Chapter 8: Lake Okeechobee Protection Program

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SUMMARY

Lake Okeechobee is the largest lake in the southeastern United States. The lake is shallow, turbid, and eutrophic, and it is a central component of the hydrology and environment of South Florida. Lake Okeechobee supplies water for nearby towns, agriculture, and downstream ecosystems, and provides flood control for surrounding areas. 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 *2012 South Florida Environmental Report* (SFER) – *Volume I* provides the Water Year 2011 (WY2011) (May 1, 2010–April 30, 2011) 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 total phosphorus (TP) 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), United States Army Corps of Engineers (USACE), 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 it provides, while maintaining other societal functions such as water supply and flood control.

Despite a FDEP Dairy technology-based rule and a performance-based regulatory program for a portion of the watershed, 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.). The LOPA also requires the coordinating agencies — District, FDACS, and FDEP — to work together to address TP loading and exotic species control. The LOPA was subsumed in 2007 by the NEEPP.

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WATERSHED UPDATES

The Lake Okeechobee Watershed Protection Program is being implemented as part of the NEEPP, which promotes a comprehensive, interconnected watershed approach to protecting the lake and its downstream estuaries (Caloosahatchee and St. Lucie). The watershed protection program is a cooperative effort between the District, FDEP, and FDACS and is currently being implemented. This program addresses pollutant loading reductions, natural hydrology restoration, and applicable state water quality standards compliance.

Major developments and accomplishments under the Lake Okeechobee Watershed Protection Program during WY2011 include the following:

1. The NEEPP requires that the Lake Okeechobee Watershed Protection Plan be updated every three years. The plan update was completed in March 2011 (SFWMD et al., 2011).
2. TP load to the lake from all drainage basins and atmospheric deposition was 177 metric tons (mt) in WY2011, which is 301 mt less than WY2010. The loading during this past water year was low in comparison to other water years and it is most likely a result of lower flows due to the drought conditions in WY2011. The current five-year average (WY2007–WY2011) was 352 mt, which is still 2.5 times greater than the 140 metric tons per year (mt/yr) Total Maximum Daily Load (TMDL).
3. Numerous efforts have begun under the Lake Okeechobee Watershed Construction Project, including (1) the Chemical Treatment Pilot Project Phase II study to conduct an implementation cost and site selection analysis for TP removal technologies; (2) the hybrid wetland treatment technology (HWTT), which represents a combination of chemical and wetland treatment technologies to remove TP at sub-basin and farm scales; (3) the Lakeside Ranch Stormwater Treatment Area Phase I construction, which is designed to remove P from stormwater runoff in the Taylor Creek/Nubbin Slough Basin before it enters Lake Okeechobee; (4) the Fisheating Creek Feasibility Study, which is identifying potential locations for TP removal and water storage; (5) the Taylor Creek Site Feasibility Study to develop a preferred plan for water quality and storage options for the Taylor Creek/Grassy Island property; and (6) the Watershed Assessment Model (WAM) documentation and application.
4. Research and assessment projects completed during WY2011 were (1) Wetland Soils Nutrient Criteria Development and Evaluation of “Safe” Soil Phosphorus Storage Capacity; (2) WAM Documentation and Validation, (3) Nutrient Budget Analysis for the Lake Okeechobee Watershed; (4) Evaluation of Cow-calf Water Quality Best Management Practices (BMPs); and (5) Lake Istokpoga Environmental Evaluation and Vegetation Mapping. Ongoing projects include (1) WAM Applications in the Lake Kissimmee Sub-watershed; (2) continued operation and evaluation of the five HWTT projects; (3) New Alternative Treatment Technologies (NATA); and (4) Permeable Reactive Barrier Technology (PRBs).
5. In support of Chapter 40E-61, Florida Administrative Code (F.A.C.) and 2007 NEEPP amendments, the District continues to develop technical documents to establish performance measures for collective source control programs in the Lake Okeechobee Watershed. This effort is captured within Chapter 4 of this volume of the SFER.

The flow of water to Lake Okeechobee was 0.933 million acre-feet (ac-ft) or about 1,151 million cubic meters (m^3) in WY2011, which is 38 percent of the baseline average (calendar years 2001–2009) of 2.433 million ac-ft or about 3,000 million m^3. Lake stage at the beginning of WY2011 was 15.13 feet National Geodetic Vertical Datum of 1929 (ft NGVD) or 4.6 meters (m). Despite some small reversals during the summer, pulse releases to both the St. Lucie and Caloosahatchee estuaries brought the lake into the beneficial use sub-band by mid-December

2010. Environmental releases to the Caloosahatchee River commenced at the end of January 2011 and continued through mid-March. The lake ended WY2011 in the water management sub-band at an elevation of 10.96 ft NGVD. Detailed information on regional hydrology during WY2011 is presented in Chapter 2 of this volume.

ECOLOGY

Submerged aquatic vegetation (SAV) in Lake Okeechobee declined from more than 46,000 total acres (ac) in 2009 to 27,388 ac in 2010. However, the proportion of the SAV community consisting of vascular species, which are generally preferred as habitat over the macroalga chara (*Chara* spp.), increased. The decline in SAV coverage relative to 2009 appears to be related to generally lower lake stages resulting from both the implementation of the Lake Okeechobee Regulation Schedule (LORS 2008) interim lake operating schedule and recent dry conditions, which resulted in the replacement of SAV by meadows of spike rush (*Eleocharis* spp.) and other emergent plants. As these plants generally provide excellent aquatic habitat, the shift from SAV to emergent vegetation probably will not negatively impact lake ecology.

In general, the faunal component of the lake ecosystem appears to be in good condition. Both nearshore and pelagic zone sport fish and forage fish populations continue to recover from the effects of the 2004–2005 hurricanes, including modest improvements in the black crappie (*Pomoxis nigromaculatus*) population whose recovery has lagged relative to other important lake species. Wading bird use of the lake for foraging was high this year and generally increased during the course of the winter and spring as water levels declined, and perhaps as foraging opportunities in the surrounding area disappeared due to the ongoing drought conditions. Wading bird nesting on the lake was also quite successful with approximately 5,600 nests identified in ten colonies. These numbers were similar to the values for the preceding nesting season, which was the seventh best in the 30 years monitored since 1957. Little herpetofaunal data was acquired during the current reporting period due to a lack of available technical expertise in the early part of the monitoring period, and low lake stage conditions that left many of the monitoring sites inaccessible during the latter portion of the monitoring period.

Due to the prolonged low lake stages that characterized the end of this water year, it is probable that native apple snail populations in the lake's littoral zone experienced significant mortality. In response, a pilot project was begun in the Lemkin Creek isolated wetland to develop a cost-effective method for producing apple snail eggs on artificial substrates for use in stock enhancement in the lake. Low lake stages provided an opportunity to plant over 5,000 cypress (*Taxodium distichum*), pond apple (*Annona glabra*), and red maple (*Acer rubrum*) trees in Lakes Okeechobee and Istokpoga to improve habitat for birds, fish, and other wetland organisms.

LAKE ISTOKPOGA

Annual monitoring of SAV was performed in Lake Istokpoga in spring 2010. It occurred in 206 of the 475 sampled grids (43 percent). The most commonly observed plants included hydrilla (*Hydrilla verticillata),* an invasive exotic, and the native eelgrass (*Vallisneria americana*). Other observed, but less common species, included bladderwort (*Utricularia* spp.), pondweed (*Potamogeton illinoensis*), naiad (*Najas* spp.), and coontail (*Ceratophyllum* spp.).

INTRODUCTION

Lake Okeechobee (located at 27° North latitude and 81° West longitude) is a central part of the South Florida watershed and the United States Army Corps of Engineers (USACE) regional flood control project. The lake has a surface area of 445,560 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). Lake Okeechobee receives water from a 5,400 square mile (14,000 km^2) watershed that includes four distinct tributary systems: Kissimmee River Valley, Lake Istokpoga–Indian Prairie/Harney Pond, Fisheating Creek, and Taylor Creek/Nubbin Slough. With the exception of Fisheating Creek, all major inflows to Lake Okeechobee are controlled by gravity-fed or pump-driven water control structures (**Figure 8-1**). These four major tributary systems are generally bound by the drainage divides of the major water bodies and are further divisible into nine sub-watersheds based on hydrology and geography.

The nine sub-watersheds of the Lake Okeechobee Watershed are Upper Kissimmee, Lower Kissimmee, Taylor Creek/Nubbin Slough, Lake Istokpoga, Indian Prairie, Fisheating Creek, Eastern Lake Okeechobee (C-44/L-8 Basin), Western Lake Okeechobee (C-43 Basin), and Southern Lake Okeechobee [includes Everglades Agricultural Area (EAA) and Chapter 298 Districts] (**Figure 8-1**). Each of these sub-watersheds is further divisible into basins based on hydrologic and/or geographic divides. The entire Lake Okeechobee Watershed can be divided into 61 such drainage basins, each draining downhill into a body of water, such as a river or lake.

The Upper Kissimmee, Lower Kissimmee, Taylor Creek/Nubbin Slough, Lake Istokpoga, Indian Prairie, and Fisheating Creek sub-watersheds primarily drain into Lake Okeechobee by gravity. The S-133 Basin (part of the Taylor Creek/Nubbin Slough Sub-watershed) and other urban areas can also pump water into the lake from the north. When high lake stages make gravity flows impossible, urban areas north of the lake are drained via pumps. The East and West Lake Okeechobee sub-watersheds contribute flow by gravity, but only when Lake Okeechobee water levels are below 14.5 ft and 11.5 ft in relation to the National Geodetic Vertical Datum of 1929 (NGVD), respectively.

Lake Okeechobee provides numerous services to diverse users with tremendous economic interest in its health and fate. The lake provides water supply to urban areas, agriculture, and downstream estuarine ecosystems. It supports multimillion-dollar sport and commercial fisheries, and various recreational activities. It also 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 provides a comprehensive update and discussion of lake and watershed conditions presented in Chapter 10 of the *2011 South Florida Environmental Report* (SFER) – *Volume I,* focusing on water quality, water levels, aquatic vegetation, and phosphorus (P) control activities. Results of recently completed research projects are presented, as well as the status for ongoing watershed and in-lake management projects. More information about the Kissimmee Chain of Lakes and the Kissimmee River can be found in Chapter 9 of this volume. Additional information on P source control programs and exotic species status in South Florida and are presented in Chapters 4 and 7 of this volume, respectively.

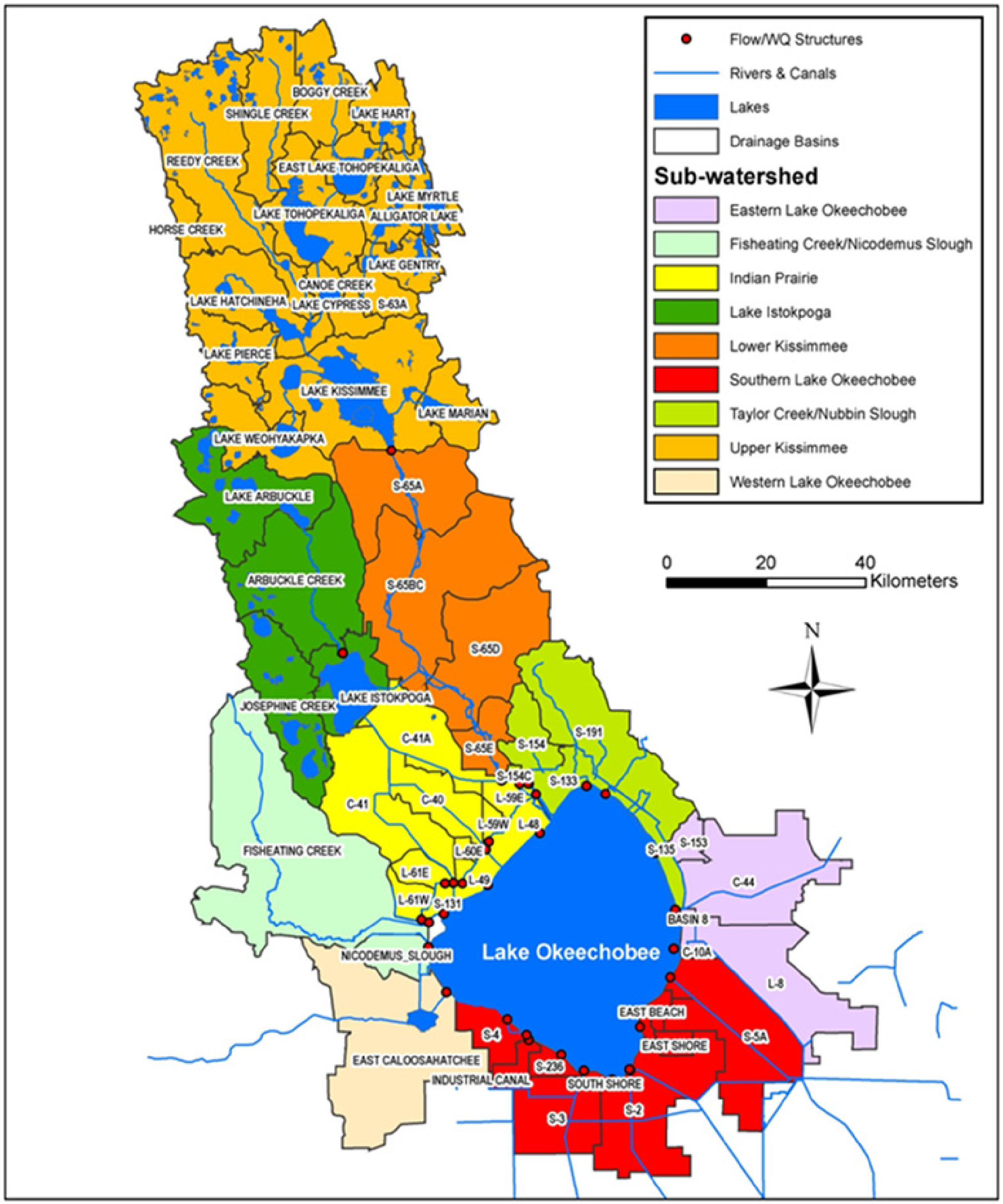

Figure 8-1. The Lake Okeechobee Watershed detailing sub-watersheds, major hydrologic features, and structure locations where total phosphorus loads were determined from tributary basins that drain into Lake Okeechobee (red dots).

OVERVIEW OF LAKE OKEECHOBEE WATERSHED PROTECTION PROGRAM

Passed in 2000, the Lake Okeechobee Protection Act (LOPA) [Section 373.4595, Florida Statutes (F.S.)] established 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 the LOPA with Section 373.4595, F.S., now known as the Northern Everglades and Estuaries Protection Program (NEEPP). The NEEPP promotes a comprehensive, interconnected watershed approach to protect the lake and the Caloosahatchee and St. Lucie rivers (SFWMD et al., 2008). The NEEPP includes the Lake Okeechobee, Caloosahatchee River, and St. Lucie River watershed protection programs. 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 and updates are presented in Appendices 10-1 and 10-2 of this volume. A cross-reference list for NEEPP reporting is provided in Appendix 8-1 of this volume.

The South Florida Water Management District (District or SFWMD), in cooperation with the Florida Department of Environmental Protection (FDEP) and Florida Department of Agriculture and Consumer Services (FDACS), known as the coordinating agencies, developed the Lake Okeechobee Protection Plan, which was submitted to the Florida legislature on January 1, 2004 (SFWMD et al., 2004). The plan was considered the best strategy, utilizing the best available technologically, to achieving the water quality goals, particularly for P, in Lake Okeechobee and its downstream receiving waters by 2015. The LOPA 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). Most recently, coordinating agencies completed the 2011 Lake Okeechobee Protection Plan update to fulfill the legislative requirement for the three-year update (SFWMD et al., 2011). The 2011 update focuses on the progress of the coordinating agencies in reducing TP loads consistent with the TMDL established for the lake, as well as increasing watershed storage to achieve healthier lake levels and to reduce harmful discharges to the estuaries.

The Lake Okeechobee Watershed Construction Project (LOWCP) Phase II Technical Plan was submitted to the Florida legislature in February 2008 as required by the NEEPP (SFWMD et al., 2008) and is currently being implemented. The technical plan identifies construction projects and on-site measures that prevent or reduce pollution at the source. These include implementation of the agricultural and urban Best Management Practices (BMPs), needed to achieve the TP TMDL established for Lake Okeechobee. In addition, the technical plan 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.

Elements of the LOWPP include the (1) Lake Okeechobee Watershed Protection Plan, (2) LOWCP Phase I and Phase II Technical Plans, (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 reports. The annual progress report requirement is fulfilled by this chapter and Volume III, Appendix 4-1. More details on exotics within the District boundaries and certain source control programs for surrounding watersheds are presented in Chapters 9 and 4 of this volume, respectively. **Figure 8-2** is a diagram illustrating the relationship among the protection programs, associated elements, and projects.

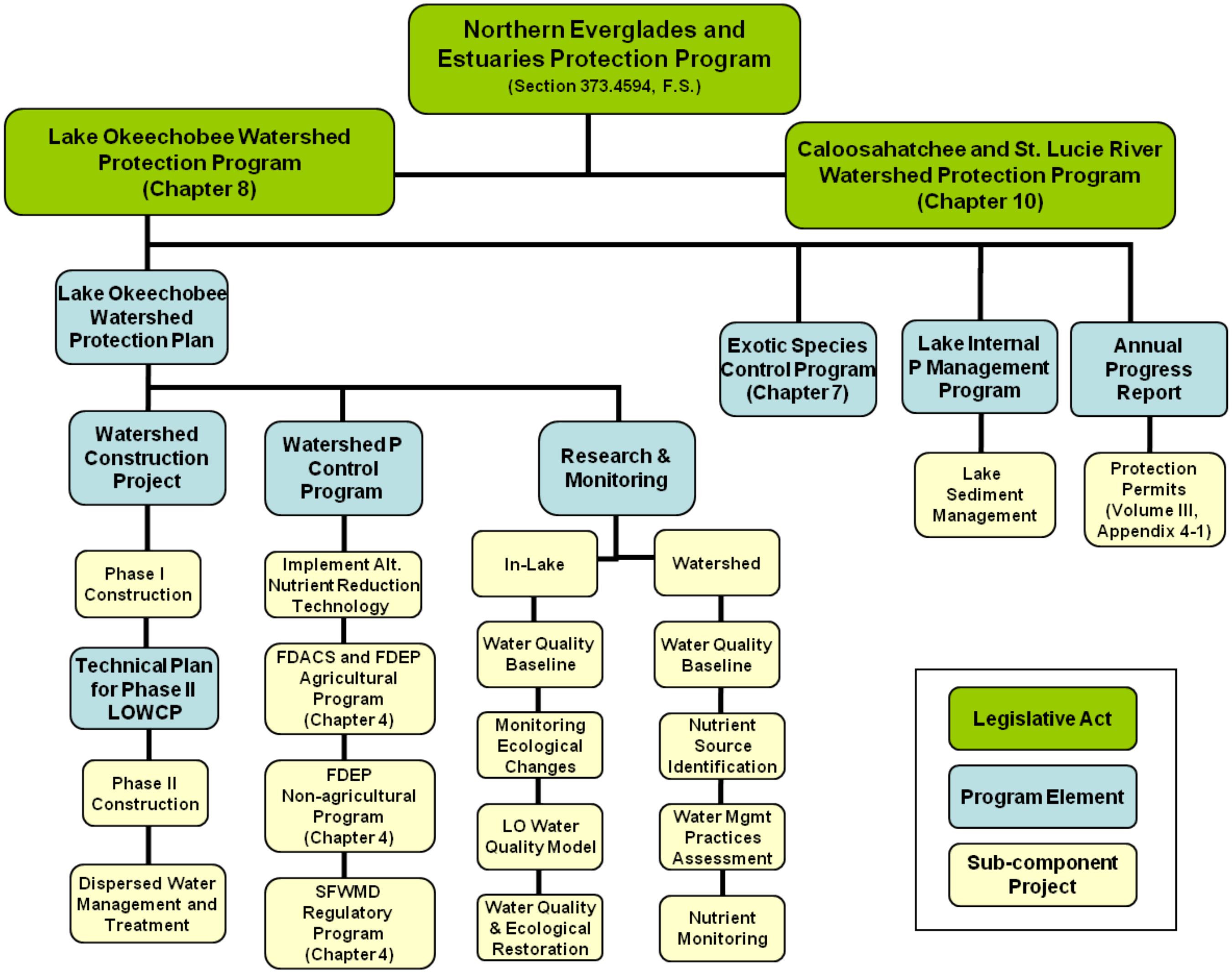

Figure 8-2. Northern Everglades and Estuaries Protection Program (NEEPP) structure, detailing the Lake Okeechobee Watershed Protection Program's elements and projects. [Note: F.S. – Florida Statutes; LOWCP – Lake Okeechobee Watershed Construction Project; P – phosphorus; Alt. – Alternate; FDACS – Florida Department of Agricultural and Consumer Services; FDEP – Florida Department of Environmental Protection; SFWMD – South Florida Water Management District; and LO – Lake Okeechobee.]

Also in 2011, the coordinating agencies amended the original memorandum of understanding as specified by the 2007 legislation in order to establish agreement on NEEPP comprehensive implementation. This memorandum between the District and the other coordinating agencies, allows for the seamless delivery of programs and services needed to accomplish the goals associated with the protection and restoration of the Lake Okeechobee, St. Lucie River and Caloosahatchee River watersheds.

WATERSHED CONSTRUCTION PROJECT

The Taylor Creek Stormwater Treatment Area (STA) is one of the two pilot-scale STAs being implemented north of the lake (**Figure 8-3**). Constructed in April 2006, this STA is a long, narrow enclosure located about two miles north of the city of Okeechobee in central Okeechobee County. It is bordered on the east by U.S. Highway 441 and the west by Taylor Creek. The STA is approximately 142 ac with an effective treatment area of 118 ac. 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).

Figure 8-3. Taylor Creek Stormwater Treatment Area (STA) (photo by the SFWMD).

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 culvert at the outfall structure failed. Repairs to the culvert were completed on August 23, 2010, keeping the STA in a stagnant condition for over a year. After demonstration of compliance with pre-discharge requirements, as laid out in Taylor Creek Permit No. 0194485-008-GL, flow-through operations resumed on September 8, 2010. As of April 30, 2011, the STA has removed 2.4 mt of TP from the Taylor Creek drainage basin, exceeding the expected annual reduction of 2.08 mt in only seven months of operation.

The USACE was the federal sponsor of the project and was 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 was the local project sponsor and was responsible for the operation, monitoring, and maintenance of the facility as a contractor to the USACE until the project was transferred over to the District on May 5, 2011. The facility is now being operated by the District under its own operating permit from the FDEP.

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 ac with an effective treatment area of 773 ac. The projected long-term average TP reduction within the STA was estimated at 5 mt/yr or about 85 percent of the TP load of Nubbin Slough at the project location (Stanley Consultants, Inc., 2003).

Construction of the Nubbin Slough STA was completed in September 2006. However, due to a series of mechanical problems uncovered during pump tests and, more recently, with the aggradations of sediment in the pump basin, the Nubbin Slough STA could not be operated as designed. The USACE and the District are currently evaluating alternatives to resolve issues regarding sediment transport and the basin bank stability along adjacent private lands. The USACE anticipates that Nubbin Slough STA will begin operations in the 2012 wet season.

Since the delivery of the LOWCP Phase II Technical Plan to the Florida legislature in February 2008, implementation of numerous process development and engineering components identified in the plan 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) commencement of construction of Lakeside Ranch STA Phase I, (4) implementation of the Fisheating Creek Feasibility Study, and (5) refinement 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 was designed in two phases. Phase I investigated more thoroughly the field-scale chemical treatment technologies previously tested to reduce TP loads in stormwater runoff. Phase II identified the feasibility of large-scale implementation of these technologies in the Lake Okeechobee, St. Lucie River and Caloosahatchee River watersheds. Existing information suggests that these technologies may be a cost-effective way to control P discharging from these watersheds.

Phase I of the study, completed in July 2009, concluded that various technologies may be viable and effective options for reducing TP loads (Bottcher et al., 2009). Detailed analyses and conclusions are available in the Technical Assistance for the Northern Everglades Chemical Treatment Pilot Project (Bottcher et al., 2009), which is available online at http://stormwater.ucf.edu/chemicaltreatment/Report%20July%206%20updated%20August%203.pdf.

Phase II of this study, completed in Water Year 2011 (WY2011) (May 1, 2010–April 30, 2011), analyzed implementation costs and site selection. This analysis of chemical treatment at various spatial scales in the Northern Everglades ranked sixty sites based on selected evaluation criteria (SWET, 2010). Further implementation of this project is contingent upon the availability of dedicated funding in future fiscal years. 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 FDACS in the St. Lucie River 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, a nutrient hot spot in the Lake Okeechobee Watershed. This project, expedited under the NEEPP, is a 2,700 ac STA in western Martin County on lands adjacent to Lake Okeechobee (**Figure 8-4**). The STA is expected to reduce TP loads to the lake by up to 19 mt annually. The STA will also be able to recirculate water from the lake, which may provide potential for internal P 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 http://www.evergladesplan.org/pm/projects/proj_01_lake_o_watershed.aspx).

Figure 8-4. Location and layout of Lakeside Ranch STA.

The Lakeside Ranch STA Project is designed in two phases. Phase I involves STA North, canal improvements, and the installation of the S-650 pump station. The pump station, which is under construction, will be able to pump water at a rate of 250 cubic feet per second (cfs). Canal improvements are being made along the L-63 and L-64 levees. Phase I also includes the development of a northern STA, consisting of three treatment cells with an effective treatment area of 919 ac. Existing state appropriations are being used for Phase I. Phase II includes the construction of a southern STA with an effective treatment area of 788 ac, a new pump station at structure S-191, and a discharge canal. Phase II implementation is subject to future funding.

The construction of the Phase I STA has achieved several milestones with an investment of $12.6 million in construction to date including (1) ten miles of constructed canals and seepage ditches, (2) seven miles of levees, (3) planting 135 ac of sod on the levees, (4) clearing 920 ac of land, (5) construction of seven control structures, and (6) hauling 1,000,000 cubic yards (50,000 dump trucks full) of material. Construction for the Phase I STA and the S-650 pump station are expected to be completed in March 2012. Final design of Phase II STA South was completed in December 2011. The final design submittal for the S-191A pump station (Phase II) was completed in December 2011.

Fisheating Creek Feasibility Study

The Fisheating Creek Feasibility Study identifies the best mix of storage and water quality features to improve hydrology and water quality in the Fisheating Creek Sub-watershed. Of the nine sub-watersheds in the Phase II Technical Plan study area, this sub-watershed is characterized by extremely flashy flows and is one of the major sources of TP loading to Lake Okeechobee, at an average rate of 86 mt per year from 2001 to 2009 (SFWMD et al., 2011). This sub-watershed is dominated by agricultural land uses that account for 60 percent of the total area (315,007 ac); followed by natural areas including wetlands, upland forests, and water bodies (39 percent or 122,189 ac); and urban areas (1 percent or 4,209 ac). The land use distribution in this sub-watershed is very similar to that of other sub-watersheds in the Lake Okeechobee Watershed that contribute high nutrient loads to the lake.

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 Fisheating Creek directly controlling discharge to the lake). The study consists of two phases: Phase I included an investigation of available information for the sub-watershed and the development of a detailed work plan for Phase II. Phase II plan formulation, evaluation, and selection of a preferred plan are under way. Through extensive involvement with stakeholder groups and interagency coordination, planning targets for achieving storage and water quality improvements (P-load reduction) have been established by the planning team. These targets were based on an analysis of output from WAM simulations of predrainage and existing conditions in the Fisheating Creek Sub-watershed. Conceptual water quality and storage features to address feasibility study objectives are currently being identified and will be refined through the stakeholder involvement and outreach process. The next step will combine these features into alternative plans. This will be followed by evaluation and comparison of the performance and benefits of the various alternative plans leading to the selection of the preferred plan. The Fisheating Creek Feasibility Study report will document the planning process, describe the preferred plan components, identify benefits likely to result from implementation of the preferred plan, and include conceptual costs. The feasibility study is expected to be completed by the end of 2012.

Taylor Creek Site Feasibility Study

This study evaluates alternatives and develops a preferred plan for water quality and storage options for the Taylor Creek/Grassy Island property in accordance with the proposed objectives of the Phase II technical plan. Staff evaluated prior studies and reports for this site (i.e., Lake Okeechobee interim storage report) and currently a modeling effort is underway to evaluate options for preferred plan development. This study also will address benefits associated with the proposed Brady Ranch STA and Lakeside Ranch Phase II STA projects. The study is expected to be completed by July 2012.

Watershed Assessment Model Documentation and Validation

This project is described in details under the *Watershed Research, Assessment and Monitoring* section in this chapter.

WATERSHED PHOSPHORUS CONTROL PROGRAMS

The Lake Okeechobee Watershed Phosphorus Control Program is a multifaceted program 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) use of alternative technologies for nutrient reduction. In February 2001, the District, FDEP, and FDACS entered into an interagency agreement, which was subsequently amended in 2002, 2006, and 2011, to cooperatively implement this program and coordinate with existing regulatory programs, including the Lake Okeechobee Works of the District 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 NEEPP legislation, the FDACS implements an incentive-based BMP program on agricultural lands within the Lake Okeechobee Watershed; the FDEP is responsible for overseeing the FDACS and District agricultural and non-agricultural BMP programs; and the District is responsible for the implementation of TP reduction technology projects, and implementing a nonpoint regulatory source control program that focuses on TP discharges from rule-specified agricultural and non-agricultural land uses in the watershed. More details about the District's source control programs are presented in Chapter 4 of this volume.

RESEARCH AND WATER QUALITY MONITORING PROGRAM

The NEEPP requires the Lake Okeechobee Watershed Protection Program to develop strategies to achieve the TP TMDL for Lake Okeechobee and calls for a comprehensive research and monitoring program to assess and track the status of these strategies. The agreement among the coordinating agencies states that the District will be responsible for maintaining a monitoring network for tracking progress to achieve the basin and sub-basin TP reduction targets for the collective source control programs for the Lake Okeechobee Watershed. Monitoring for source control performance is discussed in Chapter 4 of this volume.

A research and water quality monitoring program was developed by the District in cooperation with the other coordinating agencies to (1) collect data to establish long-term water quality trends in the Lake Okeechobee Watershed; (2) develop a water quality model for the lake; (3) continue to identify and quantify P 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 Phase II technical plan. 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 nonplant organisms, are used to maintain exotics at low levels. As a result, the marsh landscape has been altered in a generally positive manner by vegetation management activities.

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 centimeters (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 P to the open water column.

More than 10,000 ac of torpedograss were treated with this method from 2004 to 2006, and more than 20,000 ac of torpedograss were treated from 2007 to 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 Vegetation* section of this chapter). More information regarding the status of exotic species in the District is presented in Chapter 7 of this volume. Additional exotic vegetation treatments are noted throughout this chapter under area-specific sections.

INTERNAL PHOSPHORUS MANAGEMENT PROGRAM

P-rich sediments have accumulated in Lake Okeechobee over several decades. The current volume of these P-rich sediments in the lake is estimated at 260 million cubic yards (yd^3) or 199 million cubic meters (m^3). TP loads from these sediments to the water column will delay the response of the lake to significant reductions in external TP loads as NEEPP-sponsored projects and others are completed within the Lake Okeechobee Watershed.

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 TP 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 parts per billion (ppb) — as established by the TMDL and described by Havens and James (1997) and Havens and Walker (2002) — will take decades to achieve (James and Pollman, 2011).

To evaluate the effectiveness of chemical compounds on reducing P 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 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 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 that 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 P 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 EAA will be very difficult to achieve without improving the quality of the water from Lake Okeechobee.

Further evaluation of new technologies and approaches for P management or reduction are planned. As a matter of process, a new study would begin by reviewing the recommendations from the 2003 effort. The study would reevaluate previous recommendations and 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 NEEPP requires the District submit an annual progress report to the Florida legislature. This chapter constitutes the twelfth 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 LOWPP during Fiscal Year 2011 (FY2011) (October 1, 2010–September 30, 2011) are included in this chapter. The Northern Everglades Annual Work Plan for FY2012 is also provided as Appendix 8-2 of this volume.

WATERSHED STATUS AND MANAGEMENT

WATERSHED STATUS

The Lake Okeechobee Watershed is dominated by agricultural land uses that account for 51.2 percent of the total area (1.7 million ac); followed by natural areas including wetlands, upland forests, and water bodies (35.7 percent or 1.2 million ac); and urban areas (11.9 percent or approximately 410,000 ac) (**Table 8-1** and **Figure 8-5**). Agricultural land uses can be further classified as (1) improved pasture (19.7 percent) for beef cattle grazing and unimproved pasture/rangeland (9.4 percent) north of the lake; sugarcane production (11.6 percent) south of the lake within the EAA; (2) citrus groves (7.1 percent) located primarily within the eastern portion of the watershed and Lake Istokpoga Basin; and (3) sod farms, row crops, dairies, and "other areas," which make up the remaining (3.4 percent) land uses within the watershed. Although dairy farms in the northern basins cover less than one percent of the land use area, they represent a considerable source of P to some tributaries and up to five percent of the total external TP loading to the lake (Bottcher, 2006). The nutrient levels in surface water runoff are directly related to land use and land management practices within the watershed (Zhang et al., 2002; Hiscock et al., 2003). The District uses the Florida Land Use, Cover, and Forms Classification System to define land use types. The District's minimum mapping unit standards for land cover and land use are 5 ac for upland and 2 ac for wetlands. For example, a wetland area less than 2 ac and located within pastures will be included in the pasture total.

Table 8-1. 2006 land use data for the Lake Okeechobee Watershed.

Land Use	Area [acres (ac)]	
	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	220,127	6.4%
Wetlands	615,081	17.9%
Watershed Total Acreage	3,442,141	100%

TP 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 8-2**). From WY1981–WY2011, 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 352 mt (WY2007–WY2011), which exceed the TMDL by 212 mt and was a decrease from 476 mt during the previous five-year period (WY2006–WY2010). This decrease is attributable to the substantially lower loading rate to the lake in WY2011 (177 mt), resulting from lower flows due to drought conditions. The most recent five-year average is the lowest average value since 1981 because it includes three of the driest years (WY2007, WY2008, and WY2011). These extremes confirm the rationale for the TMDL being based on a five-year average that can account for large variations in water flow and related nutrient loads.

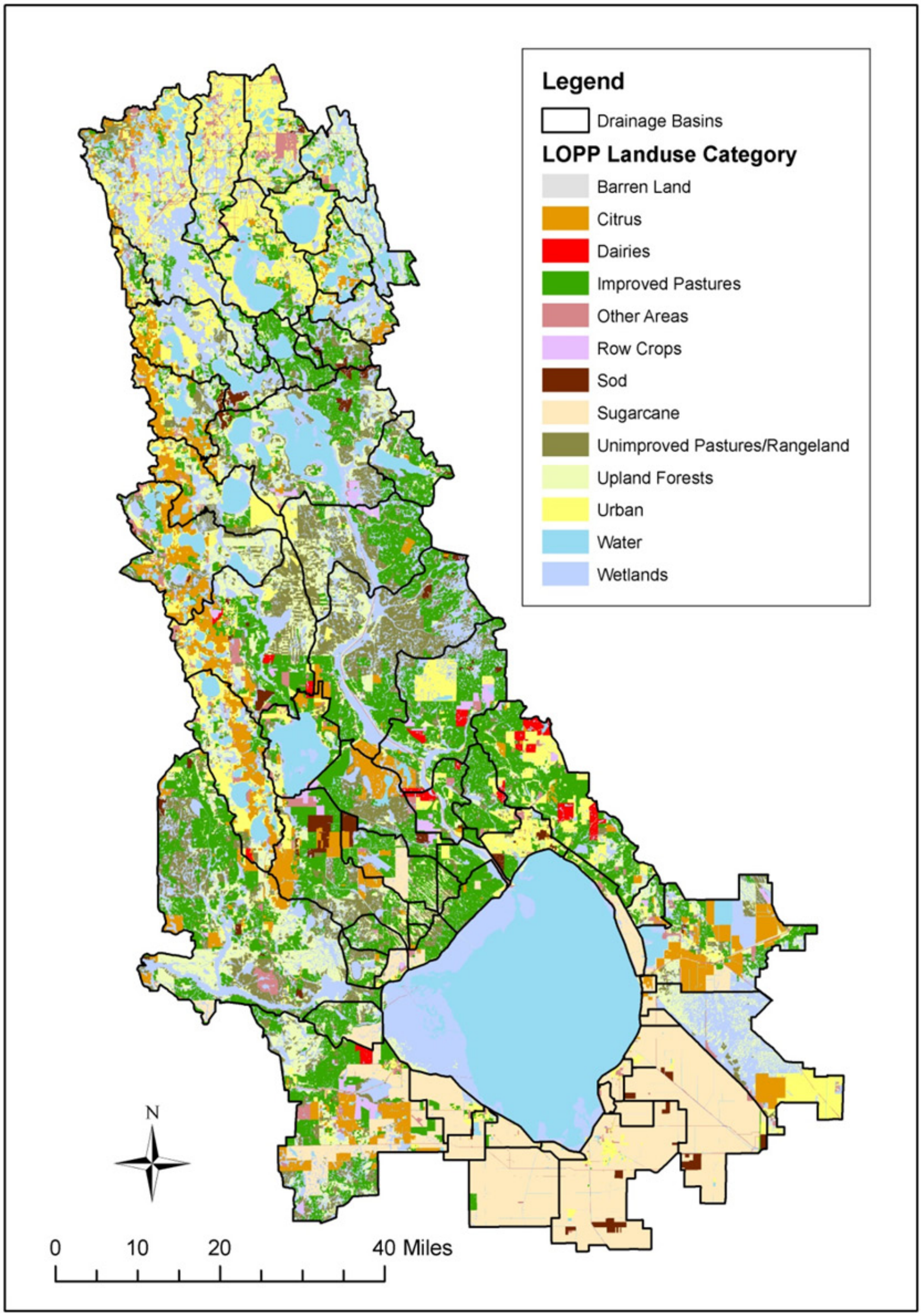

Figure 8-5. Land use distribution in the Lake Okeechobee Watershed.

Table 8-2. Annual total phosphorus (TP) loads to Lake Okeechobee from both controllable and uncontrollable sources for Water Years 1981 to 2011 (WY1981–WY2011) (May 1, 1980–April 30, 2011). [Note: NA – not available]

Water Year (May–April)	Measured Load[a] (metric tons [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	384	244
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	534	394
2003	639	479	339
2004	553	527	387
2005	960	582	442
2006	795	714	574
2007	203	630	490
2008	246	551	411
2009	656	572	432
2010	478	476	336
2011	177	352	212

[a] Includes an atmospheric load of 35 mt per year based on the Lake Okeechobee Total Maximum Daily Load (TMDL) (FDEP, 2001).

[b] Target is the Lake Okeechobee TMDL of 140 mt compared to a five-year moving average.

WATERSHED MANAGEMENT

The Lake Okeechobee Protection Plan contains comprehensive management strategies that are based on the implementation of P control programs including onsite BMPs, flow detention projects, and in-lake remediation activities. Research and model applications continue to provide predictive evaluations as to the effectiveness of alternative strategies.

Watershed Water Quality Evaluation

The WAM and a Microsoft Excel spreadsheet tool were used to estimate the contribution of each project and activity toward meeting the Lake Okeechobee TP TMDL of 140 mt per year, which consists of 105 mt of TP from the watershed tributaries and 35 mt from atmospheric deposition. The WAM has been calibrated and applied to the Lake Okeechobee watershed to evaluate the TP load reductions associated with various BMPs that, based on the modeling results, were found to be the most cost-effective approach for initial TP load reductions. However, to see the full benefit of BMP implementation at the regional scale, implementation of BMPs throughout the watershed will need to be completed and adequate response time should be allowed. Once BMPs are verified to be fully implemented, monitoring by the District will quantify the actual level of effectiveness of the collective source control programs. Load reductions from other projects were estimated based on best available data or other models. It should also be noted that the amount of TP reduction is dependent upon the number of projects and at what rate they are being implemented. Thus, the faster these projects are implemented, the higher the reduction of P will be and the faster the TMDL goal will be reached.

During the baseline period of 2001–2009 (calendar year), the actual TP load to the lake was 539 mt/yr (not including the 35 mt from atmospheric deposition), which is 434 mt above the targeted load of 105 mt/yr. The 2011 Lake Okeechobee Protection Plan Update (SFWMD et al., 2011) outlined the P reduction strategies, the lead agency responsible for implementing these strategies, and the anticipated TP load reduction upon full implementation of the protection plan. The detail description of these activities is in Appendix B of the plan update. The section below provides a brief description of the reduction activities. As these activities could provide approximately 85 percent load reduction needed for achieving the lake's TMDL (**Table 8-3**), additional watershed P reduction projects will need to be identified.

Agricultural and Urban Best Management Practice Programs

The WAM provided simulation results for the effectiveness of BMPs. Based on WAM simulations and the BMP implementation rate, it is estimated that roughly 12 percent of TP reduction could be achieved through agricultural and urban BMPs currently being implemented in the watershed. In addition, the WAM model estimated that an eight percent reduction could be achieved from future BMPs. BMPs in the Lake Kissimmee and Lake Istokpoga sub-watersheds were not considered in this analysis because these reductions are unlikely to affect discharges from their respective lakes due to internal buffering capacities. Over time, however, nutrient loads to Lakes Istokpoga and Kissimmee could affect their nutrient retention capacity. Furthermore, these upstream nutrient loads could eventually affect discharges to Lake Okeechobee. Source controls, including BMPs, and the development of methods to measure the actual water quality impacts from the implementation of source controls are discussed in more detail in Chapter 4 of this volume.

Table 8-3. Ongoing and future TP reduction activities in the Lake Okeechobee Watershed with lead agencies [Florida Department of Agriculture and Consumer Services (FDACS), Florida Department of Environmental Services (FDEP), and South Florida Water Management District (SFWMD)] and estimated percent of total load reduction.

Category	Lead Agency	Estimated Percent TP Load Reduction
TP Load Reduction Activities Underway		
Agricultural and Urban Best Management Practices (BMPs)	FDACS. FDEP, and SFWMD	12%
Watershed Phosphorus Control Projects	SFWMD	6%
Regional Public Works Projects [Everglades Agricultural Area (EAA) Reservoir and Flow Diversion Projects, Kissimmee River Restoration, and Critical Projects]	SFWMD	8%
Regional and Subregional Projects (Florida Ranchlands Environmental Services Project/Dispersed Water Management/Payment for Environmental Services, and hybrid wetland treatment technology (HWTT)	SFWMD	3%
Subtotal		**29%**
Future TP Load Reduction Activities Requiring Funding		
Agricultural and Urban BMPs	FDACS. FDEP, and SFWMD	8%
Regional and Subregional Projects [Dispersed Water Management/Payment for Environmental Services, Aquifer Storage and Recovery (ASR), and Lakeside Ranch]	SFWMD	9%
CERP Lake Okeechobee Watershed Project	USACE and SFWMD	12%
Long-term TP Reduction Strategies (BMPs, Chemical Treatment at the Parcel Level and within Reservoirs, Additional Regional Storage and Treatment Projects)	FDACS. FDEP, and SFWMD	27%
Subtotal		**56%**

Watershed Phosphorus Control Projects

State funding through the Lake Okeechobee Watershed Phosphorus Control Program has funded construction of more than 30 TP reduction projects located mainly in the four priority basins (**Figure 8-6**). These BMP implementation projects continued to provide TP load reductions to the lake during WY2011. Average annual TP load reduction from all implemented and competed projects is approximately 22 mt per year (data not shown). All these projects have some level of performance monitoring to validate the effectiveness of these technologies in reducing TP loads.

The Lake Okeechobee Phosphorus Source Control Grant Program funded the early implementation of projects that have potential for reducing P 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.

Historically, isolated wetlands covered a considerable area of the four priority basins within the Lake Okeechobee Watershed (**Figure 8-6**). These wetlands captured stormwater runoff and retained P. Many of these wetlands were drained to increase the amount of land in agricultural production, which increased P 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 TP reduction of 20 percent or greater was expected. As more wetlands are restored, TP loads to the lake should decrease and regional water storage in the watershed should increase.

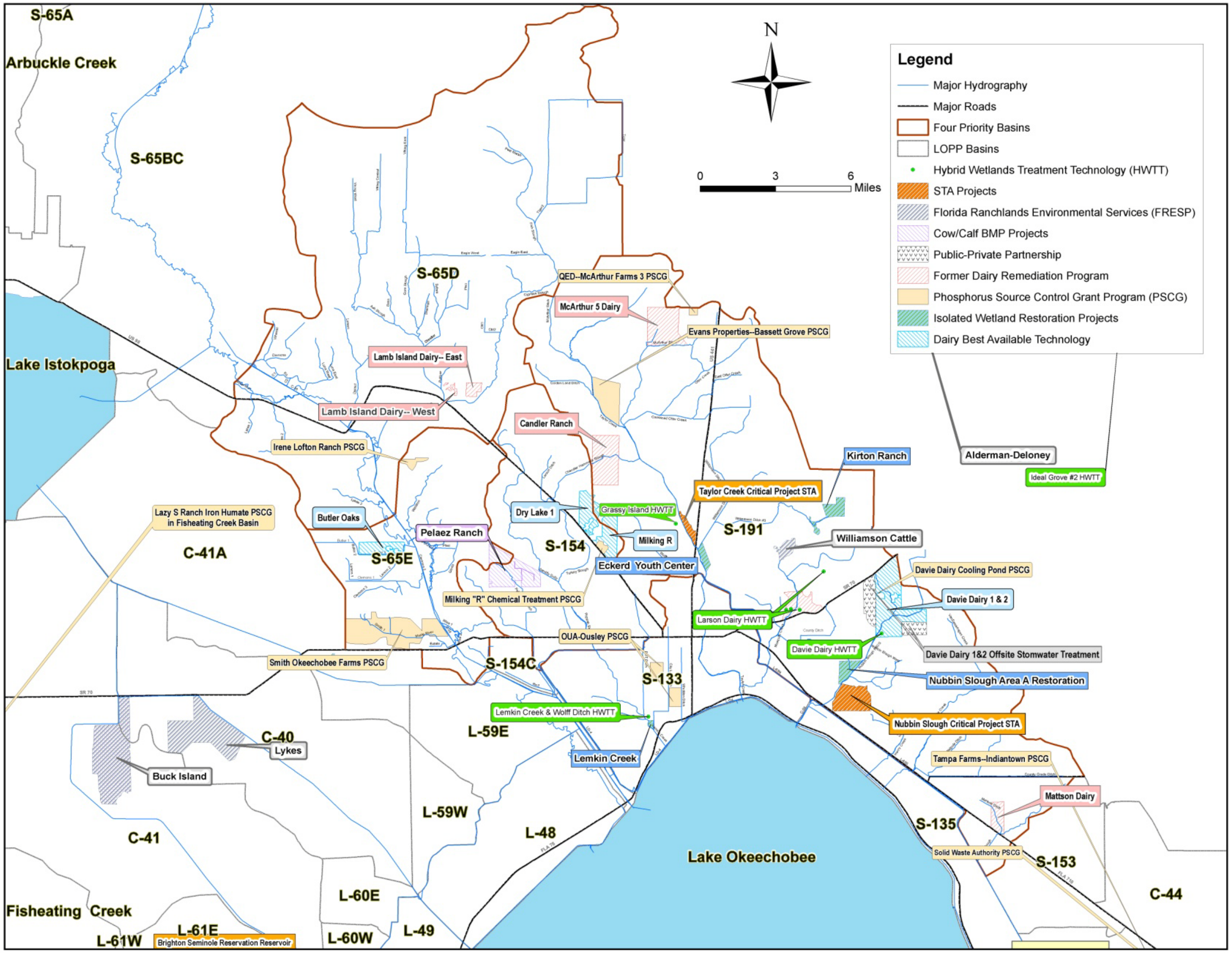

Figure 8-6. SFWMD project locations under the Lake Okeechobee Watershed Phosphorus Control Program.

The load reduction estimates from the four projects funded by this program were obtained from the design report or feasibility studies and the reductions were mainly due to flow volume reductions. Isolated wetland restoration efforts have also taken place at sites on Lamb Island Dairy, Lofton Ranch, and Smith Okeechobee Farms. However, the Lamb Island Dairy site is categorized under Former Dairy Remediation projects and the last two are grouped under the Phosphorus Source Control Grant Program.

The District initiated Former Dairy Remediation projects to reduce stormwater discharge from these properties. One or more remedial alternatives identified in the Agriculture Nutrient Management Assessment guidelines, developed to minimize P discharges, were implemented at 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. Based on agriculture nutrient management assessment recommendations, the following remediation practices were implemented to minimize P discharges from the properties: (1) runoff retention from old high intensive areas, (2) amendment of high-P soils, (3) rehydration of on-site wetlands, and (4) reduction of stormwater flow off-site via minor impoundments. These implementations were completed from calendar years 2004 to 2008. The effects of these projects in improving water quality over time are being assessed at critical sub-basin-scale monitoring locations through a program implemented and supported by the District, FDACS and the United States Geological Survey (USGS).

Edge-of-farm stormwater treatment was implemented on three dairy properties in the Lake Okeechobee Watershed under the Dairy Best Available Technology Project. This technology originally consisted 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) chemically treating stormwater discharge prior to release. Three Dairy Best Available Technology projects are fully constructed, and performance monitoring was initiated in May 2004. A fourth 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 to 1.62 mt (SWET, 2008). 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 Best Available Technology project was terminated. None of the original Dairy Best Available Technology projects are still operating as originally designed due to lack of funding for the alum injection system. However, water quality reductions may still be attributable to the large on-site retention systems at each farm. Davie Dairy is a participant of both the dairy Best Available Technology and the Public-Private Partnership programs. Based on the drainage area, the load reduction from Davie Dairy Best Available Technology is estimated to be 9 percent. 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).

Regional Public Works Projects

Some projects are constructed outside the purview of the Lake Okeechobee Protection Plan but will have water quality benefits for the lake. These include the diversion of 298 Districts flows (Everglades Construction Projects and Kissimmee River Restoration Project). Also included under this category are Lake Okeechobee Water Retention Phosphorus Removal Critical Projects (Taylor Creek and Nubbin Slough STA Critical Projects).

Regional and Subregional Projects

- **Florida Ranchlands Environmental Services Project.** This is the pilot project for the Payment for Environmental Services Program (discussed below). The project's partners include eight ranchers, the World Wildlife Fund, Florida Cattlemen's Association, FDACS, FDEP, University of Florida's Institute for Food and Agricultural Sciences (UF/IFAS), the United States Department of Agriculture National Resources Conservation Service, MacArthur Agro-ecology Research Center, and the District.
- **Dispersed Water Management – Northern Everglades Payment for Environmental Service Program (PES).** The Lake Okeechobee Watershed restoration efforts are not only in the form of large-scale publicly owned and operated projects. They also include both public and private landowners participating in a variety of efforts that spread excess water across the landscape and distribute it at shallow depths. These smaller-scale projects optimize the use of existing facilities and require little new construction to retain significant volumes of water. Low installation and maintenance costs associated with water retention and nutrient reduction projects make them a cost-effective complement to the larger regional storage and treatment projects. A total of 124,529 acre-feet (ac-ft) of water have been stored on 239,302 ac in the Northern Everglades since October 2005 (SFWMD et al., 2011). Landowners typically have participated in dispersed water management program under three types of approaches. These approaches include cost-sharing, easements, and Payment for Environmental Services Program (PES). Once a landowner has successfully participated in one type of program, there is often willingness to participate in other, longer-term programs with the potential to retain more water and reduce nutrients in even larger amounts.
- **Hybrid Wetland Treatment Technology (HWTT).** This treatment technology combines wetland and chemical treatment approaches within a wetland system to further reduce TP loads. Six HWTT projects are included under the current activities and the Grassy Island site is included in this future activity list.

Comprehensive Everglades Restoration Plan Project

Currently, the state is working with the USACE on the CERP Lake Okeechobee Watershed Project Implementation Report to obtain Congressional authorization to share construction costs for water quality improvement features identified in the tentatively selected plan. In addition, the operation, maintenance, repair, replacement, and rehabilitation of water quality improvement features in the tentatively selected plan can be cost-shared in accordance with Congressional authority and to sustain the long-term benefits produced in the Lake Okeechobee Watershed Project area and the downstream Everglades.

Long-term Phosphorus Reduction Strategies

This category includes reductions resulting from BMPs, the dispersed water management projects to be implemented at several potential sites, Brady Ranch STA, Lakeside Ranch STA Phase II, aquifer storage and recovery (ASR), chemical treatment to several reservoirs and at the parcel level, and additional regional storage and treatment projects.

Assumptions and Uncertainties

Certain assumptions made in the evaluation effort include the following categories: hydrology, lake functions, P reduction estimates (project and BMP performance and implementation rates), amount of residual P in soils and associated P assimilative capacity, land use changes, lag effects, and overall schedules and funding. Rainfall affects flow in the system, which in turn affects P transport. Flows can vary dramatically on an annual basis, as evidenced by the last 10 years of very wet or dry conditions. Some uncertainties associated with BMP performance include the influence of different soils and hydrologic conditions, the quantity of water that can be held on a parcel without affecting an agricultural operation, residual P in the soils, and the rate of implementation of the BMPs. Long-term TP loading in the watershed has created residual P in the soils. The increase in residual P has reduced the P assimilative capacity of soils and wetlands in the watershed, resulting in more P discharge to the lake. The BMP performance estimates were based on model simulations and best professional judgment.

Uncertainties also exist regarding the biological functions of Lakes Istokpoga and Kissimmee. Trends in water quality indicate that these lakes are shifting from TP sinks to possible sources in the near future and implementation of projects that reduce sources directly to these lakes should be considered a priority for future success. As a result, projects to reduce TP loads upstream of these lakes will not affect TP loads leaving the lakes for several years. Other uncertainties are focused around implementation schedules and funding. Without appropriate funding, implementation schedules can be delayed. Additionally, these TP reductions may be delayed even if the projects are implemented on time, due to the residual P remaining in the soil from past practices.

WATERSHED RESEARCH, ASSESSMENT AND MONITORING

RESEARCH AND ASSESSMENT

The District, in cooperation with the FDACS, FDEP, UF/IFAS, and other agencies and interested parties, has implemented a comprehensive research and assessment program for the Lake Okeechobee Watershed. Research and assessment projects are assessed and prioritized each year by an interagency team to ensure 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 Caloosahatchee River and St. Lucie River watersheds. The work of this group is an integral component of the overall restoration program.

Nine research, demonstration, and assessment projects were under way or completed in WY2011 (**Table 8-4**). Three of these projects (two completed and one ongoing) are highlighted in detail in this section. More information on the other projects may be found on the District's website at www.sfwmd.gov/okeechobee.

Evaluation of Cow-Calf Water Quality Best Management Practices

This project evaluated the effectiveness of the cow-calf BMPs that appear most promising for ranches in the Lake Okeechobee Watershed, and assessed the change in nutrient loads to surface waters and groundwater (Shukla et al., 2011). The BMPs included (1) ditch fencing and culvert crossing (DFCC) to keep cattle out of waterways and (2) wetland water retention (WWR) to increase ranch storage of water and nutrients. The two BMPs were implemented at a commercial cow-calf ranch in Okeechobee. For the DFCC 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 total nitrogen (TN) discharge and concentrations between pre- and post-BMP periods.

Table 8-4. Status of Lake Okeechobee Watershed research, demonstration, and assessment projects during WY2010.

Project Name (Investigator)[a]	Major Objectives and Results	Status
Wetland Soils Nutrient Criteria Development and Evaluation of "Safe" Soil Phosphorus Storage Capacity University of Florida's Institute for Food and Agricultural Sciences (UF/IFAS)	This study identified routine soil tests that can be used as indicators of phosphorus (P) release from the soil to the water column in wetland soils across wetland locations and types. The threshold P saturation ratio of 0.1 based on Mehlich-I extractable P, iron, and aluminum is believed to be a reasonable value that can be used at this time to evaluate soil P storage capacity for wetland soils. As results from this study are considered preliminary, this value needs refinement as more data becomes available. This project was completed in January 2011.	Complete
Watershed Assessment Model (WAM) 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 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 were geared toward improving documentation of the model, ensuring scientifically sound calibration and validation procedures were followed using established and objective goodness-of-fit measures. Model testing and validation for the S-191 and C-139 basins were performed and the project was completed in April 2011.	Complete
Nutrient Budget Analysis for the Lake Okeechobee Watershed (HDR, Inc.)	The overall objective of this study was to determine the relative contribution and sources of total phosphorus (TP) and total nitrogen (TN) from identifiable sources and land uses. Based on data collected from 2009, approximately 6,088 metric tons (mt) of P was imported into the Lake Okeechobee Watershed annually for anthropogenic land use activities; 5,047 mt of the total net P imported was stored on-site in upland soils. The net import of nitrogen (N) from anthropogenic land use activities was 42,513 mt. The current P budget results by land use were compared to the previous data. The net P import decreased by 25 percent from the previous budget, from 8,085 to 6,088 mt. This is primarily due to changes in P import from three land uses: truck crop, sugarcane, and improved pasture.	Complete
Evaluation of Cow-calf Water Quality Best Management Practices (BMPs) (UF/IFAS)	This project evaluated the potential of ditch fencing and culvert crossing (DFCC) and wetland water retention (WWR) for controlling nutrient losses from a commercial cow-calf ranch in Okeechobee. Hydrologic and water quality data collected during pre- and post-BMP periods were used to evaluate the effectiveness of the two BMPs. Keeping the cattle away from waterways with DFCC resulted in average TP and TN load reduction of 11 percent. The effects of WWR BMP on water storage and nutrient retention differed for the two wetland-upland sites. Results for the first wetland indicate increased P concentrations and loads during the post-BMP period due to increased connectivity to uplands containing areas with high and low P retention capacity. At the second wetland, however, WWR resulted in about a 60 percent reduction in both TN and TP loads. Although water retention on ranchlands for increased water storage and nutrient retention had potential to be a promising BMP, results from this study seem to indicate that depending on the upland-wetland characteristics, WWR BMP can either increase or decrease flow and TP loads. WWR involves interaction of surface and subsurface water and nutrient processes that, when combined with natural climatic variability, makes it difficult to attribute changes in water and P dynamics to WWR alone. The project was completed in May 2011.	Complete
Lake Istokpoga Environmental Evaluation and Vegetation Mapping (SFMWD)	Geographic 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 marsh plant communities in response to hydrologic conditions and management activity (e.g., exotic and nuisance vegetation control), as well as efforts to enhance wildlife habitat through various activities, such as tree planting projects, can effectively be evaluated using vegetation maps. A detailed vegetation distribution map was constructed by dividing Lake Istokpoga into a series of 25 one-square meter grids and recording the dominant emergent species within each grid. A vegetation distribution map indicating the distribution and areal coverage of the dominant emergent vegetation communities for the nearshore and pelagic island regions of Lake Istokpoga was completed in 2010.	Complete

Table 8-4. Continued.

Project Name (Investigator)	Major Objectives and Results	Status
WAM Applications in the Lake Kissimmee Sub-watershed (SFWMD)	The overall goal of this project is to apply the WAM to the Lake Kissimmee Sub-watershed to identify the hydrologic and water quality data needed to develop a nutrient budget for the Upper Chain of the Lakes. WAM can be used to evaluate various P control programs to maximize water quality improvements from a drainage area. Specific objectives are to (1) update WAM input datasets with the latest rainfall data and P control efforts, (2) identify nutrient loading data needed for the lake nutrient budget analysis, and (3) calibrate WAM for the Lake Kissimmee Sub-watershed using available monitoring data. The project is scheduled to be completed by September 2012.	Ongoing
Hybrid Wetland Treatment Technology (HWTT) (Watershed Technologies, LLC, under contract to SFWMD and other state agencies)	This project involves the design, deployment, and monitoring of HWTT facilities in the St. Lucie River 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 ac Ideal 2 Grove system, the 1.7 ac Nubbin Slough system, and the 1.4 ac 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. 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 to 95 percent. Five systems — the dairy lagoon system was discontinued — are being operated for TP load reduction and evaluated for cost-effectiveness through June 2012. An additional system has been constructed and began operations at the District's Taylor Creek/Grassy Island property during WY2012.	Ongoing
New Alternative Treatment Technologies (NATA) (SFWMD)	This SFWMD initiative provides a forum to explore additional nutrient reduction technologies. Interested vendors are invited to demonstrate potential technologies for reducing TN and TP loading in both water and sediments, to help reduce loads in the Northern Everglades watersheds. Three technologies are currently being tested in either test cells within Stormwater Treatment Area 1 West (STA-1W), or in bench studies. All three products use proprietary clay-like materials that bind N and P, and products selected for testing through a request for proposals.	Ongoing
Permeable Reactive Barrier Technology (PRB) (UF/IFAS)	This project evaluates the incorporation of water treatment residuals (WTRs), capable of interception and long-term sequestration of P, into permeable reactive barriers (PRBs) in the Lake Okeechobee Watershed before P enters the water conveyances into Lake Okeechobee. The objectives are to (1) assess the feasibility of significantly reducing TP 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. Laboratory analysis included a systematic evaluation of aluminum (Al)-WTRs from six facilities in South Florida. The protocols included standard total elemental analysis of each amendment, short-term laboratory equilibrations, small column leaching studies, and simulated rainfall studies. Two Al-WTRs were selected for field investigation. Based on availability and P-sorption capacity, Al-WTR from the Manatee County treatment facility is being tested in this study. The PRB field installation at Candler Ranch in Okeechobee County was completed in April 2011. The PRB monitoring and reporting is expected to be completed by January 2012.	Ongoing

Hydrologic and water quality data collected during pre- and post-BMP periods were used to evaluate the effectiveness of these two BMPs. The 2005 wet season (June–October) was the pre-BMP period and the 2006–2008 wet seasons were the post-BMP periods. Keeping cattle away from waterways with DFCC resulted in average inflow and outflow TP loads of 300 and 268 kilograms (kg), respectively, for an 11 percent reduction. DFCC also provided an average TN load reduction of 11 percent, with average inflow and outflow TN loads of 682 and 609 kg, respectively. Conservative TP removal cost estimate for the DFCC BMP was $17.02 per kg of TP, which is considerably less than the cost of other TP reduction strategies in the watershed.

The effects of WWR BMPs on water storage and nutrient retention differed for the two wetland sites (Shukla et al., 2011). Average pre- and post-BMP nutrient loads indicate that Wetland 1 was a nutrient source. At Wetland 2, however, WWR resulted in about 60 percent reduction in both TN and TP loads. When nutrient loads from the two wetlands were averaged together for pre- and post-BMP periods, a 6 percent reduction in TN loads (pre-BMP – 214 kg; post-BMP – 201 kg) and a 21 percent reduction in TP loads were obtained. Although water retention on ranchlands for increased water storage and nutrient retention could be a useful BMP, results from this study are inconclusive. WWR involves interaction of surface and subsurface water and nutrient processes that, when combined with natural climatic variability, makes it difficult to attribute changes in water and P dynamics to WWR alone.

Watershed Assessment Model Documentation and Validation

The WAM is a geographic information systems (GIS)-based model that simulates the complex hydrology and water quality responses within a watershed based on detailed characterization data (SWET, 2011a). WAM was first developed in the 1980s to take advantage of the spatial datasets just becoming available. Today, WAM is a fully integrated ArcMap application where watershed characterization data can easily be imported and edited, and simulation results reviewed via the ArcMap interface.

In April 2009, a panel of five experts completed a peer review of the WAM and gave seven major recommendations in a final report (Graham et al., 2009). The overall objective of this project was to address all major recommendations by the panel, except Recommendations 2 (sensitivity analysis) and 5 (uncertainty analysis) due to funding unavailability. WY2011 efforts were geared toward improving documentation of the model and using the established goodness-of-fit measures to provide a scientifically sound calibration and validation process.

The documentation included development of a user manual, tutorial, technical manual, and developer manual. The user manual and tutorial are designed to function as a guide, stepping through the tasks required to set up a watershed, running the model, and reviewing the output results. The physical watershed processes handled by the model and their mathematical representation are discussed in the technical manual. The structure and coding of WAM are discussed in the developer manual.

- **User Manual –** Includes an overview to briefly introduce the WAM modeling concepts and the graphical user interface (GUI). Input data requirements are discussed and the various model outputs are listed. It also discusses the GUI in detail and how it is used to setup a scenario, execute the model, and review output.
- **Technical Manual –** Provides detailed descriptions of the model processes and algorithms used to represent the natural processes simulated by WAM.
- **Developer Manual –** Provided to advanced users, this includes information necessary to customize and extend WAM and sections on the model code, default parameter values, data flow diagrams, folder and file structures, and model input/output files.

- **Tutorial –** Provides step-by-step examples of the various WAM functions including setting up a new watershed, changing model inputs for scenario testing, and evaluating simulation results through the output reporting tools.

Calibration and validation of watershed models require special considerations because of the temporal and spatial variation that occur in the measured datasets (SWET, 2011b). The classical definition of the calibration process is the adjustment of the input parameters, also referred to as parameterization, of a mathematical or numerical model in order to optimize the agreement between observed data and the model's simulated output. However, when the model parameters represent actual physical quantities, (e.g., fertilizer rates, stream layout dimensions, land slope, irrigation rate, to name just a few) the adjustment of such parameters must be limited by the physical knowledge of the basin. Therefore, the calibration and validation process used for all physically-based watershed models has an additional step not typically included in classical calibration procedures for statistically-based models. The extra step is a verification of the accuracy of the physical parameters that characterize land use activities and the watershed before the statistical or empirical model parameters can be adjusted to obtain a good fit. This means that a parameter verification process is the initial step during the calibration process.

The criteria for the goodness-of-fit are important and similar for both the calibration and validation processes. Goodness-of-fit should be evaluated with both a visual and statistical approach. The visual approach is useful for the initial assessments because it can quickly reveal deviations from the general trend between the simulation results and the observed data. The visual approach should then be followed by commonly used statistical approaches, including relative error measures (such as Nash-Sutcliff coefficient of efficiency) and absolute error measures (i.e., root mean square error) to better quantify the goodness-of-fit. Root mean square and mean bias errors give error measures in the same units as the observations/simulations being evaluated. Both are measures of how close the model fits the data points. The mean bias error provides the overall bias (e.g., the model over or under predicted, on average, by a certain amount). The root mean square error provides the magnitude of the overall error of the model.

Better model fits have root mean square and mean bias errors close to zero. There is no definition of what an acceptable root mean square error or mean bias error is and it should be determined by the goal or objective of the simulation. However, they are useful in comparing models and comparing the error in the calibration period to that in the validation period. The Nash-Sutcliffe coefficient of efficiency ranges from negative infinity to one. A value of one indicates a perfect fit. A value of zero indicates that the mean of the observations is just as good a predictor as the model. Any value greater than zero is considered ‘good’ (i.e., it was a better predictor than the mean of the observations). A value less than zero means that the mean of the observations is a better predictor than the model and would fit the data better.

Monthly simulated and observed TP loads at the S-191 structure in the Taylor Creek/Nubbin Slough Sub-watershed were very similar (**Figure 8-7**). The Nash-Sutcliffe coefficient of efficiency values are 0.88 and 0.77 for calibration and validation periods, respectively, and indicate the simulated results matched the observed data well.

The model has proven itself useful as a planning and decision making tool for assessing alternative abatement strategies for improving water quantity and quality in the Lake Okeechobee Watershed. It has been used to estimate TP load reductions associated with implementing BMPs as part of the 2011 Lake Okeechobee Protection Plan Update. It also has been used to identify areas of concern for each of the modeled constituents on either a parcel or regional spatial level. Through this ability to isolate each of the major components of the hydrologic and nutrient cycles in the simulation, the efficacy of different abatement strategies can be tested and quantified relative to each other. This capability can provide additional confidence to the potential success of a chosen abatement strategy before proceeding with costly implementation programs.

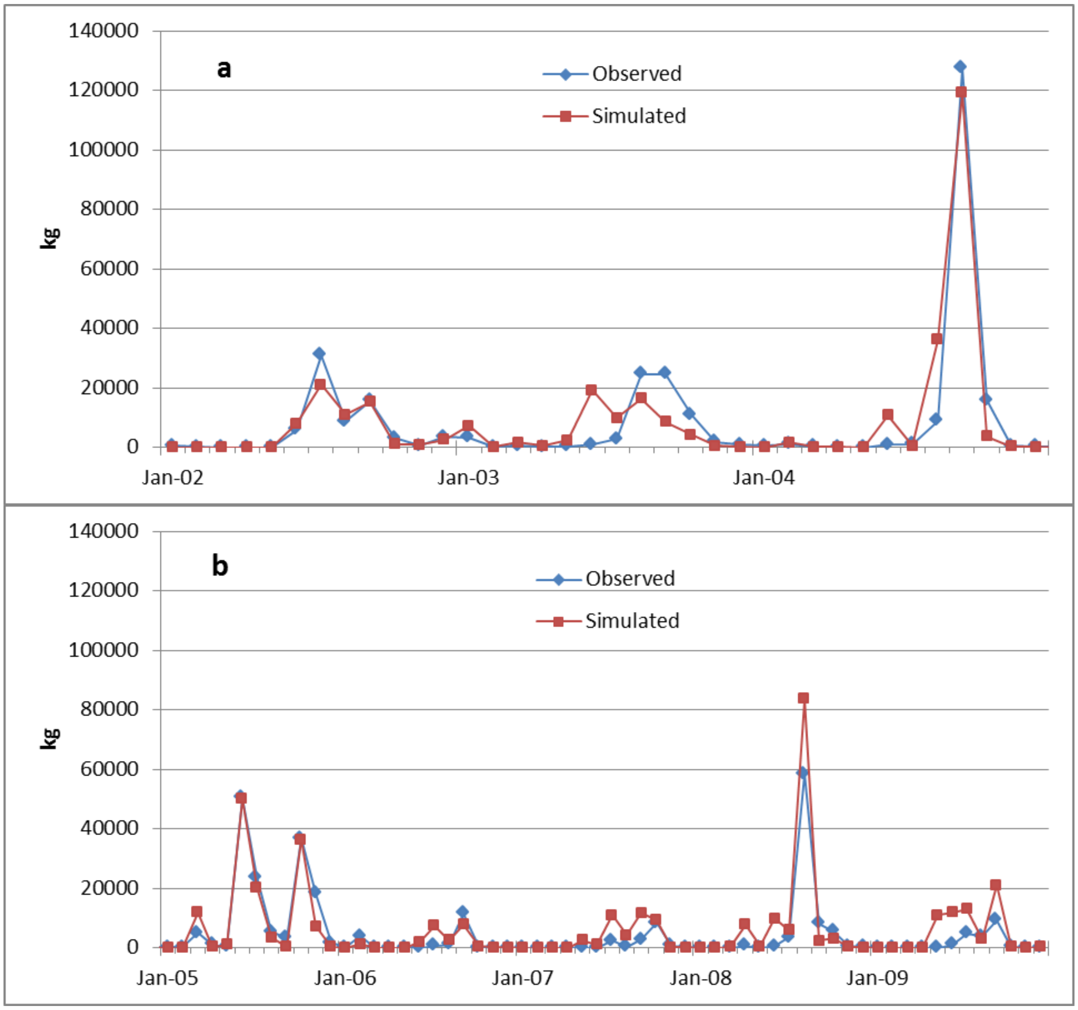

Figure 8-7. Simulated and observed monthly total phosphorus (TP) load at the S-191 structure for the (a) calibration and (b) validation periods.

Hybrid Wetland Treatment Technology

These studies use a combination of wetland and chemical treatment approaches. 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 P 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 (N) and P 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 ac Ideal 2 Grove system, the 1.7 ac Nubbin Slough system, and the 1.4 ac 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 as adequate data had been obtained. Two HWTT facilities (Lemkin and Wolff Creek systems) were constructed and brought online during WY2010 and an additional site at Grassy Island was completed at the beginning of WY2012. Effective performance of the HWTT technology is demonstrated by the change in TP concentrations from inflow compared to outflow during the study period (Watershed Technologies, LLC, 2010). TP flow-weighted mean concentration reductions ranged from 64 to 90 percent (**Figure 8-8**).

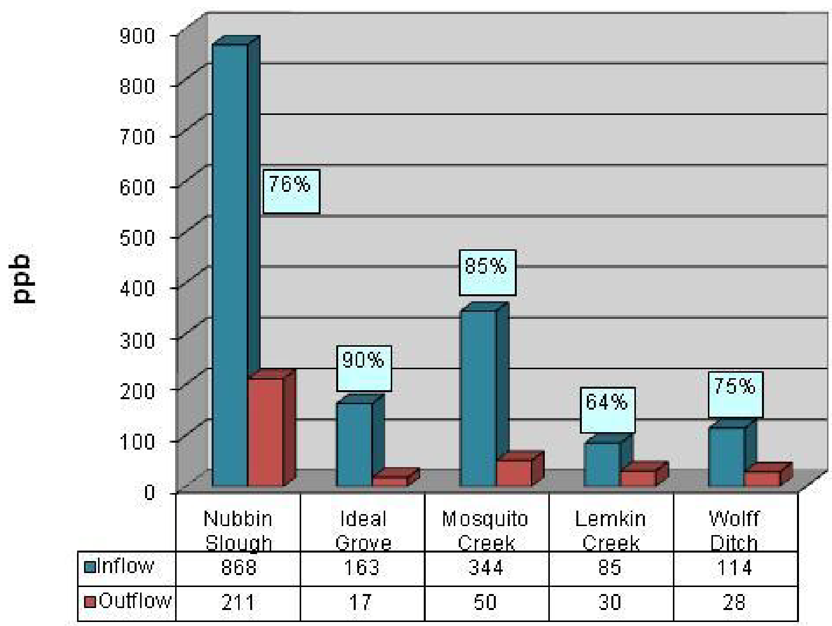

Figure 8-8. Flow-weighted TP concentrations and percent reductions in parts per billion (ppb). The period of record for TP concentrations is November 21, 2008–March 8, 2011 for Nubbin Slough, Ideal Grove, and Mosquito Creek, and March 9, 2010–March 8, 2011 for Lemkin Creek and Wolff Ditch.

WATER QUALITY MONITORING IN THE WATERSHED

To achieve the monitoring required by the NEEPP, the District monitors the water quality of inflows to and outflows from Lake Okeechobee at District-operated control structures and maintains a long-term water quality monitoring network within the Lake Okeechobee Watershed (**Figure 8-9**). This network is continuously reviewed for efficiency and to ensure all data objectives associated with legislatively mandated and permit required monitoring are being met. This enables taxpayers to be kept informed about the progress of state and federally funded restoration efforts. In addition, the District coordinates monitoring efforts with the FDACS, FDEP, and USGS to leverage monitoring sites and reduce duplication of efforts.

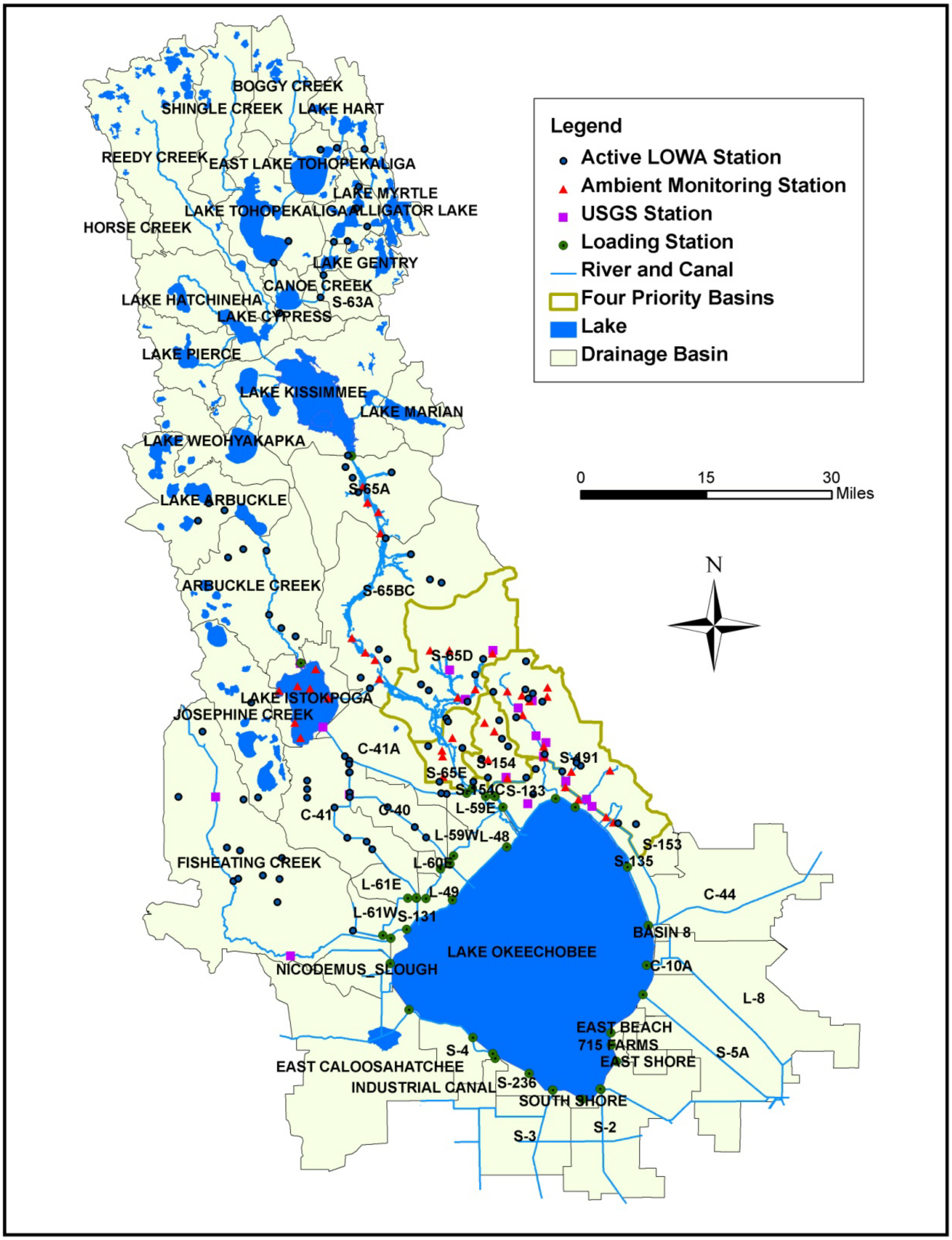

Figure 8-9. Locations of Water Year 2011 (WY2011) (May 1, 2010–April 30, 2011) sampling stations under various monitoring programs in the Lake Okeechobee Watershed. [Note: LOWA - Lake Okeechobee Watershed Assessment]

The District's current monitoring network collects data from three hydrologic levels within the Lake Okeechobee Protection Plan area through the use of several project-level initiatives. Monitoring is conducted at loading stations at the sub-watershed and drainage basin level (within the sub-watersheds) for flow, TP, TN, and other parameters at 35 control structures discharging directly into Lake Okeechobee as mandated by the Lake Okeechobee Operating Permit issued by the FDEP (Project X). Upstream-level monitoring is conducted under three different projects: the ambient long-term trend projects (KREA and TCNS), the sub-basin loading project (OKUSGS), and the Lake Okeechobee Watershed Assessment. Project-specific, parcel- or farm-level monitoring is also conducted. Data from these monitoring efforts reside in the District's DBHYDRO database and are associated with the project names listed above in parentheses.

Total Phosphorus and Total Nitrogen Loading Data by Drainage Basin

Surface water flow, and TP and TN loads to the lake for WY2011 were calculated for the major drainage basins (**Tables 8-5** and **8-6**). 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 smaller surrounding drainage basins (**Figures 8-1** and **8-9**). Data are based on monitoring stations where flow is continuously monitored and TP and TN samples are collected biweekly, based on flow, or monthly at a minimum. During WY2011, the TP load to the lake from all drainage basins and atmospheric deposition (estimated as 35 mt; FDEP, 2001) was 177 mt (**Tables 8-2** and **8-5**). The largest surface water inflow came from the Upper Kissimmee Sub-watershed (above structure S-65), followed by the Lake Istokpoga Sub-watershed and Fisheating Creek Basin. The Upper Kissimmee Sub-watershed covers about 30 percent of the drainage area in the Lake Okeechobee Watershed, and contributed about 50 percent of total inflow and 25 percent of total TP load during WY2011 (**Table 8-5**). The Lake Istokpoga Sub-watershed covers eleven percent of the drainage area in the Lake Okeechobee Watershed, and discharged 13 percent of the total inflow and five percent of the total TP load in WY2011. The Fisheating Creek Basin comprises nine percent of the drainage area in the Lake Okeechobee Watershed, and contributed about seven percent of total inflow and 14 percent of total TP load during WY2011. The highest flow-weighted TP concentration came from the S-154C drainage basin (833 ppb; Taylor Creek/Nubbin Slough Sub-watershed), followed by C-41 (564 ppb; Indian Prairie Sub-watershed), S-154 (496 ppb; Taylor Creek/Nubbin Slough Sub-watershed), the Lower Kissimmee Sub-watershed (458 ppb), and Taylor Creek/Nubbin Slough Basin(458 ppb; Taylor Creek/Nubbin Slough Sub-watershed).

During WY2011, TN load to the lake from all drainage basins and atmospheric deposition (estimated as 1,233 mt; James et al., 2005) was 2,913 mt (**Table 8-6**). The highest TN load came from the Upper Kissimmee Sub-watershed, followed by the Lake Istokpoga Sub-watershed and Fisheating Creek Sub-watershed. In terms of flow-weighted TN concentration, the S-2 basin (Southern Lake Okeechobee Sub-watershed) had the highest value (4.43 ppm), followed by the C-41 (2.93 ppm; Indian Prairie Sub-watershed), and S-4 (2.77 ppm; Southern Lake Okeechobee Sub-watershed) basins.

Table 8-5. WY2011 surface water inflows and TP loads in mt and concentrations in parts per billion (ppb) from the drainage basins in the Lake Okeechobee Watershed.

Source	Area (ac)	Area (%)	Discharge [acre-feet (ac-ft)]	Discharge (%)	TP Load (mt)	TP Load (%)	Average TP Concentration (ppb)
715 Farms (Culvert 12A)	3,302	0.1	0	0.0	0.0	0.0	no flow
C-40 basin (S-72) – S-68	43,965	1.3	6,599	0.7	3.1	2.2	375
C-41 basin (S-72) – S-68	94,655	2.8	19,792	2.1	13.8	9.7	564
C-41A basin (S-84) – S-68	58,488	1.7	53,175	5.7	5.0	3.5	77
S-308C (St. Lucie – C-44)	129,430	3.8	8,461	0.9	1.2	0.8	113
East Beach Drainage District (Culvert 10)	6,624	0.2	0	0.0	0.0	0.0	no flow
East Shore Drainage District (Culvert 12)	8,416	0.2	0	0.0	0.0	0.0	no flow
Fisheating Creek at Lakeport (includes L-61W basin)	297,817	8.7	62,377	6.7	13.9	9.8	181
Industrial Canal	13,024	0.4	11,266	1.2	1.2	0.8	90
L-48 basin (S-127 total)	20,744	0.6	3,486	0.4	0.5	0.4	124
L-49 basin (S-129 total)	12,093	0.4	4,085	0.4	0.4	0.3	89
L-59E basin (G-33 + G-34)	14,409	0.4	1,034	0.1	0.3	0.2	245
L-59W basin (G-74)	6,440	0.2	9,546	1.0	3.6	2.5	307
L-60E basin (G-75)	5,038	0.1	1,435	0.2	0.2	0.1	95
L-60W basin (G-76)	3,271	0.1	1,606	0.2	0.2	0.1	93
L-61E basin	14,286	0.4	42,966	4.6	7.5	5.3	141
Taylor Creek/Nubbin Slough (S-191)	120,754	3.5	33,979	3.6	19.2	13.5	458
S-131 basin	7,164	0.2	1,764	0.2	0.2	0.1	80
S-133 basin	25,660	0.7	7,779	0.8	1.8	1.3	190
S-135 basin	18,088	0.5	5,420	0.6	0.4	0.3	54
S-154 basin	31,619	0.9	12,018	1.3	7.3	5.1	496
S-154C basin	2,179	0.1	1,825	0.2	1.9	1.3	833
S-2 basin	106,372	3.1	517	0.1	0.1	0.1	132
S-3 basin	62,946	1.8	268	0.0	0.0	0.1	102
S-4 basin	26,389	0.8	13,277	1.4	2.8	2.0	171
Lower Kissimmee Sub-watershed (S-65E-S65)	425,196	12.4	22,931	2.5	13.0	9.1	458
South Florida Conservency Drainage District (S-236)	4,134	0.1	0	0.0	0.0	0.0	no flow
South Shore/South Bay Drainage District (Culvert 4A)	11,028	0.3	0	0.0	0.0	0.0	no flow
Nicodemus Slough Basin (Culvert 5)	25,641	0.7	499	0.1	0.1	0.1	130
Upper Kissimmee Sub-watershed (S-65)	1,021,674	29.7	464,297	49.8	36.0	25.3	63
Lake Istokpoga Sub-watershed (S-68)	392,147	11.4	122,293	13.1	7.2	5.1	48
S-5A basin (S-352 West Palm Beach Canal)	119,443	3.5	0	0.0	0.0	0.0	no flow
East Caloosahatchee Basin (S-77)	200,993	5.8	587	0.1	0.1	0.1	118
L-8 basin (Culvert 10A)	108,402	3.1	2,641	0.3	0.4	0.3	126
Culvert 5A	NA	NA	17,062	1.8	1.1	0.8	53
Totals from Lake Okeechobee Watershed	**3,441,861**	100	**932,945**	100.0	**142**	100	**124**
Atmospheric Deposition					35		
Total Loads to Lake Okeechobee					**177**		

Table 8-6. WY2011 surface water inflows, and total nitrogen (TN) loads in mt and concentrations in parts per million (ppm) from the drainage basins in the Lake Okeechobee Watershed.

Source	Area (ac)	Area (%)	Discharge (ac-ft)	Discharge (%)	TN Load (mt)	TN Load (%)	Average TN Concentration (ppm)
715 Farms (Culvert 12A)	3,302	0.1	0	0.0	0.0	0.0	no flow
C-40 basin (S-72) – S-68	43,965	1.3	6,599	0.7	20.7	1.2	2.54
C-41 basin (S-72) – S-68	94,655	2.8	19,792	2.1	71.5	4.3	2.93
C-41A basin (S-84) – S-68	58,488	1.7	53,175	5.7	99.5	5.9	1.52
S-308C (St. Lucie – C-44)	129,430	3.8	8,461	0.9	15.2	0.9	1.46
East Beach Drainage District (Culvert 10)	6,624	0.2	0	0.0	0.0	0.0	no flow
East Shore Drainage District (Culvert 12)	8,416	0.2	0	0.0	0.0	0.0	no flow
Fisheating Creek at Lakeport (includes L-61W basin)	297,817	8.7	62,377	6.7	154.7	9.2	2.01
Industrial Canal	13,024	0.4	11,266	1.2	33.5	2.0	2.42
L-48 basin (S-127 total)	20,744	0.6	3,486	0.4	8.0	0.5	1.85
L-49 basin (S-129 total)	12,093	0.4	4,085	0.4	8.4	0.5	1.67
L-59E basin (G-33 + G-34)	14,409	0.4	1,034	0.1	3.4	0.2	2.65
L-59W basin (G-74)	6,440	0.2	9,546	1.0	26.4	1.6	2.24
L-60E basin (G-75)	5,038	0.1	1,435	0.2	3.0	0.2	1.69
L-60W basin (G-76)	3,271	0.1	1,606	0.2	2.8	0.2	1.44
L-61E basin	14,286	0.4	42,966	4.6	75.3	4.5	1.42
Taylor Creek/Nubbin Slough (S-191)	120,754	3.5	33,979	3.6	73.5	4.4	1.75
S-131 basin	7,164	0.2	1,764	0.2	3.3	0.2	1.51
S-133 basin	25,660	0.7	7,779	0.8	15.0	0.9	1.57
S-135 basin	18,088	0.5	5,420	0.6	10.3	0.6	1.54
S-154 basin	31,619	0.9	12,018	1.3	36.3	2.2	2.45
S-154C basin	2,179	0.1	1,825	0.2	4.8	0.3	2.12
S-2 basin	106,372	3.1	517	0.1	2.8	0.2	4.43
S-3 basin	62,946	1.8	268	0.0	0.8	0.0	2.44
S-4 basin	26,389	0.8	13,277	1.4	45.3	2.7	2.77
Lower Kissimmee Sub-watershed (S-65E-S65)	425,196	12.4	22,931	2.5	32.1	1.9	1.13
South Florida Conservency Drainage District (S-236)	11,028	0.3	0	0.0	0.0	0.0	no flow
South Shore/South Bay Drainage District (Culvert 4A)	4,134	0.1	0	0.0	0.0	0.0	no flow
Nicodemus Slough Basin (Culvert 5)	25,641	0.7	499	0.1	1.3	0.1	2.15
Upper Kissimmee Sub-watershed (S-65)	1,021,674	29.7	464,297	49.8	676.7	40.3	1.23
Lake Istokpoga Sub-watershed (S-68)	392,147	11.4	122,293	13.1	217.4	12.9	1.44
S-5A basin (S-352 West Palm Beach Canal)	119,443	3.5	0	0.0	0.0	0.0	no flow
East Caloosahatchee Basin (S-77)	200,993	5.8	587	0.1	1.3	0.0	1.86
L-8 basin (Culvert 10A)	108,402	3.1	2,641	0.3	8.3	0.5	2.56
Culvert 5A	NA	NA	17,062	1.8	28.0	1.7	1.33
Totals from Lake Okeechobee Watershed	**3,441,861**	100	**932,945**	100.0	**1,680**	100	**1.46**
Atmospheric Deposition[a]					1,233		
Total Loads to Lake Okeechobee					**2,913**		

[a]From James et al. (2005).

USGS and Ambient Water Quality Data Analysis

The USGS network, designated as OKUSGS in DBHYDRO, consists of 14 flow proportional tributary stations that provide real-time nutrient loadings in locations key to understanding nutrient transport and evaluating trends over time as restoration projects come online. The nutrient loads for the 14 USGS sites are currently being verified and calculated according to District standards and will be reported on in future reports. The ambient project (KREA and TCNS in DBHYDRO) consists of tributary-level monitoring on a biweekly flow-only basis at 35 stations for both TP and TN concentrations. It has primarily focused assessment in those basins considered critical to the nutrient concentration issues in the Lake Okeechobee Watershed, which are Taylor Creek/Nubbin Slough and Kissimmee basins. The TP and TN trend analyses were conducted using these data collected from 1991 to 2007 (Zhang et al., 2011). Lake Okeechobee Watershed Assessment (LOWA in DBHYDRO) monitoring network sites are used to highlight areas of concern and are a part of the Lake Okeechobee Watershed Regulatory Phosphorus Source Control Program. Lake Okeechobee Watershed Assessment monitoring results are discussed in Chapter 4 of this volume.

Table 8-7 presents basic statistics for WY2011 TP and TN concentration data by basin for 14 USGS sites and the 35 ambient sites. 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 because 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.

Due to its size and the numbers of monitoring stations, the S-191 basin (Taylor Creek/Nubbin Slough) is further divided into two sub-basins: Taylor Creek (S-191TC) and Nubbin Slough (S-191NS). During WY2011, the highest median TP concentration came from the S-154 drainage basin (483 ppb), followed by the S-191TC (411 ppb) and C-41 (323 ppb) basins. In terms of median TN concentrations, the S-154 basin had the highest value (2.17 ppm), followed by the C-41 (2.12 ppm), Fisheating Creek (1.95 ppm), and S-65E (1.93 ppm) basins.

Table 8-7. WY2011 TP and TN data collected from the USGS and ambient networks in the Lake Okeechobee Watershed.

Basin	Total Phosphorus				Total Nitrogen			
	Mean (ppb)	Median (ppb)	Standard Deviation	Number of Samples	Mean (ppm)	Median (ppm)	Standard Deviation	Number of Samples
C-41	502	323	429	25	2.56	2.12	1.26	25
C-41A	46	41	23	37	1.35	1.31	0.22	39
Fisheating Creek	242	184	189	44	2.16	1.95	0.76	43
Lake Istokpoga	109	92	62	40	1.32	1.30	0.18	40
S-65A	65	59	29	48	1.26	1.30	0.26	48
S-65BC	63	58	29	48	1.17	1.12	0.17	48
S-65D	325	296	273	136	1.60	1.53	0.63	137
S-65E	281	167	276	28	2.12	1.93	0.83	27
S-154	538	483	350	31	2.41	2.17	0.86	31
S-191TC (Taylor Creek)	472	411	343	143	1.97	1.77	0.95	143
S-191NS (Nubbin Slough)	332	287	193	48	1.65	1.67	0.37	47

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 LOPA (Section 373.4595, F.S.). These measures describe the status of the ecosystem and its responses to implemented restoration programs. Measures are five-year rolling 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 8-8**). The TP load is the only goal that is to be met by a set date, 2015, as specified in the TMDL (FDEP, 2001). The Lake Okeechobee Protection Plan provides a technical foundation for these restoration goals (SFWMD et al., 2004).

Table 8-8. Summary of Lake Okeechobee rehabilitation performance measures, rehabilitation program goals, and lake conditions for WY2007–WY2011 as specified in the Restoration Assessment Plan of the Lake Okeechobee Protection Program. WY2011 and WY2010 values are included to show annual changes.

Performance Measure[1]	Goal	Five-Year Average	WY2011	WY2010
TP load	140 tons per year (to be met by 2015)	352 metric tons per year (mt/yr)	177 mt/yr	478 mt/yr
TN Load	NA	4,457 mt/yr	2,913 mt/yr	6,325 mt/yr
Pelagic TP	40 ppb	152 ppb	108 ppb	118 ppb
Pelagic TN	NA	1.55 ppm	1.46 ppm	1.48 ppm
Pelagic SRP	NA	51 ppb	32 ppb	42 ppb
Pelagic DIN	NA	206 ppb	178 ppb	201 ppb
Pelagic TN:TP	> 22:1	10.2:1	13.4:1	12.5:1
Pelagic DIN:SRP	> 10:1	4:1	5.6:1	5.2:1
Plankton nutrient limitation	P > N	N >>> P	N >>> P	N >>> P
Diatom:cyanobacteria ratio[2]	> 1.5	2.0	NA	NA
Algal bloom frequency	< 5% of pelagic chlorophyll *a* exceeding 40 micrograms per liter (µg/L)	7.6%	16.5%	11.0%
Water clarity	Secchi disk visible on lake bottom at all nearshore submerged aquatic vegetation (SAV) sampling locations May–September	54.0%	28%[4]	53.0%
Nearshore TP	Below 40 ppb	80 ppb	61 ppb	57 ppb
SAV[3]	Total SAV > 40,000 ac Vascular SAV > 20,000 ac	28,157 ac total 9,809 ac vascular	27,388 ac total 19,596 ac vascular	46,418 ac total 30,171 ac vascular
Extremes in low lake stage (current water year)	Maintain stages above 10 feet National Geodetic Vertical Datum (ft NGVD)	NA	Goal attained	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	NA	Goal attained	Goal attained
Spring recession (January to June 2007)	Stage recession from near 15.5 ft in January to near 12.5 ft in June	NA	Goal not attained	Goal not attained

[1] SRP – soluble reactive phosphorus; DIN – dissolved inorganic nitrogen; TN:TP – ratio of TN to TP; DIN:SRP – ratio of DIN to SRP; SAV – submerged aquatic vegetation
[2] Mean values from May 2005 to February 2010
[3] Mean yearly acreages (from August 2006–2010 maps)
[4] SAV transparency readings taken only in June 2010

Of the 11 performance measures given as current five-year (WY2007–WY2011) averages, only one met its goal. The diatom-to-cyanobacteria ratio by biovolume was 2:1, exceeding the performance measure goal of greater than 1.5:1. While this value exceeds its goal, it is lower than the average reported in the previous annual report of 3.6:1 for WY2006–WY2010 (see Table 10-12 in the 2011 SFER – Volume I, Chapter 10).

The WY2007–WY2011 TP load averaged 352 mt/yr (**Table 8-8**), a 26 percent reduction from the WY2006–WY2010 average of 476 mt/yr (**Table 8-2**)**.** This 26 percent reduction is due to the removal of the WY2006 value of 795 mt from the calculation and to the addition of the low WY2011 value of 177 mt. As load is generally proportional to flow, this low load is a direct result of lower flows caused by the drought conditions in WY2011. The current five-year average is still 2.5 times greater than the 140 mt/yr TMDL considered necessary to achieve the in-lake TP goal of 40 ppb.

The WY2006–WY2011 TN load averaged 4,457 mt/yr (**Table 8-8**), an 18 percent decrease from the WY2006–WY2010 average of 5,477 mt/yr (Table 10-12 in the 2011 SFER – Volume I, Chapter 10). The WY2011 load was estimated at 2,913 mt, a reduction of 54 percent compared to the WY2010 load (**Table 8-8**). As with TP load, this reduction is due to the drought conditions and low flow. There is no in-lake goal for TN; however, a tributary TMDL for N has been established (USEPA, 2008).

Pelagic nutrient concentrations for WY2011 improved compared to WY2010 (**Table 8-8**). TP declined by more than eight percent, while TN remained relatively stable declining less than 1.4 percent. SRP declined by more than 23 percent and dissolved inorganic nitrogen (DIN) declined by more than 11 percent. However, both the ratios for TN-to-TP (by mass) and DIN-to-SRP (by mass) increased by more than seven percent. Thus N was still the most limiting nutrient for algae based on these low ratios. TP in the nearshore region also increased by seven percent.

In the previous report, the algal bloom frequency for the WY2006–WY2010 period was 4.3 percent, meeting the performance measure goal of less than five percent (Table 10-12 in the 2011 SFER – Volume I, Chapter 10). However the WY2011 value increased from 11 percent to 16.5 percent, which added to the five-year increase (**Table 8-8**). In many lake systems, algal bloom frequency increases with improved light conditions, which allow for greater light penetration into the water column to sustain increases in photosynthetic algal species (James and Havens, 2005). However the lake experienced poorer light conditions in WY2011 than in WY2010 (data not shown) and reduced transparency during the May to September period for the SAV stations (28 percent).

The performance measure goal for areal coverage of SAV (greater than 40,000 ac total coverage with greater than 20,000 as vascular plants) was not met in the August 2010 survey or in the average of the previous five years of data (August 2006–August 2010; **Table 8-8**). A further evaluation of the last survey is provided in the *Submerged Aquatic Vegetation* section of this document.

Despite dry conditions throughout most of WY2011, lake water levels remained above the 10 ft low lake criteria (**Figure 8-10**, **Table 8-8**). Because of the dry conditions, the high lake stage criterion was not exceeded either. However, from January 2011 to May 2011, water levels declined from 12.43 ft (3.79 m) to 10.43 ft (3.33 m) NGVD (**Figure 8-10**). This was well below the criteria of 15.5 ft (4.72 m) in January and 12.5 ft (3.81 m) in June.

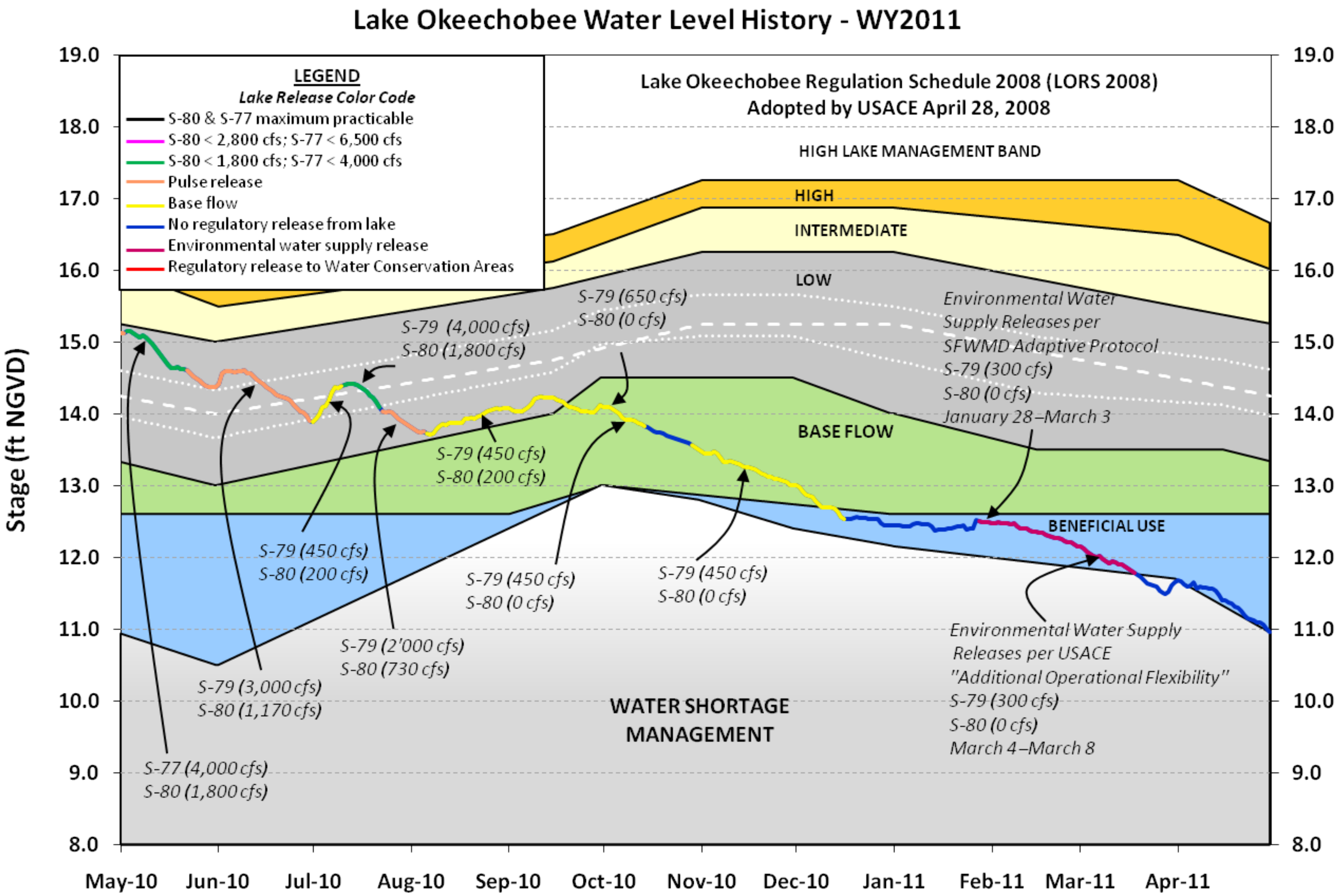

Figure 8-10. Annotated Lake Okeechobee hydrograph. [Note: cfs – cubic feet per second; ft NGVD – feet National Geodetic Vertical Datum]

ADAPTIVE PROTOCOLS FOR LAKE OKEECHOBEE RELEASES

In response to concerns regarding the integrity of the Herbert Hoover Dike, the USACE adopted a new regulation schedule for Lake Okeechobee in April 2008, which is commonly referred to as the Lake Okeechobee Regulation Schedule 2008 (LORS 2008). LORS 2008 is considered an interim schedule because its primary purpose is to regulate high lake levels while repairs are being made to the dike. Until the dike repairs are complete, the lake will be operated approximately one foot lower than the previous schedule, making management of the limited supply of water for multi-use purposes more difficult during dry periods. As a consequence, adaptive protocols were developed to be used when the lake stage is in the low, baseflow and beneficial use sub-bands to provide guidance to water managers for discretionary releases for ecosystem benefits or to improve conditions related to the operation of the Central and Southern Florida Flood Control Project (C&SF Project) (**Figure 8-10**).

The analyses conducted for this version of the adaptive protocols were based on assumptions regarding how water would be released by the USACE in the low, baseflow and beneficial use sub-bands. The performance gains demonstrated by the analyses are a result of both components of the release guidance as follows: (1) concerning releases in the baseflow and beneficial use sub-bands and (2) the strategy to request the USACE to limit the low sub-band maximum release rates during the early part of the dry season. This second component helps conserve early dry season water to increase its potential availability for later in the dry season when the demand is highest. The USACE is not mandated to follow this second component per the Final Supplemental Environmental Impact Statement for the Lake Okeechobee Regulation Schedule (USACE, 2007).

HYDROLOGY

Lake Okeechobee began the water year at an elevation of 15.13 ft NGVD. Being close to the usual onset of the annual wet season, efforts were made to lower the lake by a series of pulse releases in anticipation of an active tropical season. Despite some small reversals during the summer, periodic pulse releases discharged to the St. Lucie and Caloosahatchee estuaries continued through mid-September and brought the lake into the baseflow sub-band. Periodic pulse releases through mid-December 2010, coupled with the driest October–June period on record, dropped the lake into the beneficial use sub-band in mid-December. Environmental releases to the Caloosahatchee River commenced at the end of January 2011 and continued through mid-March. The lake crossed into the water shortage management band on March 18, 2011, rebounded into the beneficial use sub-band on April 4, and crossed back into the water shortage management sub-band on April 29, ending the water year in the water shortage management sub-band at an elevation of 10.96 ft NGVD on April 30, 2011 (**Figure 8-10**).

NUTRIENT BUDGETS

TP loads to the lake from tributaries and atmospheric deposition (estimated as 35 mt/yr; FDEP, 2001) totaled 177 mt in WY2011 (**Tables 8-2** and **8-9**; **Figure 8-11**). This was a decrease from the previous year and was primarily due to reduced inflow (**Figure 8-9**) and inflow concentration (**Figure 8-11**). Mean lake TP mass in WY2011 was also less than the previous water year due to lower water volumes and water column concentrations (**Table 8-9** and **Figure 8-12**). Net change in lake TP content was negative and was attributed to the decline of water volume over the course of the water year (**Figure 8-11**). TP loads out of the lake were greater in WY2011 than WY2010 as discharge was greater. The net load (inputs minus outputs) in WY2011 was negative because of the higher load out than the load in (**Table 8-9**). Sediment accumulation was also higher as more of the TP mass in the water column settled into the sediments. The higher sediment accumulation resulted in a higher net sedimentation coefficient (sediment accumulation divided by mean lake TP mass (**Figure 8-12**).

Table 8-9. TP budget for Lake Okeechobee for the most recent 10 water years.

May 1–April 30 Water Year	Mean Lake TP Mass	Net Change in Lake Content[1]	Load In[2] (mt)	Load Out (mt)	Net Load[3] (mt)	Sediment Accumulation[d]	Net Sedimentation Coefficient (σ_y)
2002	425	264	624	81	543	279	0.66
2003	594	143	639	317	322	179	0.30
2004	578	113	553	302	251	138	0.24
2005	1108	270	960	582	378	107	0.10
2006	1104	-194	795	798	-3	191	0.17
2007	593	-269	203	176	27	296	0.50
2008	462	132	246	26	220	88	0.19
2009	602	-276	656	242	414	691	1.15
2010	490	291	478	77	401	110	0.22
2011	428	-338	177	208	-31	307	0.72
Average	638	14	533	281	252	239	0.42

[1] Net change from the start (May 1) through the end (April 30) of each water year.

[2] Includes 35 metric tons per year to account for atmospheric deposition.

[3] Difference between load in and load out.

[4] Difference between net change in lake content and net load (positive value is accumulation in sediments).

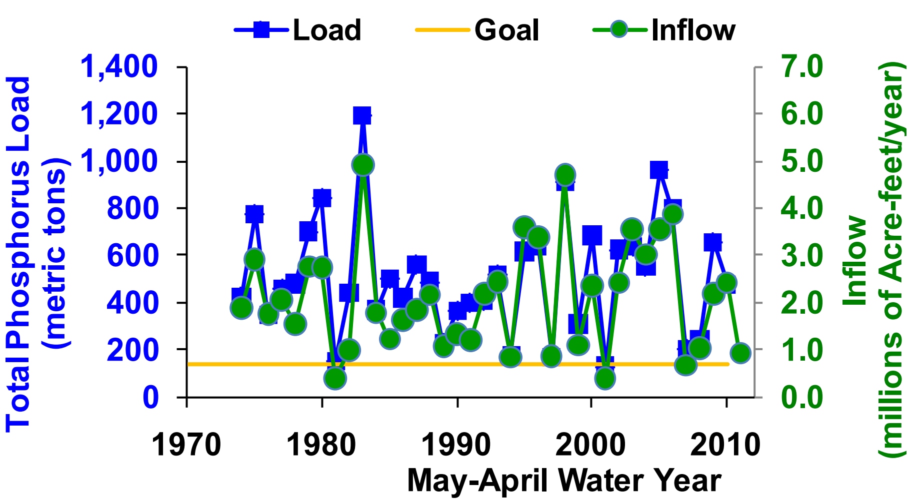

Figure 8-11. Timelines of water year TP load and inflow entering Lake Okeechobee from its tributaries calculated from the phosphorus (P) budget of Lake Okeechobee.

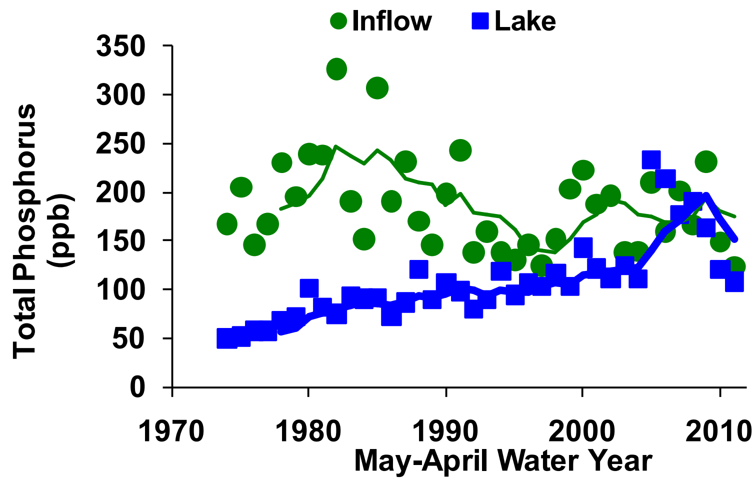

Figure 8-12. Timelines of inflow and lake average TP concentrations (five-year moving average trend lines calculated from the P budget of Lake Okeechobee).

P concentrations in the lake water column have declined each year after reaching a maximum yearly average value of 233 ppb in 2005 (**Figure 8-13**). In WY2011, the average value was down to 108 ppb (**Table 8-9**), similar to pre-hurricane values (before WY2005, **Figure 8-13**). This drop in TP concentrations can be attributed to lower water levels, which result in increased abundance of submerged and emergent plants, reduced sediment resuspension, and improved light conditions (James and Havens, 2005). The net sedimentation coefficient, σ_y (per year), of the P budget is the amount of TP that accumulates in the sediment per year divided by the average lake water TP mass (**Table 8-9** and **Figure 8-12**). A low σ_y indicates the lake absorbs less excess TP loads from the watershed. For WY2011, the σ_y value was 0.72 per year (**Table 8-9**), which is above the 10-year average value of 0.45 per year. The WY2011 value is higher than values estimated in recent years and indicates increased absorption of P by sediments. Over the past four decades σ_y declined from around 2.5 in the 1970s to below 1.0 in the 1990s (**Figure 8-12**) (James et al., 1995; Janus et al., 1990; Havens and James, 2005).

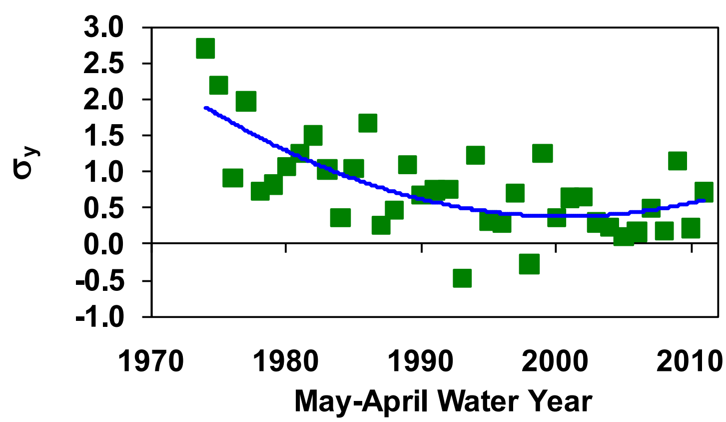

Figure 8-13. Timeline of the net sedimentation coefficient (σ_y) calculated from the WY2009 P budget of Lake Okeechobee. Trend line is a second-order polynomial.

TN loads to the lake are approximately tenfold greater than TP (**Table 8-10**). Annual TN loads are also closely related to lake hydrology, fluctuating between 2,500 and 14,000 mt/yr (**Figure 8-14**). Discharge loads from the lake are approximately half of the inflow loads (**Table 8-10**). Inflow TN concentrations tend to be higher than either in-lake or outflow concentrations, while outflow concentrations tend to be slightly higher than in-lake concentrations (**Figure 8-15**). This is probably a result of the intra-annual variability of N 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. Despite this difference between loads into and out of the lake, lake TN concentrations have been relatively stable since the 1980s (**Figure 8-15**). This stability is likely due to biological processes in the lake that remove N through the denitrification process (James et al., 2011).

Table 8-10. TN budget 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[1]	Load In[2] (mt)	Load Out (mt)	Net Load[3] (mt)	Lake Adsorption[4]	Net Adsorption Coefficient (σ_y)
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
2011	5,762	-3,402	2,913	3,018	-105	3,297	0.57
Average	6,752	68	6,168	3,406	2,763	2,694	0.44

[1] Net change from the start (May 1) through the end (April 30) of each water year.

[2] Includes 1,233 metric tons per year to account for atmospheric deposition.

[3] Difference between load in and load out.

[4] Difference between net change in lake content and net load (positive value is accumulation in sediments).

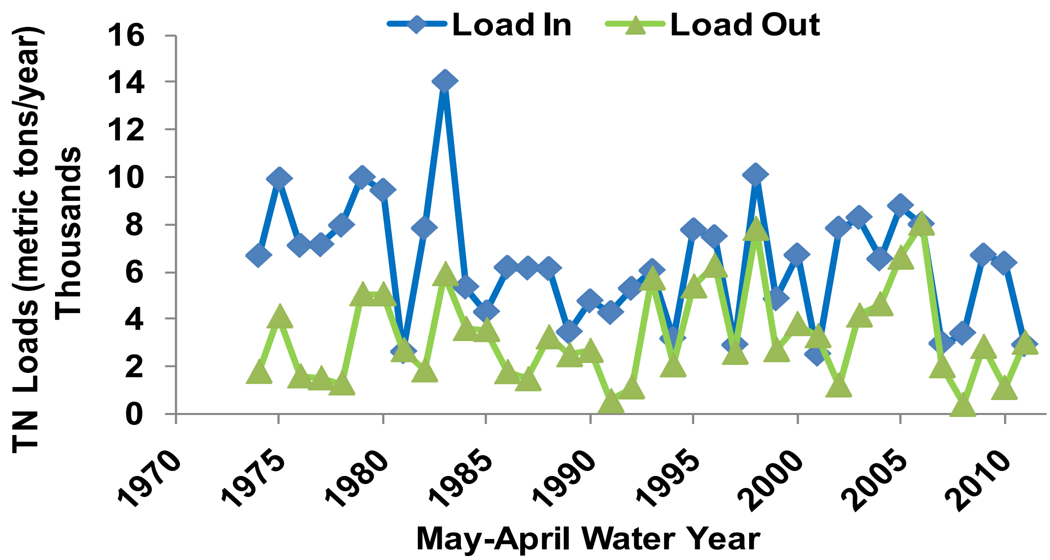

Figure 8-14. Timeline of water year inflow and outflow TN load to and from Lake Okeechobee calculated from the nitrogen (N) budget of the lake.

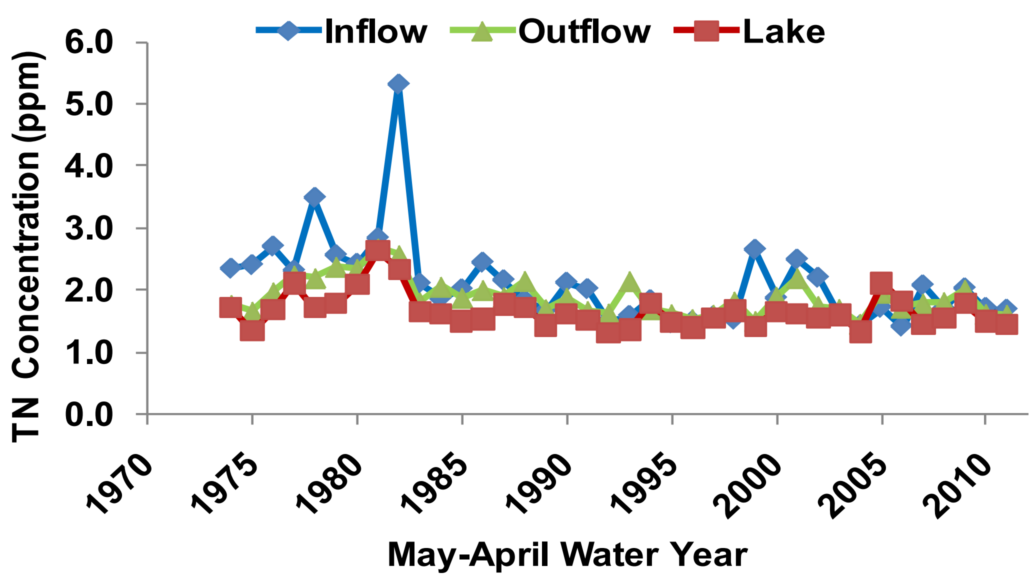

Figure 8-15. Timelines of inflow, outflow, and lake average TN concentrations in parts per million (ppm) calculated from the N budget of Lake Okeechobee.

LAKE MONITORING AND RESEARCH

SUBMERGED AQUATIC VEGETATION

Submerged aquatic vegetation (SAV) abundance is a key indicator of the lake's overall ecological health. From April 1999 to December 2009, routine biological monitoring of SAV consisted of quantitatively measuring biomass at stations located along 16 fixed transects encompassing the lake's north, south and west shoreline on a monthly basis. Triplicate SAV samples were harvested at each site, stripped of periphyton, separated by species, and dried and weighed. Dry mass [grams dry weight per square meter (g dry wt/m^2)] was calculated for each site and values from all sites were averaged together to obtain a monthly average biomass estimate. Qualitative estimates of sparse, moderate, and dense were also recorded for each sample prior to processing. Comparisons with weight data indicated that the qualitative estimates generally corresponded to specific ranges in dry mass (quantitative estimates), leading to the following three qualitative–quantitative relationships: (1) sparse = less than 5 g dry wt/m^2, (2) moderate = 5 to 50 g dry wt/m^2, and (3) dense = greater than 50 g dry wt/m^2. Beginning in January 2010, the labor intensive quantitative sampling was eliminated and only visual estimates of biomass (sparse, moderate, and dense) were made. Sampling frequency was reduced from monthly to quarterly. Consequently, only the qualitative data can be used to compare pre-2010 data to the post-2010 results (**Figure 8-16**). Based on these data, SAV in Lake Okeechobee has recovered from the 2004–2005 hurricanes and the 2007–2008 drought. As lake levels returned to near average conditions in 2009, SAV gradually increased with more sites having moderate (5 to 50 g dry wt/m^2) to dense (>50 g dry wt/m^2) biomass.

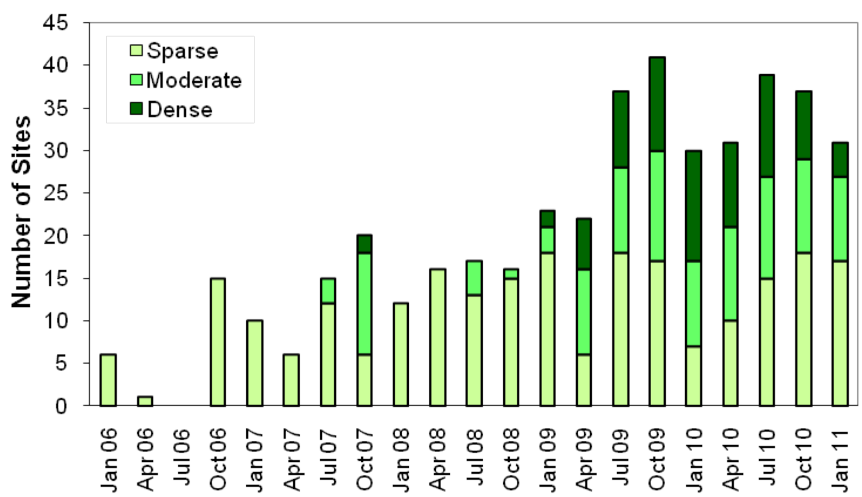

Figure 8-16. Quarterly submerged aquatic vegetation (SAV) density estimates from transect sampling from 2006 to 2011.

Areal coverage of SAV, as measured in August of each year, supports this conclusion (**Figure 8-17**). Much of the initial increase was due to the growth of chara (*Chara* spp.), a nonvascular macroalga with a competitive advantage under low light conditions. By August 2009, there were 25,278 ac of chara. However, in August 2010, chara coverage decreased to 7,792 ac, accounting for most of the decrease in ac of total SAV between 2009 and 2010 (**Figure 8-17**). One reason for the decrease in chara was the development of a dense cattail (*Typha* spp.) and spike rush (*Eleocharis* spp.) marsh in the south, which reduced the colonizable area for chara.

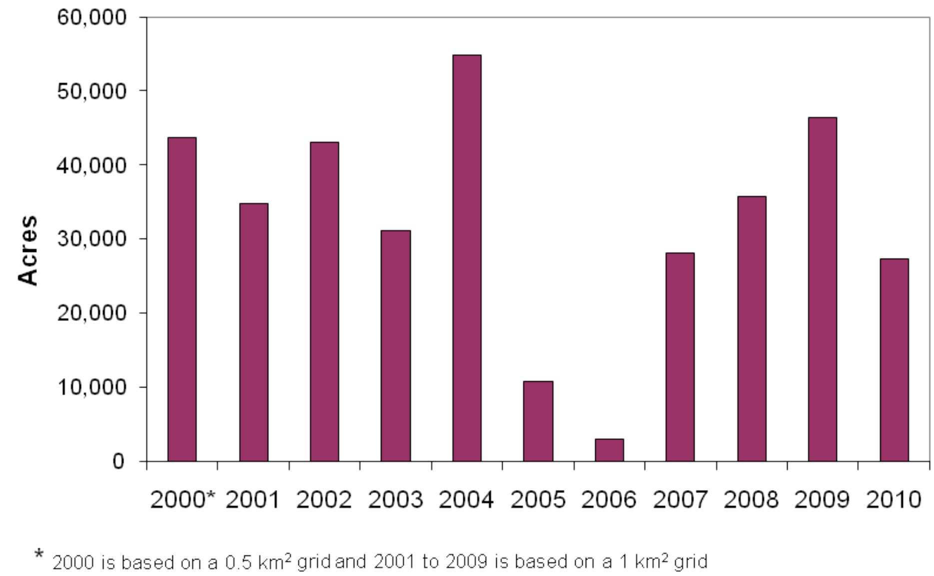

Figure 8-17. Acres of total SAV (vascular and nonvascular species) measured from the annual August SAV mapping results from 2000 to 2010.

Currently, moderate to dense beds of vascular species, including 4,004 ac of eelgrass (*Vallisneria americana*), 8,695 ac of coontail (*Ceratophyllum* spp.), 2,667 ac of peppergrass (*Potamogeton* spp.), and 12,327 ac of the exotic hydrilla (*Hydrilla verticillata*), dominate the northern and western shorelines. These vascular species, which also provide better habitat than the nonvascular species, account for over 80 percent of the total SAV. The replacement of chara habitat with emergent marsh habitat is a positive development, and one which may reflect successional changes in vegetation related to the lower lake operating schedule of LORS 2008.

Given that lake levels fell to under 11 ft NGVD by spring 2011, higher elevation sites that were colonized by SAV in August 2010 are now dry and no longer support SAV. While some lakeward expansion of SAV might be expected, due to improved light penetration under shallow water conditions, it is probable that the net effect of this most recent drought will be an overall reduction in SAV coverage as measured during the August 2011 mapping event.

EMERGENT VEGETATION

Emergent Vegetation Mapping

The composition, distribution, and areal coverage of Lake Okeechobee's emergent marsh community is strongly influenced by hydrologic conditions, vegetation management actions, and competition between species, especially when native habitats are impacted by invasive exotic plants (Hanlon and Langeland, 2000; Hanlon and Brady, 2006; Johnson et al., 2007). As part of an ongoing periodic effort begun in 1996, a new set of color infrared aerial photography was collected in 2010 to evaluate and map the plant communities (e.g., habitat) in Lake Okeechobee's central marsh. The marsh was equally divided into a series of 100 m by 100 m grids (> 87,000 grids). The dominant and secondary plant communities within each grid are being identified and recorded. A detailed GIS map quantifying the areal coverage and spatial distribution of the lake's central marsh will be completed during September 2011.

Impact of Water Hyacinth and Water Lettuce Treatments on Nontarget Native Bulrush

The floating exotic plants water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) pose the risk of significant ecological harm to Lake Okeechobee's marsh community. In addition to obstructing navigation, dense mats of floating exotic plants can damage native emergent vegetation (Thayer and Joyce, 1990). One of the native plants commonly impacted by water hyacinth and water lettuce is bulrush (*Schoenoplectus californicus*). Bulrush is desirable because it provides important habitat for fish and wildlife. However, due to its location along the lakeward edge of the marsh, mats of water hyacinth and water lettuce often are pushed into or through stands of bulrush by wind currents. The physical force that large moving mats of floating exotic plants have on bulrush often results in bulrush stems being damaged and/or the entire plant being uprooted.

When floating exotic plants become entangled in bulrush, vegetation managers often are faced with the decision to either (1) treat and kill the exotic vegetation with a contact herbicide (nonsystemic) causing significant damage to the unprotected bulrush stems above the water line, or (2) avoid treating until the floating exotic plants are blown out of the bulrush and can be treated with minimal or no nontarget damage. This second option allows the exotic plants to continue rapidly increasing their areal coverage, which may increase their potential for causing damage, while attempting to protect nontarget plants.

During fall 2009 mixed stands of bulrush and water hyacinth were treated. The response of bulrush to the treatments was monitored and compared to untreated control plots. Seven months after the initial treatment (1X), half of each treated plot was treated a second time (2X) to evaluate the effect of multiple treatments within a 12 month period.

Initially, no significant differences in stem density were observed between the treated and control plots. However, at 10, 17, 25, and 42 weeks post-treatment, the untreated control plots had significantly greater stem densities ($p < 0.05$) than the treated plots. At 37, 50, and 59 weeks post-treatment, significant differences were no longer observed between the treated and untreated sites (**Figure 8-18**).

Twenty-nine weeks following the second treatment, stem densities averaged 13.0 stems per square meter (/m^2) in the untreated controls, 11.7 stems/m^2 in the 1X sites (treated only in 2009) and 8.5 stems/m^2 in the 2X sites (treated in 2009 and 2010). The differences in stem densities were significant ($P < 0.05$) between the untreated controls and the 2X sites, and between the 1X and 2X sites.

The results indicate that while bulrush can recover from exposure to herbicide treatments, it may take many months to recover to pretreatment densities. Treating bulrush a second time further increases time to recovery. From a management perspective, these results seem to suggest that the decision whether or not to treat floating vegetation in bulrush stands must be made on a case by case basis weighing the potential damage to bulrush from the herbicide against the potential physical damage to bulrush and other habitats posed by moving and expanding mats of floating vegetation

Exotic Species Control Program

The Exotic Species Control Program identifies exotic species that threaten native flora and fauna within the Lake Okeechobee Watershed, and develops and implements measures to protect native species. Exotic plants and animals identified as threatening to native species require management or, in the case of some animal species, monitoring to keep track of possible future invasions. The District's Exotic and Nuisance Vegetation Management Program is designed to protect threatened native habitat in Lake Okeechobee and to restore areas of the marsh that have

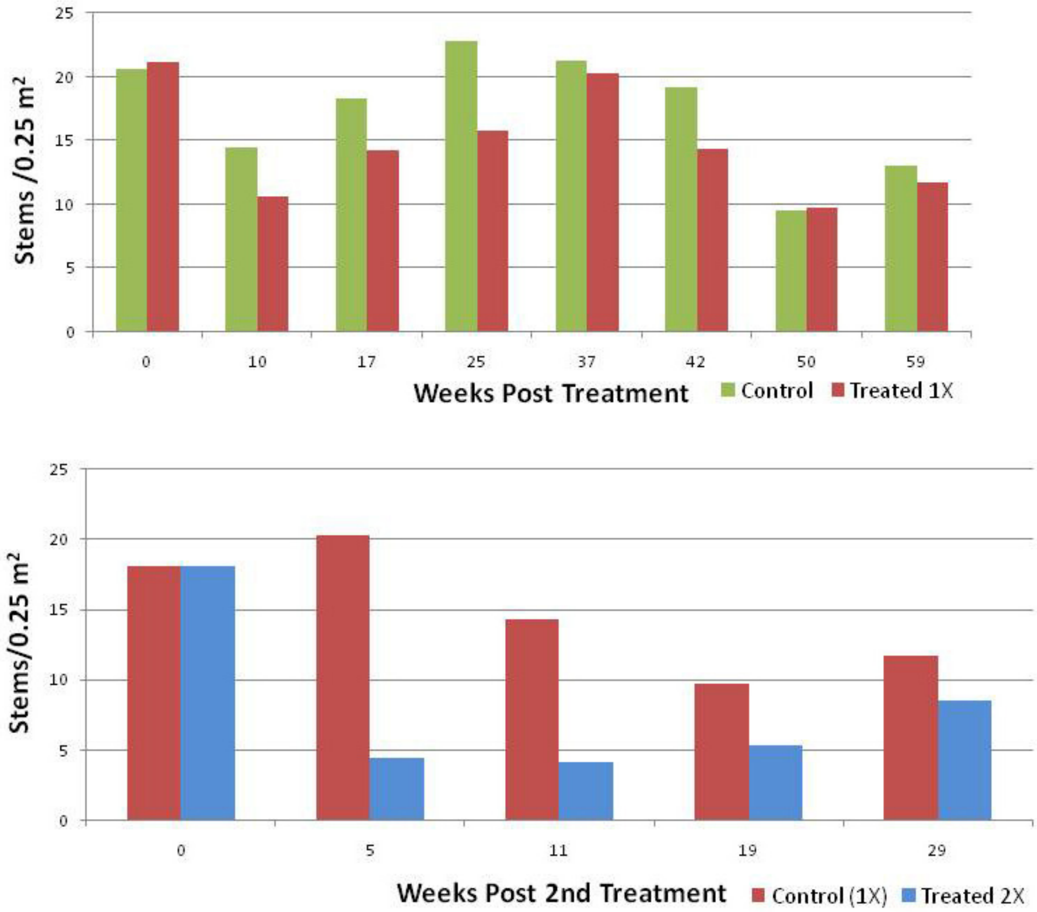

Figure 8-18. Effects of herbicide treatments of floating aquatic vegetation on bulrush.

been impacted by undesirable species. Torpedog**r**ass continues to be the most common emergent exotic plant in the lake's marsh and extensive efforts to reduce its coverage are ongoing. An evaluation of treatment efficacy indicated that many of the historical and recent treatments provided excellent torpedograss control (90–100 percent), some for as long as six years following a single or, in some instances, multiple treatments. Of the 29 treatment sites evaluated, control was rated as 90 percent or greater at 25 locations.

During WY2011, more than 6,470 ac of torpedograss were treated in the lake's western marsh (**Figure 8-19**). Without the treatment program, 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 been reduced dramatically. Native plant communities have colonized some of the treated sites and monthly wading bird surveys conducted in winter and spring 2011 documented thousands of birds foraging in shallow open water areas previously impacted by torpedograss (see the *Wading Birds* section in this chapter).

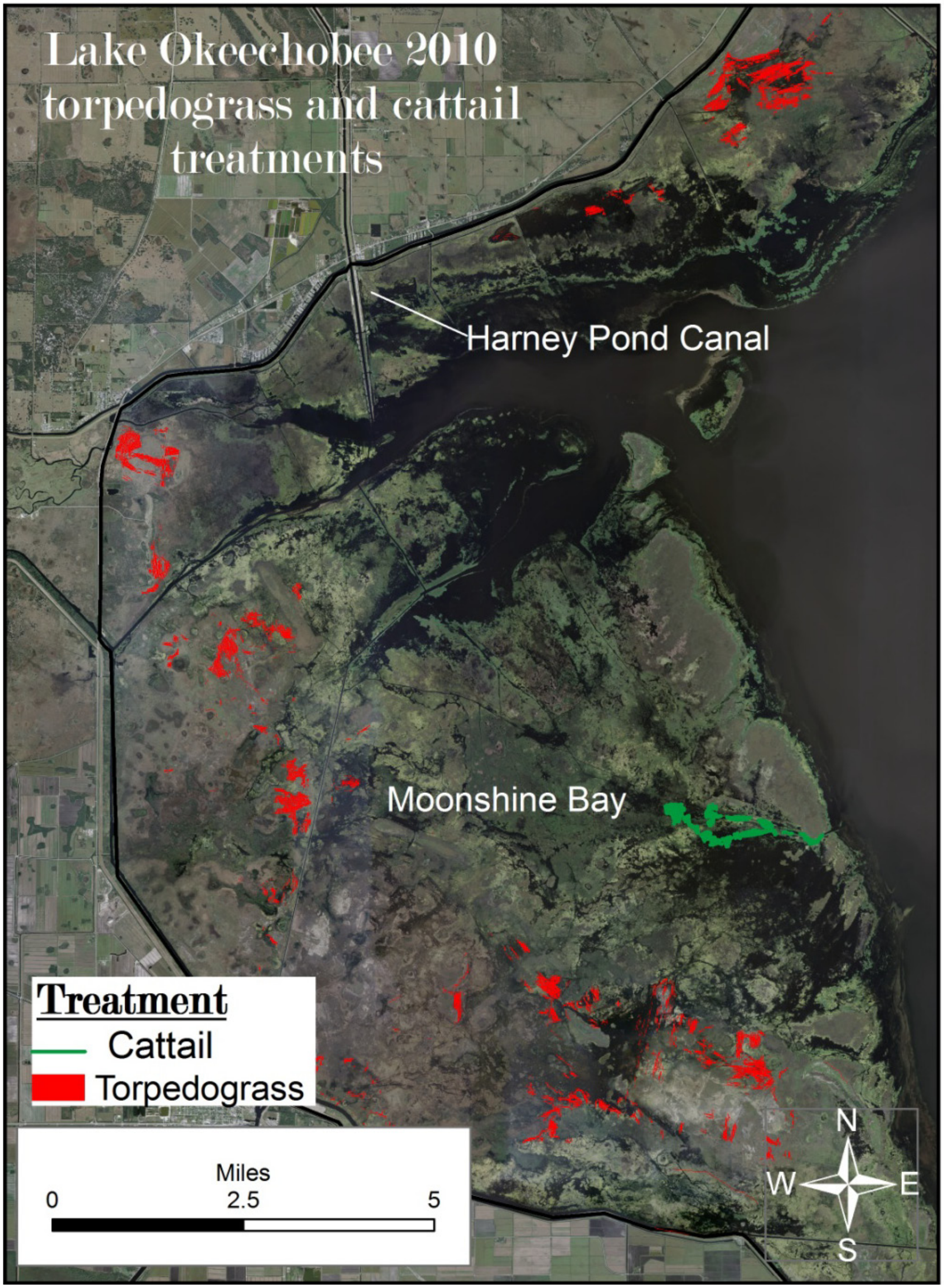

Figure 8-19. Location of 2010–2011 torpedograss (red) and cattail (green) treatments in Lake Okeechobee's western marsh.

The floating exotic plants water hyacinth and water lettuce, along with Brazilian pepper (*Schinus terebinthifolius*), watergrass *(Luziola subintegra*), and cattail, also were targets of the vegetation management program during the past year. Combined, the District treated more than 9,600 ac of vegetation in the lakes western marsh and the USACE treated more than 12,600 ac of floating exotic plants (**Figure 8-20**).

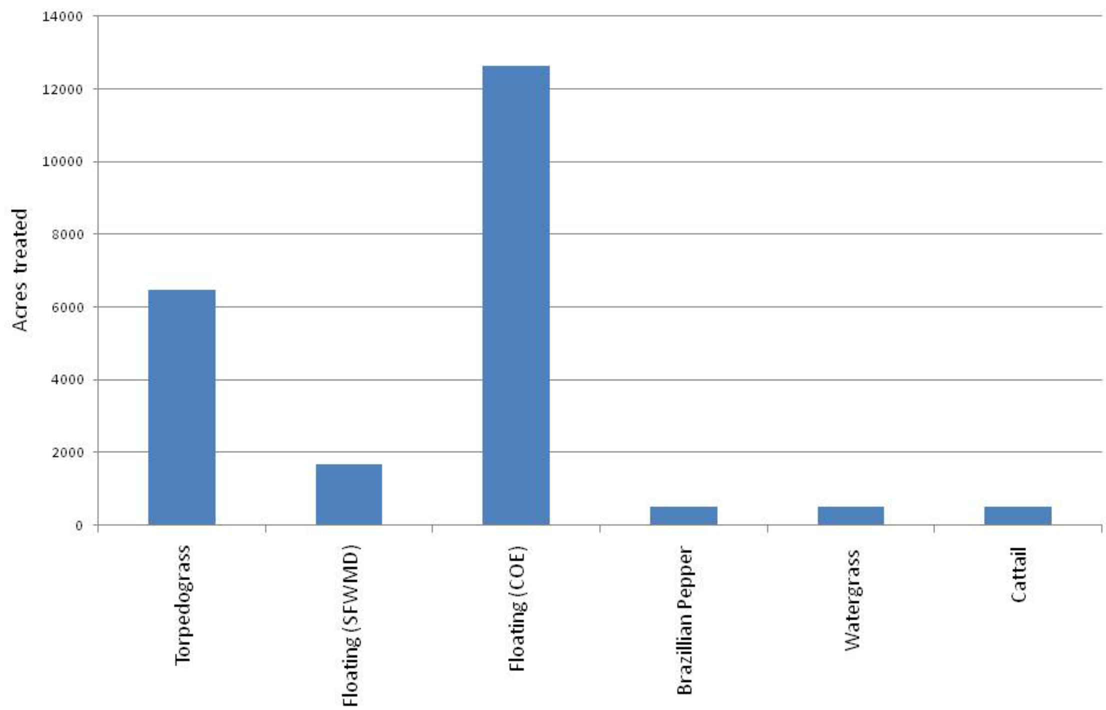

Figure 8-20. Number of acres of the five most commonly treated plants in Lake Okeechobee in 2010. Depending primarily on location, water hyacinth and water lettuce may be treated by either the SFWMD or United States Army Corps of Engineers (USACE).

PHYTOPLANKTON

Routine Monitoring

Routine quarterly plankton monitoring continued throughout the past water year. However, due to delays in processing samples and analyzing data no results are reported at this time.

Algal Bloom Monitoring

Lower lake levels associated with both the LORS 2008 and recent drought conditions have resulted in less hydrologic connectivity between the usually turbid pelagic zone and the nearshore zone. Although these conditions have the potential to favor bloom formation, only minor isolated surface blooms have occurred since the prolific blue-green algal blooms that occurred in summer 2005. Additionally, with the exception of one elevated microcystin concentration in a sample collected along the southwest shoreline of Lake Okeechobee in summer 2010, toxin concentrations have been below the analytical limit of detection (0.2 ppb) since Hurricane Wilma struck in October 2005. Additionally, only one sample has been collected in this time period that had a chlorophyll *a* concentration exceeding 40 μg/L, the value that defines algal bloom conditions. In this context, it should be noted that through WY2011, the algal bloom monitoring stations consisted of a subset of our standard in-lake water quality sampling considered to have potentially increased public significance. Hence, the results reported in this section do not necessarily correspond to the results reported in **Table 8-8**. However, beginning in WY2012, the two sets of stations have been made consistent, which should eliminate these apparent reporting discrepancies.

Periphyton

Periphyton is an important food source for herbivorous macroinvertebrates and fish in Lake Okeechobee (Havens et al., 1996; 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., 1996; Rodusky et al., 2001).

The most recent periphyton monitoring on Lake Okeechobee started in August 2002 and ended in September, 2010. Methods and sampling sites were reported in Chapter 10 of the 2010 SFER – Volume I 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 levels and positively associated with the amount of available colonizable substrate. This hypothesis was tested by monitoring periphyton abundance, taxonomic composition, and N, P, and total carbon (C) storage in periphyton on host plants 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.

Communities sampled included periphyton growing on SAV and emergent plant stems (epiphytes) and periphyton growing on the bottom sediments (epipelon). Monitoring was suspended during most of 2006 because of SAV and emergent plant loss in the nearshore region after the passage of Hurricanes Frances, Jeanne, and Wilma between 2004 and 2005. In 2007 and 2008, very little SAV substrate was available for periphyton due to drought conditions (Chapter 10 of the 2010 SFER – Volume I). Additionally, epipelon sampling sites were moved lakeward because of very low water levels.

As water levels increased, some of the original sites were re-inundated 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 west region in fall 2010; and bulrush (south) in spring 2010. Spikerush and cattail spread throughout formerly open water SAV habitat in the southern portion of the nearshore region, thus delaying the reestablishment of SAV and dependent sampling activities in South Bay, Pelican Bay, and west of Rita Island.

Periphyton biomass from 2002 to 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, and the 2004–2005 hurricanes, all of which dramatically reduced emergent vegetation and vascular SAV host substrate coverage (Rodusky, 2010). Due to the number of replicate sites added upon the recommencement of monitoring in 2007, a direct comparison of periphyton from the two sampling periods (2002–2006 and 2007–2010) is not possible. Nevertheless, general trends can be examined. 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 2008–2010 as it was during 2003–2004. There were neither epiphyte data for chara in fall 2004, nor for bulrush for fall 2008 because of seasonal senescence of host plants or a delay in recovery of host plants after the 2004–2005 hurricanes. With an increase in SAV and emergent plant coverage since 2007, there has been a general increase in epiphytic biomass. The highest epiphytic biomass was observed on chara [1,761 milligrams per gram of host dry weight (mg/g dw)] and hydrilla near King's Bar (356 mg/g dw). The amount of mean epiphytic biomass per unit host plant dry weight between 2008 and 2010 is very similar to that reported during 1989–1991, when lake stage was lower than the long-term average (Zimba, 1995). For the epiphyte host substrates present during most of these years, the mean epiphyte biomass was either the same or higher during 2008–2010 as it was during 2003–2004. There is a general trend of higher epiphytic biomass for chara and bulrush in recent sample periods (**Figure 8-21**).

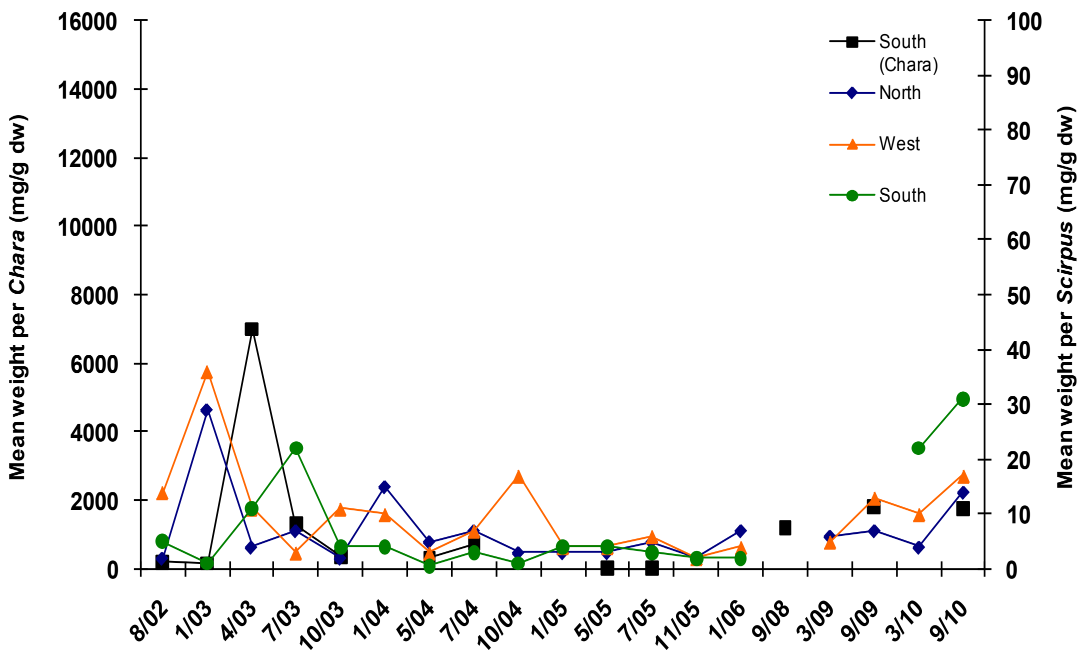

Figure 8-21. Nearshore *Chara* and *Schoenoplectus* epiphytic mean abundances (+1 standard deviation) in Lake Okeechobee.

Since 2007, epipelic mean biomass has been highest in the south [165 milligrams per square centimeter (mg/cm^2)] and west (409 mg/cm^2) regions and was similar during fall 2010 (491 mg/cm^2) to all but the highest value documented in the north (**Figure 8-22**). Mean post-hurricane (2008–2010) epipelic biomass in the south and west regions was approximately three and five times higher than pre-hurricane period mean values, respectively. In the north region, post- and pre-hurricane mean biomass values are similar. Mean epipelic biomass was generally lowest in all three regions during 2003, ranging from 5 mg/cm^2 (south) and 12 mg/cm^2 (north).

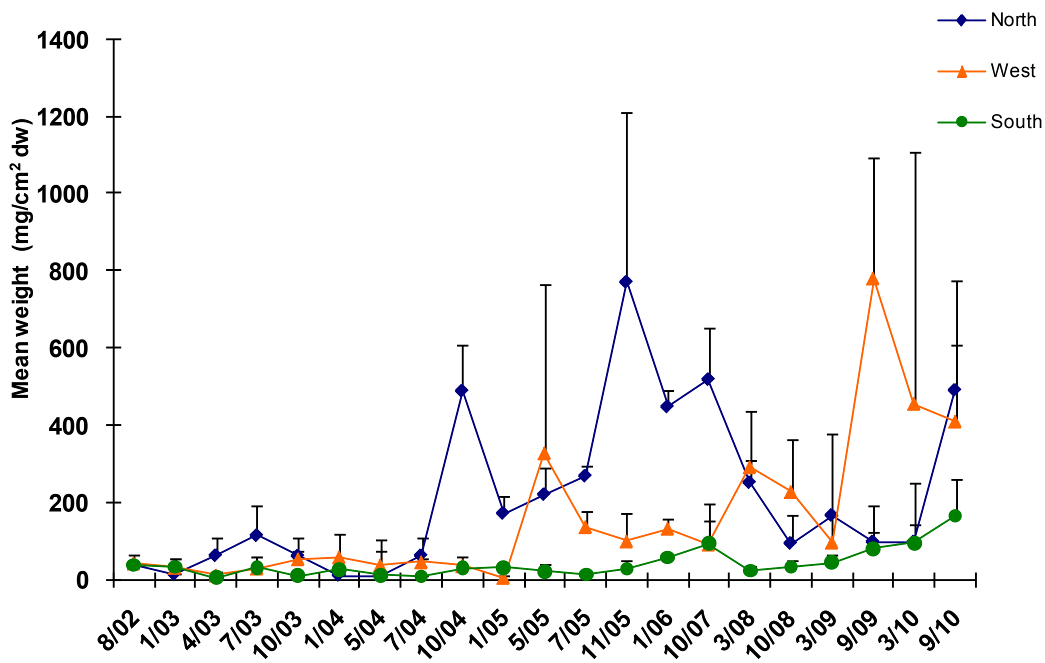

Figure 8-22. Nearshore epipelic mean abundances (+1 standard deviation) in Lake Okeechobee as dry weights.

Periphyton abundance (as biovolumes) prior to 2008 was generally less than in 1995 (Carrick and Steinman, 2001; Rodusky, 2010). Between summer 2002 and fall 2010, both the epiphytic and epipelic communities were dominated (> 80 percent) by diatoms. In 1995, cyanobacteria (56 percent) and diatoms (40 percent) dominated the epipelic community and both of these groups comprised a significantly larger portion (> 20 percent) of the total epiphytic community biovolume. When comparing the pre- and post-hurricane period mean periphyton community composition, both the epiphytic and epipelic community group composition were little changed. Diatoms comprised more than 80 percent of the mean community biovolume during both periods. During the pre-hurricane period, cyanobacteria (7 percent) and chlorophytes (6 percent) were the second and third most dominant epiphytic groups, while during the post-hurricane period these two groups reversed positions, with chlorophytes comprising 10 percent and cyanobacteria comprising 9 percent of the mean community biovolume, respectively.

Periphyton N, P, and C mean storage concentrations were compared among the pre- and post-hurricane periods. For the pre-hurricane period, the bulrush associated epiphytes and western site epipelon contained the largest amounts of epiphytic N, P, and C, respectively. The lowest mean storage concentrations for the pre-hurricane period were found for the eelgrass-associated epiphytes and northern epipelon, respectively. Total N-to-P ratios were typically between five and nine, suggesting strong N limitation. The exception to N limitation was at the southern epipelic site, where the epipelon displayed weak to moderate (35) P limitation.

For the post-hurricane period, the southern epipelon had the highest mean N, P, and C storage concentrations, while eelgrass-associated epiphytes had the highest mean P storage value. Cattail-associated epiphytes had the highest mean N and C storage values, while chara–associated epiphytes and the western epipelon had the lowest mean nutrient and C storage concentrations.

Among the two (pre- and post-hurricane) study periods, the highest mean epiphytic nutrient and C storage concentrations on the bulrush and eelgrass host substrates occurred during the pre- and post-hurricane periods, respectively. The western epipelon site during the pre-hurricane period had higher mean nutrient and C storage concentrations than during the post-hurricane period, while the reverse was documented for the northern site and region epipelon. The among-study period differences in mean nutrient and C storage for the southern epipelic site and region were variable; mean P concentrations were very similar, while mean N concentrations were higher during the post-hurricane period, with the reverse being observed for mean C storage concentrations.

The estimate of overall mean periphyton P 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).

It is evident when comparing the 1995–2010 datasets that periphyton abundance was highest in 1995 and was lower until roughly 2008. Since 2008, periphyton abundance has been similar to that reported for the 1989–1991 and 1995 studies (Zimba, 1995; Carrick and Steinman, 2001). After 1995, the community structure shifted to dominance by diatom taxa such as *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. Therefore, maximal periphyton abundance and nutrient storage may occur if the lake is more frequently within the desired stage range considered conducive to emergent plant and SAV growth (12.5–15.5 ft NGVD). With lower lake stages during the post-hurricane period, mean summertime total seasonal epiphytic biovolume is greater during the post-hurricane period, relative to that during the pre-hurricane period. The trend in the amount of summer season mean epiphytic biovolume per amount of colonizable SAV appears to generally be positively associated with SAV areal coverage and negatively associated with lake stage. Lower lake water levels and higher periphyton biomass and nutrient storage may be important in indirectly reducing the frequency of phytoplankton blooms via nutrient competition (Phlips et al., 1993; Havens et al., 1996; Rodusky et al., 2001). Maximizing SAV areal coverage and periphyton abundance in the nearshore region of Lake Okeechobee may be very important over the next decade, since P concentrations are in the range where shallow subtropical lakes can switch from SAV to phytoplankton dominance (Liboriussen and Jeppesen, 2006; Bécares et al.,2008; Yang et al.,2008; Rodusky, 2010). Thus, maintaining lower water levels along with continued reductions in watershed nutrient loading may be critical in preventing the nearshore region of the lake from switching to a phytoplankton dominated stable state. Periphyton abundance (as biovolumes) prior to 2008 was generally less than in 1995 (Carrick and Steinman, 2001; Rodusky, 2010). Between summer 2002 and fall 2010, both the epiphytic and epipelic communities were dominated (> 80 percent) by diatoms as represented for the epiphytes in **Figure 8-23**.

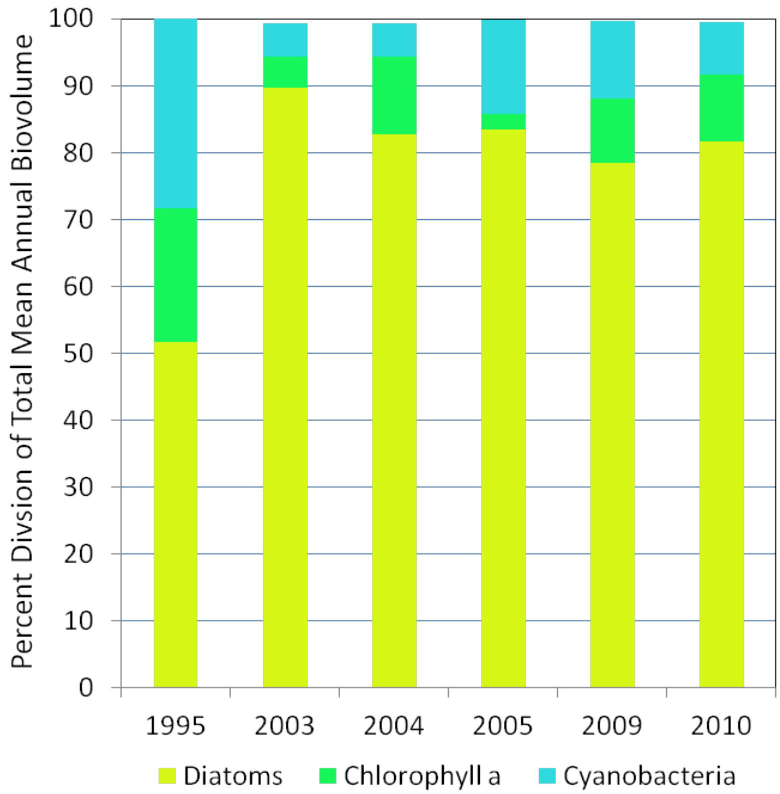

Figure 8-23. Percent composition by division of epiphyte biovolume in the nearshore region of Lake Okeechobee. Data are averaged by year from four quarters (1995–2005) and two quarters (2009–2010), respectively.

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 Chapter 10 of the 2010 SFER – Volume I. 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 macroinvertebrates.

Since 2008, biannual sampling has been conducted by the FWC during February and September at the same nearshore and pelagic sites (Warren et al., 2008). However, those preserved samples have been archived and placed on-hold prior to completing the sample processing and taxonomic identification stages. Therefore, changes and trends in the macroinvertebrate community since 2008 have not been analyzed or reported yet, thereby reducing the ability to elucidate the relationship between water quality variables and the macroinvertebrate community in Lake Okeechobee.

FISH

Lake Okeechobee's fishery is monitored annually by the FWC. They use a standardized lake-wide electrofishing protocol to monitor the nearshore fishery and lake-wide trawling protocol to monitor pelagic species.

Electrofishing

Lake-wide electrofishing was conducted during fall 2010 and resulted in the capture of 7,255 fish with a combined biomass of 736,674 grams. These were the largest values recorded since 2005 and represent a 345 percent increase in total number and a 50 percent increase in biomass compared to 2005 (**Figure 8-24**). Forty fish species were represented in the catch. Five dominant species (more than 5 percent composition) collectively comprised 74 percent of the catch by number and were, in order of abundance: bluegill (*Lepomis macrochirus*), threadfin shad (*Dorosoma petenense*), largemouth bass (*Micropterus salmoides*), inland silverside (*Menidia beryllina*), and redear sunfish (*Lepomis microlophus*). Five species collectively comprised 73 percent of the catch by weight and were, in order of biomass: largemouth bass, bowfin (*Amia calva*), striped mullet (*Mugil cephalus*), bluegill, and Florida gar (*Lepisosteus platyrhincus*).

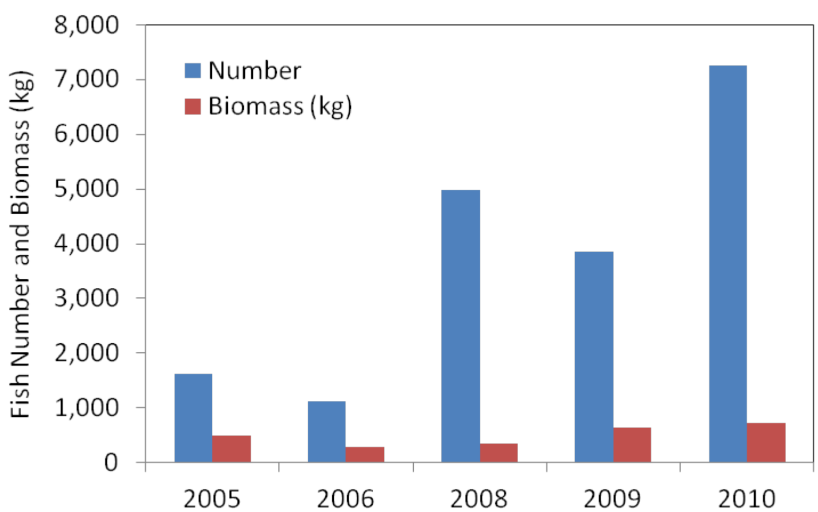

Figure 8-24. Comparison of lake-wide electrofishing data indicating the total number of fish (blue) and total biomass (red) collected during fall 2005, 2006, 2008, 2009, and 2010.

Comparison of lake-wide electrofishing data indicated that changes in abundance of selected prey and piscivorous species were common (**Figure 8-25**). The abundance of gizzard shad, threadfin shad and Eastern mosquitofish (*Gambusia holbrooki*) was greatest in 2008, while the abundance of the piscivorous fish were generally low. The decline in abundance of the forage species in 2009 and 2010 was concurrent with increases in abundance of predator species (**Figure 8-25**).

In addition to abundance, the size and composition of the fish population can be evaluated using catch per unit effort (CPUE) data. From 2005 to 2010 there was an increasing trend in the number (indicated by CPUE) of many dominant fish species. Threadfin shad and largemouth bass increased more than 375 percent and the number of bluegill and redear sunfish increased by more than 1,000 percent (**Figure 8-26**).

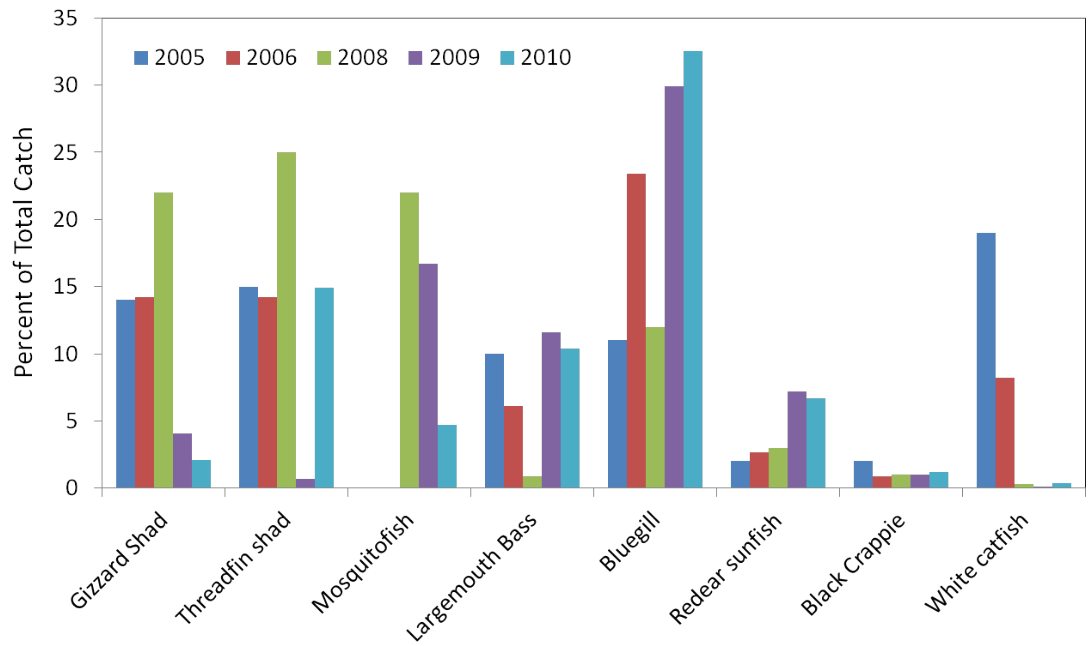

Figure 8-25. Abundance of selected prey (gizzard shad, threadfin shad and mosquitofish), piscivorous species [largemouth bass, black crappie and white catfish] and omnivorous species (redear sunfish and bluegill) collected by electrofishing during fall 2005, 2006, 2008, 2009, and 2010.

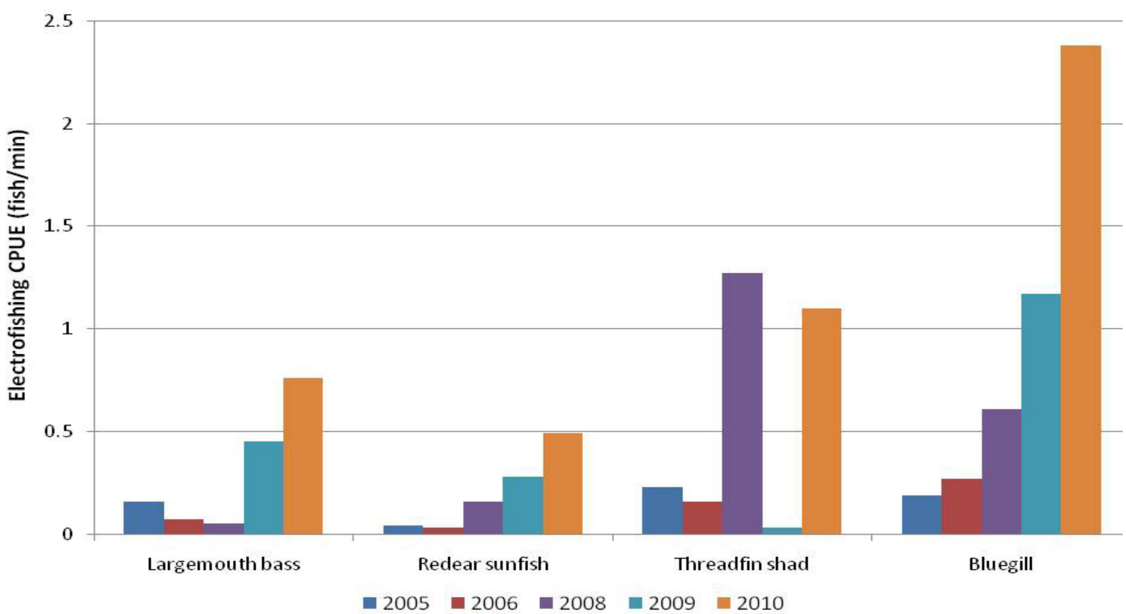

Figure 8-26. Electrofishing catch per unit effort (CPUE) values for 2005, 2006, 2008, 2009, and 2010. Much of the increase in the 2010 fish population compared to 2005 was attributed to large increases in largemouth bass, redear sunfish, threadfin shad, and bluegill.

Trawling

Lake-wide trawl sampling resulted in the capture of 13,544 fish with a combined biomass of 652,480 grams. Twenty-four fish species were represented in the catch. Four species collectively comprised 92 percent of the catch by number and were, in order of abundance: threadfin shad, gizzard shad (*Dorosoma cepedianum*), bluegill, and white catfish (*Ameiurus catus*). Five species collectively comprised 84 percent of the catch by weight and were, in order of biomass: white catfish, Florida gar, gizzard shad, bluegill, and threadfin shad (**Figure 8-27**).

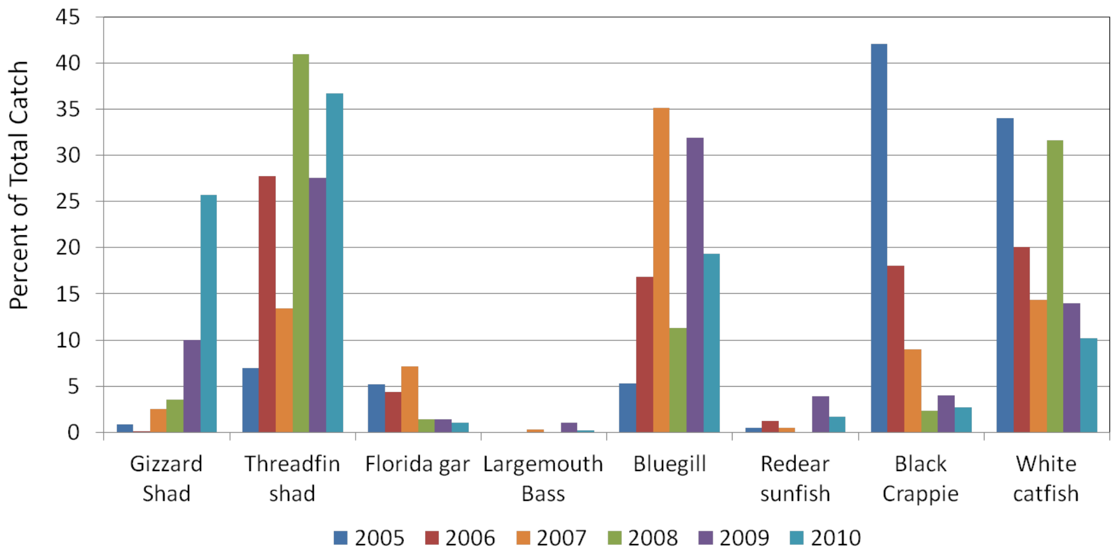

Figure 8-27. Selected species that accounted for 92 percent of the total pelagic trawl catch by number (threadfin shad, gizzard shad, bluegill, and white catfish) and 84 percent of the catch by weight (white catfish, Florida gar, bluegill, and threadfin shad).

Comparisons of lake-wide trawling data (2005–2010) indicated large temporal changes in fish abundance were also common in the pelagic region of the lake. The total catch (number of fish) and biomass increased by 1,083 percent and 662 percent, respectively, in 2010 compared to 2005 (**Figure 8-28**). Much of the change was attributed to large increases in the abundance of gizzard shad (> 28,900 percent), threadfin shad (> 5,420 percent) and bluegill (> 3,800 percent) (**Figure 8-29**). Although the abundance of black crappie declined in 2010 compared to 2005. Its abundance increased by 94 percent compared to 2009.

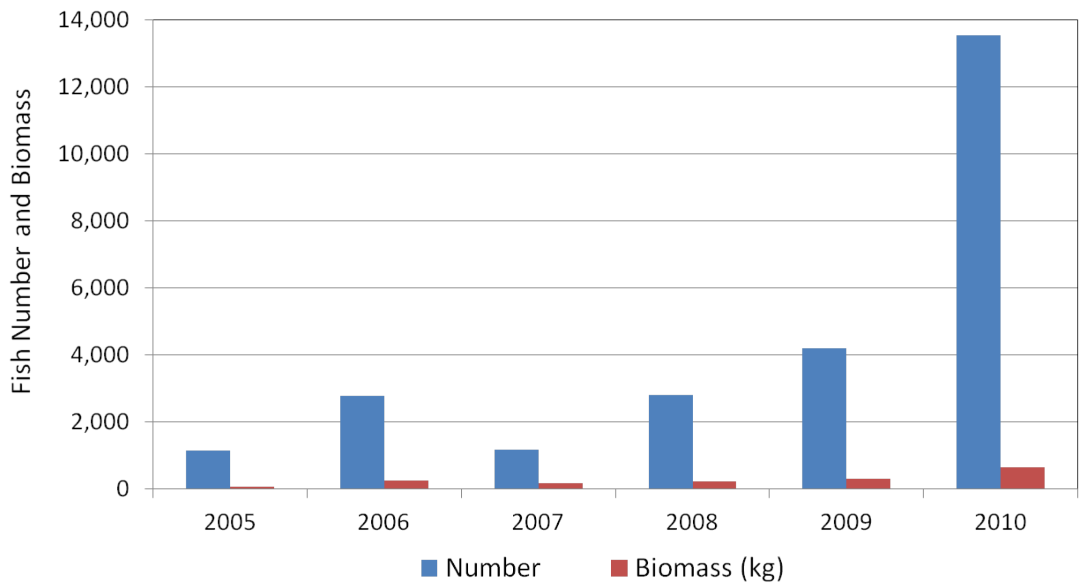

Figure 8-28. Comparison of lake-wide trawling data indicating the total number of fish (blue) and total biomass (red) collected during fall 2005–2010.

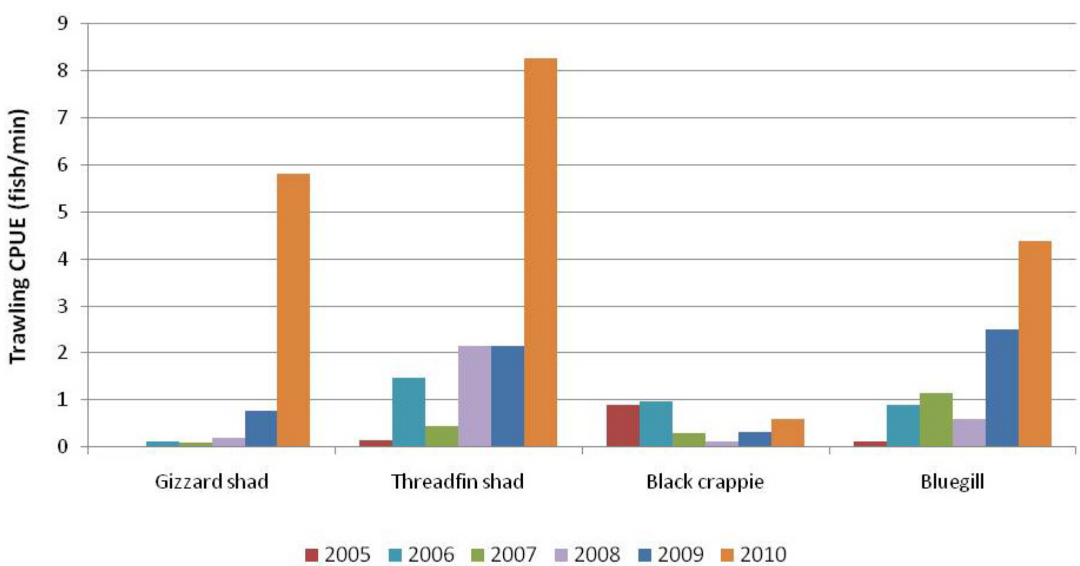

Figure 8-29. Trawling CPUE values for 2005–2010. Much of the increase in 2010 fish abundance was attributed to large increases in prey species (gizzard shad and threadfin shad), and bluegill and black crappie.

Sport Fish Recovery

The largemouth bass and black crappie (*Pomoxis nigromaculatus*) populations were likely depressed due to a combination of high lake levels and the subsequent loss of habitat and primary and secondary production following hurricane disturbances in 2004 and 2005. The catch rates for largemouth bass in 2005 were the second lowest observed since the monitoring program was initiated in 1992. Length frequency plots indicate that very little recruitment of largemouth bass young of the year occurred that year. The black crappie population also experienced a significant decline. Only five adult fish (> 200 millimeter in length) were collected in 2005. The decline in the black crappie population exceeded 99 percent when compared to the average annual catch of more than 2,000 fish in 1988–1991. A similar decline (97 percent) also was reported for the threadfin shad, a primary forage fish for adult black crappie in Lake Okeechobee. The populations of largemouth bass and black crappie have recently showed signs of recovery (**Figure 8-30**). Largemouth bass produced consecutive strong year classes in 2009 and 2010 and the black crappie population produced a strong year class in 2010 (**Figure 8-30**).

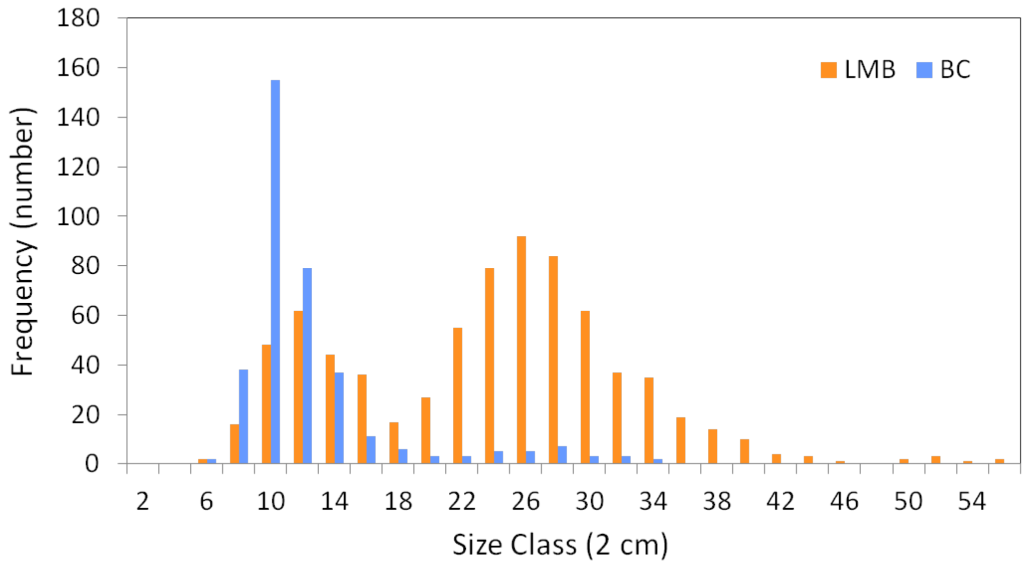

Figure 8-30. Length distribution per 2 centimeter (cm) size class for largemouth bass (LMB)(orange), n=753, collected in Fiscal Year 2010 to Fiscal Year 2011 (FY2010–FY2011)(October 1, 2009–September 30, 2011) lake-wide electrofishing samples and black crappie (BC) (blue), n=359, collected in FY2010–FY2011 lake-wide trawling samples. The bimodal peaks for the largemouth bass population indicate successful spawning (year class) occurred in 2009 and 2010. Black crappie produced a strong year class in 2010 (< 14 cm) but there was little evidence of a 2009 year class.

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 (Vitt et al., 1990) and herpetofauna can serve as excellent indicators of environmental conditions (Gibbons, 1988). Understanding the influence of herpetofauna 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 fluctuations, introduction of exotic species, and in-lake management practices such as controlled burns, and scraping or tilling (Aresco and Gunzberger, 2004; Betzer el al., 2006; Gibbons, 1988).

A sustained and comprehensive herpetofaunal inventory of Lake Okeechobee marshes has never been conducted. The only information available was a single study undertaken more than ten years ago (USACE, 1999). To describe the herpetofauna 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 are 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.

Initially, the formal survey was to have begun in April 2010. However, due to a lack of available technical expertise, it did not begin until January 2011. The survey takes place along three transects that capture different habitat types along a depth gradient that runs from near 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 are measured at each site using methods developed during a preliminary study in summer and fall 2009 and 2010. During normal water levels, a combination of call surveys, Fyke nets, pyramid traps, and funnel traps are used. Under dry conditions, when aquatic sampling is not possible but it is still possible to access the site, call surveys, artificial cover, and funnel traps set in drift-fence arrays are used.

During each sampling event, the appropriate sampling devices are deployed and allowed to sit in place for 24 hours. The devices are then retrieved and all captured animals are identified, sirens, amphiuma, and nonvenomous snakes are measured weighed and released. Sediment type, water depth, and environmental conditions are also noted.

All of the sites in this study have been sampled at least once. However, lake levels have been low and many of the sites have been dry and inaccessible since the formal survey began.

The most common herpetofauna species sampled so far in this ongoing study include tadpoles, sirens, and snakes. Sirens have been captured at all sites sampled. Snakes are ubiquitous as well, but the dominant snake species seem to change with depth and habitat type. Generally there are more water moccasins (*Agkistrodon piscivorus*) and brown water snakes (*Nerodia taxispilota*) in the shallower smartweed (*Polygonum* spp.) dominated sites, Florida water snakes (*Nerodia pictiventris floridana*) in the beakrush and water lily (*Nymphaea* spp.) dominated habitats, and green water snakes (*Nerodia floridana*) in the deeper areas near the bulrush wall.

NATIVE APPLE SNAILS

Lake Okeechobee is designated as critical habitat for the federally endangered Everglade snail kite by the United States Fish and Wildlife Service (Federal Register, 1976). However, recently kites have rarely used the lake for foraging and nesting due primarily to low densities of the Florida apple snail (*Pomacea paludosa*), the bird’s primary food source (Sykes, 1987). Extreme variations in water levels within Lake Okeechobee during the past decade have affected apple snail survival and recruitment resulting in reduced abundance (Audubon of Florida, 2011). Since 2007, the District, with the assistance of Harbor Branch Oceanographic Institute at Florida Atlantic University, has investigated the potential of using aquaculture for the large-scale production of apple snails for use in a stocking program where the main goal is to assist the recovery of the snail population to ecologically meaningful densities (2011 SFER – Volume I, Chapter 10). While the production program has been successful in developing a culture protocol necessary for producing large numbers of snails, the estimated costs associated with this method have been prohibitive, prompting research into cheaper methods of animal production. One possible approach to reducing production cost is to develop an in situ captive breeding program in which snails are cultured within an enclosed area in a local marsh, and egg clutches are harvested on artificial substrates for use in the stocking program. This method would be less costly because it would eliminate expenses related to overhead, facility maintenance, food, and staff time necessary to care for captive populations.

To explore the feasibility of an in situ program, District scientists constructed snail enclosures in an isolated wetland along Lemkin Creek. The wetland is a 33 acre hydrologically restored marsh located a short distance north of Lake Okeechobee. This marsh receives a nearly constant flow of water from the Lemkin Creek HWTT system and, on average, remains inundated with one foot of low nutrient water. Since restoration several years ago, this marsh has developed a healthy native vegetation community comprised primarily of spike rush, lotus (*Nelumbo* sp.), and southern naiad (*Najas* sp.). This marsh was chosen as the location of the apple snail hatchery primarily due to the high quality food source and the absence of a native or nonnative apple snail (*Pomacea insularum*) population.

Nine 27 square meter snail enclosures were constructed using polyethylene plastic mesh attached to a polyvinyl chloride (PVC) frame and buried beneath the sediment. Enclosures were stocked with three different densities of adult snails (0.5, 2, and 4 snails per square meter; three replicates each) to determine whether reproduction of snails is affected by stocking density. Each enclosure was covered in bird netting to protect the brood stock from avian predation. All nine enclosures were supplied with 200 bamboo stakes (¾ inch) each as artificial egg laying substrates. Enclosures were built in an area of the marsh having little to no emergent vegetation to encourage snails to oviposit on the artificial bamboo substrate to make harvesting egg clutches easier. Egg clutches laid on the bamboo stakes will be harvested every two weeks during the breeding season (May to October) and transferred to an area in Lake Okeechobee lacking an existing native apple snail population. Data obtained from the 2011 apple snail breeding season will allow scientists to optimize stocking density, conduct a cost analysis, and determine the efficacy of stocking egg clutches to assist local apple snail population recovery.

WADING BIRDS

Monitoring of wading bird foraging in Lake Okeechobee's littoral zone was begun in 2010, following implementation of the LORS 2008 regulation schedule, to assess whether ecological conditions were adequate to support wading bird reproduction. As a key trigger for wading bird reproduction and reproductive success is the availability of patches of concentrated prey (Botta and Gawlik, 2010), monitoring wading bird feeding behavior prior to and during the breeding season is an effective way of characterizing the status of the resource. Every dry season, this monitoring effort provides water managers with baseline information regarding the effects of hydrological changes on wading bird use of the lake. Continued monitoring will result in a dataset that allows the District to derive a set of performance measures for spring recession rates.

Wading birds were surveyed monthly by helicopter from December 2010 through June 2011 along east-west transects established at two kilometer intervals throughout the entire littoral zone of Lake Okeechobee. Additional survey methods are described in detail in Chapter 10 of the 2010 SFER – Volume I.

In December 2010, lake stage was at 12.7 ft NGVD. Stage continued to exhibit a strong and steady recession throughout the entire 2011 breeding season (**Figure 8-31**). As is typical, wading birds were strongly affected by water depth and closely followed the receding water front as it moved across the littoral zone. Wading birds heavily utilized marsh areas closer to the levee early

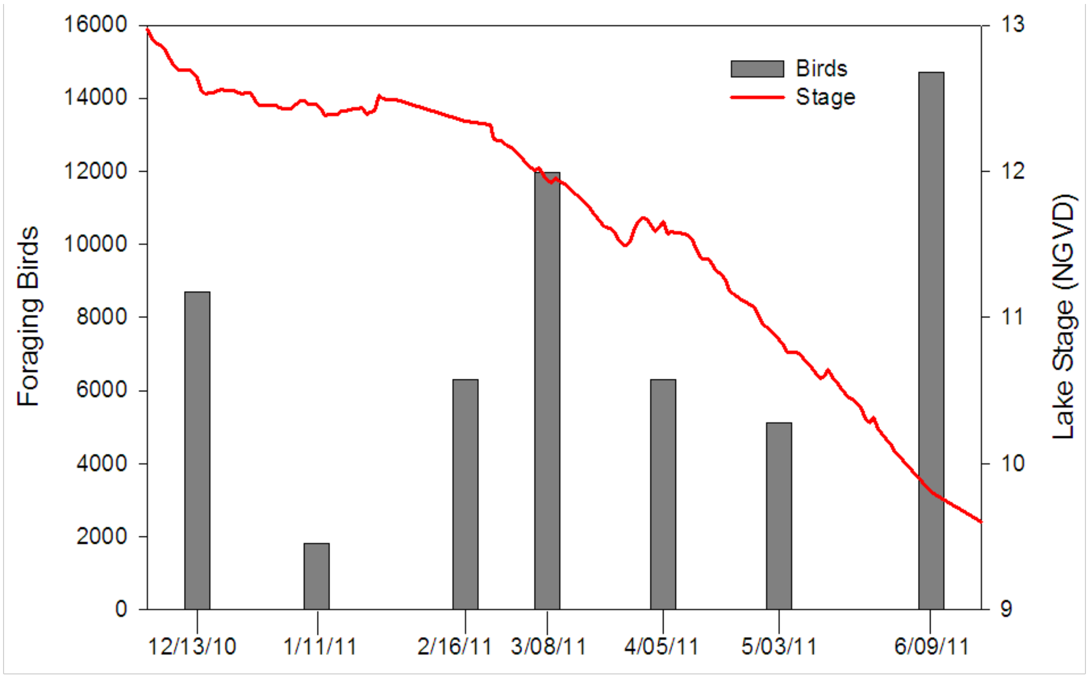

Figure 8-31. The total number of foraging birds surveyed each month from December 2010 to June 2011 in relation to lake stage.

in the season, whereas foraging locations were located beyond the edge of the littoral emergent vegetation zone, sometimes miles from the levee, later in the season (**Figure 8-32**).

Mean wading bird flock size remained similar throughout the season with little variation between months. Mean wading bird flock size was 230 birds with a range of from 110 to 340 birds. Exceptions were January, when mean flock size was 110 birds, and June, when mean flock size peaked at 350. The low mean flock size in January was an outlier and likely was the result of conducting the survey later in the day, due to foggy conditions that precluded flying early in the morning when surveys are generally conducted. The peak in June may reflect birds being attracted to the lake as foraging conditions declined elsewhere in the system due to the persistent drought conditions, or it may be indicative of fledglings coming into the system. Regardless, the increase in mean flock size in June suggests that high quality foraging patches might still be available along the periphery of the littoral zone late in the season.

Most of the flocks encountered throughout the season consisted of mixed species dominated by white ibis (*Eudocimus albus*) and snowy egrets (*Egretta thula*). This is different from the 2010 breeding season where wading bird flock size decreased dramatically as water depths increased throughout the season and the species composition of flocks shifted exclusively to great egrets (*Ardea alba*) later in the season.

High numbers of birds foraging in the lake also equated to successful nesting. Wading birds nested in ten colonies on the lake, the largest being the Eagle Bay colony. Nesting peaked in April with 5,600 nests comprised of great egrets, great blue herons (*Ardea hero*), white ibises, and snowy egrets. This is similar to the level of nesting that occurred during the 2010 nesting season, which itself was the seventh largest of the 30 years monitored since 1957 (Botta and Gawlik, 2010). Of the 5,600 nests, 96 percent were comprised of snowy egret and white ibis, two species that have seen dramatic population declines in the Everglades system (Crozier and Gawlik, 2003).

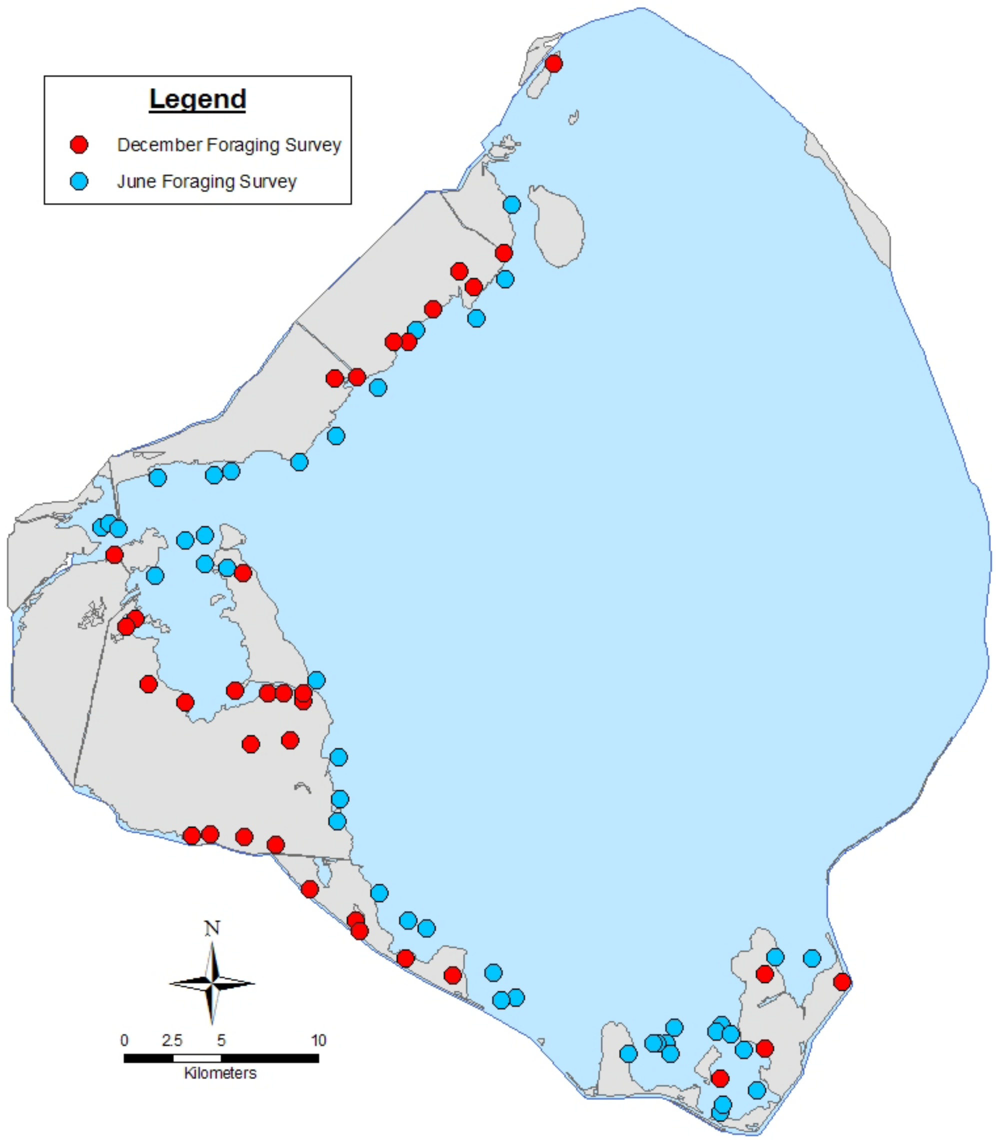

Figure 8-32. An illustration of the spatial change in wading bird foraging locations as the 2011 dry season progressed.

Despite being one of the driest dry seasons on record, wading bird foraging and nesting utilization was high on the lake. With so little rain in South Florida for the 2011 breeding season, foraging conditions were poor elsewhere in the surrounding watershed (Don Fox of FWC, personal communication, 2011), potentially attracting birds from outside the lake boundary. This emphasizes the importance of the lake as a refuge during seasons with poor hydrological conditions and is likely a contributing factor to the overall success of wading birds in other parts of the system.

HABITAT CREATION

Lower lake stages in Lakes Okeechobee and Istokpoga made it possible to plant cypress (*Taxodium distichum*), pond apple (*Annona glabra*), and maple trees (*Acer rubrum*) in a number of locations that often are difficult to access in wetter years (**Table 8-11**). Most of these plantings were extensions of work conducted in previous dry years. Planting trees stabilizes soils and creates foraging and nesting opportunities for a wide variety of birds, as well as providing shelter and feeding habitat in inundated roots for fish and other aquatic organisms (Phipps and Vares, 2003).

Table 8-11. Location and species distribution of habitat enhancement tree plantings.

Planting Location	Number and Species of Trees Planted
Lake Istokpoga – Big Island	2,000 pond apples
Lake Istokpoga – Spoil Islands	380 mixed pond apples, cypress, and maples
Lake Okeechobee – Rita Island Berm	2,028 pond apples
Lake Okeechobee – Rim Canal	660 cypress
Lake Okeechobee – Jaycee Park Pier	70 cypress
Lemkin Creek Wetland	20 cypress, 3 maples

Approximately 13,000 bulrush plants, originally intended for planting along the new rip rap line north of the Pahokee Marina were planted in the Lemkin Creek wetland after changing lake levels and weather conditions made it impossible to plant them in the originally planned location. In addition to improving the habitat at Lemkin Creek, these bulrush plants, as they grow and expand, will serve as a propagule bank from which plants can be harvested for other environmentally beneficial bulrush plantings in the future.

LAKE ISTOKPOGA SUBMERGED AQUATIC VEGETATION

The distribution and areal coverage of SAV in Lake Istokpoga was evaluated during spring 2010. The lake was equally divided into 501 grids each covering an area of 500 m by 500 m. Sampling occurred near the center of the accessible grids and was considered representative of the grid. Plant presence or absence, plant density (qualitatively categorized as sparse, moderate, or dense), and species composition were recorded. SAV occurred in 206 of the 475 sampled grids (43 percent) (**Figure 8-33**). The most commonly observed plants included invasive exotic hydrilla and native eelgrass. These plants occurred in 43 and 31 percent of the vegetated sites, respectively (**Figure 8-34**). Other observed, but less common, species (< 25 percent occurrence) included bladderwort (*Utricularia* spp.), pondweed (*Potamogeton illinoensis*), naiad, and coontail.

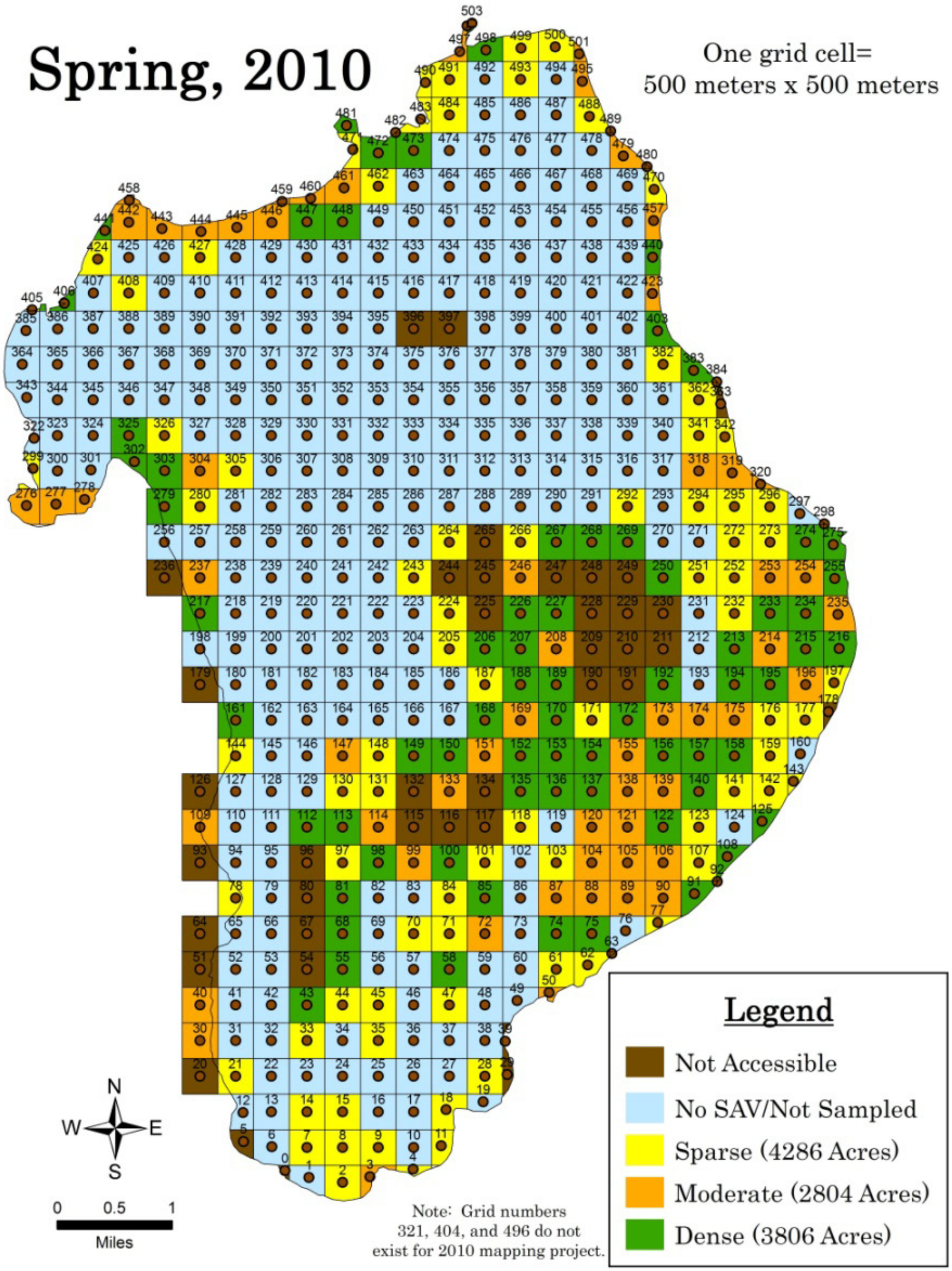

Figure 8-33. Distribution of SAV in Lake Istokpoga in spring 2010.

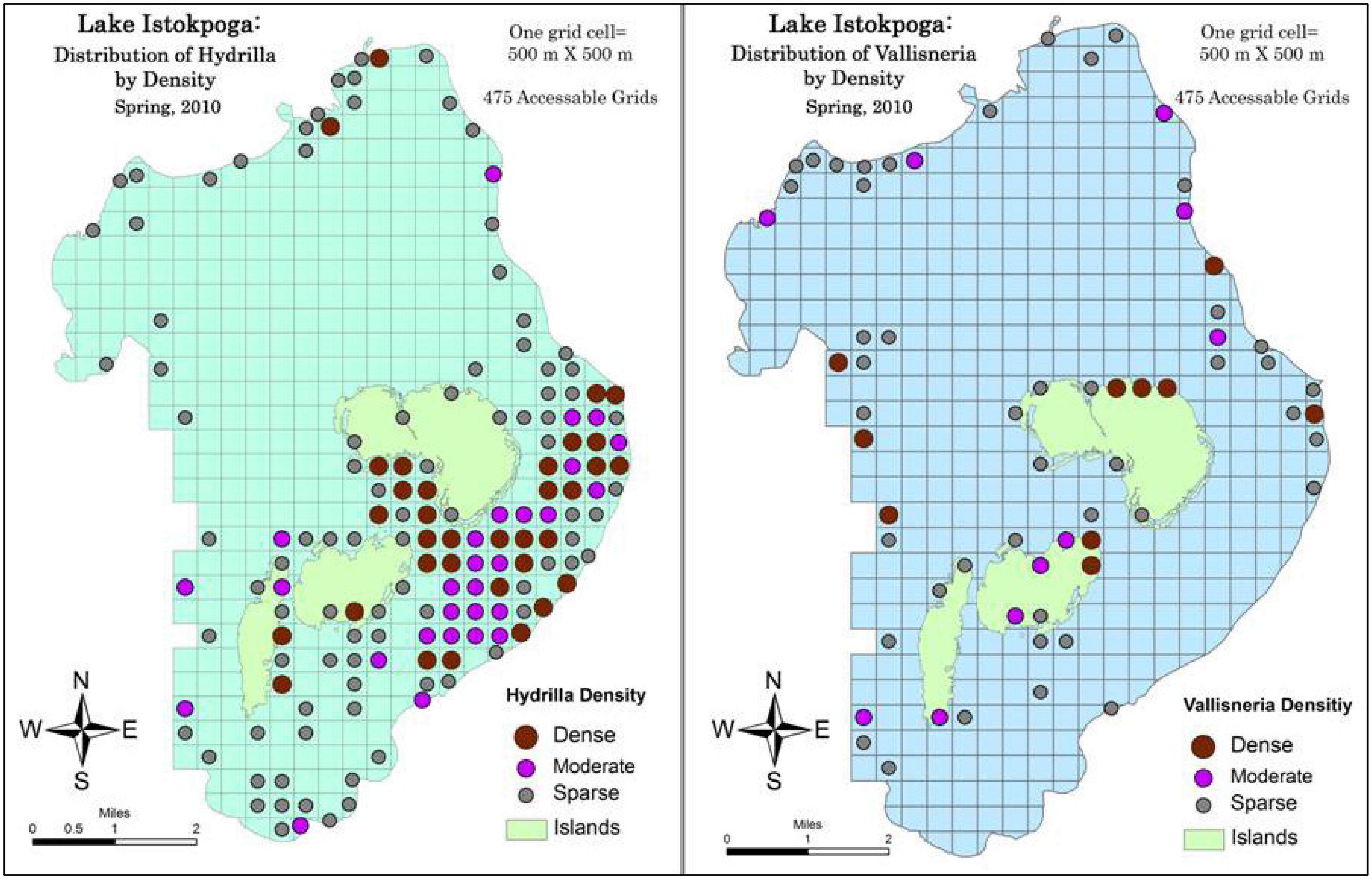

Figure 8-34. Distribution and density of hydrilla (left) and eelgrass (right) in Lake Istokpoga in spring 2010. [Note: m – meters]

APPROPRIATIONS/EXPENDITURES

The FY2002–FY2011 summary of state of Florida funding appropriations and expenditures for the Lake Okeechobee Protection Program is presented in **Table 8-12**.

Table 8-12. State funding appropriations and expenditures for the Lake Okeechobee Watershed Protection Program for Fiscal Years 2002–2011 (FY2002–FY2011) (October 1, 2001–September 30, 2011). [Note: FY2011 financial data are preliminary as of September 30, 2011.]

Appropriation Year	SFWMD Appropriation	Expended to Date	Available
FY2001 SFW11 (1519G)[1]	$8,500,000	$8,478,572	
FY2001 SFW12 (1591G)	$15,000,000	$15,000,000	
FY2001 SFWMD Total	**$23,500,000**	**$23,478,572**	**$0**
FY2002 SFSWP1 (1748)	$10,000,000	$10,000,000	
FY2002 SFWMD Total	**$10,000,000**	**$10,000,000**	**$0**
FY2003 FDEP Total Maximum Daily Load Implementation Funds	$850,000	$850,000	
FY2003 SFW31 (1769) grant 42	$7,500,000	$7,087,118	$412,882
FY2003 SFWMD Total	**$8,350,000**	**$7,937,118**	**$412,882**
FY2005 SFW51 – Nubbin Slough G44	$4,300,000	$2,366,158	$1,933,842
FY2005 SFW61 grant 46	$5,000,000	$2,087,815	$2,912,185
FY2005 – FDEP Nubbin Slough/Lake Okeechobee Fast Track LOFT) G3	$3,300,000	$2,174,912	$1,125,088
FY2005 – Hydromentia	$1,800,000	$1,800,000	
FY2005 SFWMD Total	**$14,400,000**	**$8,428,884**	**$5,971,116**
LOFT Projects – Reimbursable Expenditures G4	$25,000,000	$25,000,000	
101 Ranch 17.2 Acre Reservoir	$42,000	$42,000	
C&B Farms Trail Water Recovery	$93,600	$93,600	
101 Ranch 44 Acre Reservoir	$30,864	$30,864	
Stormwater Irrigation	$51,920	$51,920	
FY2006 Sub-basin Monitoring Network	$225,000	$225,000	
FY2006 SFWMD Total	**$25,443,384**	**$25,443,384**	**$0**
FY2007 Hydromentia – Algae Turf Scrubber® – FDEP G41	$750,000	$750,000	
FY2007 Hydromentia – Algae Turf Scrubber® – FDACS G39	$221,610	$221,610	
LOFT Projects – Reimbursable Expenditures G66	$24,925,000	$24,925,000	
Community Budget Issue Requests – Taylor Creek PL566 and Alternative Storage/Disposal of Excess Water G47	$6,200,000	$3,754,876	$2,445,124
FY2007 Cody's Cove and Eagle Bay Grant 52	$2,478,548	$2,478,548	
Indiantown Citrus Growers Association G54[2]	$287,808	$267,853	
Raulerson & Sons Ranch Stormwater Reuse Alternative Water Use G56	$330,000	$330,000	
FY2007 SFWMD Total	**$35,192,966**	**$32,727,887**	**$2,445,124**
FY2008 Sub-basin Monitoring Network	$225,000	$225,000	
FY2008 SFWMD Total	**$225,000**	**$225,000**	**$0**
FY2012 Lake Okeechobee Predrainage Characterization	$175,000		$175,000
FY2012 SFWMD Total	**$175,000**	**$0**	**$175,000**
Grand Total – SFWMD State Appropriation – 221	**$117,286,350**	**$108,240,845**	**$9,004,121**
FY2001 FDACS Appropriation	$15,000,000	$15,000,000	
FY2005 FDACS Appropriation	$5,000,000	$5,000,000	
FY2005 FDEP Pahokee Wastewater Treatment Plan	$700,000	$700,000	
FY2007 FDACS Appropriation	$3,900,000	$3,900,000	
FY2008 FDACS Appropriation	$6,000,000	$6,000,000	
FY2009 FDACS Appropriation	$3,000,000	$3,000,000	
FY2010 FDACS Appropriation	$3,000,000	$3,000,000	
FY2011 FDACS Appropriation	$3,000,000	$3,000,000	
FY2012 FDACS Appropriation	$6,000,000	$2,000,000	$4,000,000
Total Outside Agency State Appropriation	**$45,600,000**	**$41,600,000**	**$4,000,000**
Save Our Everglades Trust Fund			
FY2008 Northern Estuaries (NE) – Caloosahatchee, St. Lucie, and Lake Okeechobee) – Grant 58	$2,623,146	$2,623,146	
FY2008 NE – Lake Okeechobee Protection Project – Grant 59	$31,045,000		$4,182,132
LOFT – Lakeside Ranch Stormwater Treatment Area (STA)		$20,057,155	
NE Water Storage Disposal Projects		$6,254,657	
Technical Plan		$551,056	
FY2008 Biological Wetland and Chemical/Hybrid Technologies - Grant 62	$5,000,000	$5,000,000	
FY2009 NE – Best Management Practices (BMPs) – Grant 96	$3,009,120	$3,009,120	
FY2010 NE – BMPs – Grant 94	$1,500,000	$1,500,000	
FY2011 NE – BMPs – Grant 94	$1,500,000	$1,500,000	
FY2012 NE – LOPP – Grant 99	$6,178,642		$6,178,642
LOFT – Lakeside Ranch STA			
NE Water Storage Disposal Projects			
Total – Save Our Everglades Trust Fund – 412	**$50,855,908**	**$40,495,134**	**$10,360,774**
Grand Total – Lake Okeechobee	**$213,742,258**	**$194,335,980**	**$19,364,895**

[1]$21,428 returned to the state in FY2010

[2]Reimbursement grant expired March 2010; $19,955 balance of grant not used.

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