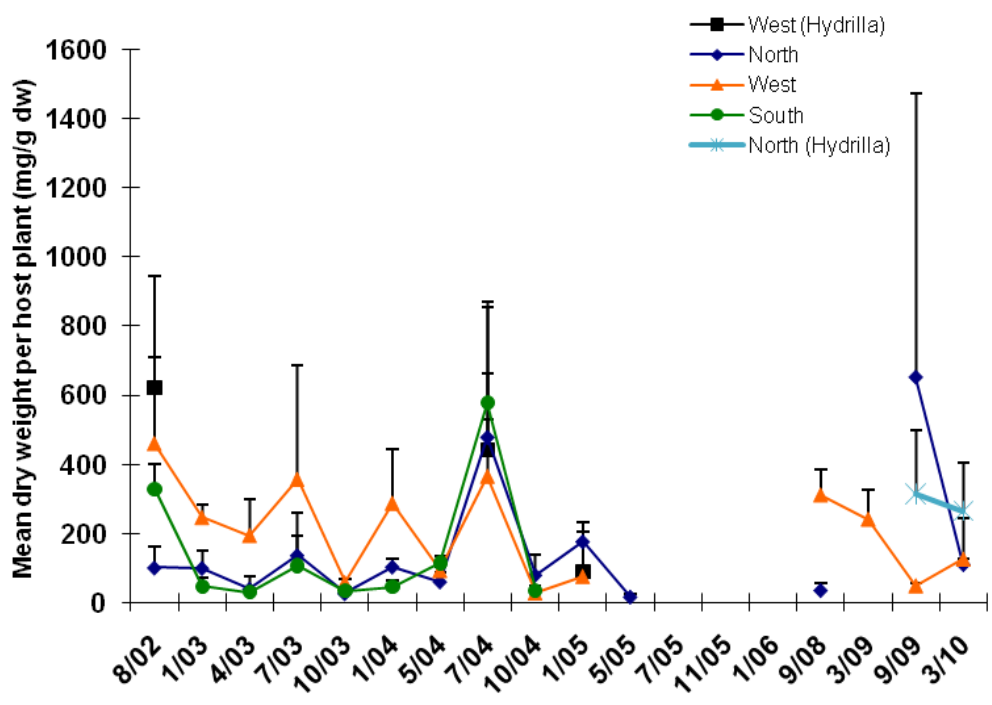


Figure 10-36. Nearshore *Hydrilla* and eelgrass (*Vallisneria sp.)* epiphytic mean abundances (+1 SD) in Lake Okeechobee as mg/g host dry weight.

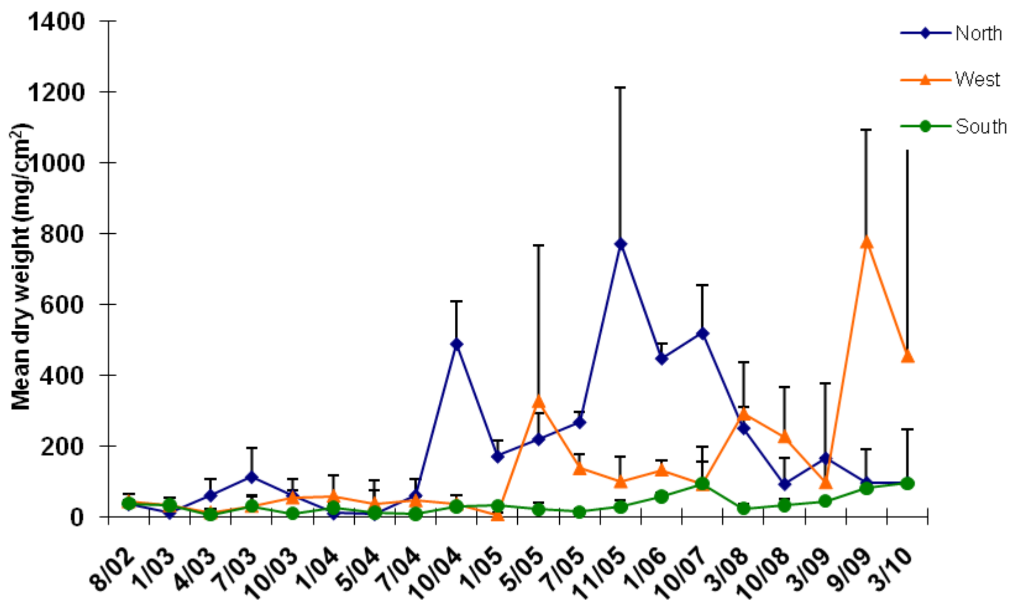


Figure 10-37. Nearshore epipelic mean abundances (+1 SD) in Lake Okeechobee as dry weights in milligrams per square centimeter (mg/cm^2).

Periphyton abundance (as biovolumes) prior to 2008 was generally less than in 1995 (Carrick and Steinman, 2001). Between summer 2002 and fall 2008, both the epiphytic and epipelic communities were dominated (> 80 percent) by diatoms (**Figure 10-38**). In 1995, cyanobacteria (56 percent) and diatoms (40 percent) dominated the epipelic community (**Figure 10-39**).

The estimate of overall mean periphyton phosphorus storage for the entire nearshore region during the 2002–2006 study period was low (8 mt) and approximately 11 percent of that measured from 1989–1991 (Zimba, 1995). Several ecological factors and one methodological factor may have contributed to this difference. During the earlier study (Zimba, 1995), (1) lake stage was lower, (2) SAV (especially vascular taxa) coverage and, thus, available epiphytic host substrate was higher, and (3) an additional plant type (cattail) was sampled that was not included in the latter study. There also were differences in taxonomic composition of the periphyton communities between the mid 1990s and 2002–2006 that may have contributed to differences in nutrient storage capacity among the periphyton communities (Carrick and Steinman, 2001; Rodusky, 2010). Periphyton nitrogen, phosphorus, and carbon storage has increased with the recent increase in periphyton abundance. The 2007–2009 nutrient and carbon storage data are planned to be compared with previously collected data in the 2012 SFER.

It is evident when comparing the 1995–2009 datasets that periphyton biomass was highest in 1995, and was lower until roughly 2008. After 1995, the community structure shifted to diatom dominance. Common taxa in this community include *Cocconeis* sp., *Synedra* spp., and *Fragilaria* sp., which are tolerant of high nutrient concentrations and variation in other environmental factors such as light (Carrick and Steinman, 2001; Yang et al., 2005; Bellinger et al., 2006).

In general, lake stage as it relates to light availability and host-substrate areal coverage in the nearshore region may be the most influential factors affecting periphyton biomass, and the availability of suitable host substrate appears to be more influential than seasonality. Thus, maximal periphyton abundance and nutrient storage may occur if the lake is more frequently within the desired stage range (12.5–15.5 ft NGVD) considered conducive to emergent plant and SAV growth.

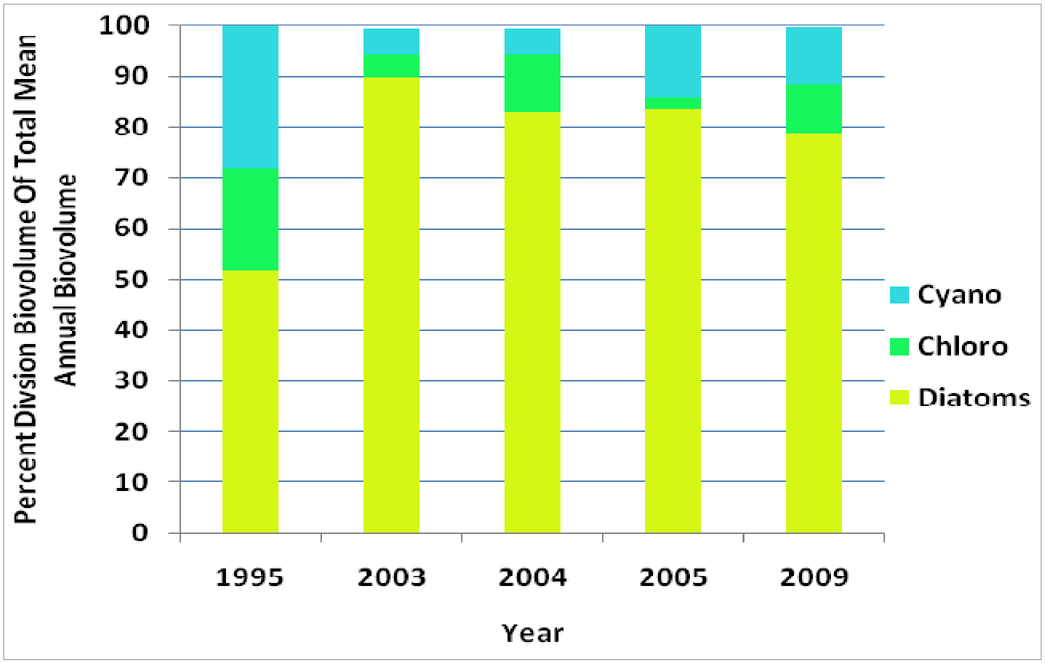


Figure 10-38. Percent composition (by Division) of epiphyte biovolume in the nearshore region of Lake Okeechobee. Data are averaged by year from four quarters (1995–2005) and two quarters (2009), respectively.

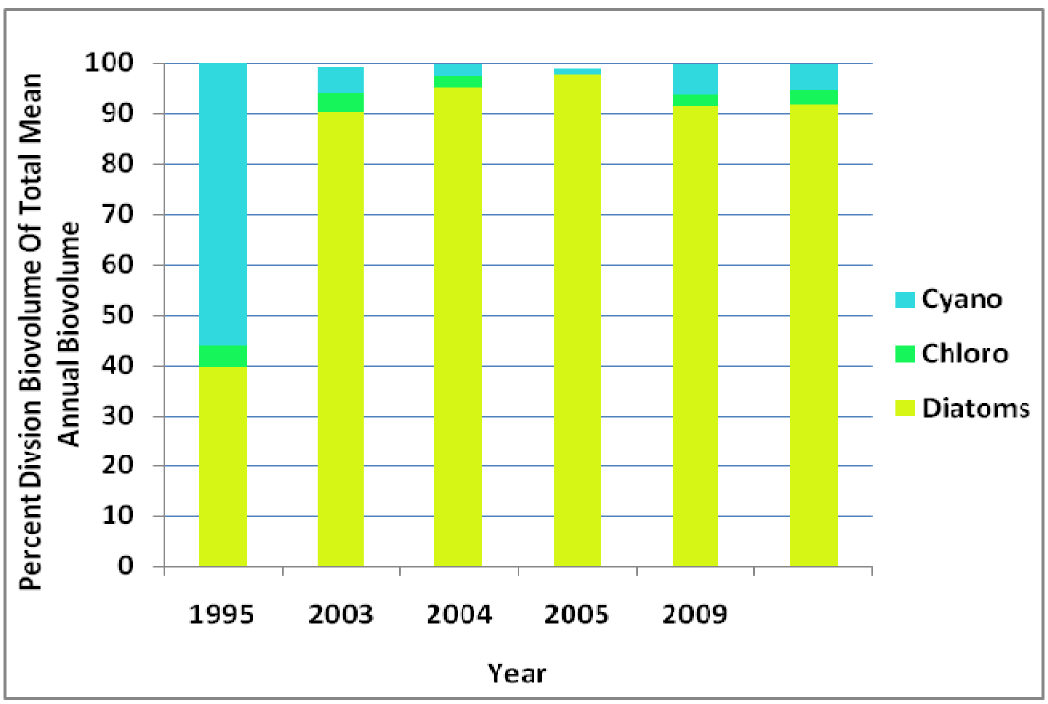


Figure 10-39. Percent composition (by Division) of epipelon biovolume in the nearshore region of Lake Okeechobee. Data are averaged by year from four quarters (1995–2005) and two quarters (2009), respectively.

MACROINVERTEBRATES

A three-year baseline monitoring study of macroinvertebrates in the pelagic region of Lake Okeechobee was conducted by the Florida Fish and Wildlife Conservation Commission (FWC) (under contract to the District) from August 2005 through February 2008 (Warren et al., 2008). Results were summarized in the 2010 SFER (McCormick et al., 2010). As water quality in the lake improved over the study period and water levels declined, midges, segmented worms, Asian clams (*Corbicula fluminea*), and water mites increased. Based on taxonomic composition, densities, species richness and diversity, macroinvertebrate communities in peat and sand sediments improved, which should enhance the lake's food web and increase recruitment of fish and other vertebrates that eat the macroinvertebrates.

Florida Apple Snail

The Florida apple snail (*Pomacea paludosa*) is the primary food of the Everglade snail kite (*Rostrhamus sociabilis plumbeus*) and is a key ecological component of wetlands in South Florida. The extreme variations in water levels within Lake Okeechobee during the past decade have reduced the snail's abundance. Although small remnant snail populations still exist within the lake, recovery to meaningful densities will take years. Therefore, the District, with the assistance of Harbor Branch Oceanographic Institute at Florida Atlantic University developed a pilot apple snail production and stocking program. The production program was successful and is described in the 2010 SFER; however, the cost-effectiveness and success of stocking of captive reared animals in the wild remains unclear.

Mark-and-Recapture Study

To understand how captive reared apple snails respond to stocking efforts in the wild, a mark-and-recapture study was begun. The objective was to monitor post-release survival and reproduction of the cultivated animals. In April and June 2009, 4,500 adult Florida apple snails were tagged with a unique identification number and released at two sites within Eagle Bay Marsh. Two control sites were also identified. The 65-hectare (ha) marsh, located at the northern end of Lake Okeechobee, is situated just outside of the Herbert Hoover Dike adjacent to State Road 78. This location was chosen for its ease of access, predictable water depths, and diverse vegetative community to support apple snail survival and reproduction.

The tagged apple snails were systematically released at two 0.5 ha (70 m x 70 m) sites within the marsh at a density of one snail per two square meters (0.5 snail/m^2), an average density for native apple snail populations in the wild. Trapping grids consisting of 10 rows of 10 pyramid crayfish traps were set up within the release sites to capture and recover snails (**Figure 10-40**). The grid was checked four times per month at 3-4 day intervals to ensure sufficient capture rates and minimize trap escape. The identification number of each snail found within a trap was recorded per Darby et al. (2001).

The number of apple snails captured within the pyramid traps was small. These traps are very effective in trapping apple snails in shallow-water environments, but have not been tested in deeper water. At the time of the release in April 2009, water depth averaged 45 cm within the marsh. Water depth increased with the onset of the rainy season in May, effectively negating trapping efforts. Consequently, an accurate survival rate could not be calculated using standard mark-recapture formulas.

Figure 10-40. Trapping grid for the mark-and-recapture Florida apple snail (*Pomacea paludosa*) study, consisting of 10 rows of 10 crayfish pyramid traps in Eagle Bay marsh (photo by Harbor Branch Oceanographic Institute, used with permission).

Reproduction

There was evidence that the released animals quickly acclimated to the natural environment and successfully reproduced. At each study site, egg cluster surveys were conducted every three weeks from the time of release until the end of October 2009. Each survey sampled approximately 20 percent of the study area and the average number of egg clutches produced per square meter was determined. The percent cover of vegetation for each release site was determined (26 percent for site 1 and 37 percent for site 2) to scale the number of egg clutches to m^2 of emergent vegetation available for oviposition. Additionally, two control sites were monitored to determine if production at each study site was due to the presence of the captive released or wild population of snails.

Study Site 1

An egg clutch survey was conducted in April at study site 1, approximately one week prior to release, to determine recruitment produced by the existing snail population. Production at this time was 0.4 egg clutch/m^2. The first survey following the release of captive snails was conducted two weeks later and a two-fold increase in production was observed. This may have been evidence that the captive reared animals survived long enough to reproduce, although, since reproduction is both seasonal and cued by water depth, other factors may have resulted in the spike in clutch production post-release.

Subsequent bi-weekly surveys showed declines in egg clutch production through October and no difference could be found between the experimental site and control site production through the remainder of the study. One month following the initial release of apple snails at study site 1, the water depth increased from 45 cm to 80 cm, which could explain the decreased reproduction at both this site and control site 1.

Study Site 2

An egg clutch survey was not conducted at this site prior to the June stocking. A visual inspection of the area, however, did reveal a small number of apple snail egg clutches. Given that the two study sites were close to each other and the water depth at the time of release was ideal for apple snail reproduction, it is possible that the density of the remnant population of wild apple snails may have been lower at study site 2 than at study site 1.

Egg clutch production at site 2 declined through time as evidenced through the bi-weekly surveys, but not at the same temporal rate as at site 1. The higher elevation at study site 2 produced much shallower water depths than at site 1. The shallower conditions allowed additional time before increased water depth reduced breeding. This additional production time made measuring a difference in egg clutch production between the study and control sites possible. Results appeared to indicate that the captive-reared apple snails survived long enough to produce eggs (**Figure 10-41**). Since pre-stocking parity between experimental and control site 2 was not quantified, the possibility exists that observed differences were the result of differences in natural population density between the two sites. Similar experiments conducted in more controlled environments (e.g., enclosures) are indicated.

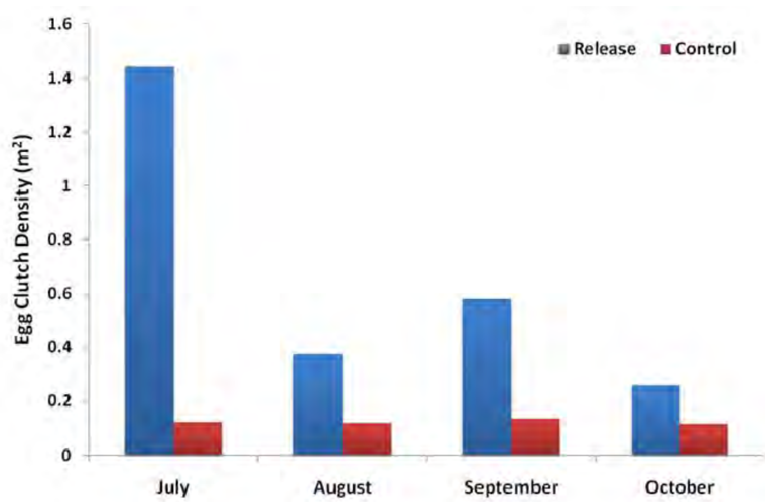


Figure 10-41. The density of Florida apple snail egg clusters per square meter at study site 2 and control site 2 during monthly surveys (July–October 2009).

FISH

Population Surveys

The largemouth bass (*Micropterus salmoides*) (LMB) and black crappie (*Pomoxis nigromaculatus*) (BC) populations in Lake Okeechobee are monitored by the FWC. A standardized lake-wide electrofishing protocol is used to monitor LMB and a similar lake-wide trawling protocol is used to monitor black crappie (BC). Recruitment of both species has varied over time due to variations in water levels, hurricanes, and droughts (Havens et al., 2005; James and Zhang, 2008). Bluegill (*Lepomis macrochirus*) and redear (*Lepomis microlophus*) sunfish populations also are monitored by electrofishing in the nearshore and littoral regions.

After the hurricanes of 2004 and 2005, both LMB and BC populations declined (**Figure 10-42**). The LMB population is recovering more quickly than the BC population, possibly because the LMB is more robust in feeding and reproductive habits. LMB eat a great variety of forage from the time they hatch through adulthood. BC tend to forage primarily on rotifers after hatching. Black crappie eventually move off shore where they eat invertebrates then switch to young-of-year shad (*Dorosoma* spp.) when they reach a length of about 200 millimeters (mm). The lake-wide turbid conditions that occurred after the hurricanes reduced phytoplankton and zooplankton production. The decline in primary and secondary producers may have negatively affected both shad and BC populations. The BC population has not recovered to densities observed in 2002, but the LMB population has increased as a result of a strong young-of-year class produced in 2009 (**Figure 10-43**).

The bluegill and redear sunfish populations also changed during the 2005–2008 period. In 2005, there was nearly no recruitment of redear (**Figure 10-44**) or bluegill sunfish (**Figure 10-45**). The population of these sunfish consisted mostly of adult fish. Following improvements in habitat and water quality, both species showed strong signs of production of young in 2008.

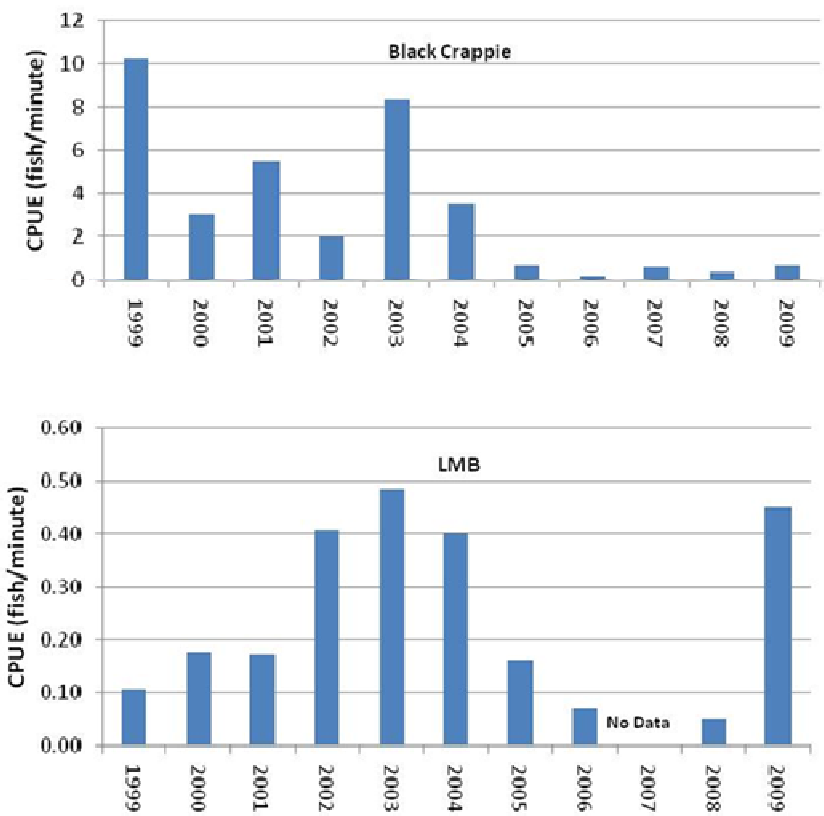


Figure 10-42. Abundance of black crappie (*Pomoxis nigromaculatus*) and largemouth bass (*Micropterus salmoides*) (LMB) based on catch per unit effort (CPUE) data. The black crappie population has shown little sign of recovery compared to LMB that produced a strong year class in 2009.

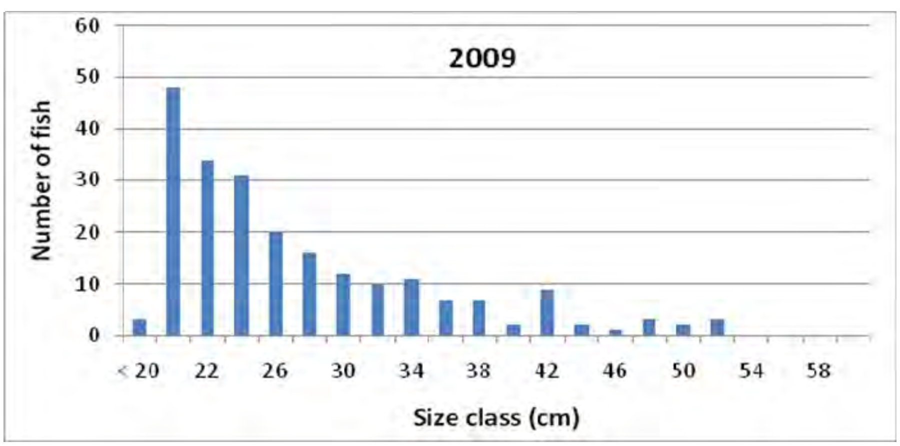
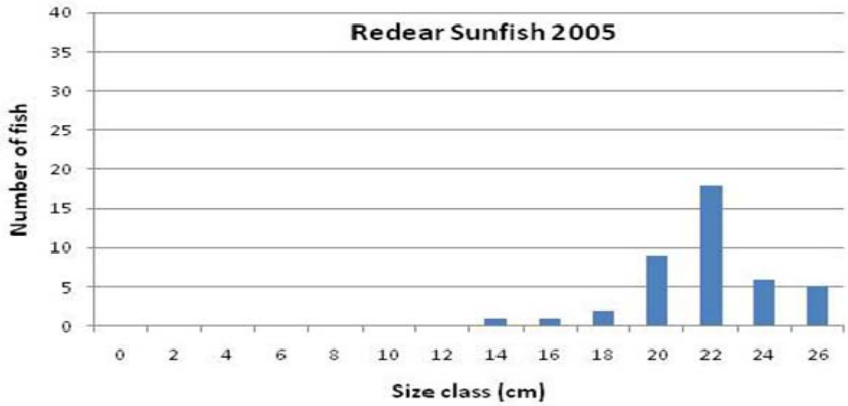


Figure 10-43. Length frequency distribution of LMB in 2009. Most of the LMB population in 2009 consisted of young-of-year and age 1 and 2 fish.



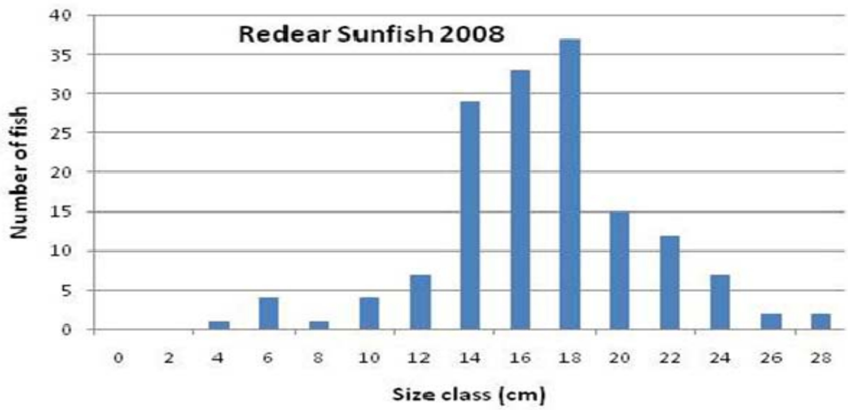


Figure 10-44. Length [in centimeters (cm)] frequency distribution of redear sunfish (*Lepomis microlophus*) in 2005 and 2008. Most of the population consisted of adult fish in 2005, but young-of-year fish were present in 2008.

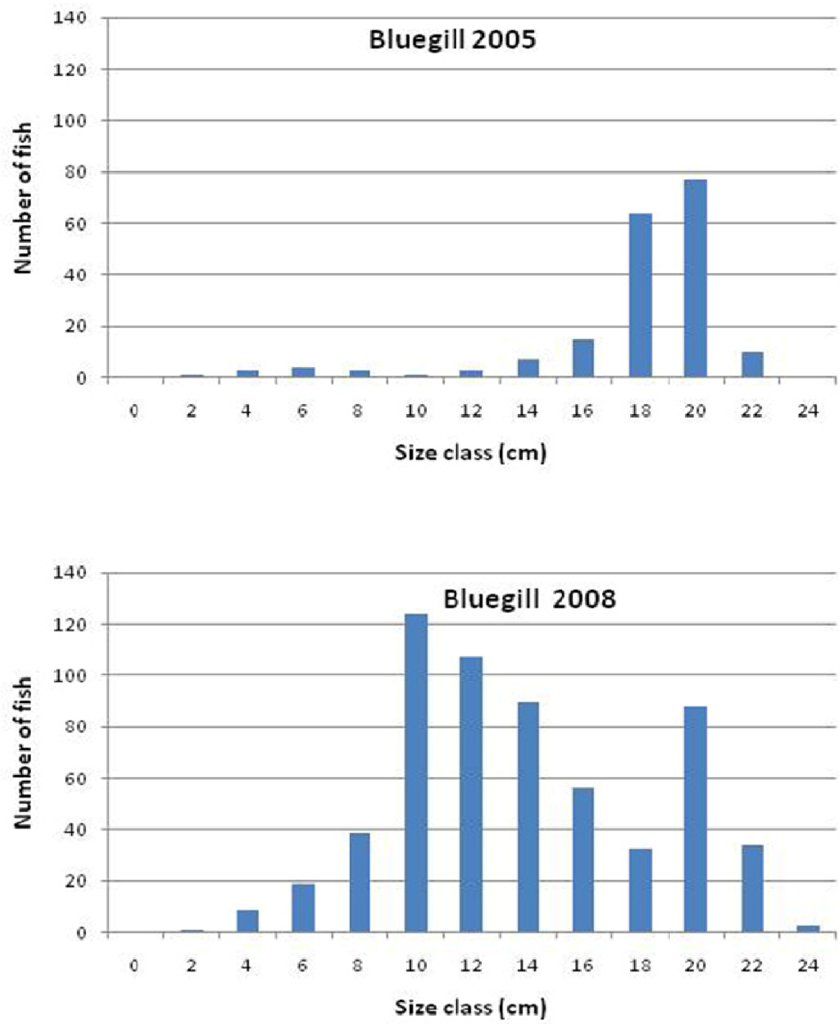


Figure 10-45. Length frequency distribution of bluegill (*Lepomis macrochirus*) in 2005 and 2008. Most of the population consisted of adult fish in 2005, but young-of-year fish were present in 2008.

Largemouth Bass Stocking Assessment

LMB density in Lake Okeechobee has been below historical numbers since the hurricanes of 2004 and 2005 caused extensive habitat loss (see **Figure 10-42**). The drought of WY2006–WY2009 allowed waters to clear, permitting submerged and emergent aquatic plants to grow, re-establishing habitat for fish recruitment. Fall 2008 littoral zone fish community population assessments by electrofishing indicated a resurgence of forage fish numbers. With adequate forage present, a project was developed to determine if supplemental stocking of LMB was a viable approach to augment the population in a relatively localized area of the larger water body. This project was the first documented stocking of hatchery-produced fish directly into Lake Okeechobee.

In February 2009, 80 sexually mature male and female LMB were collected from the rim canal of Lake Okeechobee by electrofishing. For each collected fish, a fin was clipped for genetic identification, and sex was determined. The fish were transferred to the Florida Bass Conservation Center for spawning. The fingerlings (25–50 mm) produced from the collected parent stock were released in an isolated area of northwestern Lake Okeechobee, known as Cody's Cove. On March 26, 2009, approximately 22,000 fingerlings were released into four areas. On April 8, 2009, approximately 52,000 more fingerlings were released into another 10 areas of Cody's Cove. The final stocking on April 22, 2009, was approximately 25,000 fingerlings into six more regions of the cove (**Figure 10-46**).

The sampling area of Cody's Cove in Lake Okeechobee was divided into two zones of seven sampling sites each. The western sites, closest to shore, were areas stocked with fingerlings from the hatchery. This location was referenced as the "stocked" area. Seven adjacent eastern sites were closer to open water where it was assumed the stocked fish would relocate if they dispersed due to declining lake levels. This location was referenced as the "dispersal" area. Post-stocking sampling was initiated in May 2009 and concluded in July 2009. Sampling by electrofishing (boat and backpack) was conducted at two-week intervals. During each sampling event, four sites were randomly selected and surveyed within the stocked area and dispersal area. Four funnel traps were set for 24 hours in the shallow vegetated areas of each sample site. Traps were removed from the water and the site was sampled by electrofishing for 15 minutes. Fluctuating lake levels during the post-stocking evaluation period required changes in sampling protocols. For sites where the water depth was too shallow or vegetation density was too great, two traps were added to the sample site as a substitute for electrofishing. In sites where the water was too deep to properly set traps, an additional site was sampled by electrofishing sample for each trap not set. At each sample site and event latitude/longitude, air temperature, percent cloud cover, wind speed and direction, vegetation type and percent coverage, water temperature, dissolved oxygen concentration and percent saturation, pH, conductivity, salinity, turbidity, bottom sediment composition, Secchi disk depth, and water depth were measured.

The length and weight of each captured young-of-year LMB were recorded. Fin clips, for genetic identification, were taken from every LMB sampled that was smaller than 127 mm in length because stocked LMB fry could not have grown beyond that size during the sampling period. Fin clips were sent for genetic analysis to determine if the fish were wild or broodstock progeny. In addition, approximately 30 young-of-year LMB were collected per sampling event and returned to the lab to identify, count, and weigh stomach contents.

A total of 443 young-of-year LMB were collected. Genetic results indicated six stocked fish were present in the 443 captures, or 1.3 percent of the sample. A second LMB fry stocking is planned for WY2011 in Lake Okeechobee to assess the results of a higher stocking density in a different location of the lake, Tin House Cove, with results slated for reporting in the 2012 SFER.

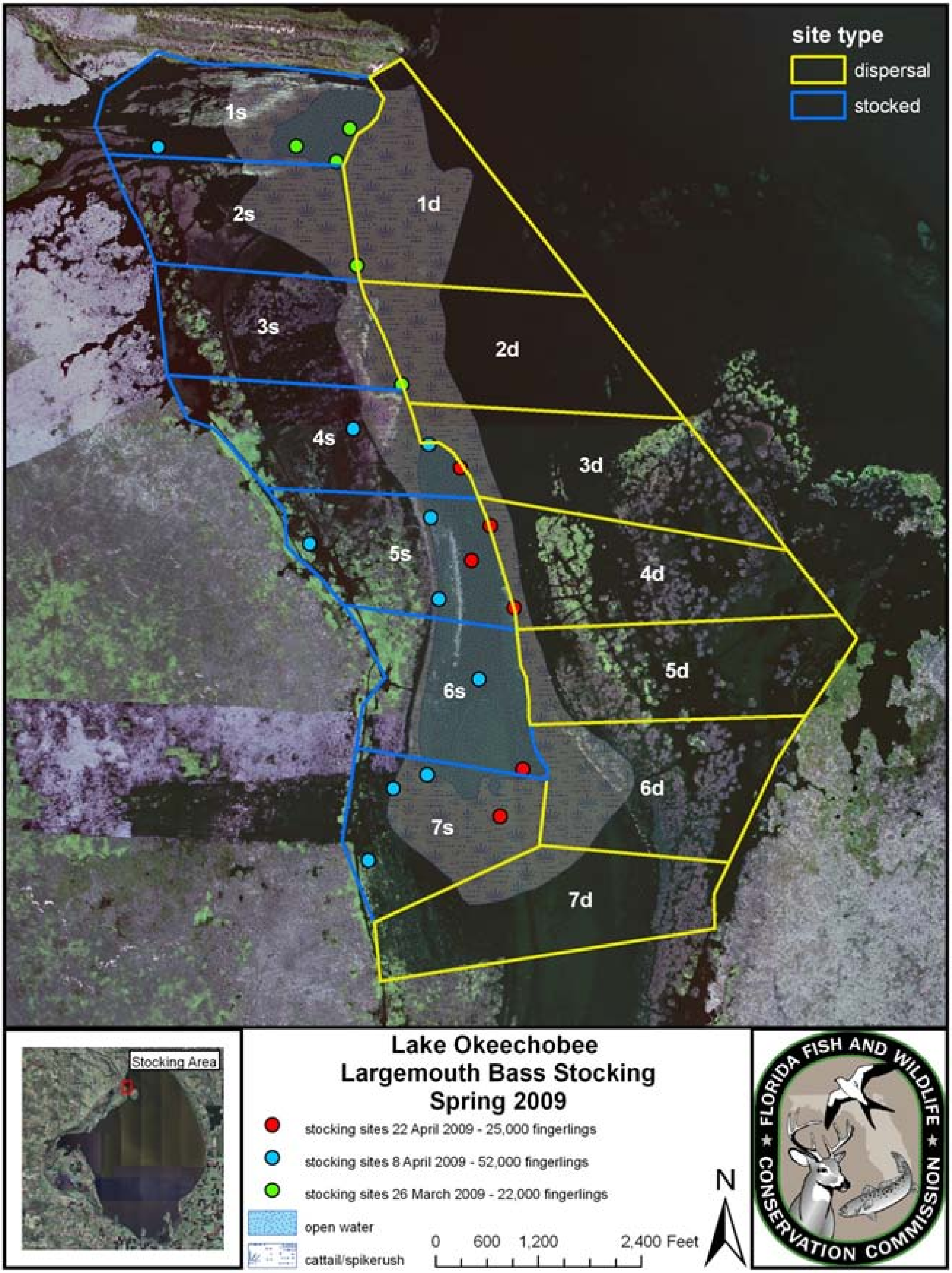


Figure 10-46. Cody's Cove showing stocking sites and sampling sites in 2009.

HABITAT USE BY MACROINVERTEBRATES AND FISH

In their synthesis of food web interactions on Lake Okeechobee, Havens et al. (1996a) emphasized the macroinvertebrate > fish > wading bird food chain in the lake's littoral zone, but the importance of habitat type to support these aquatic and wetland fauna is not well understood. A one-time sampling event quantified the forage and sport-fish communities and macroinvertebrates associated with emergent spikerush (*Eleocharis cellulose*), cattail, and bulrush communities, and submerged eelgrass habitat.

Abundance and distribution of fish and macroinvertebrates were measured at 40 sites along the western edge of the marsh in July 2009 (**Figure 10-47**). Three levels of vegetation coverage (sparse, moderate, and dense) were sampled within each plant type listed above. Fish were collected using 0.01 ha block nets treated with rotenone, then sorted by species, measured, and weighed. Aquatic macroinvertebrates were sampled by six sweeps of a D-frame net within three replicate 1 m^2 throw traps. For identification and enumeration, the three replicate samples were combined to produce one macroinvertebrate sample for each block net site. Metrics for macroinvertebrate samples from each habitat type were density and species richness. Emergent plant community metrics were stem counts from five 0.25 m^2 quadrats placed within the block nets and from three throw traps adjacent to the block nets. Eelgrass was sampled over a 1 m^2 area using a hinged rake and harvested biomass was reported as a dry weight value (g/m^2). Density, biomass, and species richness were estimated from each habitat type.

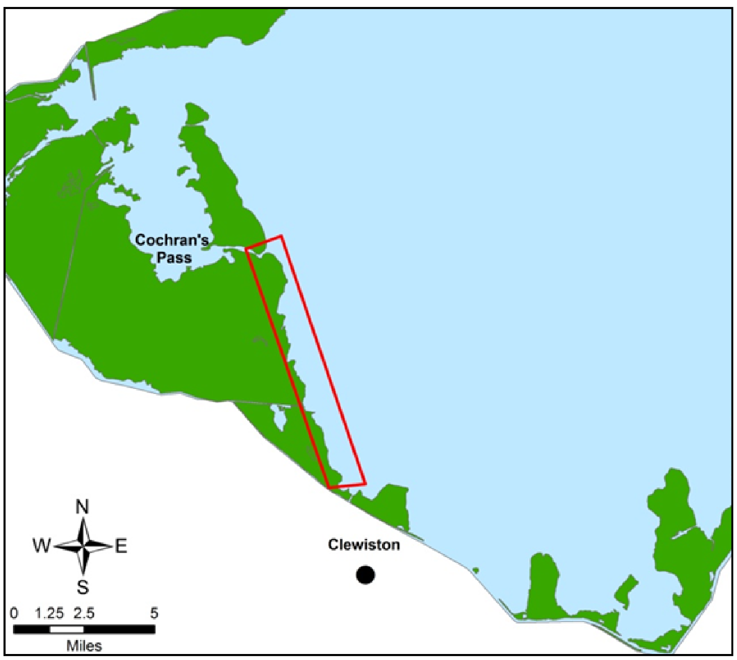


Figure 10-47. Location of the 2009 study area (red box) to assess the emergent and submerged aquatic vegetation habitat used by fish and macroinvertebrates in Lake Okeechobee.

Twenty-five fish species were collected. The most dominant game fish were bluegill and redear sunfish, and the most dominant forage fish were bluefin killifish (*Lucania goodie*), flagfish (*Jordonella floridae*), eastern mosquitofish (*Gambusia* spp.), and Seminole killifish (*Fundulus seminolis*) (**Table 10-15**).

Table 10-15. Blocknet species catch composition among four vegetation types in Lake Okeechobee, July 2009. The value is the percent of catch that an individual species represents in the total catch for each vegetation type.

Species	Eelgrass (*Vallisneria* sp.)	Bulrush (*Scirpus californicus*)	Spikerush (*Eleocharis cellulose*)	Cattail (*Typha* spp.)
Atlantic needlefish (*Strongylura marina*)		<1		
Blue tilapia (*Oreochromis aurea*)	< 1	1	< 1	1
Bluefin killifish (*Lucania goodei*)	8	19	34	17
Bluegill (*Lepomis macrochirus*)	34	11	20	21
Brown bullhead (*Ameiurus nebulosus*)	3	< 1	< 1	
Brown hoplo (*Hoplosternum littorale*)	1	0		< 1
Brook silverside (*Labidesthes sicculus*)	1	4	9	9
Dollar sunfish (*Lepomis marginatus*)	< 1	1	< 1	< 1
Flagfish (*Jordonella floridae*)	7	25	3	5
Golden shiner (*Notemigonus crysoleucas*)			< 1	< 1
Golden topminnow (*Fundulus chrysotus*)	< 1	< 1	1	
Largemouth bass (*Salmoides micropterus*)	2	1	1	1
Mayan cichlid (*Cichlasoma urophthalmus*)	3	2	< 1	< 1
Eastern mosquitofish (*Gambusia* spp.)	2	5	10	< 1
Naked goby (*Gobiosoma bosc*)	< 1			< 1
Redear sunfish (*Lepomis microlophus*)	27	24	17	39
Sailfin molly (*Poecilia latipinna*)	1	1	< 1	
Seminole killifish (*Fundulus seminolis*)	12	3	2	4
Spotted sunfish (*Lepomis punctatus*)	< 1		1	
Striped mullet (*Liza tricuspidens*)				< 1
Swamp darter (*Etheostoma fusiforme*)	< 1	< 1		< 1
Tadpole madtom (*Noturus gyrinus*)	< 1	< 1		< 1
Taillight shiner (*Notropis maculates*)	< 1	< 1	< 1	< 1
Threadfin shad (*Dorosoma petenense*)			1	1
Warmouth sunfish (*Lepomis gulosus*)	1	< 1	1	< 1

There was little variation in fish species richness across plant type or vegetation coverage. Species richness ranged from 21 species in eelgrass habitats to 19 species in spikerush. The lowest richness (8) was associated with sparse spikerush, while the highest richness was associated with moderate and dense eelgrass (17). Fish community composition varied little across plant type or vegetation coverage. Flagfish were most abundant in bulrush and percent contribution of Seminole killifish was highest in sparse eelgrass. There were significant differences in both fish density and biomass among plant types but not among vegetation density. Eelgrass and cattail habitats had greater mean fish density and biomass than bulrush or spikerush (**Figure 10-48**). Blue tilapia (*Oreochromis aurea*) was the most common exotic species. Exotic species were a minor portion of the fish population in all habitats.

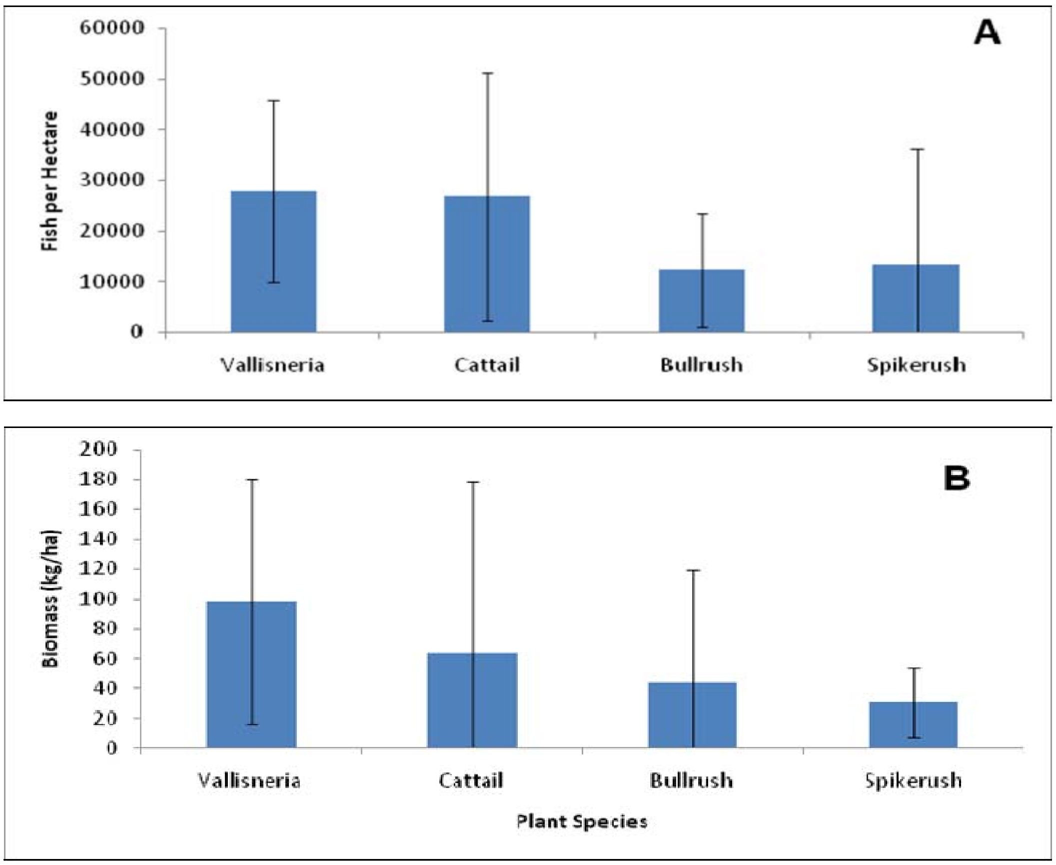


Figure 10-48. Mean fish density (A) and biomass (B) versus plant type from blocknet samples taken in Lake Okeechobee, July 2009. Error bars show 90 percent confidence intervals. Biomass units are kilograms per hectare.

A total of 1,923 aquatic macroinvertebrates were collected representing 85 taxonomic groups (**Table 10-16**). The most abundant taxa across all vegetation types was Ostracods followed by Chironomidae. The greatest total density of macroinvertebrates was found in cattail, followed by spikerush, bulrush, and eelgrass. Cattail samples were heavily dominated by Ostracoda (small crustaceans, also called seed shrimp), followed by *Koenikea* (water mites) and Chironomidae (non-biting midges). Spikerush samples were dominated by Dicrotendipes (non-biting midges), *Koenikea*, and *Caenis diminuta* (mayflies), respectively. Bulrush samples were dominated by

Caenis diminuta, Ostracoda, and *Koenikea* (in descending order). Eelgrass samples contained Dicrotendipes at the highest numbers followed by *Planorbella scalaris* (mesa rams-horn, a snail) and *Palaemonetes* spp. (grass shrimp).

The short duration and small sample size of this effort resulted in high variability of fish density and biomass. However, patterns across vegetation type and coverage were evident. The data suggested substantial differences in the macroinvertebrate communities among plant types and fish biomass. For example, eelgrass had the lowest aquatic macroinvertebrate species richness and density, yet it supported high fish biomass, density, and diversity of fish. Some evidence suggests that the fish community has not fully recovered from the 2004–2005 hurricanes and the recent drought. Rogers and Allen (2008) sampled with the same gear in similar habitats in the northwest region of the lake prior to the hurricanes and documented an average density of 40,000 fish per hectare. The average fish density in the current study was 20,000 fish per hectare. Additionally, the abundance of juvenile largemouth bass decreased from 1,200 fish per hectare to 260 fish per hectare and golden shiners (*Notemigonus crysoleucas*) decreased from 1,000 fish per hectare to 8 fish per hectare between the two studies.

Longer studies are needed to establish accurate relationships between fish and macroinvertebrates across vegetation types and coverage in the lake's littoral zone. A better understanding of changes in these food web components could be used to improve water level and aquatic plant management efforts to maximize habitat use and biodiversity.

Table 10-16. Estimated mean number of most abundant macroinvertebrates per meter squared found among four plant species. Samples collected in Lake Okeechobee, July 2009.

	Taxon	Bulrush	Cattail	Spikerush	Eelgrass
Arachnida	Arachnida	0.33	1.67	1.33	
	Spider	0.33	1	1.33	0.5
	Albia	0.33	3.67	0.67	0.2
	Koenikea	10.67	23.33	8.67	1
Annelida	*Bratislavia unidentata*	8.33		1	0.1
	Naididae[1]	0.33			0.1
	Nais[1]		0.33	0.33	0.1
	Tubificidae[1] genus		0.33	0.33	
Insecta					
Coleoptera:	Agabetes	0.33			
Diptera:					
Chironomidae	Chironomidae	6.67	20	4.33	4.2
Chironominae:	Chironominae	0.66	1.33	2.33	0.2
	Chironomus			1	
	Cladotanytarsus sp.	0.66	1.66	5.33	
	Cryptochironomus		0.33		
	Dicrotendipes	5	0.67	13.67	14.2
	Glyptotendipes	0.33	1.33	3	0.2
	Microspectra sp. D			0.67	
	Parachironomus chaetoalus complex[1]	2.67	1.33	1.67	0.5
	Paratanytarsus				0.2
	Polypedilum halterale group		0.33	1.33	
	Polypedilum tritum			0.67	
	Tanytarsini	0.66		1	0.1
	Tanytarsus	0.33		0.33	
Orthocladinae:	*Nanocladius alternantherae*	0.67	0.33	1.33	0.2
	Thienemanniella lobapodena		0.33	2.33	0.9
Tanypodinae:	Larsia[1]	2.66			
	Labrundinia	0.67			
	Procladius			0.33	
	Tanypodinae #1		0.33	0.33	
Ephemeroptera:	Ephemeroptera	0.33		0.67	0.4
	Caenis diminuta	18	0.33	10.67	
	Callibaetis floridanus			1.33	
Heteroptera:	Mesovelia	0.33			
	Saldidae			0.67	

Table 10-16. Continued.

	Taxon	Bulrush	Cattail	Spikerush	Eelgrass
Lepidoptera:	Lepidoptera	0.33			
	Crambidae	0.33			
	Langessa[1]			0.33	
	Parapoynx			0.33	
Odonata:	*Aphylla williamsoni*				0.1
	Anisopteran	0.33			
	Enallagma	1	3	2.33	0.1
	Erythemis simplicicollis	0.33			
	Libellula			0.33	
	Nehalennia[1]	0.33			
Trichoptera:	Trichoptera	0.33	0.67	1	
	Berosus	0.33	0.33		
	Nectopsyche sp.	1	3.33	6.33	5.9
	Oxyethira			0.33	
Mollusca	Campeloma			0.33	
	Ferrissia hendersoni	0.33			
	Haitia cubensis		0.33	0.67	
	immature gastropod	0.33	0.67		
	Planorbella scalaris			0.67	11.3
	bivalve[1]		1.33	1	
Isopoda	*Cassidinidea ovalis*	1	11.33	2.33	1.3
Crustacea	amphiopod		0.33	0.33	
	Gammarus		1.67	0.33	0.2
	Hyalella	0.67	0.33		
	Cladocera	2.33	3.33	1.33	
	Ostracoda	11.33	204	1	0.1
	Copepoda	2	1.33	2.67	
	Palaemonetes	2	1.33	1.67	7.6
	Taphromysis bowmani[1]			0.67	
Incidentals	Thysanoptera	0.33			
	Chrysomelidae (adult)	0.33			
	Curculionidae (adult)		0.33		
	Cryptochironomus		0.33		
	Formicidae (adult)		0.33	0.33	0.1
	Cicadellidae (adult)			0.33	
	terrestrial caterpillar[1]			0.33	
	Total	85.25	292.93	91.62	49.8

[1] Identification uncertain

HERPETOFAUNA

Reptiles and amphibians (herpetofauna) are often overlooked components of aquatic ecosystems. The overall biomass of these animals can, in many areas, exceed that of all other vertebrates combined and herpetofauna can serve as excellent indicators of environmental degradation. Understanding the influence of these predators within the larger food web, both as consumers and as prey, is critical for the management of the Lake Okeechobee ecosystem. Herpetofauna are sensitive to many of the same factors that affect other native species, including extreme water levels, deleterious changes in water quality, rapid water level changes, and the introduction of exotic species.

Herpetofauna Trapping Project

There has never been a sustained and comprehensive herpetofaunal inventory of Lake Okeechobee marshes. The only information available is a single study undertaken more than 10 years ago (USACE, 1999). To describe the fauna of the littoral zone, a survey study was begun to monitor populations along elevation gradients and in differing habitat types of the marsh. The three objectives of this study were to (1) provide a species list of native and introduced species for the Lake Okeechobee marsh, (2) estimate species diversity and abundance in various habitats within the marsh, and (3) track seasonal activity patterns and behavioral changes brought about by water level fluctuations.

Surveys began in April 2010 along three transects (**Figure 10-49**). These transects capture different habitat types along a depth gradient and each runs from the shoreline at the base of the Herbert Hoover Dike lakeward to the bulrush wall. Three sites were established along each transect, an inner site towards the dike, an outer site towards the lake, and a mid-site equidistant to both. Herpetofauna were measured at each site using methods developed during a preliminary study in the summer and fall 2009 (which determined the optimal methods of sampling to use at each site based on hydrologic conditions). During normal water levels, a combination of call surveys, Fyke nets, pyramid traps, and funnel traps were used. Under dry conditions, when aquatic sampling was not possible, call surveys, artificial cover, funnel, and pitfall traps set in drift-fence arrays were used.

On each sampling event, the appropriate sampling devices were deployed and allowed to sit in place for 24 hours. The devices were then retrieved and all captured animals were identified, measured (to the nearest centimeter), weighed (to the nearest gram) and released. Sediment type, water depth, and environmental conditions were also noted.

Six of the nine sites have been sampled (twice over a three-month period). There was not enough data to draw any conclusions. The dominant species sampled so far in this ongoing study include tadpoles, sirens, and snakes (**Figure 10-50** and **Table 10-17**).

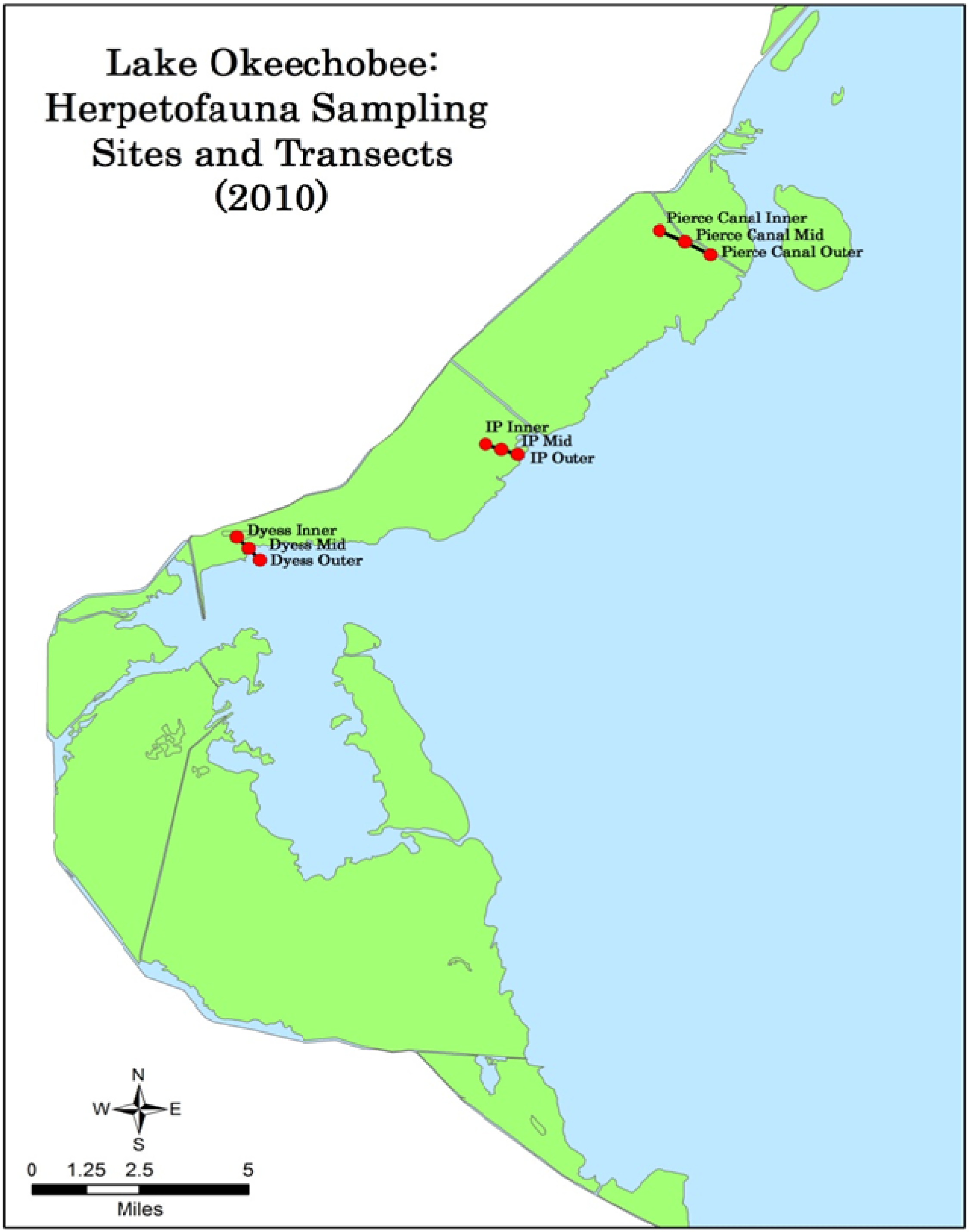


Figure 10-49. Lake Okeechobee herpetofaunal survey transects in 2010.

Figure 10-50. A mud snake (left) (*Farancia abacura*), a specialist predator of Sirens and Amphiumas, and a greater siren (*Siren lacertina*) (right).

Table 10-17. List of most common animals found in herpetofauna traps in the Lake Okeechobee marsh during an April 2010 survey.

Herpetofauna	Fish	Invertebrates
Ranid tadpoles (*Rana* spp.)	Mosquitofish (*Gambusia affinis*)	Grass shrimp (Palamonidae)
Greater siren (*Siren lacertina*)	Bluefin killifish (*Luciana goodei*)	Predaceous diving beetle (Dystiscidae)
Brown water snake (*Nerodia taxispilota*)	Flagfish (*Jordanella floridae*)	Predaceous diving bug (Bellostomatidae)
Green water snake (*Nerodia floridana*)	Sailfin molly (*Poecilia latipinna*)	Water scorpion (Nepidae)

Alligator Population Status

The FWC has managed and monitored Lake Okeechobee's American alligator (*Alligator mississippiensis*) population since 1988. The lake is divided into four alligator management units (AMUs). AMU 601 consists of the shoreline and emergent marsh between the Clewiston Lock Canal and the Indian Prairie Canal (west Lake Okeechobee). AMU 602 consists of the shoreline and emergent marsh between the Indian Prairie Canal and the Taylor Creek Lock Canal (north). AMU 603 consists of the shoreline and emergent marsh between the Taylor Creek Lock Canal and the West Palm Beach Canal (east). And AMU 604 consists of the shoreline and emergent marsh between the West Palm Beach Canal and the Clewiston Lock Canal (south).

Each AMU is monitored separately and receives individual harvest quotas for the state-wide alligator hunt. Night-light surveys are conducted on the lake annually during spring (late April through mid-June). Spotlights (200,000 candlepower) are used to locate alligator eye reflections. The size of the alligator is estimated to the nearest foot (~0.3 m) if possible. Data from these surveys are used to analyze trends on an area-by-area basis for various size categories of the populations. Size categories include total populations, juveniles (0.3–1.2 m), adults (≥ 1.8 m), breeders (1.8–2.7 m), and bulls (≥ 2.7 m). A family of six generalized additive models (GAMs) containing linear and nonlinear elements, with and without water level effects were evaluated for the 1998–2009 period. An Akaike Information Criterion, which takes into account both the goodness-of-fit and the complexity of the model, was used to select the simplest model that does the best job of fitting trend data. Estimated numbers of alligators were obtained by adjusting the estimated counts (obtained from the GAM analyses) by a detection rate factor of 0.14 (Woodward et al., 1996).

Population trends for each of the size categories and each of the AMUs are summarized in **Table 10-18**. The percent change from 1988 and 2009 estimates for juveniles was negative for all of the AMUs. However, the populations were considered stable based on a conservative alpha level ($\alpha = 0.30$, two-tailed) or all AMUs except AMU 604, which exhibited a 56.1 percent decline (**Figure 10-51**). AMU 604 represents about 35 percent of the lake's juvenile population. The comparison of relatively high counts in 1989 and 1990 with low counts in 2008 and 2009 seem to be a major factor in the significant decline of this unit.

Adult population trends were stable in AMUs 601 and 602, and increasing in AMUs 603 and 604 (**Figure 10-52**). This segment of the population is important because it represents the alligators that are sexually mature. Many wildlife management decisions (e.g., harvest quotas) are based heavily on the status of adult alligator population trends. Based on these results, there appear to be no problems with the adult alligator population on Lake Okeechobee.

Bull population trends were stable in AMUs 601, 602, and 604, and increasing in AMU 603 (**Figure 10-53**). Bull alligators are often targeted by alligator trappers for their monetary and trophy values. The trends of these alligators in the lake indicate that their populations continue to thrive after 20 years of hunting.

Trends of total populations were determined to be stable for all of the AMUs (**Figure 10-54**). The 2009 population estimates were less than the 1988 estimates on all AMUs except 603. This most likely reflects the influence of the juvenile population trends on the overall population trends for units 601, 602, and 604. However, AMU 603 has less suitable nesting habitat than the other units, which is reflected in the lower juvenile population estimates. The total population estimates for this unit appear to be influenced by the numbers of adult alligators.

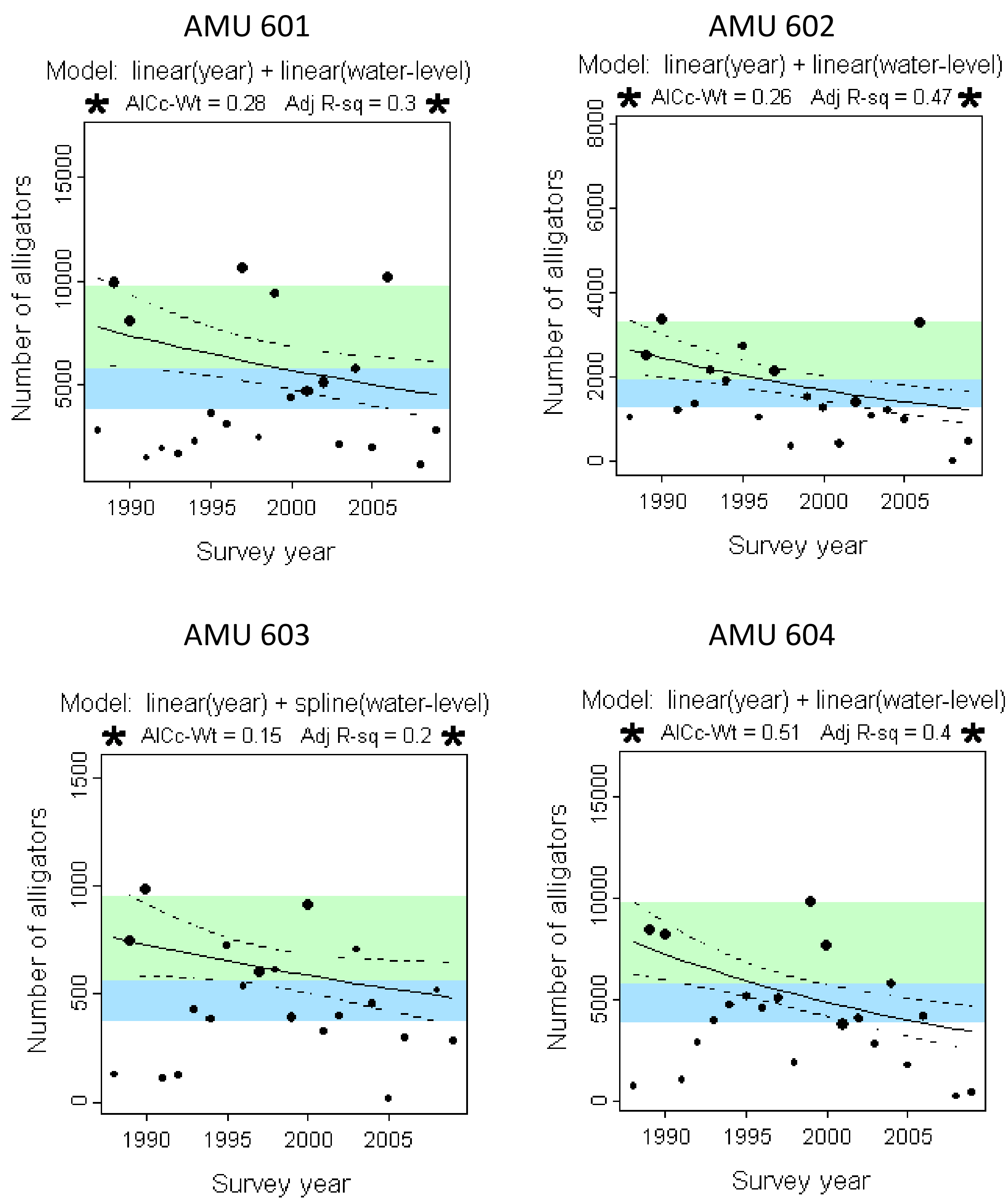
Of the four different size categories evaluated on the four AMUs, only one trend (juveniles in AMU 604) was determined to be decreasing. The conservative alpha levels used to make determinations can often result in frequent changes in trend designations (from either increasing or decreasing to stable) from year to year, especially when the actual p-values are marginal.

Consideration of these factors, and based on the assessment of survey data from 1988 through 2009, Lake Okeechobee's alligator population appears to be doing well overall.

Table 10-18. Alligator population trend information for Lake Okeechobee based on available survey data from 1988 through 2009.

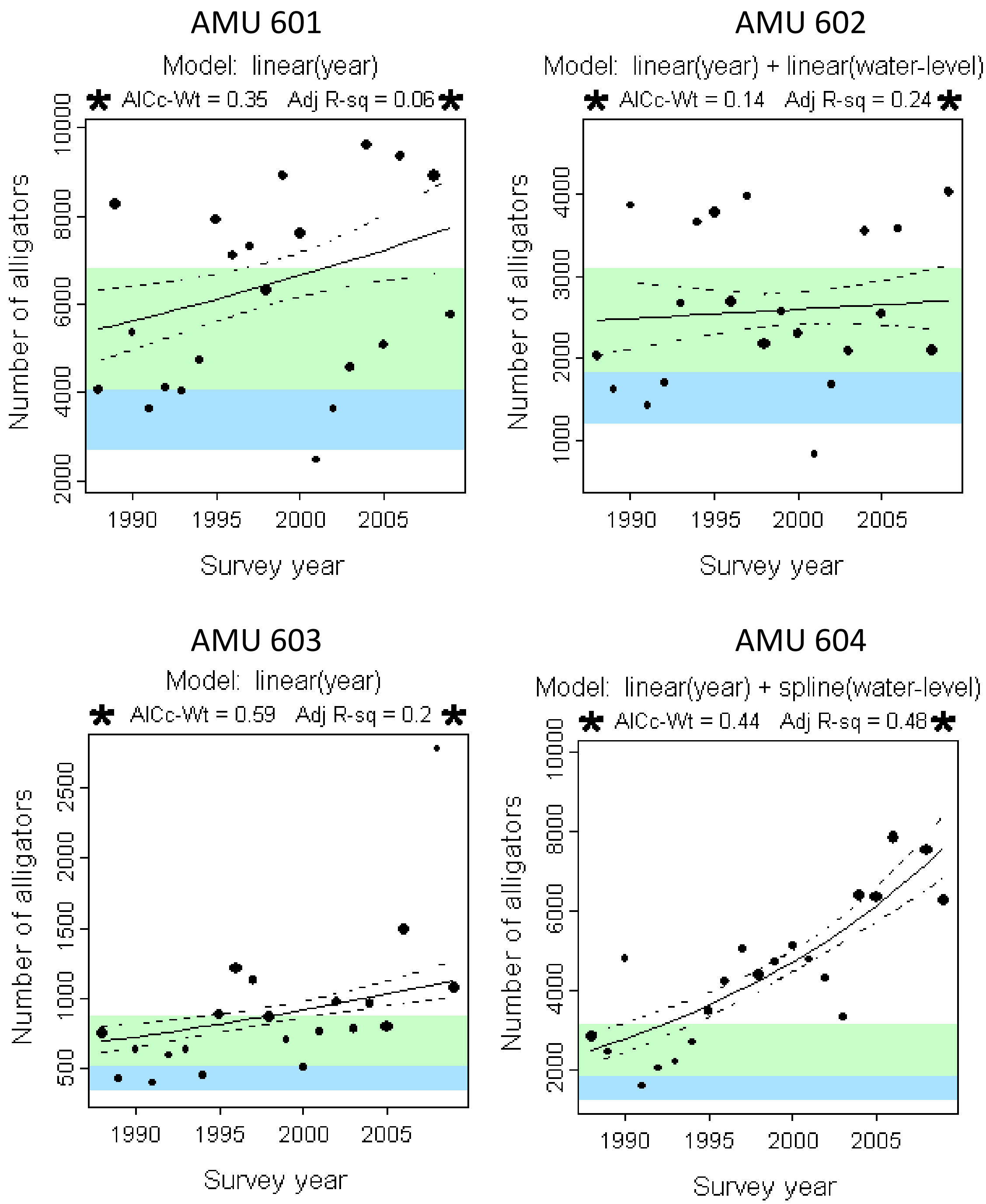
AMU	Size Class	Trend ($p \leq 0.30$)	Beginning Pop. Est.	Ending Pop. Est.	% Change	GAM p-value of < -25%	GAM p-value of > +25%
601	Juveniles	Stable	7,781	4,546	-41.6	0.354	0.876
601	Adults	Stable	5,447	7,722	41.8	0.994	0.287
601	Bulls	Stable	1,820	1,110	-39	0.351	0.769
601	Total	Stable	14,156	12,472	-11.9	0.675	0.809
602	Juveniles	Stable	2,645	1,219	-53.9	0.31	0.895
602	Adults	Stable	2,467	2,705	9.7	0.943	0.633
602	Bulls	Stable	845	820	-2.9	0.876	0.685
602	Total	Stable	6,509	3,813	-41.4	0.267	0.974
603	Juveniles	Stable	760	482	-36.6	0.427	0.812
603	Adults	Increased	694	1,128	62.5	1	0.06
603	Bulls	Increased	354	1,125	217.3	0.986	0.015
603	Total	Stable	1,113	1,492	34.1	0.988	0.367
604	Juveniles	Decreased	7,832	3,436	-56.1	0.141	0.935
604	Adults	Increased	2,501	7,575	202.9	1	0
604	Bulls	Stable	1,156	1,186	2.6	0.967	0.518
604	Total	Stable	7,997	4,225	-47.2	0.293	0.832

AMU – alligator management unit
GAM – generalized additive model



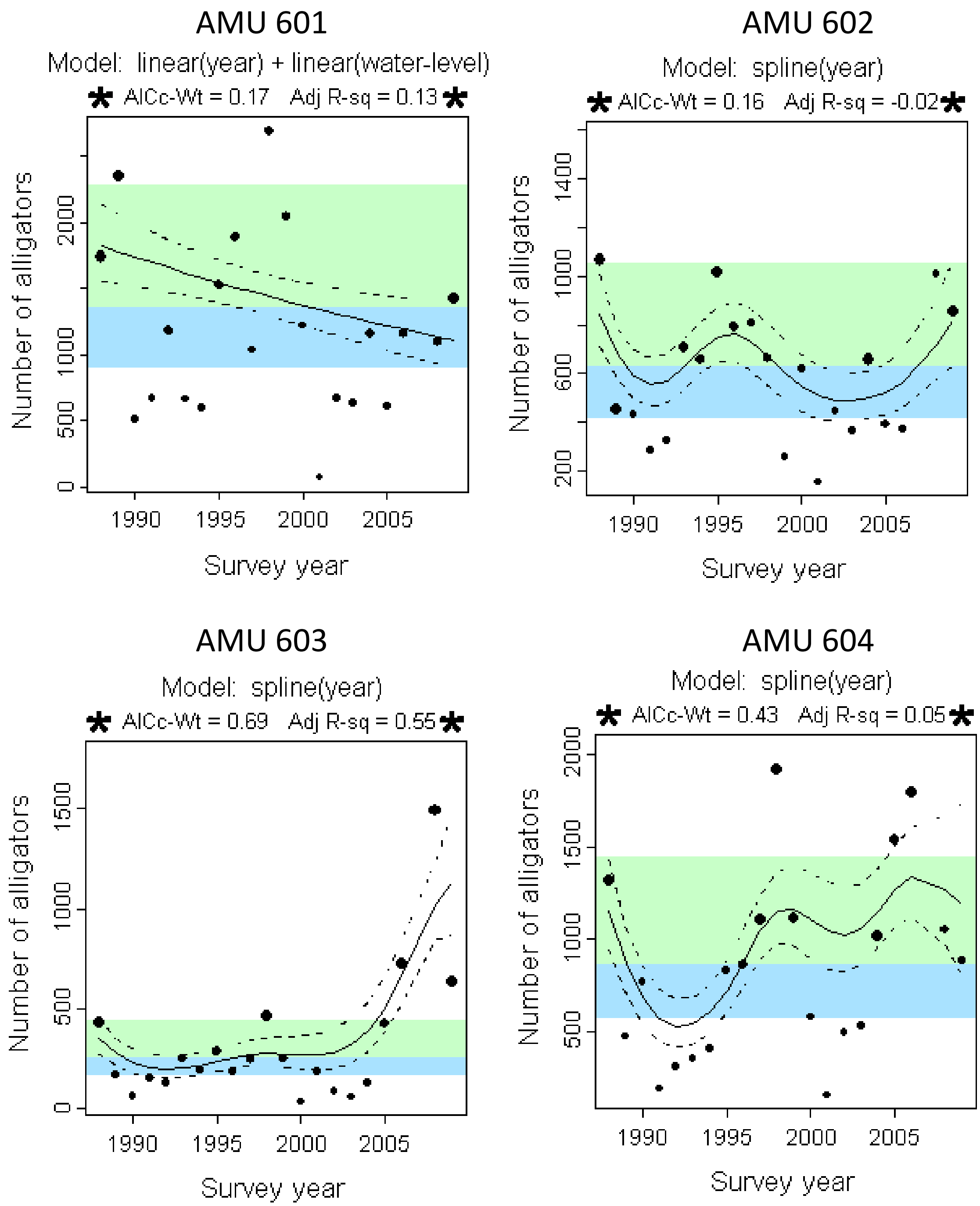
Green horizontal zone: +/-25% of the estimated beginning population.
Lower edge of the blue horizontal zone: -50% of the estimated beginning population.
Dashed lines: pointwise 70% confidence bands for the trend lines.

Figure 10-51. Estimated populations of juvenile [0.3-1.4 meters (m)] alligators in Lake Okeechobee Alligator Management Units (AMUs) based on night-light surveys conducted from 1988–2009.



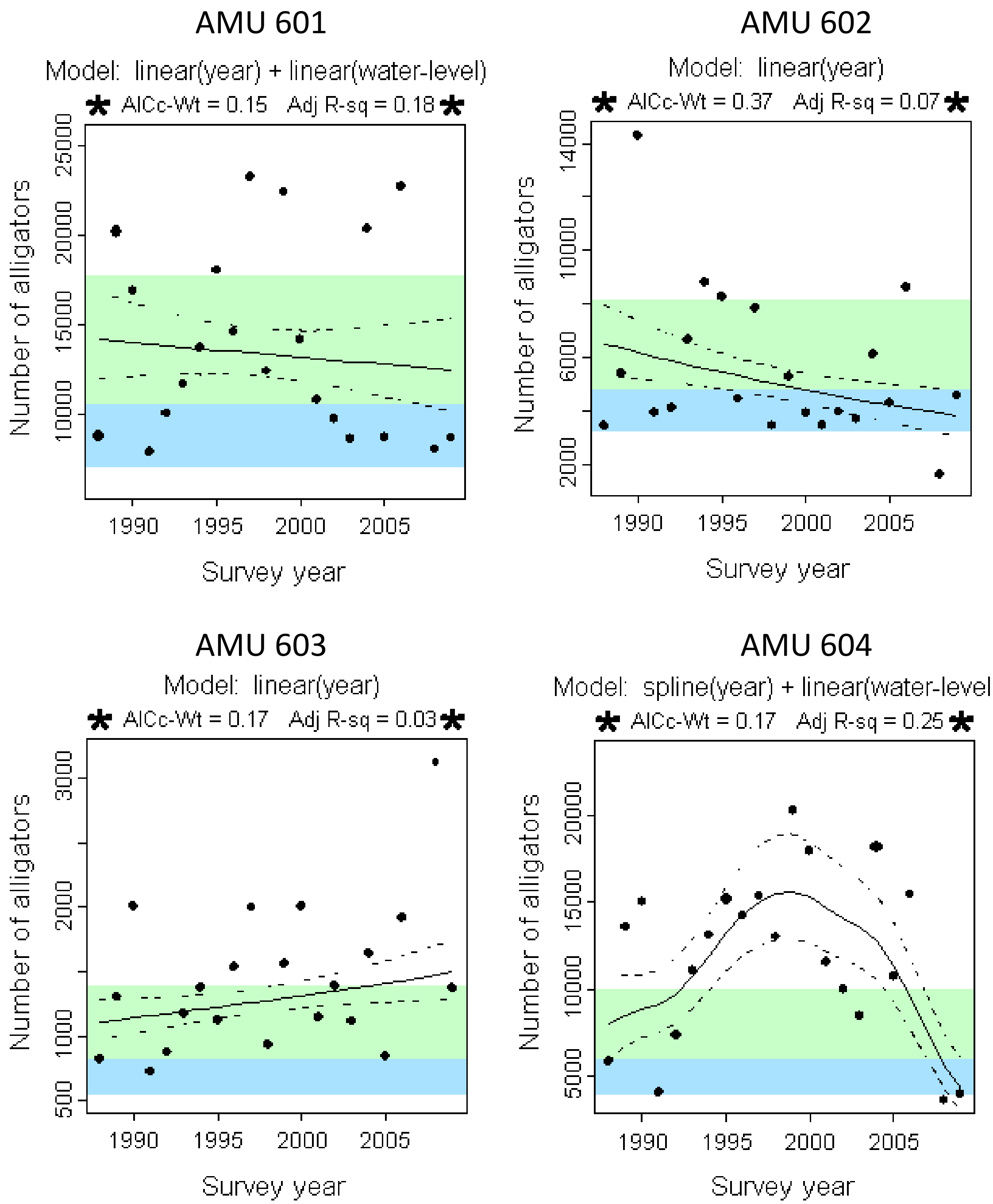
Green horizontal zone: +/-25% of the estimated beginning population.
Lower edge of the blue horizontal zone: -50% of the estimated beginning population.
Dashed lines: pointwise 70% confidence bands for the trend lines.

Figure 10-52. Estimated populations of adult (≥ 1.8 m) alligators in Lake Okeechobee AMUs based on night-light surveys conducted from 1988–2009.



Green horizontal zone: +/-25% of the estimated beginning population.
Lower edge of the blue horizontal zone: -50% of the estimated beginning population.
Dashed lines: pointwise 70% confidence bands for the trend lines.

Figure 10-53. Estimated populations of bull (≥ 2.7 m) alligators in Lake Okeechobee AMUs based on night-light surveys conducted from 1988–2009.



Green horizontal zone: +/-25% of the estimated beginning population.
Lower edge of the blue horizontal zone: -50% of the estimated beginning population. Dashed lines: pointwise 70% confidence bands for the trend lines.

Figure 10-54. Estimated total populations of alligators in Lake Okeechobee AMUs based on night-light surveys conducted from 1988–2009.

WADING BIRDS

Wading birds are an integral part of the freshwater ecosystems of South Florida and have long been used as a measure of ecological integrity (see also Chapters 6 and 11 of this volume). Lake Okeechobee historically supported large numbers of nesting wading birds, but the numbers have declined over the past three decades. In 1978, changes to the Lake Okeechobee Regulation Schedule began to allow higher lake stages, for example, an increase up to 17.5 ft. Wading birds are highly sensitive to changes in hydrology, especially during the breeding season. Higher lake levels reduce prey availability and wading bird access to critical foraging habitat in the littoral zone (David, 1994). The response by birds to these changes in hydrology and food resources was immediate and resulted in the severe decline of nesting effort in Lake Okeechobee over the following decades. In 2008, the Lake Okeechobee Regulation Schedule was modified to a lake stage envelope more conducive to wading bird nesting.

Wading Bird Surveys

The District began monitoring wading bird foraging (after the 2008 regulation schedule was implemented) in Lake Okeechobee's littoral zone to assess whether ecological conditions were adequate to support wading bird reproduction. This monitoring effort provided water managers with baseline information regarding the effects of hydrological changes on wading bird use of the lake.

Methods

Wading birds were surveyed along east-west transects established at 2 kilometer (km) intervals throughout the entire littoral zone of Lake Okeechobee (**Figure 10-55**). Each month, from January–May 2010, all 29 transects were flown by helicopter to determine the number of long-legged wading birds foraging in the lake throughout the dry season.

One observer on each side of the helicopter would survey 1 km of the 2 km strip transect so that the entire littoral zone was surveyed for foraging birds. When a group of foraging wading birds ($\geq$ 50 birds) was detected, the helicopter would circle the location so the number and species of birds could be counted. A global positioning system (GPS) coordinate was recorded to locate the foraging area on a map and to correlate this location to water depth conditions. Hydrology data were obtained from the District's DBHYDRO database.

Results

In December 2009, lake stage was at 13.5 ft NGVD and remained at this water depth without much fluctuation until early March 2010 (**Figure 10-56**). January, February, and March 2010 surveys indicated that prey availability in the lake was high and thousands of wading birds were foraging primarily in the lake's littoral zone to prepare for the onset of the nesting season. Foraging flocks were mixed, with the dominant species usually being either great egret (*Casmerodius albus*) or white ibis (*Eudocimus albus*). Mixed-species flocks were found most often in water depths less than 1 ft and these flocks were highly correlated with water depth.

As of March 11, 2010, South Florida began experiencing wetter than normal conditions and the lake stage began to climb steadily (**Figure 10-56**). A foraging survey conducted immediately following the onset of wet conditions in March measured a decline of foraging activity by more than half. Species composition of the foraging flocks that were located in April and May had shifted almost exclusively to great egrets. As lake stage increased to over 14 ft NGVD, water depths almost everywhere in the lake exceeded the maximum foraging depth for smaller herons. The occurrence of wet conditions at the beginning of wading bird breeding season had serious ramifications for nesting efforts in the lake.

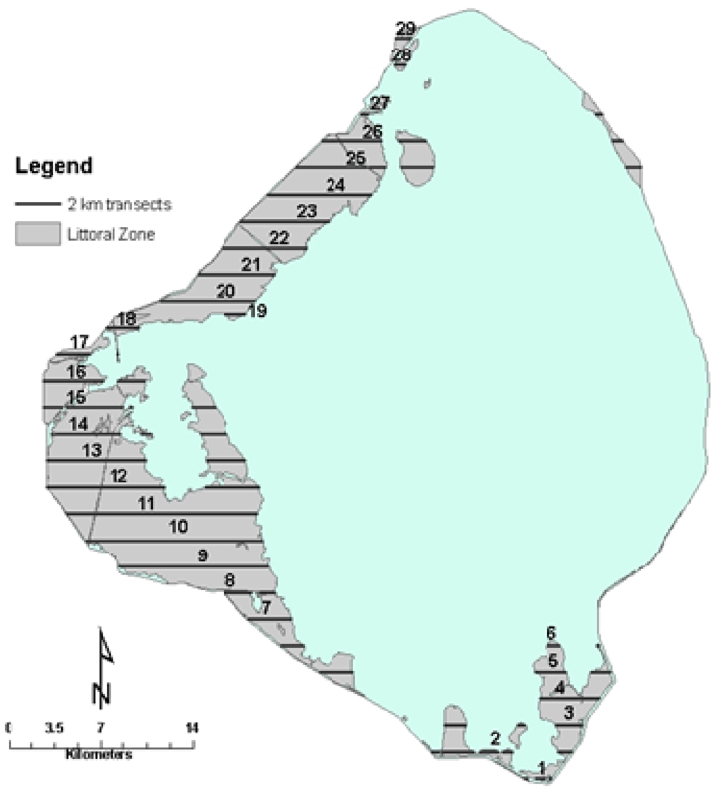


Figure 10-55. Map of wading bird foraging transects that were surveyed on Lake Okeechobee from January to May 2010.

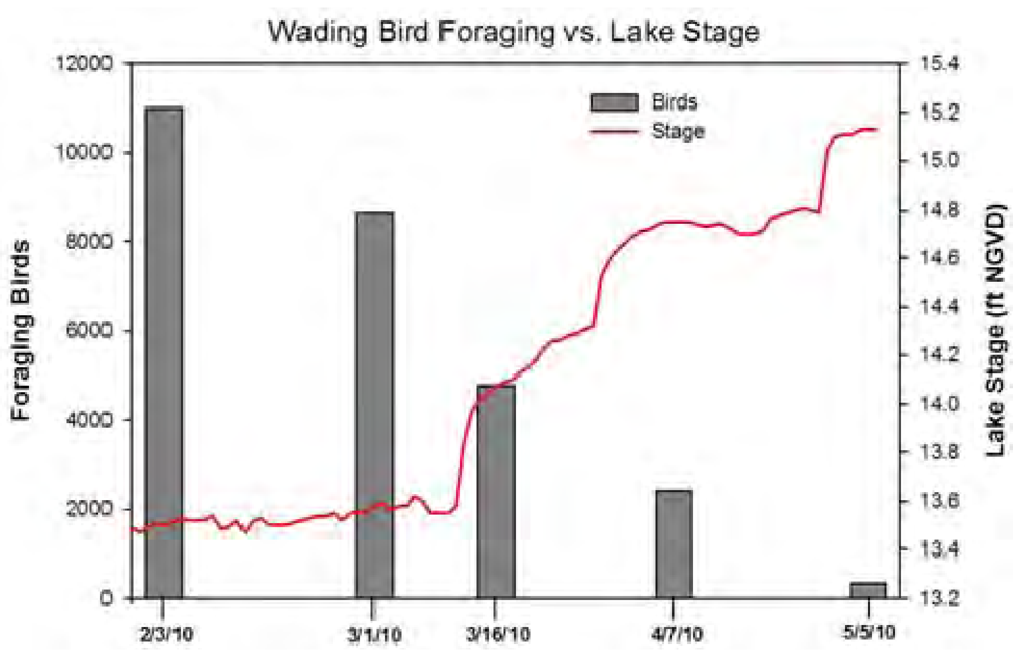


Figure 10-56. The number of foraging wading birds in relation to lake stage (ft NGVD) in Lake Okeechobee throughout the 2010 dry season (February–May).

IN-LAKE MANAGEMENT

SEDIMENT MANAGEMENT

Internal Phosphorus Management

NEEPP required a study to examine the engineering, ecological, and economic feasibility of removing or treating internal phosphorus loads. If treating internal loads was determined to be feasible, then the SFWMD was directed to pursue design, funding, and permitting of such a project. The feasibility study was completed in 2003, and it was determined that sediment removal would not be effective in reducing internal phosphorus loads.

Habitat Creation / Vegetation Mapping

Low water levels in 2007 provided a management opportunity to effectively scrape muck sediments from several nearshore regions of the lake (James and Zhang, 2008). A second type of sediment management project was conducted in 2008 on a 40-acre site located adjacent to Indian Prairie canal in the lake's northwest littoral zone. The purpose of this project was to evaluate the effectiveness of tilling the surface organic layer into the underlying sand substrate as a mechanism for reducing the surficial total and extractable phosphorus levels and reducing internal phosphorus loading (Zhang et al., 2009). As lake waters quickly rose to average conditions in August 2008, further muck removal was put on hold pending a return to lower water levels.

The long-term effects that scraping or tilling surface soils have on the marsh seed bank and ultimately the marsh landscape were uncertain. Thus, vegetation maps were created for the areas where the two types of sediment management techniques were implemented. The marsh landscapes inside the management areas were evaluated before (2006) and after (2009) scraping or tilling. Each vegetation map consists of multiple grids measuring 269 ft x 269 ft or 82 m x 82 m (1.67 acres or 0.68 ha). The dominant or co-dominant plant species were identified inside each grid and temporal changes within a site were quantified.

Scraped Site

The pre–post comparison at the Harney Pond East site illustrates a common pattern reported for other scraped sites. Prior to scraping, cattail was the most abundant emergent plant in Harney Pond East (**Figure 10-57**), covering 65 percent of the area (85 acres or 34.4 ha). American cupscale (*Sacciolepis striata*) and other grasses (8 acres or 3.2 ha) were the second most common plant community and 29 percent of the site (38 acres or 15.4 ha) had no emergent plants. Two years after scraping, the native plants spikerush and smartweed (*Polygonum hydropiperoides*) covered 73 and 35 acres (29.5 and 14.2 ha, respectively) of the management area, respectively. Cattail mostly disappeared but South America watergrass (*Luziola subintegra*), an exotic water grass, started to aggressively invade regions of Fisheating Bay, including part of the scraped management area. At the time aerial images were collected in 2009, *Luziola* had been treated chemically inside 11 grids (18 acres, or 7.3 ha).

Tilled Site

Plant communities were evaluated inside 13 grids (21.7 acres or 8.8 ha) at a tilled site located adjacent (south) to the Indian Prairie canal (**Figure 10-58**). Two years prior to tilling (pre-drought), cattail was the dominant plant species and covered most of the management area. Just prior to tilling, the drought resulted in a major change of the ground cover to primarily smartweed, with low-density patches of macrophytes such as cattail and bulrush, and shrubs such as willow (*Salix* sp.) and primrose willow (*Ludwigia* sp.). Two years after tilling (2010), the area was much wetter with the prominent species being the desirable fragrant water lily (*Nymphoides* or *Nymphaea*) and emergent bulrush. Cattail coverage was low.

Fish and Wildlife Habitat

Fish and wildlife habitat improved following scraping or tilling. The quantified changes in landscape coverage were, in part, the result of management activity. Hydrologic conditions also influenced plant community composition and distribution. Thus, temporal landscape changes in these and other management areas to determine the long-term effects of these sediment management practices on the lake's fauna and flora will continue to be monitored.

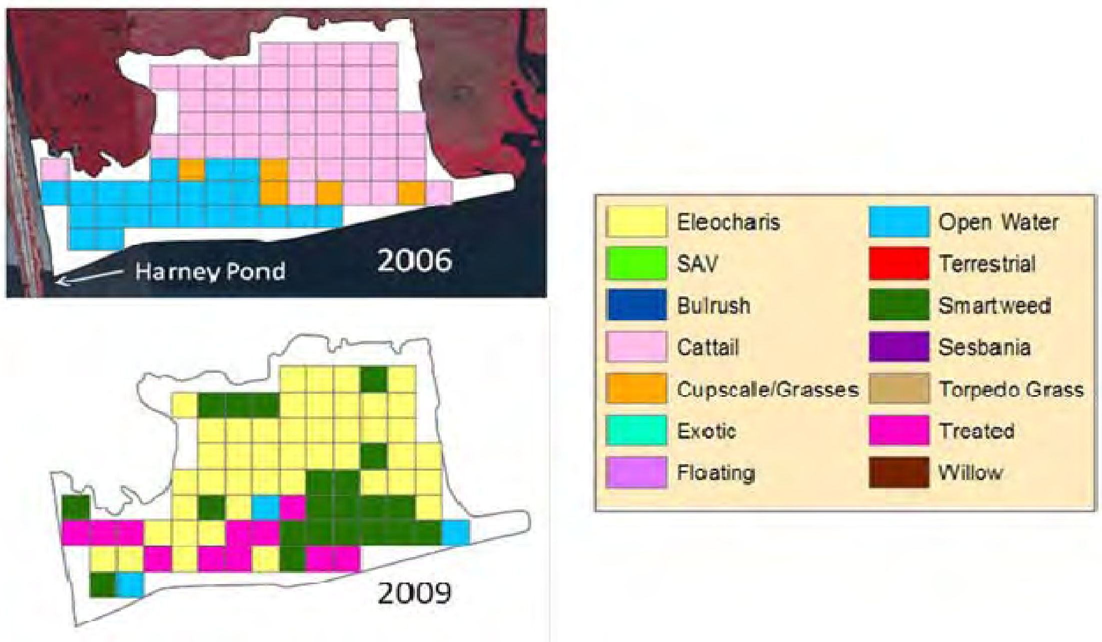


Figure 10-57. Dominant vegetation in the Harney Pond East management area in 2006 (pre-scrape) and in 2009 (two years post-scrape).

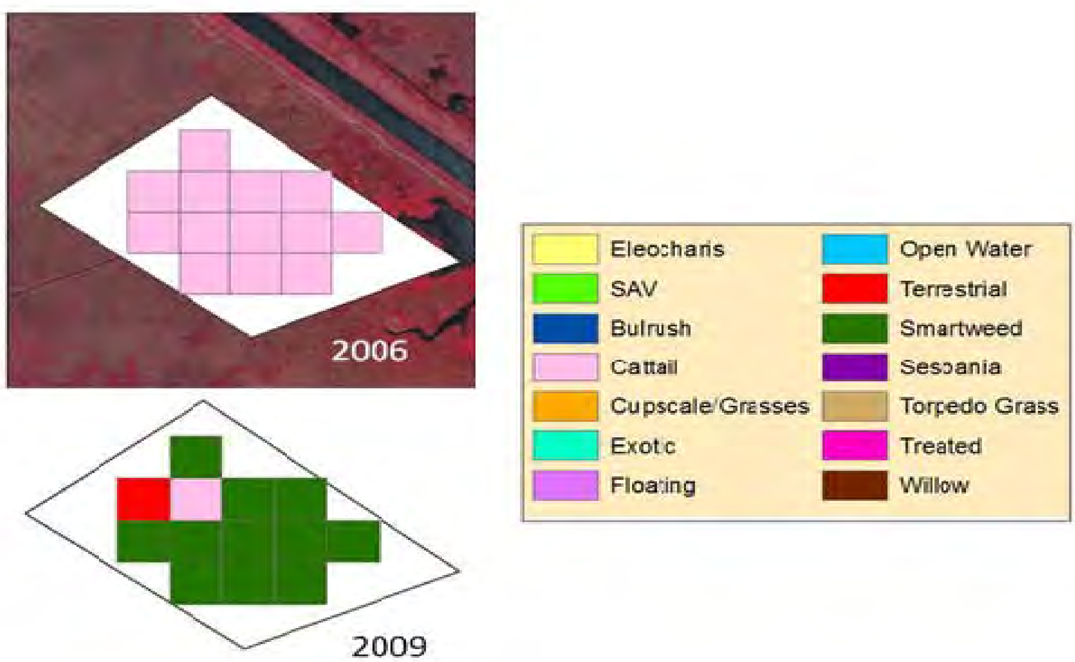


Figure 10-58. Dominant vegetation in the Indian Prairie Canal site in 2006 (pre-till) and in 2009 (two years post-till).

LAKE ISTOKPOGA

The distribution and areal coverage of SAV on Lake Istokpoga was evaluated during spring 2009. The lake was equally divided into 501 grids measuring 500 m x 500 m. The presence or absence of plants near the center of each grid was recorded and was considered representative of the whole grid. SAV occurred in 197 of the 475 accessible grids (40 percent) (**Figure 10-59**). The most common SAV were the exotic species hydrilla (*Hydrilla verticillata*) and the native plant eelgrass. Hydrilla was found in 66 percent of the vegetative sites while eelgrass was observed in 53 percent of the sites. Other less common plants included coontail (*Ceratophyllum* spp.), bladderwort (*Utricularia* spp.), pondweed (*Potamogeton illinoensis*), and water nymph (*Najas* spp.). These plants were found in 5–16 percent of the sites containing SAV.

Lake sediment samples were collected near the center of each grid at the same time SAV was evaluated. The type of sediment collected was considered representative of the grid. The lake's sediment consists mostly of sand (52 percent) and mud (47 percent). A small area of peat also is present near the south shore (**Figure 10-60**).

Hydrilla first became a problem in Lake Istokpoga in the late 1980s. Since that time more than 25,000 acres of the invasive exotic plant have been treated. Most recently, 1,200 acres of hydrilla were treated primarily in the north and northeast region of the lake in November 2009 (**Figure 10-61**), and 644 acres were treated near the central and southern islands and along the south and southwest shore in April 2010.

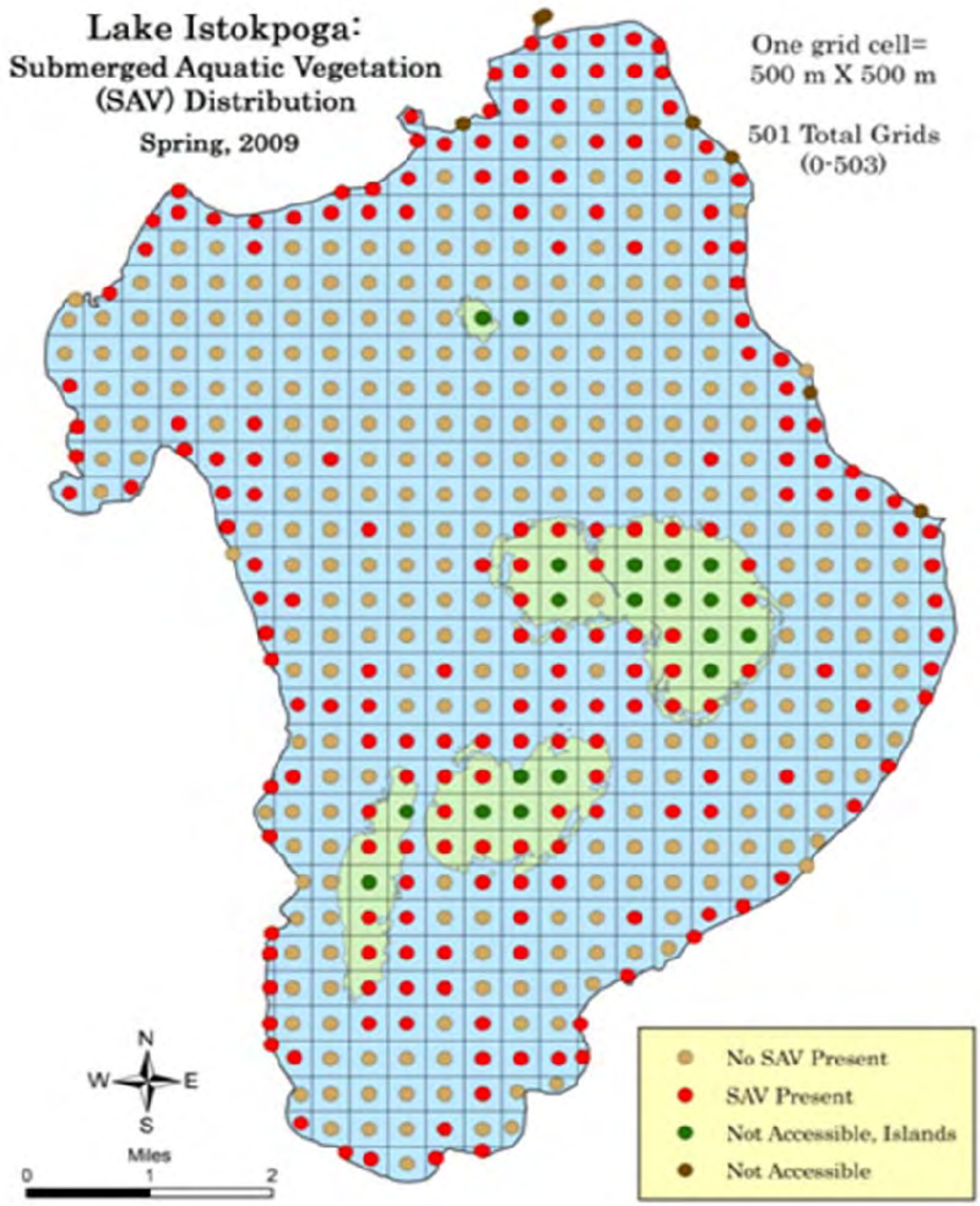


Figure 10-59. Location of grids containing SAV in Lake Istokpoga in 2009. SAV was present in 40 percent of the sampled grids.

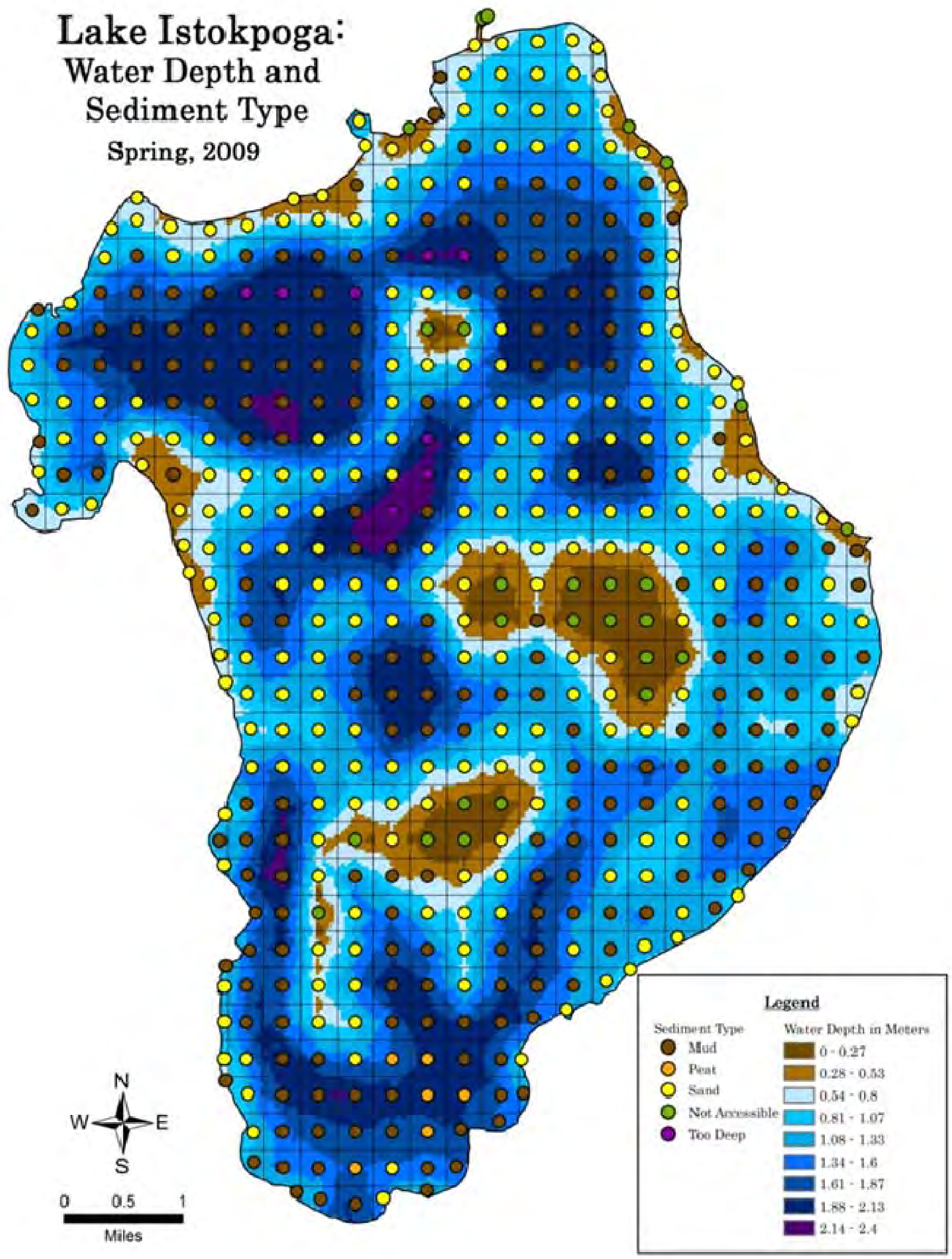
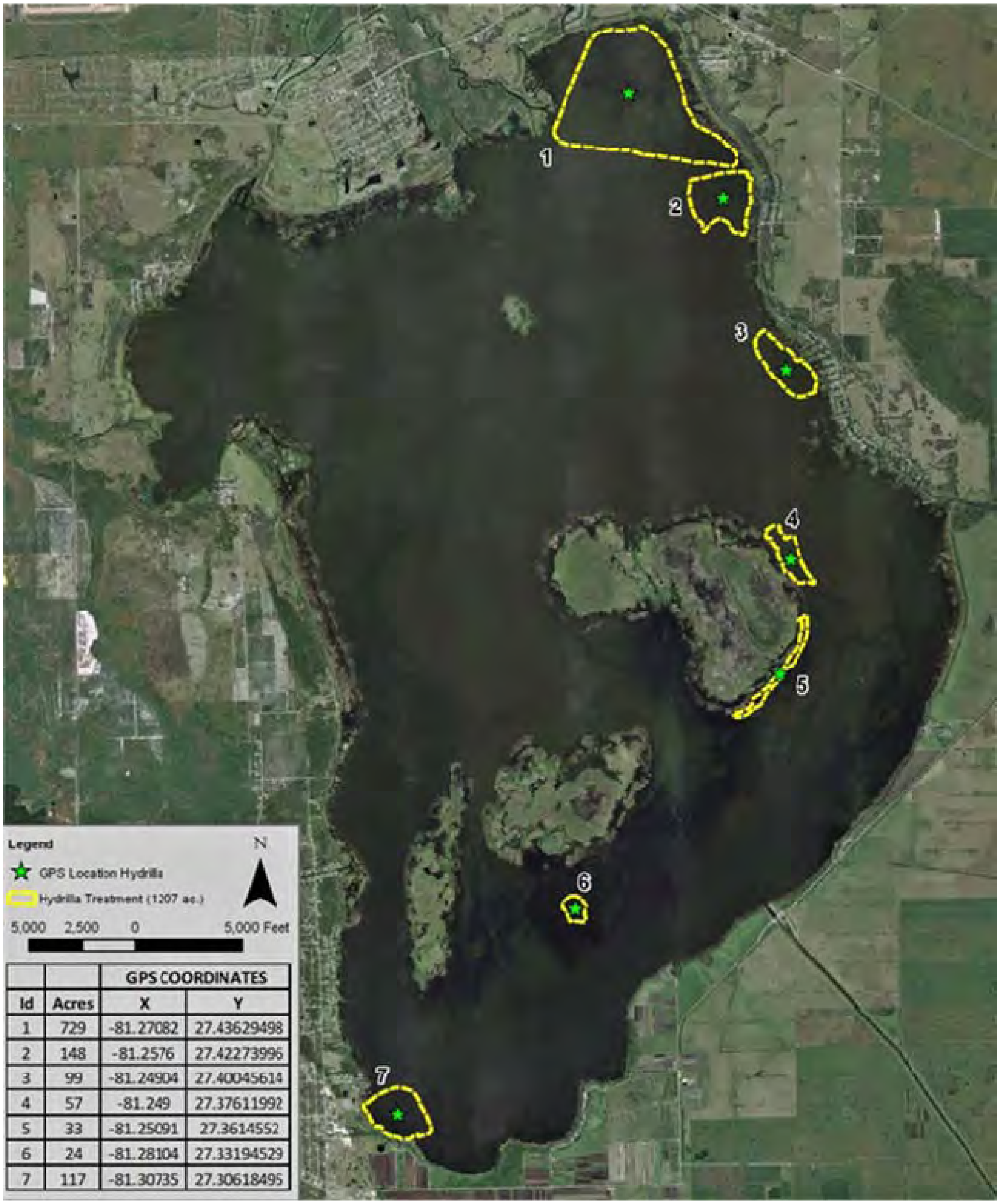


Figure 10-60. The location of sand, mud, and peat in Lake Istokpoga, 2009.



		GPS COORDINATES	
Id	Acres	X	Y
1	729	-81.27082	27.43629498
2	148	-81.2576	27.42273996
3	99	-81.24904	27.40045614
4	57	-81.249	27.37611992
5	33	-81.25091	27.3614552
6	24	-81.28104	27.33194529
7	117	-81.30735	27.30618495

Figure 10-61. Location and size of treatments for hydrilla (*Hydrilla verticillata*) conducted in November 2009 within Lake Istokpoga. Data provided by the Florida Fish and Wildlife Conservation Commission.

CONCLUSIONS

Under NEEPP, a comprehensive array of state and federal projects have been undertaken within the watershed and in Lake Okeechobee to address the key issues of excessive phosphorus loading, harmful high water levels, and exotic plants. Considerable progress has been made to control the spread of exotic plants in the lake and projects have been implemented at the basin, sub-basin, and farm scales to reduce phosphorus transport from the watershed and capture runoff during high rainfall periods. While many of these projects are still at the pilot stage, early results show that several technologies have the ability to control phosphorus loading if deployed regionally and sited strategically.

Because of the complex nature and long history of problems associated with the lake and its watershed, full implementation of NEEPP will require more than a decade. Clear evidence of resulting water-quality improvements in lake inflows are expected to require an even longer timeframe. Tracking the cumulative effects of various projects on watershed phosphorus loads is complicated by large inter-annual variation in rainfall, which controls discharge volumes and, therefore, phosphorus loading. Consequently, many years of monitoring likely will be required to detect statistically significant downward trends in phosphorus loading rates. Finally, sustained decreases of in-lake phosphorus concentrations are expected to be slowed by internal phosphorus recycling from the mud sediments that have accumulated within the lake. As reported in previous years, pilot studies conducted to date have yet to identify a feasible means of reducing these internal phosphorus loads.

Lake Okeechobee environmental conditions showed improvement in WY2010 since storm events in 2004 and 2005 and droughts in 2007 and 2008. Nutrient concentrations have declined to near pre-hurricane levels as sediments resuspended by the 2004–2005 hurricanes continue to consolidate. SAV has increased to pre-hurricane conditions, highlighting the resilient nature of this community. Fish populations have increased. The macroinvertebrate community has improved. Neither stocking of largemouth bass nor Florida apple snails has shown definitive improvements, but indications are such that further work would be beneficial.

Despite several encouraging trends, many of the metrics used to assess lake conditions remain below acceptable levels. Overall, the water-quality and ecological trends documented over the past several years illustrate the susceptibility of the lake to natural and human disturbances, the resilience of the lake ecosystem, and the long-term nature of current plans to reduce phosphorus and improve lake-level management. Emerging issues such as the identification of new exotic invasive plant species in the lake’s littoral zone highlight the need for an adaptive approach to lake management as these long-term efforts proceed.

APPROPRIATIONS/EXPENDITURES

The FY2001–FY2010 summary of state of Florida funding appropriations and expenditures for the Lake Okeechobee Protection Program is presented in **Table 10-19**. FY2010 values reflect preliminary financial information as of September 30, 2010.

Table 10-19. State funding appropriations and expenditures for the Lake Okeechobee Watershed Protection Program (FY2001–FY2010). Note: FY2010 financial data are preliminary as of September 30, 2010.

Appropriation Year	SFWMD Appropriation	Expended to date	Available
FY2001 SFW11 (1519G)[1] (Orig. $8,500,000, balance of $21,428 returned to state)	$8,478,572	$8,478,572	0
FY2001 SFW12 (1591G)	$15,000,000	$15,000,000	0
FY2001 SFWMD Total	**$23,478,572**	**$23,478,572**	**$0**
FY2002 SFSWP1 (1748)	$10,000,000	$10,000,000	0
FY2002 SFWMD Total	**$10,000,000**	**$10,000,000**	**$0**
FY2003 DEP TMDL Implementation Funds	$850,000	$850,000	0
FY2003 SFW31 (1769) grant 42	$7,500,000	$6,480,087	$1,019,913
FY2003 SFWMD Total	**$8,350,000**	**$7,330,087**	**$1,019,913**
FY2005 SFW51 – Nubbin Slough G44	$4,300,000	$1,901,877	$2,398,123
FY2005 SFW61 grant 46	$5,000,000	$1,919,692	$3,080,308
FY2005 – FDEP Nubbin Slough/Lk Okeechobee Fast Track G3	$3,300,000	$1,417,504	$1,882,496
FY2005 – Hydromentia	$1,800,000	$1,800,000	0
FY2005 SFWMD Total	**$14,400,000**	**$7,039,073**	**$7,360,927**
Fast Track Projects - Reimbursable Expenditures G4	$25,000,000	$24,238,994	$761,006
101 Ranch 17.2 Acre Reservoir	$42,000	$42,000	0
C&B Farms Trail Water Recovery	$93,600	$93,600	0
101 Ranch 44 Acre Reservoir	$30,864	$30,864	0
Stormwater Irrigation	$51,920	$51,920	0
FY2006 Sub Basin Monitoring Network	$225,000	$225,000	0
FY2006 SFWMD Total	**$25,443,384**	**$24,682,378**	**$761,006**
FY2007 Hydromentia – Algae Turf Scrubber® – FDEP G41	$750,000	$750,000	0
FY2007 Hydromentia – Algae Turf Scrubber® – FDACS G39	$221,610	$221,610	0
Fast Track Projects – Reimbursable Expenditures G66	$24,925,000	$24,925,000	0
Community Budget Issue Requests(CBIR) – Taylor Creek PL566 & Alternative Storage/Disposal of Excess Water G47	$6,200,000	$3,558,311	$2,641,689
FY2007 Cody's Cove & Eagle Bay Grant 52	$2,478,548	$2,478,548	0
Indiantown Citrus Growers Association G54[2] (Orig. $287,808, balance of $19,955 returned to state)	$267,853	$267,853	0
Raulerson & Sons Ranch Stormwater Reuse AWS G56	$330,000	$330,000	0
FY2007 SFWMD Total	**$35,173,011**	**$32,531,322**	**$2,641,689**
FY2008 Sub Basin Monitoring Network	$225,000	$225,000	0
FY2008 SFWMD Total	**$225,000**	**$225,000**	**$0**
Grand Total – SFWMD State Appropriation – 221	**$117,069,967**	**$105,286,432**	**$11,783,535**
FY2001 FDACS Appropriation	$15,000,000	$15,000,000	0
FY2005 FDACS Appropriation	$5,000,000	$5,000,000	0
FY2005 FDEP Pahokee WWTP	$700,000	$700,000	0
FY2007 FDACS Appropriation	$3,900,000	$3,900,000	0
FY2008 FDACS Appropriation	$6,000,000	$6,000,000	0
FY2009 FDACS Appropriation	$3,000,000	$3,000,000	0
FY2010 FDACS Appropriation	$4,500,000	$4,500,000	0
Total Outside Agency State Appropriation	**$38,100,000**	**$38,100,000**	**$0**
Save Our Everglades Trust Fund – SA1741			
FY2008 NE – CAL-STL-LO – Grant 58	$2,623,146	$2,623,146	0
FY2008 NE – LOPP – Grant 59	$49,000,000		$35,829,431
LOFT – Lakeside Ranch STA		$8,010,774	
NE Water Storage Disposal Projects		$3,690,662	
Technical Plan		$1,469,133	
FY2008 Bio Wetland & Chem/Hybrid Technologies - Grant 62	$5,000,000	$3,525,000	$1,475,000
Total – Save Our Everglades Trust Fund – 412	**$56,623,146**	**$19,318,715**	**$37,304,431**
Total – Lake Okeechobee	**$211,793,113**	**$162,705,147**	**$49,087,966**

Notes:
[1] $21,428 returned to the state in 2010.
[2] Reimbursement grant expired March 2010; and the balance of $19,955 returned to the state in 2010.

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