Chapter 1B: An Integrative Perspective on Regional Water Quality and Phosphorus

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In their review of the *2006 South Florida Environmental Report – Volume I* (SFER), the 2005 expert panel recommended that "a summary chapter or section be added that synthesizes different chapters, for example, mercury, phosphorus, nitrogen and sulfur cycling, including their interrelationships." The panel also suggested that newly added cross-cutting themes, focusing on relevant topics such as water quality, continue to be presented separately in future SFERs. Initial responses by the South Florida Water Management District (SFWMD or District) to the panelists on their 2006 report general comments are presented in Appendix 1A-1 of this volume. As a follow-up to these responses and to supplement data and supporting information presented in the individual 2007 SFER chapters, this chapter responds to these recommendations and provides an overview of the numerous programs and restoration efforts addressing water quality, and more specifically phosphorus, across the Kissimmee-Okeechobee-Everglades (KOE) region. On a regional level, this chapter summarizes (1) aspects of phosphorus as a stressor; (2) total phosphorus (TP) loads and concentrations; (3) large-scale effects on South Florida ecosystems; (4) programmatic responses including monitoring, research, and planning; and (5) general strategies for source control and treatment in South Florida. Overall, this chapter does not attempt to provide any new data but merely weaves available information into an integrative regional perspective on regional water quality, with an emphasis on phosphorus.

Water "quality" is defined as the physical, chemical, and biological condition of water as applied to a specific use. Federal and state guidelines set water quality standards based on the water's intended use, that is, whether it is for recreation, fishing, drinking, navigation, shellfish harvesting, or agriculture. Additional information on the District's 1,800+-station water quality monitoring program is available at http://www.sfwmd.gov/org/ema/envmon/wqm/index.html.

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INTRODUCTION

Water quality in many South Florida regions has declined over the last half of the twentieth century, following the construction of the Central & South Florida (C&SF) Project and extensive urbanization and agricultural development in the region. Many thousands of acres of wetlands that once acted as natural settling and retention areas either no longer perform these functions or have been lost due to drainage and/or urban and agricultural development activities. Moreover, urban and agricultural land uses and the construction of a regional drainage system have resulted in rapid discharge of stormwater runoff conveying constituents that can cause water quality problems, particularly excessive nutrients. As these substances enter the region's rivers, lakes, streams, estuaries, and wetlands, many of these areas show the effects of enrichment.

Research on South Florida's marsh ecosystems has shown that relatively small additions of nutrients, especially phosphorus, can have dramatic effects on subtropical systems consistent with cultural eutrophication (Payne et al., 2002; FDEP, 2001). The Lake Okeechobee system is also impacted by large nutrient inputs over several decades (Steinman et al., 2001). Ecosystem impacts include imbalances in aquatic vegetation communities, algal blooms, fish kills, depressed levels of dissolved oxygen, and other signs of impaired ecosystem function. These factors pose a large-scale, unprecedented challenge to the South Florida Water Management District's (SFWMD or District) mission of protecting and improving regional surface water and groundwater conditions. In addition, elevated nutrient levels have facilitated the invasions by nonindigenous species, posing an extensive problem with far-reaching effects (see Chapter 9 of this volume).

Improving and restoring the quality of South Florida's surface water and groundwater resources is a strategic priority for the District. Extensive financial and technical commitments by the agency have been made to ongoing efforts in the Kissimmee Basin, Lake Okeechobee, the Everglades, and coastal estuaries, with additional investments related to water quality aspects of the Comprehensive Everglades Restoration Plan. Through the District's strategic water quality programs and priority initiatives, most of the agency's primary programs contribute to the protection and improvement of water quality, as highlighted in the agency's 10-Year (2006–2016) Strategic Plan (http://www.sfwmd.gov/images/pdfs/stratplan_2006.pdf). Water quality is one of the cornerstones of the agency's mission and is linked to numerous legal mandates and operating permits under the federal Clean Water Act (40 Code of Federal Regulations, §131.10; Public Law 92-500) and the state of Florida's 1972 Water Resources Act (Chapter 373, Florida Statutes) (see Chapter 1A). The District, the Florida Department of Environmental Protection (FDEP), Florida Department of Agriculture and Consumer Services (FDACS), and other state, local, and tribal governments, are working collaboratively on water quality improvement actions to achieve compliance with applicable water quality standards. Many regional programs are being implemented through the Surface Water Improvement and Management Act (SWIM), Total Maximum Daily Loads (TMDLs), Everglades Forever Act (EFA), Lake Okeechobee Protection Act (LOPA), Lake Okeechobee & Estuary Recovery (LOER) Plan, and the Comprehensive Everglades Restoration Plan (CERP) to protect and restore more than 160 water bodies and to preserve ecosystem health within the jurisdictional boundaries of the District. It should be noted that these programs have been developed using a watershed-based approach, which provides a uniform, natural accounting unit – not constrained by jurisdictional boundaries – for calculating water budgets and chemical loading to surface water and groundwater and for assessing ecological health.

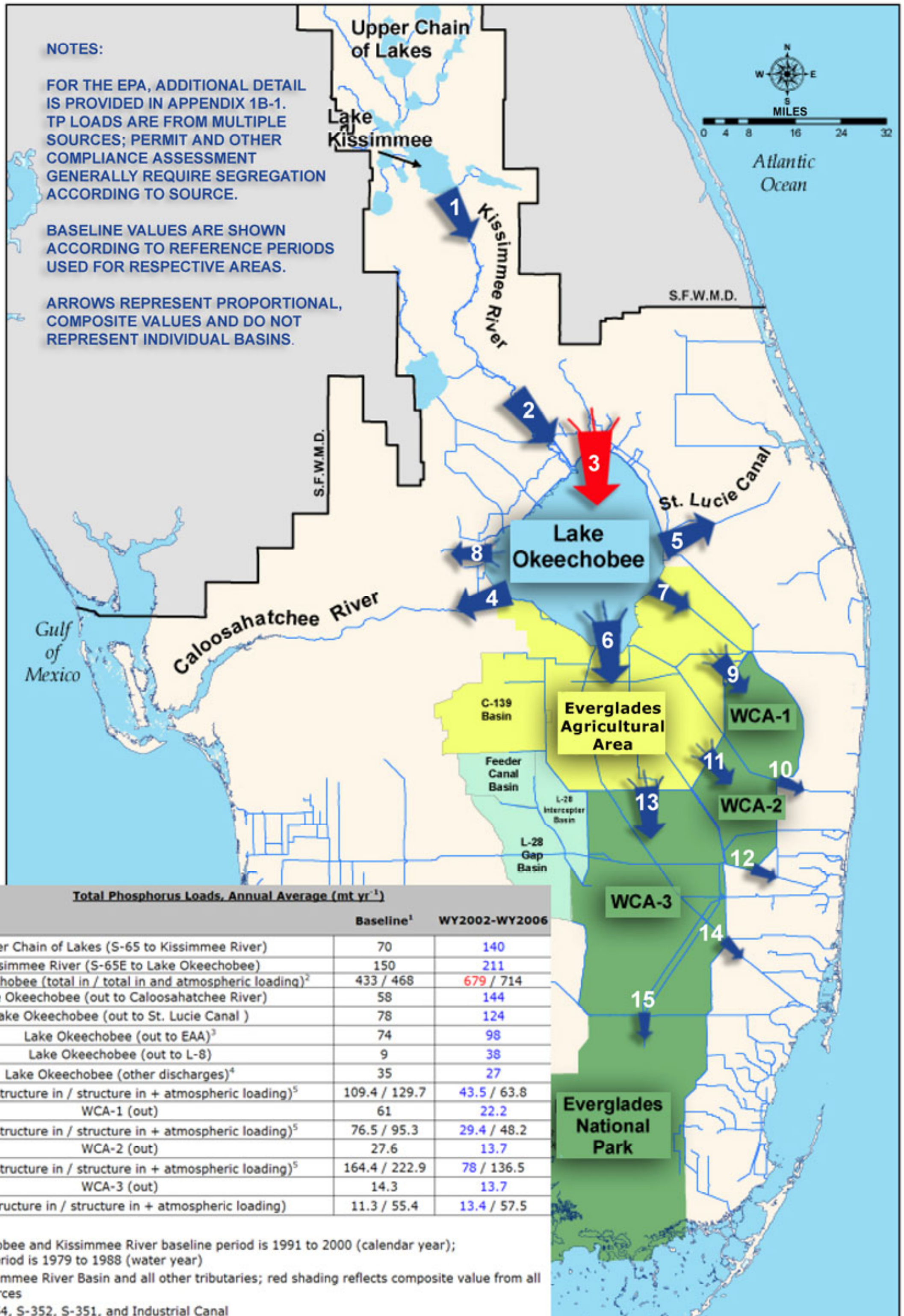
With the FDEP as the lead agency, the State of Florida has been using an independent, science-based process to establish region-specific nutrient criteria and TMDLs for the Kissimmee Basin, Lake Okeechobee, the Caloosahatchee Estuary, the St. Lucie Estuary, and tributary basins. For Class III waters in the Everglades Protection Area (EPA), the FDEP has used the results of extensive research to numerically interpret the existing narrative standard for nutrients to establish a total phosphorus (TP) criterion as a long-term geometric mean of 10 parts per billion (ppb), taking into account spatial and temporal variability (62-302.540, Florida Administrative Code). This standard was approved by the U.S. Environmental Protection Agency in July 2005. The FDEP is currently working with the District and other interested parties to establish ambient monitoring networks to assess compliance with this rule across the EPA. This assessment methodology is the subject of a special review in this volume (see Appendix 3C-1). Chapter 3 provides a complete update of TP loads and concentrations across the EPA.

REGIONAL OVERVIEW OF PHOSPHORUS LOADS AND CONCENTRATIONS

The synthesis of TP loads down through the KOE system in **Figure 1B-1a** provides the overall relative magnitude of phosphorus movement through this region. It is important to recognize that TP loads are largely a function of water flow, as depicted for the KOE system in Figure 2-1 of this volume. A cascade of phosphorus through the system begins with the Kissimmee Chain of Lakes (KCOL) in the Upper Basin, where there has been a notable increase in loading from the respective baseline period. This riverine input, in combination with phosphorus associated with stormwater runoff from the watersheds adjacent to the Kissimmee River, provides a substantial portion (i.e., about one-third) of the TP surface loading to Lake Okeechobee. As discussed in Chapter 10, the remaining TP loads come from atmospheric deposition and other basins in the 3.5-million-acre watershed that are driven largely by stormwater from agricultural and urban land uses.

As shown in **Figure 1B-1**, about two-thirds of the TP loads leaving Lake Okeechobee go to the east (to the St. Lucie Estuary) and to the west (to the Caloosahatchee Estuary). The remaining one-third of TP loads from Lake Okeechobee exits to the Everglades Agricultural Area (EAA) and other smaller basins either as water supply or regulatory releases necessary to maintain appropriate lake levels. Stormwater runoff from the EAA and nine other basins[2] contributes flow and TP load into Water Conservation Areas (WCAs). Stormwater runoff from the C-111 basin and the WCAs contributes to TP loading into Everglades National Park (ENP or Park). In addition, a substantial amount of TP loading to all three WCAs and the Park comes from atmospheric deposition. While the relative magnitude of atmospheric loading estimates presented in **Figure 1B-1a** is reasonable, it should be noted that there are no reliable direct estimates of this input to the remnant Everglades. The *Everglades Protection Area* section of this chapter demonstrates that the Everglades phosphorus control programs have been very successful, even though additional measures are under way. For each WCA, there has been a substantial reduction in recent TP loads to the WCAs compared to their respective baseline levels. Despite reductions in TP concentrations, TP loads to the Park have actually increased compared to the baseline period, which is a reflection of the increased quantity of water entering the Park needed for environmental restoration.

[2] These other basins include the C-139, L-28, Feeder Canal, Acme Basin B, North Springs Improvement District, North New River Canal, C-11 West, L-8, and C-51 West basins.



Total Phosphorus Loads, Annual Average (mt yr[-1])

		Baseline[1]	WY2002-WY2006
1	Upper Chain of Lakes (S-65 to Kissimmee River)	70	140
2	Kissimmee River (S-65E to Lake Okeechobee)	150	211
3	Lake Okeechobee (total in / total in and atmospheric loading)[2]	433 / 468	679 / 714
4	Lake Okeechobee (out to Caloosahatchee River)	58	144
5	Lake Okeechobee (out to St. Lucie Canal)	78	124
6	Lake Okeechobee (out to EAA)[3]	74	98
7	Lake Okeechobee (out to L-8)	9	38
8	Lake Okeechobee (other discharges)[4]	35	27
9	WCA-1 (structure in / structure in + atmospheric loading)[5]	109.4 / 129.7	43.5 / 63.8
10	WCA-1 (out)	61	22.2
11	WCA-2 (structure in / structure in + atmospheric loading)[5]	76.5 / 95.3	29.4 / 48.2
12	WCA-2 (out)	27.6	13.7
13	WCA-3 (structure in / structure in + atmospheric loading)[5]	164.4 / 222.9	78 / 136.5
14	WCA-3 (out)	14.3	13.7
15	ENP (structure in / structure in + atmospheric loading)	11.3 / 55.4	13.4 / 57.5

[1] Lake Okeechobee and Kissimmee River baseline period is 1991 to 2000 (calendar year); EPA baseline period is 1979 to 1988 (water year)

[2] Includes Kissimmee River Basin and all other tributaries; red shading reflects composite value from all watershed sources

[3] Includes S-354, S-352, S-351, and Industrial Canal

[4] Includes S-129, S-127, S-135, G-207, G-208, S-131, and Culvert-5A

[5] Estimates of atmospheric loading to the WCAs are based on Redfield (2002): WCA-1: 35 mg/m2/yr; WCA-2: 35 mg/m2/yr; WCA-3: 25 mg/m2/yr; ENP: 20 mg/m2/yr over the freshwater portion of Everglades National Park.

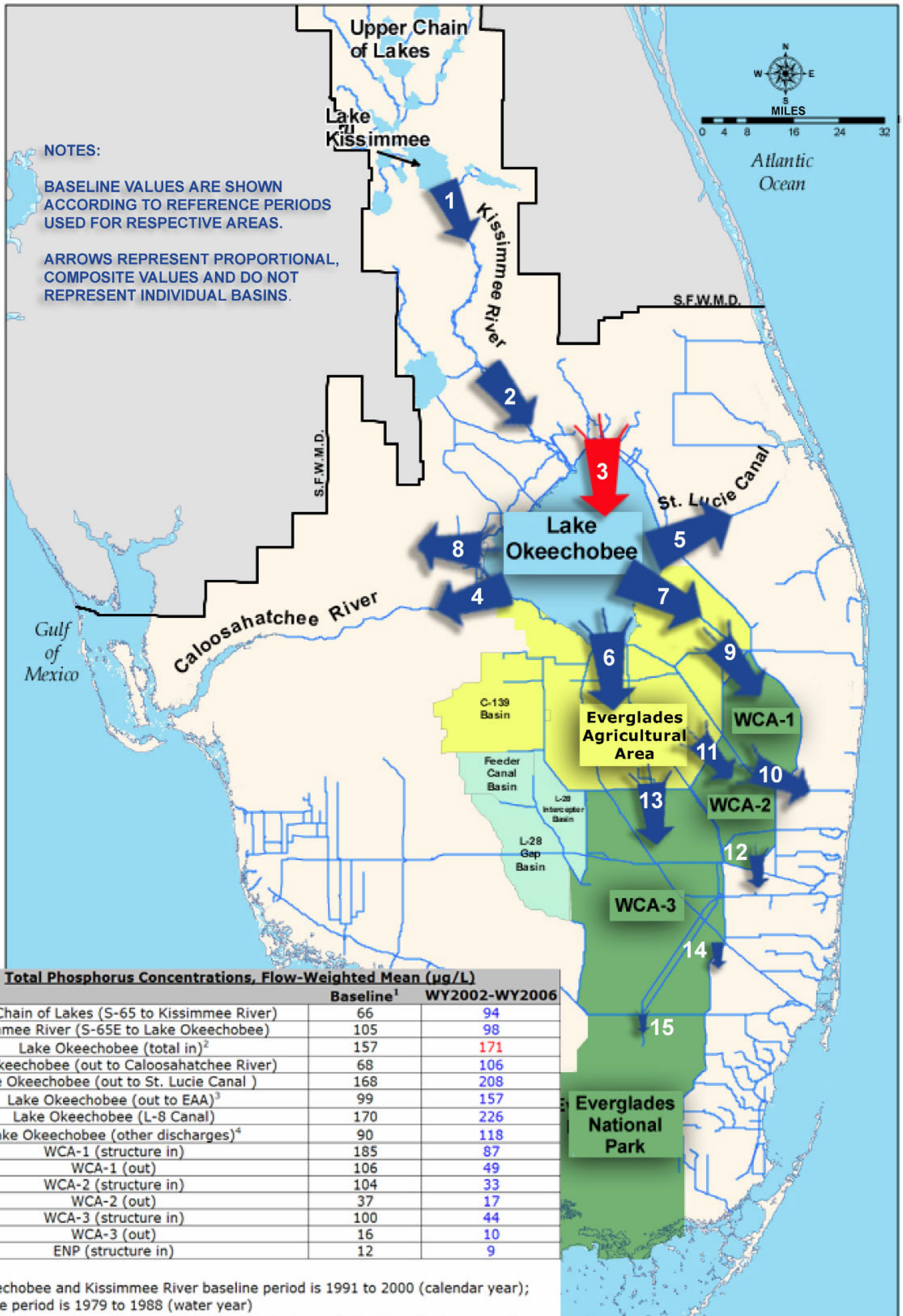
Figure 1B-1a. Summary of total phosphorus (TP) loading across the Kissimmee-Okeechobee-Everglades (KOE) region.

TP concentrations across the KOE system show similar patterns to TP loading (**Figure 1B-1b)**. Beginning with the inputs from the KCOL in the Upper Basin, the flow-weighted mean concentration of 43 ppb for the baseline increases both moving downstream through the Lower Basin and through time when compared to the respective baseline. Contributions from the Lower Basin are reflected in the higher numbers generally seen as the Kissimmee River enters Lake Okeechobee as compared to those near the middle of the river at S-65C. Variations seen in TP concentrations within the Lower Basin may reflect different land uses in the area and year-to-year variations in local sub-basins, particularly flows.

Phosphorus concentrations in Lake Okeechobee have increased threefold since the 1970s and notably were over 200 ppb in the last two water years (see Figure 10-8), primarily in association with the 2004 and 2005 hurricanes. These water years are the only time when the in-lake concentration exceeded inflow concentrations. This indicates that internal phosphorus loading (between sediments and the water column) contributes significantly to the phosphorus concentration in Lake Okeechobee and in turn, increases the export of phosphorus downstream to the estuaries and the EAA. In fact, inputs to the EAA from the lake increased substantially in the last two water years in direct correspondence to the hurricane-related increases in lake concentrations. Runoff from the EAA also appears to reflect these hurricane-related effects, increasing from less than 75 ppb in WY2003 and WY2004 to over 115 ppb in the last two water years (see Figure 4-6). Runoff concentrations from the C-139 basin were slightly above 250 ppb in WY2003 and WY2004 and showed improvement in WY2005 when concentrations decreased to below 200 ppb. There appears to have been some hurricane-related effect on the C-139 basin during WY2006, evidenced again by an increase in concentration to more than 250 ppb (see Figure 4-11). These are prime examples of the inter-basin coupling of TP concentrations and loads and demonstrate that solutions to water quality must be approached a regional level.

A source control strategy to reduce phosphorus loads has been developed for the majority of the tributary basins that discharge either directly or indirectly into the EPA, consistent with the requirements of the EFA and the Everglades Protection Area Tributary Basins Long-Term Plan for Achieving Water Quality Goals, known as the Long-Term Plan (Burns & McDonnell 2003, as amended). Chapter 4 provides an update on the source control strategy for the EAA, C-139, L-28, Feeder Canal, Acme Basin B, North Springs Improvement District, North New River Canal, C-11 West, C-111, and Boynton Farms basins. For these basins, the strategy includes implementation of Best Management Practices (BMPs) for phosphorus reduction, regulatory programs, educational programs, and integration with local and regional projects. The strategy for these basins includes regulatory programs and integration with regional projects. In addition to source controls, there has been a considerable investment in regional TP removal in Stormwater Treatment Areas (STAs), with marked reductions in TP loads entering the Everglades. TP concentrations in water entering into the WCAs, primarily from the EAA, have declined greatly from the WY1979–WY1988 baseline levels of 118 ppb to 48 ppb over the most recent five-year period (WY2002–WY2006), as described in the *Everglades Protection Area* section of this chapter. While not as dramatic in the TP concentration differences seen upstream in the WCAs, inflow concentrations to the Everglades National Park (ENP or Park) have decreased from the WY1979–WY1988 baseline period value of 12 ppb[3] to a level of just 9 ppb during the most recent five-year period (WY2002–WY2006). However, it is important to note that despite significant reductions in TP load and concentration inputs to the WCAs, concentrations entering the Park have shown no noticeable trends during the period of phosphorus control program implementation, i.e., post-1994. Inflow volumes to the Park over the last five years have increased substantially in an effort to provide a more appropriate hydroperiod to this vital region of the Everglades.

[3] The average concentration for the WY1979–WY1988 baseline period contained high levels during 1985–1986, which influenced the 10-year average.



	Total Phosphorus Concentrations, Flow-Weighted Mean (µg/L)	Baseline[1]	WY2002-WY2006
1	Upper Chain of Lakes (S-65 to Kissimmee River)	66	94
2	Kissimmee River (S-65E to Lake Okeechobee)	105	98
3	Lake Okeechobee (total in)[2]	157	171
4	Lake Okeechobee (out to Caloosahatchee River)	68	106
5	Lake Okeechobee (out to St. Lucie Canal)	168	208
6	Lake Okeechobee (out to EAA)[3]	99	157
7	Lake Okeechobee (L-8 Canal)	170	226
8	Lake Okeechobee (other discharges)[4]	90	118
9	WCA-1 (structure in)	185	87
10	WCA-1 (out)	106	49
11	WCA-2 (structure in)	104	33
12	WCA-2 (out)	37	17
13	WCA-3 (structure in)	100	44
14	WCA-3 (out)	16	10
15	ENP (structure in)	12	9

[1] Lake Okeechobee and Kissimmee River baseline period is 1991 to 2000 (calendar year); EPA baseline period is 1979 to 1988 (water year)

[2] Includes Kissimmee River Basin and all other tributaries; red shading reflects composite value from all watershed sources

[3] Includes S-354, S-352, S-351, and Industrial Canal

[4] Includes S-129, S-127, S-135, G-207, G-208, S-131, and Culvert-5A

Figure 1B-1b. Summary of TP concentrations across the KOE region.

Several landscape-level ecological concepts help to explain TP loads and concentrations throughout the South Florida region. First, undisturbed natural ecosystems assimilate and recycle phosphorus very efficiently, and a very small proportion of phosphorus is exported from such systems. Productivity in many ecosystems is often limited by the availability of phosphorus and, therefore, plant communities have evolved to use and retain the nutrient with high efficiency. Human-induced disturbance of natural systems tends to decouple the cycling of phosphorus and increase its movement out of local ecosystems. Changes in land use and development, besides altering the cycling of phosphorus, also have led to greater inputs of the nutrient from upstream systems; these changes are often associated with fertilization and imports of livestock feed. In its most basic form, pollution-control strategies are developed to counter these ecosystem changes by minimizing phosphorus movement and system inputs.

The phosphorus control strategies discussed in Chapters 4, 5, 8, and 10, as well as elsewhere in this volume, use the chemical, physical, and biological processes of natural systems to hold phosphorus in place and reduce water quality problems downstream. Although there is a long history of regulatory and voluntary incentive-based programs to control phosphorus inputs into Lake Okeechobee, there has not been any substantial reduction in loading from upstream sources to the lake during the last decade. Conversely, the source controls for the EAA basin detailed in Chapter 4 have been very effective in overall load reduction. Despite a similar BMP program, load reductions in the adjacent C-139 basin have not achieved regulatory compliance. A phased program of more aggressive measures is being implemented in the C-139 basin to achieve load reduction compliance (see Chapter 4). Source controls continue to be the first line of defense for the basins that discharge into the Everglades. Such controls include practices to decrease TP inputs in excess of localized needs and reduce TP loads and concentrations leaving developed landscapes and entering the Everglades region. These BMPs in urban and agricultural lands often involve optimized fertilization, water management, and vegetation and sediment controls. Adaptive management, using both site-specific and regional considerations, is essential for selecting the most appropriate combination of BMPs.

Despite ever-intensifying efforts in source controls, water moving throughout the region still needs to be treated to reduce TP levels. The primary strategy for removing phosphorus from regional storm waters is the use of large constructed wetlands, or STAs. These natural treatment systems have the natural retentive processes described above and have been found to retain about 70 percent of incoming phosphorus. Overall, control strategies need to blend source controls and stormwater treatment in order to effectively reduce the overall TP loads and concentrations in the region. Both source controls and stormwater treatment are integrated with other environmental management activities such as inter-basin water transfers, regional restoration projects, seepage management, and restoration of regional wetlands through the Long-Term Plan.

With this backdrop, the following sections highlight phosphorus-related issues facing South Florida's sub-regions from north to south – the Kissimmee Basin, Lake Okeechobee, and the Everglades Protection Area, the strategies and programs that address these water quality concerns, and notable challenges that lie ahead with future regional efforts. It should be noted that South Florida's estuaries are not dealt with individually in this summary. The complexity of the coastal freshwater/saltwater interactions in these downstream systems and the fact that marine environments tend to be nitrogen-limited rather than phosphorus-limited both underlie the emphasis on phosphorus in upstream components of the KOE system. Further information on the status and management of South Florida's coastal estuaries is presented in the 2006 and 2007 SFER – Volume I, Chapter 12.

KISSIMMEE BASIN

BACKGROUND

As discussed in Chapter 11, the Kissimmee River is Lake Okeechobee's largest inflow and contributes 34 percent of the lake's tributary input of phosphorus. Phosphorus exports from the Upper and Lower basins in the Kissimmee watershed have been studied as a concern for several decades. Channelization of the Kissimmee River, which included dredging of the C-38 canal and lateral drainage ditches, can facilitate transport of phosphorus to Lake Okeechobee by improving drainage and limiting opportunity for detention and assimilation in floodplain wetlands. Regarding the Upper Basin, channelization also has raised concern that nutrient-rich water from Lake Tohopekaliga in the Upper Basin can be transported downstream to Lake Okeechobee. The Kissimmee Chain of Lakes (KCOL) has been substantially altered from its historic condition through the dredging of canals, installation of water control structures, increased development, and proliferation of problematic plant and animal species. The most dramatic change is reduced water level fluctuations. Smaller water level fluctuations have allowed land uses to encroach upon historic flood zones surrounding the lakes, resulting in significant habitat loss and in higher nutrient inputs to the lakes.

Beginning the 1950s, Lake Tohopekaliga received effluent from municipal wastewater treatment plants, which resulted in deterioration of water quality and ecological resources. By 1979, the lake's annual TP loading was eleven times higher than under natural conditions (Williams, 2001). Elevated TP concentrations and frequent algal blooms were observed in Lake Tohopekaliga and downstream lakes (Jones et al., 1983; Jones, 2005). These wastewater effluents were diverted from the lake in the 1980s, and phosphorus inputs declined significantly. In the following decade, Lake Tohopekaliga demonstrated a substantial improvement in TP concentrations and water clarity (James et al., 1994). Measurable improvements in water quality also have been documented in other KCOL water bodies, specifically for Lakes Cypress, Hatchineha, and Kissimmee (Williams, 2001). Despite this success, eutrophication control in the Upper Basin is still challenged by explosive urban development.

As agreed upon by the interagency participants working on the Long-Term Management Plan for the KCOL, the water quality goal for the Upper Basin is to meet or maintain state water quality standards in lakes regulated by the C&SF Project and the Lake Okeechobee Protection Act. As the lead agency, the FDEP has identified specific lakes within the KCOL that are nutrient-impaired and is currently in the process of developing specific TMDLs for 34 water bodies in the Kissimmee Basin, including these lakes.[4] The timeline for TMDL development is 2005–2011, which will be followed by implementation of BMPs.

In the Lower Basin, the District has been working in collaboration with the U.S. Army Corps of Engineers (USACE) to implement several projects in the Kissimmee Basin including the Kissimmee River Restoration Project (KRRP) (see Figure 11-9). The objective of this project is to restore the ecological integrity of the river-floodplain system by filling in the central reach of

[4] The District conducts basic water quality monitoring programs in the five major lakes in the KCOL – East Lake Tohopekaliga, Lake Tohopekaliga, Lake Cypress, Lake Hatchineha, and Lake Kissimmee – and the Kissimmee River to support planning and implementation of phosphorus source control programs. The Florida Fish and Wildlife Conservation Commission (FWC) and Florida LAKEWATCH also monitor the lakes. The FDEP is currently utilizing the SFWMD and FWC data in its ongoing TMDL water quality assessment. The FDACS is also currently investigating potential problem areas in the basin, with the goal of implementing BMPs beginning in 2009.

the canal and reestablishing natural patterns of hydroperiod and flow. It is important to note that the KRRP is not designed as a water quality improvement project, although some benefit may be realized if phosphorus is retained in restored sloughs and marshes. However, the restoration area is located upstream of the basin's most concentrated sources of phosphorus in the watershed of the lower Kissimmee River (Pools D and E). Therefore, this project is anticipated to have a negligible effect on phosphorus reduction in these downstream areas.

TP concentrations have increased at the lake's outlet (S-65) in recent years, and this increase cannot be wholly attributed to variations in the main body of this lake. These higher TP concentrations, along with greater discharges, have resulted in a doubling of the TP load (**Figure 1B-1a**). Possible reasons for this trend are being investigated by the District and FDACS.

PHOSPHORUS CONTROL PROGRAMS

The aforementioned TMDL and BMP programs conducted by the FDEP, FDACS, and District are the main programs being planned to control phosphorus under the KCOL Long-Term Management Plan. Current phosphorus management activities in the Upper Basin are in the early stages of planning. TMDLs for the KCOL are expected to be developed by the end of 2007. BMP implementation in the Upper Basin will commence in 2009 and is scheduled to be completed by 2015. As noted above, the FDACS is currently examining possible TP sources in the Upper Basin and is scheduled to begin BMP implementation in 2009. The Lake Okeechobee & Estuary Recovery Plan also plays a significant role in phosphorus control and management in the Kissimmee Basin, as described in the *Lake Okeechobee* section of this chapter.

In contrast to the STAs that are built specifically to retain phosphorus, the Kissimmee River Restoration Project is intended to reestablish the natural river-floodplain ecosystem. Because flow patterns within the restored area are unregulated, the river-floodplain interaction follows longer-term seasonal variations in flow, making it difficult to predict reductions in TP loading through floodplain retention. The District is currently developing a hydrologic simulation model for the basin, which may help in developing nutrient budgets and understanding flow pathways, detention times, and phosphorus assimilation by the river-floodplain system.

LAKE OKEECHOBEE

BACKGROUND

As discussed in Chapter 10, over the past 30 years phosphorus concentrations in Lake Okeechobee have increased from around 40 ppb to over 120 ppb. In the past two years, phosphorus has increased to over 200 ppb (see Figure 10-8). These increases can be attributed ultimately to high TP loads to the lake from agricultural runoff. These excessive loads have steadily accumulated into the sediments, resulting in reduced assimilation of TP by the sediments. In the last two years, Hurricanes Frances, Jeanne, and Wilma passed directly over the lake. These severe storms resuspended the TP-laden sediment into the water column, resulting in higher TP concentrations in the lake. In this condition, the sediment is now more easily resuspended by winds, keeping higher TP concentrations in the lake.

As depicted on **Figure 1B-1a**, the TP load to Lake Okeechobee during the baseline period (calendar years 1991–2000) averaged 468 metric tons per year (mt yr^{-1}) [including 35 mt yr^{-1} of estimated atmospheric deposition (FDEP, 2001)], with 70 mt yr^{-1} originating from the KCOL (S-65) and 80 mt yr^{-1} coming from the Lower Basin (S-65E). The most recent five-year TP average (WY2002–WY2006) was higher: 714 mt yr^{-1} total loading, 140 mt yr^{-1} from the KCOL, and 71 mt yr^{-1} from the Lower Basin[5]. The majority of these increases can be attributed to the past two years of extremely high flow due to extreme events of the 2004 and 2005 hurricanes (Charley, Frances, Jeanne, and Wilma). Notably, WY2005 and WY2006 ranked among the top five highest-flow water years since 1974. Discharges of TP from the lake averaged 254 mt yr^{-1} during the baseline period, with 58, 78, and 74 mt yr^{-1} being discharged to the Caloosahatchee and St. Lucie estuaries and the EAA, respectively. The most recent five-year TP average load of 431 mt yr^{-1} and the associated outflows to the lake were significantly higher. Again, the majority of these increases can be attributed to the past two years of high discharge. It is important to note that the total loading to the estuaries is higher than loads contributed by the Lake Okeechobee and includes substantial local contribution of nutrients from tributary basins downstream of the lake. Further information on the status and management of South Florida's coastal estuaries is presented in Chapter 12.

Although there is a long history of regulatory and voluntary incentive-based programs to control phosphorus inputs into Lake Okeechobee, there been no substantial reduction in loading during the last decade. Consequently, the lake continues to exhibit signs of eutrophication, including blooms of noxious blue-green algae (cyanobacteria), loss of benthic invertebrate diversity, and spread of cattail (*Typha* spp.) in shoreline areas. As a result, the Florida legislature passed the Lake Okeechobee Protection Act (LOPA, § 373.4595, Florida Statutes) in 2000, mandating that the lake-specific TMDL be met by 2015 and that the SFWMD, FDEP, and FDACS work together to implement an aggressive program to address the issues of excessive TP loading and exotic species expansion.

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[5] Water quality monitoring in the Lake Okeechobee watershed is conducted through the Lake Okeechobee Watershed Project (LOWP), Lake Okeechobee Watershed Assessment micro-basin monitoring, and the District's ambient water quality monitoring program. Through the LOWP, the U.S. Geological Survey monitors 16 sub-basin sites within the LOWP boundary north of Lake Okeechobee for stream flow, phosphorus, nitrogen, and total suspended solids. Continuous flow and weekly water quality samplings are collected at these stations. Basin water quality data for WY2006 are presented in the *Watershed Status and Management* section in Chapter 10 of this volume.

In October 2005, the state launched the Lake Okeechobee & Estuary Recovery (LOER) Plan in a continuing effort to help restore the ecological health of Lake Okeechobee and the St. Lucie and Caloosahatchee estuaries (**Figure 1B-2**). As a multiagency cooperative effort, the plan consists of a combination of capital projects and numerous interagency initiatives designed to provide measurable and meaningful improvements to water quality and water quantity in Lake Okeechobee and the St. Lucie and Caloosahatchee estuaries. The plan contains five Lake Okeechobee fast-track projects, which are specifically designed to provide water quality improvements (see Figure 10-2).

Additional components of the LOER consist of a diverse suite of multiagency activities (**Figure 1B-2**). Major initiatives include revisions to the Lake Okeechobee regulation schedule, establishment of TMDLs for Lake Okeechobee tributaries, revisions to Environmental Resource Permitting criteria for new development, implementation of growth management plans to encourage innovative land use planning, and full implementation of the Lake Okeechobee Protection Plan (LOPP) and the Lake Okeechobee Watershed Project (LOWP). All LOER components are under way and once implemented collectively will improve water quality, expand water storage, facilitate land acquisition, and enhance lake and estuary health.

PHOSPHORUS CONTROL PROGRAMS

The Lake Okeechobee Protection Act was passed by the Florida legislature in 2000 to establish a restoration and protection program for the lake. This is to be accomplished by achieving and maintaining compliance with state water quality standards in Lake Okeechobee and its tributary waters, through a watershed-based, phased, comprehensive and innovative protection program. The program set forth a series of activities and deliverables for the coordinating agencies including the District, FDEP, and FDACS. Elements specifically required by the legislation include the formal Lake Okeechobee Protection Plan and annual reports, implementation of the Lake Okeechobee Construction Project, a watershed TP source control program, a research and water quality monitoring program, in-lake TP management evaluation, an exotic species control program, and associated permits.

The initial LOPP was delivered to the Florida legislature and governor in 2004. The LOPA requires that the plan be updated every three years. The plan update is in progress and is due in January 2007. This plan update defines current and proposed TP reduction projects that require future funding, the lead agency responsible for implementing the activities and the estimated total phosphorus load reduction. The load reductions under both current and future activities were estimated based on the best available information and data. The actual load reductions, as measured at the lake inflow structures, will be delayed due to phosphorus that has accumulated in soils and tributaries over time. Long-term assessment is projected to continue through the life of the activities to quantify project performance. In addition to the LOPP, the District and USACE are implementing the LOWP, which is a part of CERP. The LOWP will address, in part, phosphorus loads to the lake and also provide alternative storage locations so that water levels in the lake can be regulated in a manner that has greater environmental benefits while still supporting water supply and other water resource functions and providing the same level of flood protection.

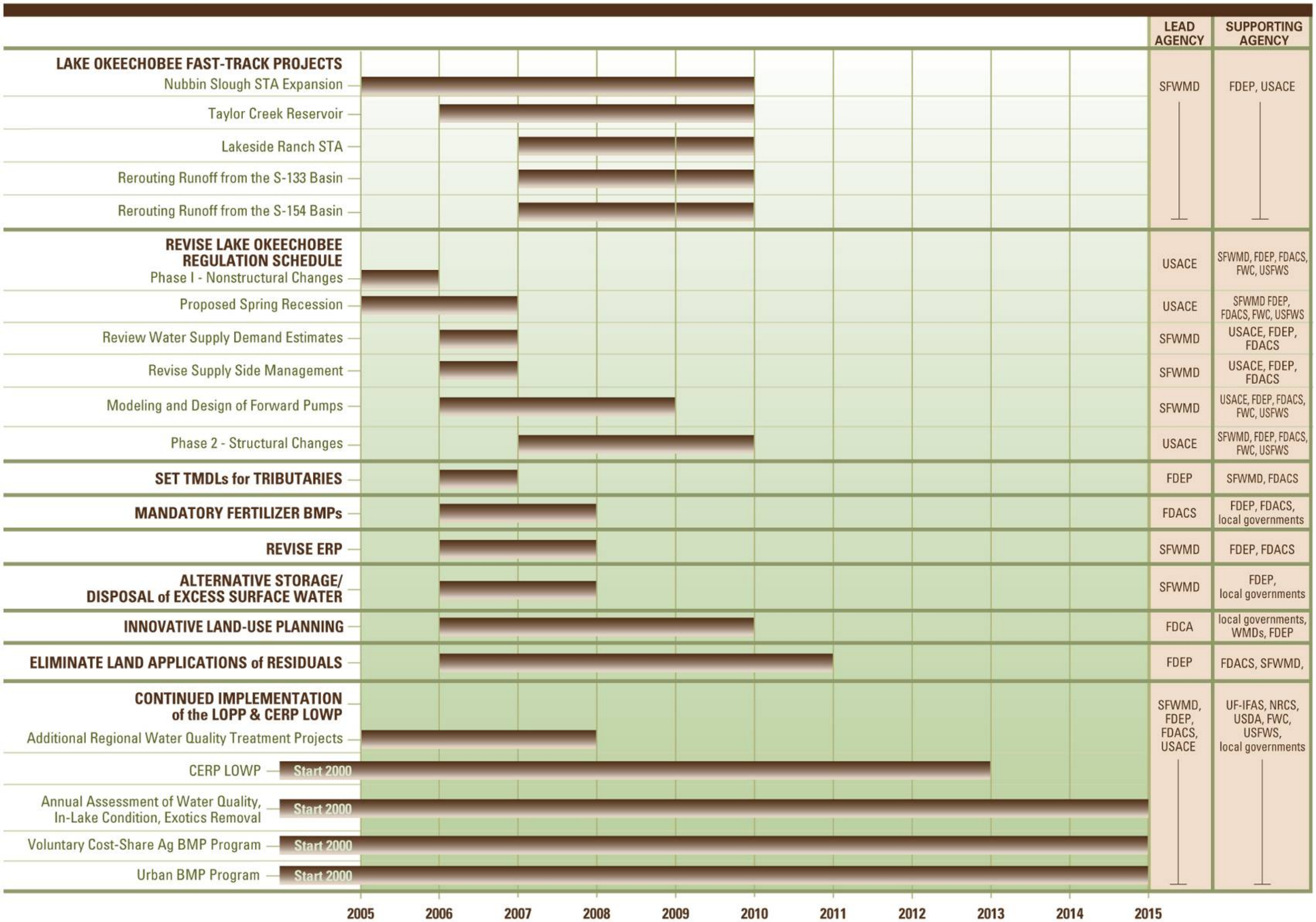

Figure 1B-2. Overview of the Lake Okeechobee & Estuary Recovery (LOER) Plan (see http://www.sfwmd.gov/newsr/lonew/final_lake_o_plan.pdf).

EVERGLADES PROTECTION AREA

BACKGROUND

EAA and C-139 Basins

The EAA and C-139 basins are south of Lake Okeechobee and north of the Everglades Protection Area (see Figure 4-1). Runoff from these two basins generally drains into the Stormwater Treatment Areas, built by the District as part of the Everglades Construction Project (ECP), for treatment prior to discharging into the EPA. The Everglades Forever Act required the District to develop a mandatory regulatory program with BMP implementation and specific phosphorus load limits in discharges from the EAA and C-139 basins. These limits are based on historical data or "baseline periods" defined by law. TP load limits from the tributary basins are critical to the success of the ECP because STAs were designed based on historical data and anticipated results of the regulatory programs. Tracking of TP load limits in accordance with the EFA began in WY1996 and WY2003 for the EAA and C-139 basins, respectively.

The EFA requires the EAA basin to achieve a 25 percent reduction in TP load in any given water year (since WY1996) when compared to a pre-BMP baseline period. For the C-139 basin, the EFA requires TP loads leaving the basin in any given water year (since WY2003) to be maintained at or below pre-BMP baseline period levels. The EFA also requires the District to collect monitoring data from the EAA and C-139 basins at representative locations to evaluate the effectiveness of the BMPs in achieving and maintaining compliance with the TP load reduction requirement. Details and background of the source control programs for these basins are described in the 2006 SFER – Volume I, Chapter 3; updates on these source control programs can be found in Chapter 4.

Other Basins Tributary to the Everglades Protection Area

In addition to the EAA and C-139, eight additional basins are tributary to the EPA but are not being treated by the ECP Stormwater Treatment Areas (STAs), as described in Chapter 4. These eight basins are also known as the non-Everglades Construction Project, or non-ECP basins (see Figure 4-1). Two additional basins, L-8 and C-51 West, are being treated by STA-1E, and relevant information is provided in Chapters 5, 7A and 8 of this volume. The L-8 and C-51 West basins are depicted in Figure 8-1. During the WY1979–WY1988 baseline period, the non-ECP basins contributed approximately 14 percent of the total load discharging to the EPA compared to the 86 percent contribution by the basins that are being treated by the ECP STAs.

A phosphorus source control strategy has been developed for each non-ECP basin consistent with the requirements of the EFA and the Long-Term Plan (see Chapters 4 and 8, respectively, of this volume). The strategy includes implementation of BMPs for phosphorus reduction, regulatory programs, educational programs, and integration with local and regional projects. The District is required to monitor and report on the effectiveness and success of the source control strategies.

PHOSPHORUS CONTROL PROGRAMS

EAA and C-139 Basins

For WY2006, as a result of continued success with the phosphorus source control program in the EAA, the basin achieved a three-year average of 56 percent reduction, and the annual reduction of 44 percent exceeded the 25 percent requirement for the eleventh consecutive year. In contrast, despite having begun implementation of a phosphorus source control program in WY2003, the C-139 basin did not meet its load requirement for the fourth consecutive year. Because it is the fourth year that the C-139 basin did not meet the TP load requirement, revisions to the existing regulatory program implemented through Rule 40E-63, Florida Administrative Code, are required by the EFA. The District will pursue revisions to the rule through a public process governed by Chapter 120, Florida Statutes, to ensure that the objectives of the EFA are met. Continued implementation of mandatory phosphorus source control BMP programs in the EAA and C-139 basins and achievement of the required levels of performance in TP loading from these basins are necessary for the District to achieve the TP criterion in the EPA and fulfill its obligations under the EFA and the federal Everglades Settlement Agreement. Refinement of the mandated program and implementation of supplementary activities will also be necessary in the C-139 basin to achieve the EFA required level of performance for this basin.

Regional Stormwater Treatment Areas

Working in concert with the EAA and C-139 basin source control programs, the ECP Stormwater Treatment Areas were originally designed to reduce phosphorus concentrations in waters entering the EPA to 50 ppb. With the adoption of a 10-ppb TP criterion in the EPA, the STAs are undergoing enhancements and expansion to ensure that discharges are sufficient to attain the 10-ppb criterion (see Chapter 5). These structural, vegetation, and operational enhancements, along with extensive monitoring and associated performance optimization research, are identified in the Long-Term Plan (see Chapter 8). Findings from these activities will be used to further refine operations and management of the STAs through adaptive implementation. Approximately 41,000 acres of treatment area have been constructed in a phased approach by the District and the USACE. Several thousand acres are progressing through a stabilization period and improved phosphorus removal is anticipated. Over 809 mt of TP have been removed by the ECP STAs since 1994. Notably, the combined phosphorus control program of the EAA BMPs and STAs has removed 2,500 metric tons of phosphorus since 1994 (see **Figure 1B-3**). This performance exceeds requirements despite highly variable inflow volumes and TP levels from year to year by hurricanes, regional droughts, and site-specific conditions (see Chapter 5).

While the performance described above is impressive, it is important to recognize that STAs are biological treatment systems that require continuous assessment and management in order to optimize treatment performance. Information provided in Chapter 5 and in earlier consolidated reports review significant challenges to STA performance. For example, as a result of its integration with regional flood control programs, these systems are subject to extreme variability in inflow volumes and phosphorus levels, and their performance capability has natural limits. In addition, the 2004 and 2005 hurricanes demonstrated that the treatment vegetation of these systems can be damaged by high-energy storms and their recovery to optimal performance can take several years. Stormwater Treatment Area 1 West (STA-1W) was severely impacted by the 2004–2005 hurricanes and large portions of the treatment area were taken off-line to implement a suite of recovery activities.

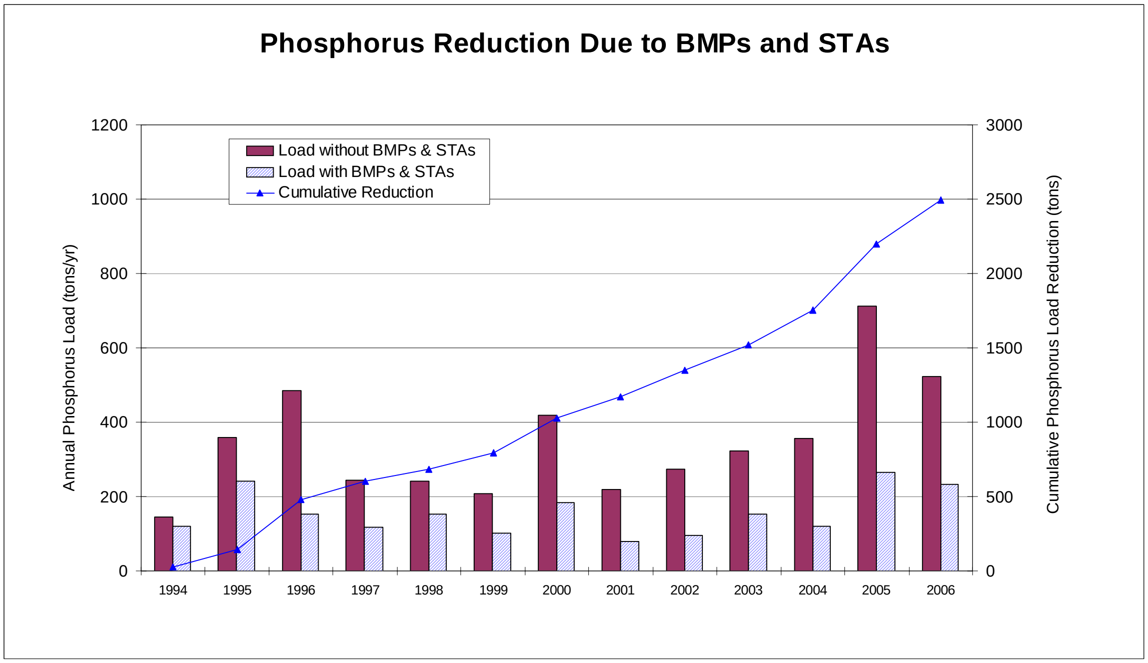

Figure 1B-3. Cumulative TP reduction in the Everglades Protection Area (EPA) from WY1994–WY2006.

Other Basins Tributary to the Everglades Protection Area

The strategy for non-ECP basins is to develop voluntary BMP programs, initiated in WY1998, and to rely on future CERP projects and other local construction projects for impoundment or diversion of flows. Because of the relatively small contribution of TP loads from these basins compared to the EAA and C-139 basins, there is not a specific load limit mandated. The EFA requires implementation of schedules and strategies for the non-ECP basins to ensure progress towards ultimately achieving established water quality standards for discharges to the EPA. Water Quality Improvement Plans (WQIPs) for each non-ECP basin have been developed to control TP at the source and include a combination of voluntary BMPs, public information and education, modification of storm water system permits to include water quality criteria, construction projects, cooperative agreements, and basin-specific regulatory programs. Detailed information regarding the background and development of the WQIPs for each non-ECP basin can be found in the 2006 SFER –Volume I, Chapter 3. Updated WQIPs can be found in Chapter 4 of this volume.

It is expected that by December 2006, the FDEP will establish long-term compliance permit requirements including technology based effluent limitations (TBELs) for each non-ECP basin. Water quality improvements to achieve TBELs will be accomplished through the basin-specific WQIPs. Therefore, continued implementation of the WQIPs for the non-ECP basins is necessary for the District to achieve the phosphorus criterion in the EPA and fulfill its obligations under the EFA and the federal Settlement Agreement.

PHOSPHORUS REDUCTIONS IN THE EVERGLADES PROTECTION AREA

Although extensive additional control measures are under way, the implementation of the EAA BMPs and STAs has already dramatically reduced TP levels entering the EPA. Compared to the WY1979–WY1988 baseline period, TP levels entering WCA-1 during WY2002–WY2006 dropped an average of 66 mt yr^{-1} and 98 ppb[6], despite less than full operation of the STAs and devastating impacts of several hurricanes in 2004 and 2005 (see **Table 1B-1** and **Figures 1B-4** through **1B-6**). For the recent five-year period (WY2002–WY2006), TP levels entering WCA-2 have dropped by 47 mt yr^{-1} and 71 ppb compared to the WY1979–WY1988 baseline period. Similarly, TP levels entering WCA-3 during WY2002–WY2006 dropped an average of 86 mt yr^{-1} and 56 ppb. Additional details of these comparisons to the baseline period are provided in Appendix 1B-1. Despite these dramatic reductions, additional work is under way to further reduce TP levels entering the Everglades sufficiently to achieve the phosphorus criterion in the EPA. In addition to enhancements to the existing STAs, approximately 17,400 acres of additional treatment area are under design and construction. Approximately 5,300 acres will be ready for flow by the end of 2006, and the remaining 12,100 acres are scheduled to be completed in the 2010–2012 time frame.

Significant District, state, and federal resources have been committed to implement massive regional water quality and water storage projects over the next several years that will significantly reduce TP levels entering the EPA. As shown in **Table 1B-2**, several regional projects are currently under way to control phosphorus inputs to the EPA. These projects are intended to supplement the ECP STAs in removing phosphorus from waters entering the Everglades or to improve the hydropattern of the EPA. Further information on these projects is presented in the Long-Term Plan and Chapters 4, 5, 7A, and 8 of this volume.

[6] Included in this reduction was the re-direction of the S-6 pump station from WCA-1 to STA-2.

Table 1B-1. Flow, TP load, and TP concentration comparisons of the baseline period (WY1979–WY1988) and the most recent five-year period (WY2002–WY2006) in the EPA, excluding atmospheric deposition.

Receiving Water	Parameter	Unit	1979-1988 Base Period	2002-2006 Observed	Change from Base Period	Percent Change
	Flow	acre feet/yr	478,734	405,217	-73,517	-15%
Into WCA-1	TP Load	kg/yr	109,416	43,466	-65,950	-60%
	TP Conc	ppb	185	87	-98	-53%
	Flow	acre feet/yr	595,495	717,899	122,404	21%
Into WCA-2	TP Load	kg/yr	76,472	29,391	-47,081	-62%
	TP Conc	ppb	104	33	-71	-68%
	Flow	acre feet/yr	1,336,804	1,440,046	103,243	8%
Into WCA-3	TP Load	kg/yr	164,426	78,031	-86,395	-53%
	TP Conc	ppb	100	44	-56	-56%
	Flow	acre feet/yr	776,550	1,140,478	363,928	47%
Into ENP	TP Load	kg/yr	11,499	12,795	1,296	11%
	TP Conc	ppb	12	9	-3	-24%
Total Into	Flow	acre feet/yr	3,187,582	3,703,640	516,058	16%
	TP Load	kg/yr	361,813	163,684	-198,129	-55%
	TP Conc	ppb	92	36	-56	-61%

Table 1B-2. Regional projects under way to control phosphorus inputs to the EPA. Project descriptions can be found in the Long-Term Plan and Chapters 4, 5, 7A, and 8 of this volume.

Project	Direct Receiving Water Beneficiary
Source Controls	WCA-1, WCA-2A, WCA-3A
Environmental Resource Permits	WCA-1, WCA-2A, WCA-3A
STA Enhancements	WCA-1, WCA-2A, WCA-3A
Acme Basin B Diversion	WCA-1
L-8 Diversion Project (partial)	WCA-1
EAA Storage Reservoir	WCA-2A, WCA-3A
Compartment B treatment areas	WCA-1, WCA-2A
Compartment C treatment areas	WCA-3A
EAA Canal Conveyance Improvements	WCA-1, WCA-2A
Hillsboro Site 1 Impoundment	WCA-2A
C-139 Annex Diversion	WCA-3A
Natural Resources Conservation Service programs	WCA-3A
Seminole Tribe Big Cypress Reservation Water Conservation Plan	WCA-3A
Broward County Water Preserve Area Project, including C-11 Impoundment and Diversion Project, WCA-3A/3B Seepage Management, and C-9 Impoundment Project	WCA-3A
G-123 Modified Operations	WCA-3A
Federal Modified Water Deliveries to Everglades National Park (USACE)	WCA-3, ENP
Federal C-111 Project (USACE)	ENP
C-111 Spreader Canal Project	ENP

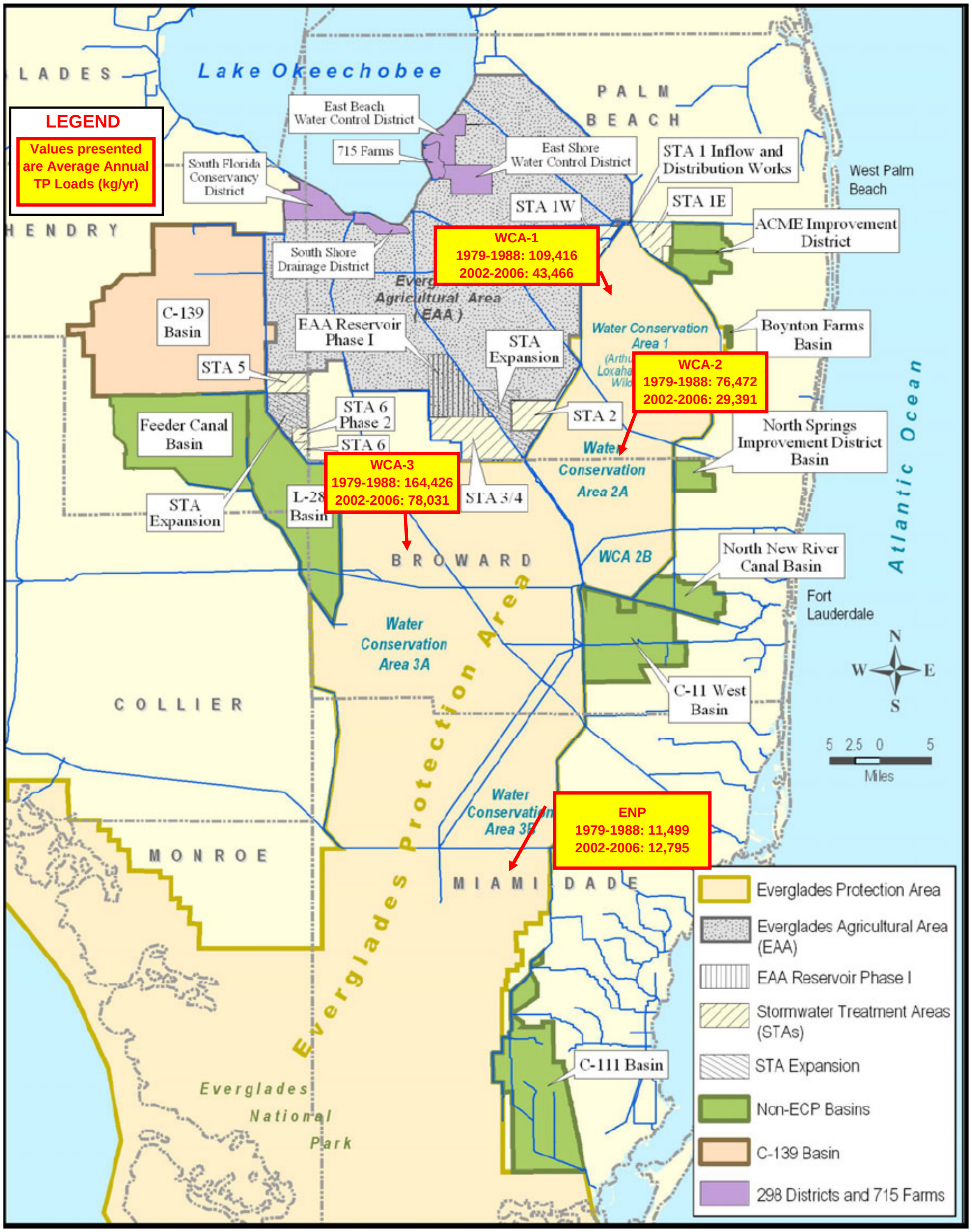

Figure 1B-4. Summary of TP loading across the EPA.
The TP loads in this figure are from multiple sources and are not intended to be used for assessment of permit and other compliance, which generally require segregation according to source. See Chapters 3C and 5 for assessment discussion.

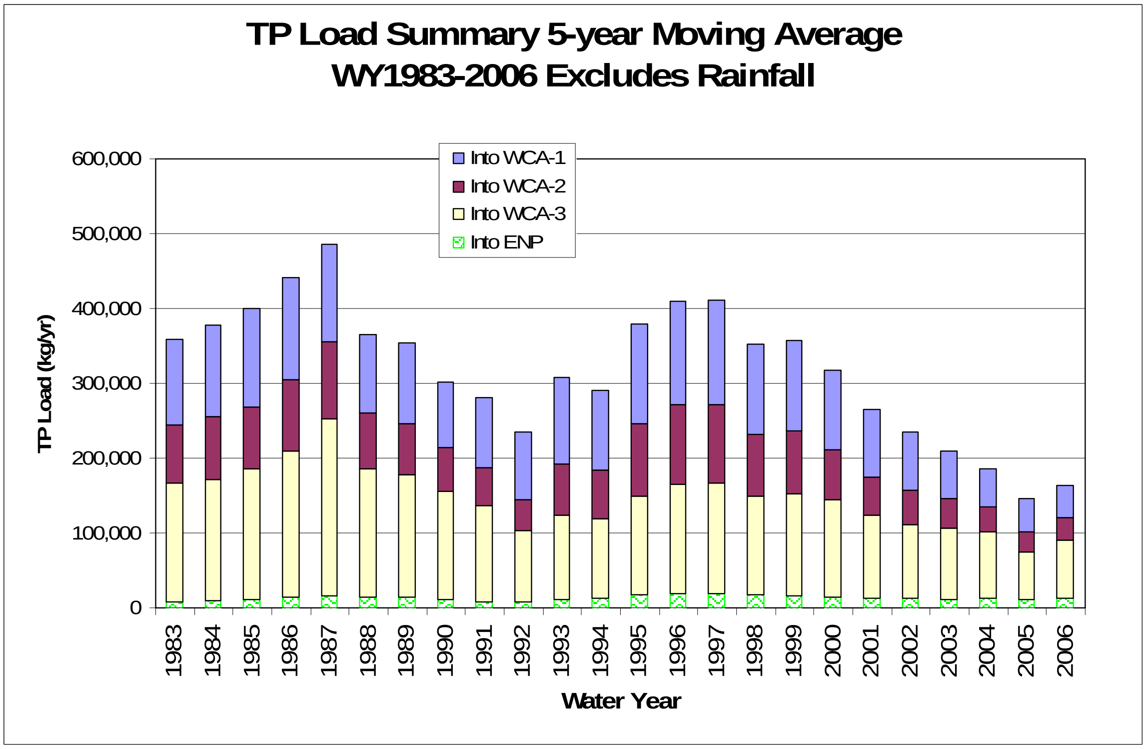

Figure 1B-5. Summary of five-year moving average TP loads into the EPA from WY1983–WY2006.

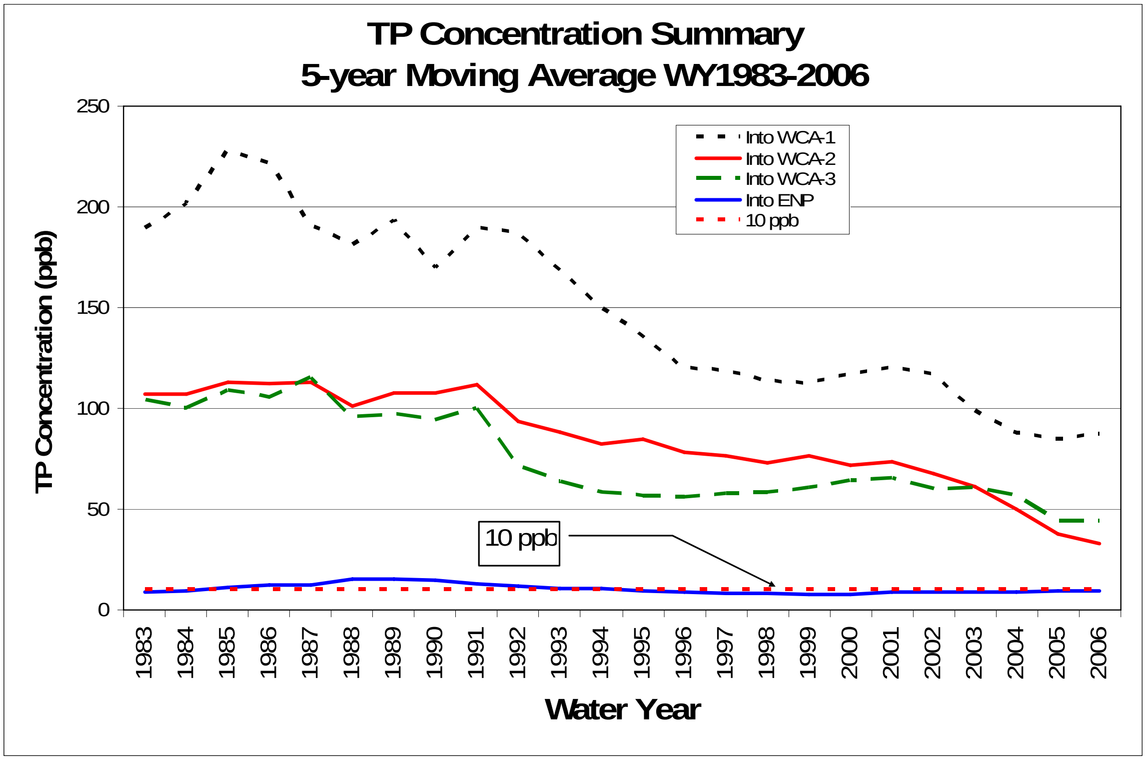

Figure 1B-6. Summary of five-year moving average TP concentrations into the EPA from WY1983–WY2006.

CONCLUSIONS AND PROSPECTUS

Water quality in many South Florida regions has declined over the last half of the twentieth century, following the construction of the C&SF Project and extensive urbanization and agricultural development in the region. Improving and restoring the quality of South Florida's surface water and groundwater resources is a strategic priority for the District. Extensive financial and technical commitments by the agency have been made to ongoing efforts in the Kissimmee Basin, Lake Okeechobee, the Everglades, and coastal estuaries, with additional investments related to water quality aspects of CERP. This chapter provides an overview of the numerous regional programs and restoration efforts addressing water quality, and more specifically phosphorus, across the KOE ecosystem.

Common to all regions, the District and state and federal agencies have taken a **watershed-based management approach** to reduce phosphorus impacts in the KOE ecosystem and the Caloosahatchee and St. Lucie estuaries. To date, there have been different levels of effectiveness – primarily a result of implementation schedules but also reflective of regional differences, e.g., differences in land use and soil conditions. Although the phosphorus control program for the EPA is only partially through its implementation, beneficial results of almost $1 billion in capital investment of public and private expenditures are already being observed. Since 1994, approximately 2,500 mt of TP has been removed from waters entering the EPA, with an associated 150 mt yr^{-1} and 90 ppb reduction in inflow levels compared to the respective baseline period.

Adaptive management is another common principle being applied to each region. Water quality improvement strategies that have proven effective in one area are being applied to other regions. In addition, those strategies are being refined as additional knowledge is gained from prior successes – and failures. It has been found that some BMPs that worked effectively in one region are not yielding similar results in other areas. Even though some of the STAs have yet to complete their initial stabilization periods, the District has begun significant structural, vegetation, and operational enhancement activities designed to optimize their performance. In addition, over 17,000 acres of additional treatment area are under design and construction.

Many challenges lie ahead as the District and state achieve the ultimate water quality goals for the KOE ecosystem: achieving TMDLs and the 10-ppb phosphorus criterion in the EPA. To this end, many District, state and federal partnerships are under way. Reducing the stormwater export of phosphorus loads from enormous landscapes through BMPs and other source control programs is a key strategic priority in the Lake Okeechobee watershed and many tributaries of the Everglades. Rounding out the collaborative effort, continued congressional authorization and appropriation for CERP projects are critical to improve the quantity, quality, timing, and distribution of water to the Everglades.

LITERATURE CITED

Burns & McDonnell. 2003. Everglades Protection Area Tributary Basins Long Term Plan for Achieving Water Quality Goals. October 2003. Report prepared for the South Florida Water Management District, West Palm Beach, FL.

FDEP. 2001. Total Maximum Daily Load for Total Phosphorus Lake Okeechobee, Florida. Florida Department of Environmental Protection, Tallahassee, FL. 47 pp.

James, R.T., K.M. O'Dell and V.H. Smith. 1994. Water Quality Trends in Lake Tohopekaliga, Florida, USA: Responses to Watershed Management. *Water Resources Bulletin*, 30: 531-546.

Jones, B.L. 2005. Water Quality in the Channelized Kissimmee River. S.G. Bousquin, D.H. Anderson, G.E. Williams and D.J. Colangelo, eds. In: *Establishing a Baseline: Pre-Restoration Studies of the Kissimmee River*. Technical Publication ERA-432. South Florida Water Management District, West Palm Beach, FL.

Jones, B.L., P.S. Millar, T.H. Miller, D.R. Swift and A.C. Federico. 1983. Preliminary Water Quality and Trophic State Assessment of the Upper Kissimmee Chain of Lakes, Florida, 1981–1982. Technical Memorandum. South Florida Water Management District, West Palm Beach, FL.

Payne, G., T. Bennett and K. Weaver. 2002. Chapter 5: Ecological Effects of Phosphorus Enrichment. G. Redfield, ed. In: *2002 Everglades Consolidated Report*, South Florida Water Management District, West Palm Beach, FL.

Steinman, A.D., K.E. Havens, H.J. Carrick and R. VanZee. 2001. The Past, Present, and Future Hydrology and Ecology of Lake Okeechobe and its Watershed. J. Porter and K.G. Porter, eds. In: *South Florida Hydroscape: The River of Grass Revisited*, Lewis Publishers, FL.

Williams, V.P. 2001. Effects of Point-Source Removal on Lake Water Quality: A Case History of Lake Tohopekaliga. *Lake and Reservoir Management*, 17: 315-329.