Final Version

Total Maximum Daily Load
for Total Phosphorus
Lake Okeechobee, Florida

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ACRONYM LIST

BMP	Best Management Practice
C&SF	Central & South Florida Project
CERP	Comprehensive Everglades Restoration Project
CFR	Code of Federal Regulations
CWA	Clean Water Act
DEP	Florida Department of Environmental Protection
DIP	Dissolved Inorganic Phosphorus
EAA	Everglades Agricultural Area
EPA	U.S. Environmental Protection Agency
FAMS	Florida Atmospheric Mercury Study
IAP	Interim Action Plan
KOE	Kissimmee-Okeechobee-Everglades System
LOTAC	Lake Okeechobee Technical Advisory Council
MOS	Margin of Safety
MSL	Mean Sea Level
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
RASTA	Reservoir Assisted Stormwater Treatment Area
RCWP	Rural Clean Waters Program
SFERWG	South Florida Ecosystem Restoration Working Group
SFWMD	South Florida Water Management District
STA	Stormwater Treatment Area
SWIM	Surface Water Improvement and Management Program
TBEL	Technology-Based Effluent Limitation
TCNS	Taylor Creek Nubbin Slough
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
USACE	United States Army Corps of Engineers
WCA	Water Conservation Areas
WMD	Water Management District
WOD	Works of the District
WQBEL	Water Quality-Based Effluent Limitation
WQL	Water Quality Limit

EXECUTIVE SUMMARY

Lake Okeechobee is a large, shallow eutrophic lake located in subtropical south central Florida that is designated a Class I water (potable water supply). It is a large multipurpose lake providing drinking water for urban areas, irrigation water for agricultural lands, recharge for aquifers, freshwater for the Everglades, habitat for fish and waterfowl, flood control, navigation, and many recreational opportunities. High phosphorus loadings resulting from man-induced hydrologic and land use modifications over the past 60 years have degraded the water quality of the lake.

This TMDL proposes an annual load of 140 metric tons of phosphorus to Lake Okeechobee to achieve an in-lake target phosphorus concentration of 40 ppb in the pelagic zone of the lake. This restoration target will support a healthy lake system, restore the designated uses of Lake Okeechobee and allow the lake to meet applicable water quality standards. The annual load was determined using computer models developed with guidance from the Lake Okeechobee TMDL Technical Advisory Committee. The entire load is allocated to the sum of all nonpoint sources. Currently, there are no point sources discharging directly to Lake Okeechobee.

The implementation of the TMDL will follow a phased approach consistent with Section 373.4595, Florida Statutes, Lake Okeechobee Protection Program, which addresses the restoration of Lake Okeechobee. Phase I includes immediately initiating activities within the Lake Okeechobee watershed to achieve the phosphorus load reductions as set forth in the South Florida Water Management District's Technical Pub 81-2. It is also the planning period for all activities to be implemented in Phase II. Phase II will include the implementation of additional phosphorus reductions in the watershed following management activities outlined in the Lake Okeechobee Protection Program to achieve the phosphorus TMDL for the lake of 140 metric tons. Phase III includes evaluating phosphorus reductions and monitoring up to this point and comparing the results to the water quality target.

INTRODUCTION

Section 303(d) of the federal Clean Water Act (CWA) directs each State to develop Total Maximum Daily Loads (TMDLs) for each water quality limited (WQL) segment reported according to Section 303(d). A TMDL reflects the total pollutant loading, from all contributing sources, that a water segment can receive, such that its capacity to assimilate the pollutant load is not exceeded and that the water body can still meet applicable water quality standards and its designated use, taking into account seasonal variation and a margin of safety. The elements of a TMDL are described in Section 303(d) of the CWA and in 40 CFR 130.2, 130.6 and 130.7. Lake Okeechobee was identified on the 1998 303(d) list, submitted to EPA by the Florida Department of Environmental Protection (FDEP), as being water quality limited (use impaired) by nutrients (particularly, phosphorus), dissolved oxygen, un-ionized ammonia, chlorides, coliforms, and iron. This document establishes a TMDL for phosphorus for Lake Okeechobee.

In addition to the Clean Water Act requirements, the state has enacted legislation (403.067 Florida Statutes (1999)), which provides a framework for how TMDLs will be developed in Florida. According to the legislation, the state is to develop a phosphorus TMDL for Lake Okeechobee.

BACKGROUND

Description of Water Body

Lake Okeechobee is a large, shallow eutrophic lake located in subtropical south central Florida and is a major feature of the Kissimmee-Okeechobee-Everglades (KOE) system (Figure 1). The KOE system is a continuous hydrologic system extending from Central Florida south to Florida Bay. Lake Okeechobee is the largest freshwater lake in Florida and the second largest freshwater lake within the contiguous United States, covering approximately 730 square miles. Since 1992, the lake has had an average lakewide depth of nine feet. The lake has a maximum storage capacity of 1.05 trillion gallons (at a depth of 19 feet). Lake Okeechobee is a multipurpose reservoir providing drinking water for urban areas, irrigation water for agricultural lands, recharge for aquifers, freshwater for the Everglades, habitat for fish and waterfowl, flood control, navigation, and many recreational opportunities (SFWMD 1997).

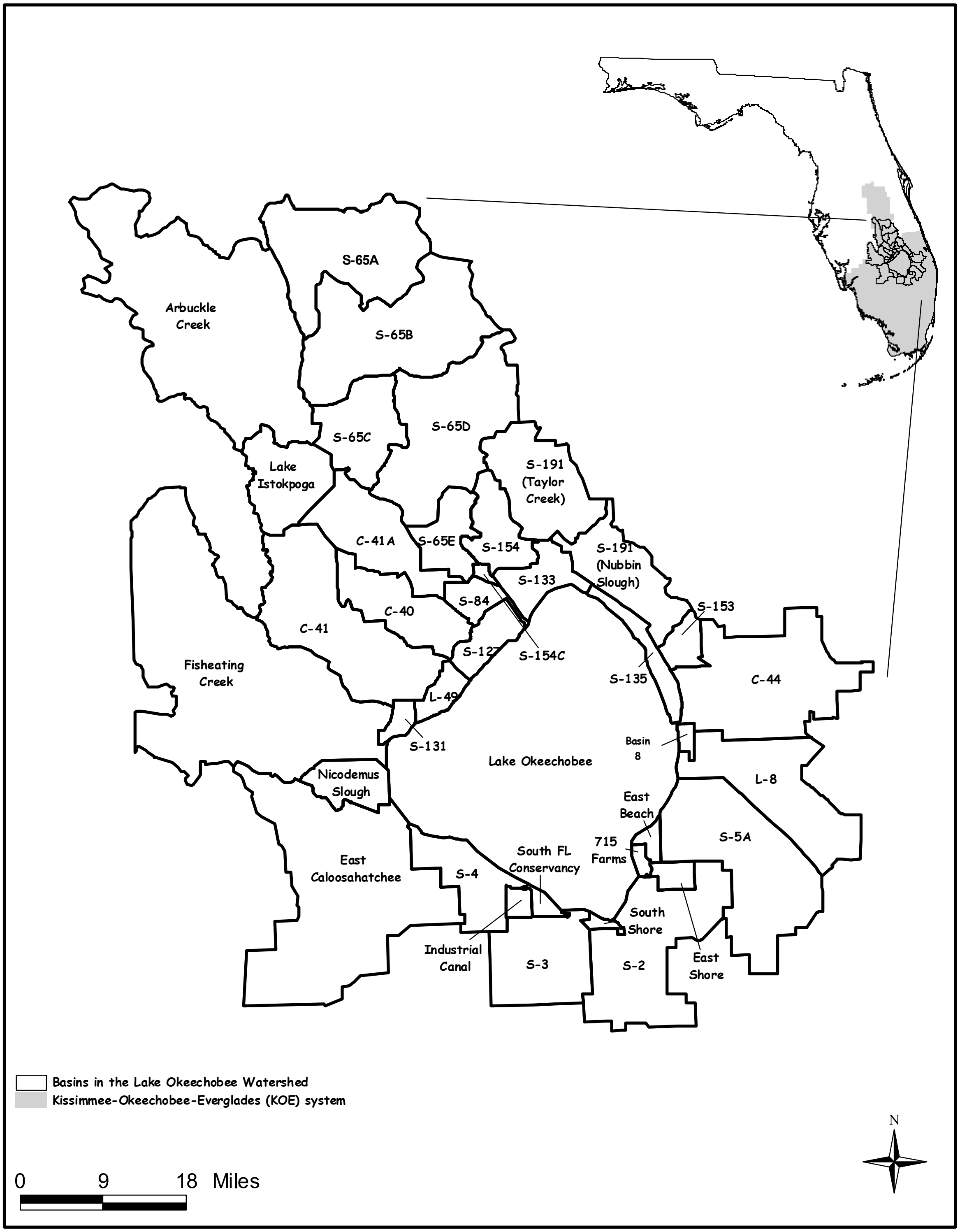


Figure 1. Basins in the Lake Okeechobee Watershed

Two hundred years ago, a large percentage of the lake bottom in Lake Okeechobee may have been covered with sand, whereas today, much of that area is overlain by organic mud (Brezonik and Engstrom 1997). The upper 10 cm of that mud is estimated to contain over 30,000 metric tons of phosphorus that has accumulated over the last 50 years (Olila and Reddy 1993). The rates of mud sediment accumulation and phosphorus deposition both have increased significantly in the last 50 years (Brezonik and Engstrom 1997).

At low lake stages (less than 15 feet), Lake Okeechobee is a spatially heterogeneous system with five distinct ecological zones: littoral, transition, edge, north and center (Figure 2) (Phlips et al. 1995). The ecological zones differ based on local water chemistry (total phosphorus, total nitrogen, chlorophyll *a* concentrations, limiting nutrient status), frequency of algal blooms, and light availability (Havens 1994). The ecological zones are closely associated with the different sediment types that have formed at the bottom of the lake. Sediment can affect the ecology of the lake with the resuspension of mud into the water column, which then affects light availability to plants and algae in the lake. The littoral zone, characterized by emergent and submergent vegetation, covers an area of approximately 150 square miles (25% of the lake's surface area), and is primarily located along the western shore of the lake (Havens et al. 1996b, SFWMD 1997). The littoral zone is typically found in areas underlain by rock. The littoral zone is sensitive to nutrient loading and light availability (Havens et al. 1999). The edge (near-shore) zone is located in the southern and western portions of the lake, between the littoral and transition zones, and is characterized by lower total phosphorus, more frequent nutrient limitation than in the other open-water zones (Aldridge et al. 1995), and frequent periods of light limitation (Steinman et al. 1997, Hwang et al. 1998). This ecological zone has developed in areas overlying sand and peat. The edge zone also is most sensitive to changing lake water levels and nutrient loading, displaying transitions between clear water with macrophyte dominance at low lake stage and turbid water with phytoplankton dominance at high stage (Havens et al. 2000). The north zone is located in the northeastern portion of the lake and around the center ecological zone. This area receives high phosphorus loading from the Taylor Creek/Nubbin Slough, S-154 and Kissimmee River basins and is characterized by high total phosphorus concentrations and nitrogen-limited phytoplankton growth. The center zone also has high total phosphorus and high chlorophyll *a* concentrations, while photosynthetic growth is typically light-limited (except in the mid-summer) due to the resuspension of the mud sediments below (Phlips et al. 1997). The transition zone is located between the north and edge zones and has moderate concentrations of total phosphorus. This zone is mostly found overlying sand sediment (SFWMD 1997).

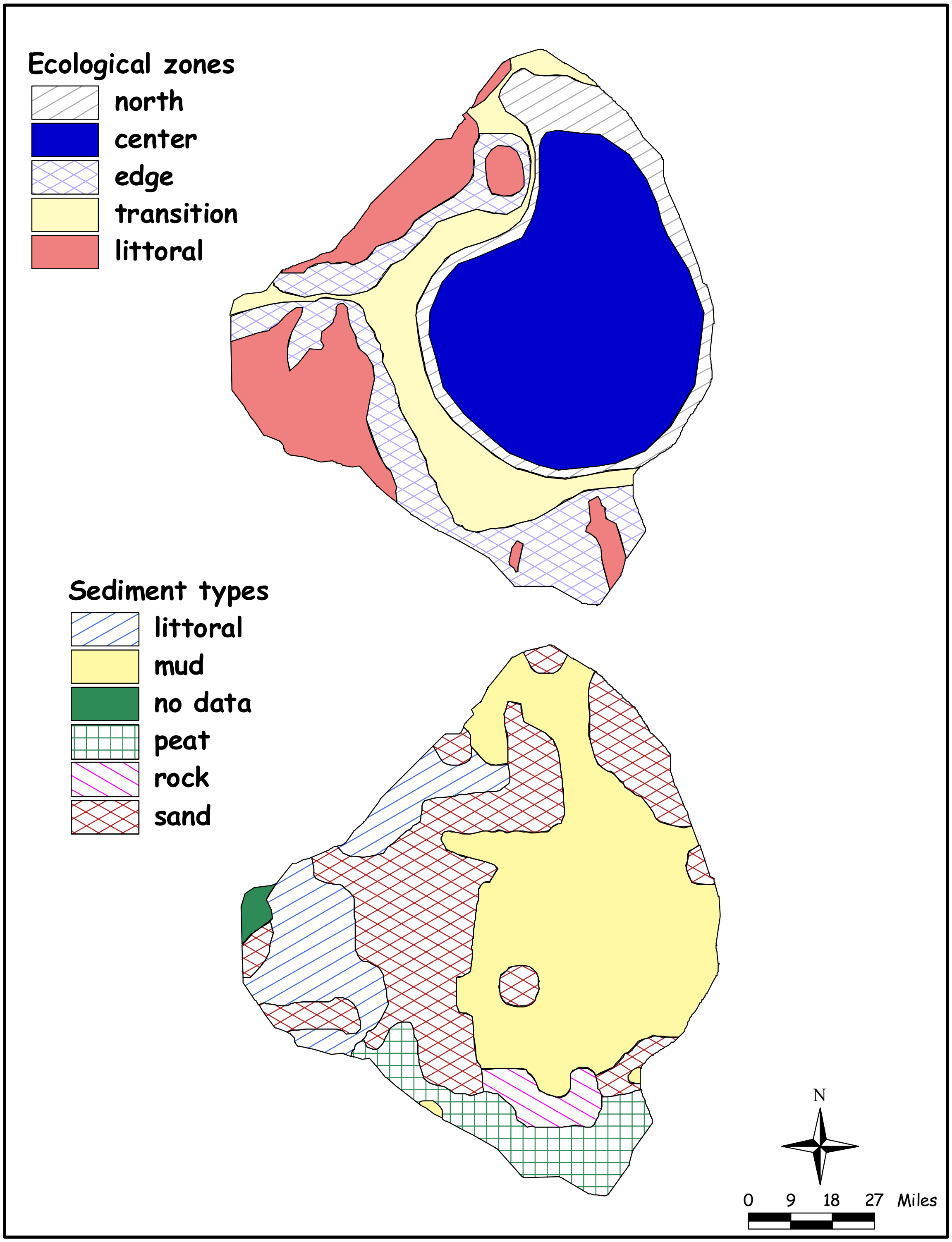


Figure 2. Ecological Zones and Sediment Types in Lake Okeechobee

Hydrology

Lake Okeechobee's drainage basin covers more than 4,600 square miles. The lake's watershed boundary has been defined under the Surface Water Improvement and Management (SWIM) program as those basins that are direct tributaries to the lake, including upstream tributaries and/or basins from which water is released or pumped into the lake on a regular basis (Figure 1). Forty-one basins fall within this boundary. Major hydrologic inputs into the lake include rainfall (39 %), the Kissimmee River (31 %), Fisheating Creek, and Taylor Creek/Nubbin Slough and numerous smaller inflows, such as discharges from the Everglades Agricultural Area (EAA), Harney Pond basin, Indian Prairie Creek basin. Major hydrologic outputs include evapotranspiration (66 %), the Caloosahatchee River to the west (12 %), the St. Lucie Canal (C-44) to the east (4 %), and four agricultural canals which discharge south into the Everglades region (Miami, North New River, Hillsboro, and West Palm Beach canals) (18%) (SFWMD 1997). Lake Okeechobee receives an average of 53 inches of rainfall per year. Approximately, 75% of this rain comes during the summer convective storms (May to October) (Purdam et al. 1998).

Water movement and currents in Lake Okeechobee are influenced by wind patterns (direction and velocity) and water depth. Distinct circulation patterns are formed on the surface and at the bottom of the lake (SFWMD 1997). The water found at the bottom of the lake typically moves south, with the presence of one clockwise circulation gyre. The water at the surface is influenced by multiple circulation gyres also moving clockwise (SFWMD 1997, Sheng 1993). The residence time (not including evapotranspiration) of water in Lake Okeechobee is approximately 3 years (SFWMD 1997). The residence time in the lake varies with rainfall, storage in the lake and outflows.

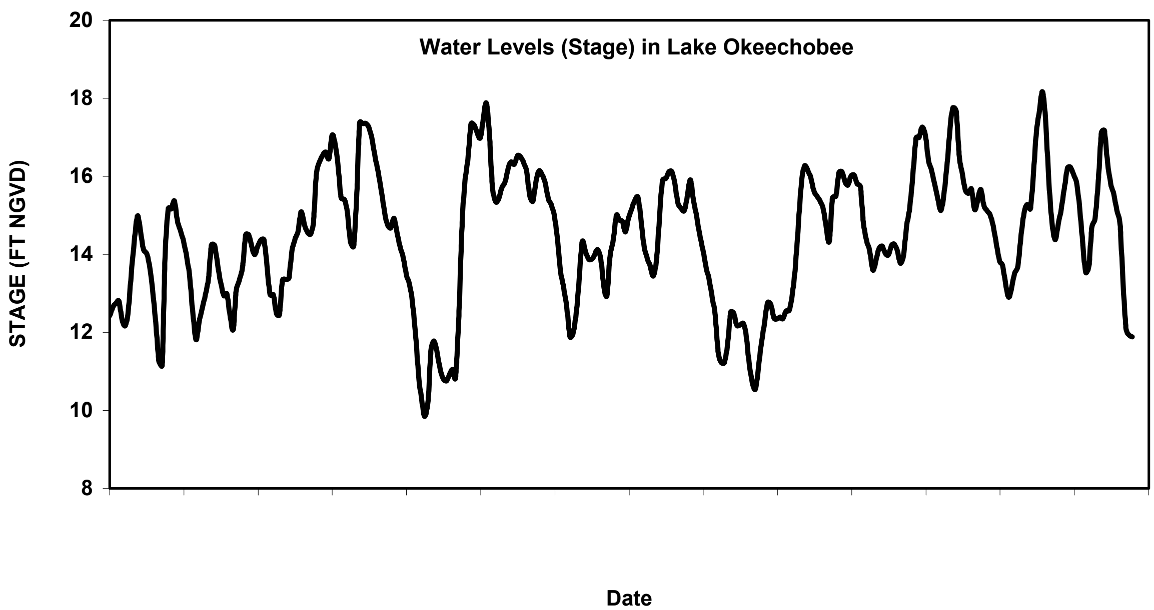
The hydrology of the Kissimmee-Okeechobee-Everglades drainage system has been greatly modified with diking and dredging to create farmland, control flooding, provide navigation, and facilitate greater water storage capacity (SFWMD 1997). The Lake Okeechobee watershed has little relief and a water table that is near the soil surface during the wet season. This area was once composed of large quantities of wetlands (Blatie 1980). Prior to human modification, the littoral zone of Lake Okeechobee was connected to the Everglades marsh and would deliver sheet flow runoff to the Everglades (Brooks 1974, Tebeau 1984). During 1926 and 1928, flooding resulted in the loss of life and property, which then resulted in the establishment of the Okeechobee Flood Control District to manage the water levels in the lake. In the 1930s, after the construction of a flood control levee (Herbert Hoover Dike) and a rim canal around the lake to control flooding, the lake levels were managed in a manner that resulted in the surface elevation being lowered from 19 ft to 17 ft, mean sea level (MSL) (Purdum et al. 1998). At present, virtually all flows into and out of the lake are managed through 140 miles of canals, control structures (gates, locks, and pumps) and levees, which were completed in the late 1950s, as part of the Central and South Florida (C&SF) Flood Control Project. The South Florida Water Management District (SFWMD), in conjunction with the United States Army Corps of Engineers (USACE), regulates these structures and canals (SFWMD 1997). This modified system has improved flood control and supplied irrigation water, however it has negatively affected the water quality of Lake Okeechobee by expediting the delivery of stormwater runoff to Lake Okeechobee.

The USACE has developed a lake regulation schedule primarily to provide flood protection during the wet season and secondarily to store water for irrigation, urban uses and deliveries to natural systems for the dry season. This schedule determines the timing and quantity of water releases from Lake Okeechobee based on its water level (Otero and Floris 1994). Regional rainfall patterns have caused the lake's levels to vary greatly over the last 60 years. The regulation schedule exacerbates the already existing problem of fluctuating lake levels. Prior to any hydrologic modifications, the lake had maximum water levels around 20 ft to 21 ft MSL. High water levels would result in water flooding adjacent wetlands, which could increase the surface area of the lake. The levee constructed in 1932 at the south end of lake was the only water control structure on Lake Okeechobee, and at this time the lake generally averaged 19 ft MSL.

The construction of the levee limited the size of the lake causing more dramatic ecological effects from the high water levels. From 1932 to 1950, the lake exhibited high average water levels (17 ft MSL) and low inter-year variability. From 1950 to 1960, the lake had lower water levels (maximums: 14 ft wet season, 15.5 dry season) and higher inter-year variability. From the

1960s to 1971, the northern portion of the Lake Okeechobee watershed experienced man-induced hydrological changes, including the channelization of the lower Kissimmee River, and the draining of 40,000 to 50,000 acres of floodplain wetlands for the development of agriculture (Loftin et al. 1990). These modifications upstream of Lake Okeechobee resulted in higher lake levels, which submerged the littoral zone of the lake reducing fish-spawning grounds and waterfowl feeding and nesting areas. In the 1970s, the maximum water level was increased (15.5 ft – wet season, 17.5 ft – dry season) creating longer periods of high water (Purdum et al. 1998). The current regulatory schedule (WSE) has the goal of reducing inter-year variability and also reducing pulse releases of freshwater from the lake to the Caloosahatchee and St. Lucie estuaries (LORSS 1996). Figure 3 illustrates changing water levels over time.

Figure 3. Annual average stage in Lake Okeechobee



WATER QUALITY CHARACTERIZATION

Use Impairment

According to FDEP's 1998 303(d) list, the water quality of Lake Okeechobee is impaired due to phosphorus, dissolved oxygen, iron, un-ionized ammonia, coliforms and chlorides. High phosphorus concentrations are the predominant reason for impairment, and at this time phosphorus is the sole pollutant considered for TMDL analysis. Elevated phosphorus loadings to the lake and high internal phosphorus concentrations have intensified the eutrophication of the lake, resulting in the development of widespread algal blooms in the lake. For example, an algal bloom in 1986 affected 25% of the lake as the wind blew the algal bloom into the near-shore zone (Jones 1987).

According to Rule 62-302 Florida Administrative Code (F.A.C.), Lake Okeechobee is designated a Class I water, which is a potable water supply. The State of Florida has a narrative criterion for nutrients, and according to this water quality criterion (Section 62-302.530(48) F.A.C.), nutrient concentrations of a water body shall not be altered so as to cause an imbalance in natural populations of aquatic flora or fauna. The development of seasonal blooms of blue-green algae (Cichra et al. 1995) and the shift in the composition of benthic macroinvertebrates toward more pollutant-tolerant species (oligochaetes) (Warren et al. 1995) are considered to be imbalances. Algal blooms in Lake Okeechobee have caused die-offs of macroinvertebrate communities due to toxic by-products of algal decay (Jones 1986), and they could threaten other ecological and societal values of the ecosystem. The algal species that occur during blooms (*Anabaena circinalis*, *Microcystis aeurginosa*, and *Aphanizomenon flos-aquae*) can sometimes produce toxic chemicals that harm fish and wildlife (Carmichael et al. 1985). Dense blooms of algae in a lake also can affect the quality of drinking water by creating taste and odor problems and contributing to the development of high levels of trihalomethane precursors (Heiskary and Walker 1988, Barica 1993).

Eutrophication

Researchers have observed an increased rate of eutrophication in Lake Okeechobee from 1973 to the present. Symptoms of this eutrophication include the following: 1) increases in algal bloom frequency since the mid-1980s (with an algal bloom being defined as chlorophyll *a* concentrations greater than 40 μg/L) (Maceina 1993, Carrick et al. 1994, Havens et al. 1995b), 2) increases in the dominance of blue-green algae following a shift in the TN:TP ratio (Smith et al. 1995), 3) increases in the lake water concentration of total phosphorus, 4) and increases in average chlorophyll *a* concentrations (Havens et al. 1995). Phosphorus is considered the key nutrient contributing to the eutrophication of the lake (Federico et al. 1981). Increases in total phosphorus concentrations in the lake, coupled with decreases in nitrogen loading from reduced backpumping from the Everglades Agricultural Area, have shifted the TN:TP ratio from greater than 25:1 in the 1970s to around 15:1 in the 1990s. This shift has created conditions more favorable for the proliferation of nitrogen-fixing blue-green algae, which are responsible for the blooms occurring in the lake (Smith et al. 1995).

Other studies could be cited to show that lake Okeechobee has been affected by phosphorus enrichment. Phosphorus enrichment is so great that phytoplankton growth is not limited by phosphorus, but by nitrogen (Aldridge et al. 1995). This type of secondary nutrient limitation induced by excessive phosphorus enrichment is a consequence of eutrophication (Schelske 1984). It can be demonstrated in Lake Okeechobee by bioassays (Aldridge et al. 1995) or from low concentrations of dissolved inorganic nitrogen that control phytoplankton growth (Schelske 1989).

According to Havens et al. (1995a), lake-wide algal bloom frequencies increased from 1980 to 1992. During the early 1980s, algal blooms only occurred in 8 months of the year, and during the 1990s have been occurring in all 12 months of the year (Havens et al. 1995a). Algal bloom frequencies increase with higher phosphorus concentrations and when there is high light penetration (Phlips et al. 1995). Algal blooms are seasonally and spatially controlled by wind-driven sediment resuspension and high summer temperatures. For example, bloom frequency in the pelagic zone is correlated with high temperature and high light transparency (Havens et al. 1995a). Blooms occur more frequently at the northern pelagic stations (L001 and L002) and in the western pelagic (L005 and L008) due to increased light availability. The lowest frequencies of blooms occur at the center of the pelagic zone (L004 and L006) because of low light transparency due to the resuspension of sediment. Overall, the highest frequency of blooms is seen in June. This is most likely due to lower wind velocities, reduced sediment resuspension, and greater underwater irradiances during summer (Havens et al. 1995a).

Phosphorus Trends in the Water Column

Total phosphorus concentrations within the pelagic region of the lake have been increasing since the early 1970s (Figure 4). The total phosphorus concentrations that currently exist in the lake are in excess of the amount needed for a healthy ecosystem. The in-lake total phosphorus concentrations have doubled over the last 50 years as a result of increased inputs from the watershed. The construction of canals and structures, as part of the C&SF Project, facilitated the delivery of stormwater runoff from intensive land uses that have developed in the surrounding watershed (Harvey and Havens 1999). During the last five years, the average concentration of total phosphorus in the pelagic region of Lake Okeechobee was approximately 100 ppb. However, perturbations of the system, such as hurricanes, have shown spikes of total phosphorus in the water column of ~400 ppb. Near-shore total phosphorus concentrations are generally lower than concentrations found in the pelagic region (Havens 1997).

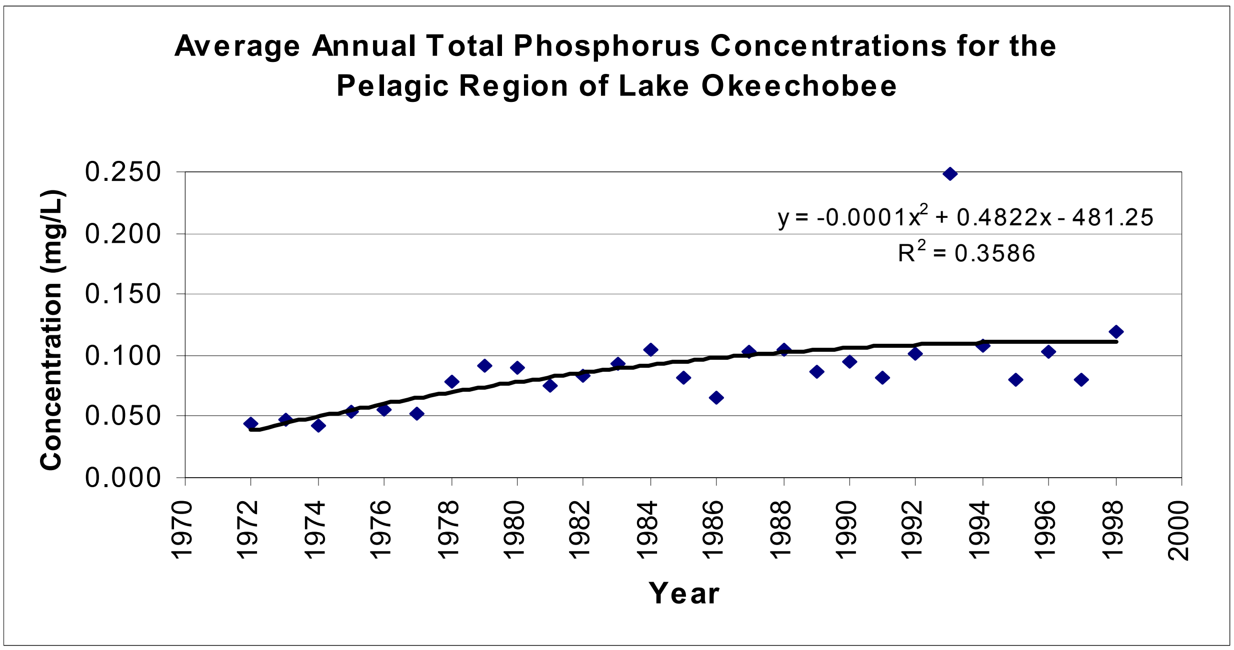


Figure 4. Annual average phosphorus concentrations in the pelagic region of Lake Okeechobee (A trend line was created from the annual average total phosphorus concentrations.)

Phosphorus trends in sediments

The concentration of phosphorus in the sediments of Lake Okeechobee has also been increasing. Prior to the 1950s, the lake bottom was comprised primarily of sand with low phosphorus concentrations (Harvey and Havens 1999). According to Engstrom and Benzonik (1993), phosphorus accumulation rates have increased between the 1950s and 1980s. This additional phosphorus accumulation has resulted in the development of mud sediments. High phosphorus loading to the lake saturates the sediments with phosphorus, which then decreases the lake's capacity to assimilate phosphorus (James et al. 1995). It is estimated that the top 10 cm of the lake sediments contain approximately 30,000 metric tons of phosphorus that has accumulated over the last 75 years. Phosphorus loading rates from the sediments to the water column are as large as 0.7 mg phosphorus/m^2/day for mud zone and 1.1 mg phosphorus/m^2/day for marsh sediments (Reddy et al. 1995b).

Currently, this internal phosphorus loading from the mud zone to the water column through diffusive fluxes is equal to the external phosphorus loading to the water column on an annual basis (Reddy et al. 1995b). A portion of the stored phosphorus becomes a significant source to the water column when this active phosphorus-laden sediment layer is resuspended into the water column by wind and waves.

The total amount of phosphorus stored in the soils of the Lake Okeechobee watershed is directly related to the intensity of land uses: unimpacted-44gP/m^2, forage-46gP/m^2, pasture-102gP/m^2, intensive agricultural areas-766gP/m^2, streams-116gP/m^2 and wetlands-75gP/m^2 (Reddy et al. 1995a). Total phosphorus concentrations found in the soils in the agricultural areas of the Taylor Creek/Nubbin Slough basins have increased 50 to 60 times as a result of phosphorus loading from manure (Graetz and Nair 1995). The phosphorus content of pastures in the Lake Okeechobee watershed has increased 3 to 4 times the background concentration. Phosphorus retention in upland sediments is at 85%; however, continuous loading of phosphorus to these soils is further decreasing the retention capacity for phosphorus in these soils (Reddy et al. 1995a).

Annual Phosphorus Mass Balance

$$\Delta R = \text{Inputs} - \text{Losses}$$

$$\Delta R = MI + AI - (SL + MO)$$

$$\text{where } SL = SU - IL$$

ΔR = Annual change in phosphorus reservoir (water mass)

MI = Monitored Inputs

AI = Atmospheric Inputs

SL = System Loss (including sedimentation and littoral zone storage)

MO = Monitored Outflows

SU = System Uptake of phosphorus (biological, chemical and physical processes)

IL = Internal Loading (recycling)

Within Lake Okeechobee, the net losses of phosphorus to the sediments from the water column can be determined by comparing measured total phosphorus inputs and outputs. The net losses have changed over time relative to loads, in that the lake now assimilates phosphorus at about 1/3 of the capacity that it did in the 1970s.

CURRENT LAKE-WIDE PHOSPHORUS LOADING

Between 1995 and 2000, phosphorus loading rates to Lake Okeechobee have averaged approximately 641 metric tons/year, with approximately 400 metric tons/year accumulating into the sediments of the lake. While the sediments provide a sink for phosphorus, a portion of the phosphorus stored in the top 10 cm of the lake's sediments is being added back into the water column at a rate almost equal to the external loading of phosphorus to the lake on an annual basis. To address excess phosphorus loadings to Lake Okeechobee and rehabilitate the ecological condition of the lake, phosphorus loading targets for each of the contributing basins within the watershed were established by the South Florida Water Management District's Works of the District permitting program, which were then adopted through the SWIM Act of 1989 (SFWMD 1989). In an effort to achieve an in-lake total phosphorus concentration of 40 ppb, a 40% reduction in phosphorus loading was specified based on the SFWMD's Technical Pub 81-2, (Federico et al. 1981). According to the 2001 SWIM plan update, to achieve the in-lake phosphorus concentration target, the total phosphorus load to the lake needs to be less than 423 metric tons/year (SFWMD 2001). Since 1995, phosphorus loading rates have exceeded the SWIM target by over 200 metric tons/year (SFWMD 2001). Currently, 14 of the 29 basins are exceeding their phosphorus loading targets. Four of the basins exceeding the SWIM targets have been identified as the key contributors of phosphorus in the watershed: Taylor Creek/Nubbin Slough (TCNS) and the three Kissimmee River basins (S-154, S-65D, and S-65E). Table 1 and Table 2 provide the phosphorus loading targets for each basin, along with their current phosphorus loading rates. The tables refer to "uncontrollable sources", which are sources and basins that are not under the regulatory authority of the SFWMD Works of the District (WOD) permitting program, while "controllable sources" are under the WOD program.

Table 1. Current annual average phosphorus loading rates and target annual phosphorus loading rates (based on 5-year rolling average) for each basin based on SWIM concentration targets during the years 1994 to 1998 (nd = no data) (Harvey and Havens 1999).

Basin	Discharge	Area	**SWIM Target**	**SWIM Target Load**	Actual	Actual Load	Over Target
Controllable Sources	(acre-ft)/yr	(sq. mi)	**TP (ppm)**	**(short tons/yr)**	TP (ppm)	(short tons/yr)	(short tons/yr)
715 Farms (Culv 12A)	12,758	4	0.18	3.1	0.1	1.7	-1.4
C-40 Basin (S-72) – S68	16,069	87	0.18	3.9	0.2	10.5	6.6
C-41 Basin (S-71) – S68	52,768	176	0.18	12.9	0.18	32.3	19.4
S-84 Basin (C41A) – S68	66,759	180	0.1	9.1	0.05	12.9	3.9
S-308C (St. Lucie-C-44)	41,480	190	0.18	10.2	0.13	8.9	-1.2
Culvert 10	11,612	10	0.18	2.8	0.53	9.8	7
Culvert 12	15,075	13	0.13	2.7	0.18	3.6	1
Fisheating Creek	256,761	462	0.18	62.8	0.18	60.7	-2.1
Industrial Canal	21,878	23	0.18	5.4	0.09	2.8	-2.6
L-48 Basin (S-127)	31,088	32	0.18	7.6	0.21	9.4	1.8
L-49 Basin (S-129)	0	19	0.18	0	0.09	2	2
L-59E	nd	15	0.16	nd	nd	nd	nd
L-59W	nd	15	0.16	nd	nd	nd	nd
L-60E	nd	6	0.1	nd	nd	nd	nd
L-60W	nd	6	0.1	nd	nd	nd	nd
L-61E	nd	22	0.09	nd	nd	nd	nd
L-61W	nd	22	0.09	nd	nd	nd	nd
TCNS (S-191)	116,022	188	0.18	28.4	0.57	94.2	65.8
S-131 Basin	11,992	11	0.15	2.4	0.12	1.9	-0.5
S-133 Basin	30,004	40	0.18	7.3	0.16	7.2	-0.2
S-135 Basin	30,097	28	0.16	6.5	0.1	4.3	-2.2
S-154 Basin	23,428	37	0.18	5.7	0.76	22.8	17
S-2	34,629	166	0.16	7.5	0.18	9	1.5
S-3	13,429	101	0.15	2.7	0.18	3.9	1.1
S-4	40,921	66	0.18	10	0.18	11.1	1.1
S65E – S65	364,526	749	0.18	89.2	0.18	91.5	2.3
S-236	9,716	15	0.09	1.2	0.1	1.5	0.3
Culvert 4A	8,954	7	0.08	1	0.09	1.1	0.2
Culvert 5	nd	28	0.06	nd	nd	nd	nd
Controllable Totals	1,209,967			282.7		403.4	120.7
Uncontrollable Sources							
Rainfall					0.03	71	
S65 (Lake Kissimmee)	1,139,602				0.08	119.4	
Lake Istokpoga (S-68)	342,212				0.04	22.4	
S5A Basin	0					0	
E. Caloosahatchee (S-77)	0					0	
L-8 Basin (Culv 10A)	60,922				0.1	8.3	
Uncontrollable Totals	1,542,737					221	
Average Total Loadings						624.3	
Vollenweider Target						458.7	
Over-Target Loads				Concentration based		120.7	
				Vollenweider		165.7	

Table 2. Current annual average phosphorus loading rates and target annual phosphorus loading rates (based on 5-year rolling average) for each basin based on SWIM concentration targets during the years 1995 to 1999 (nd = no data) (SFWMD 2001).

Basin Controllable Sources	Discharge (acre-ft)/yr	Area (sq. mi)	SWIM Target TP (ppb)	SWIM Target Load (tons/yr)	Actual TP (ppb)	Actual Load (tons/yr)
715 Farms (Culv 12A)	13,679	4	180	3.3	95	1.8
C-40 Basin (S-72) – S68	15,534	87	180	3.8	503	10.6
C-41 Basin (S-71) – S68	52,630	176	180	12.9	433	30.9
S-84 Basin (C41A) – S68	66,211	180	100	9.0	152	13.7
S-308C (St. Lucie-C-44)	22,219	190	180	5.4	197	5.9
East Beach DD (Culvert 10)	14,184	10	180	3.5	616	11.9
East Shore DD (Culvert 12)	15,699	13	130	2.8	162	3.5
Fisheating Creek	249,378	462	180	60.9	176	59.7
Industrial Canal	21,236	23	180	5.2	97	2.8
L-48 Basin (S-127)	31,629	32	180	7.7	231	9.9
L-49 Basin (S-129)	17,157	19	180	4.2	92	2.1
L-59E	nd	15	160	nd	nd	nd
L-59W	nd	15	160	nd	nd	nd
L-60E	nd	6	100	nd	nd	nd
L-60W	nd	6	100	nd	nd	nd
L-61E	nd	22	90	nd	nd	nd
L-61W	nd	22	90	nd	nd	nd
TCNS (S-191)	113,467	188	180	27.7	653	100.6
S-131 Basin	10,815	11	150	2.2	116	1.7
S-133 Basin	28,302	40	180	6.9	183	7.0
S-135 Basin	26,445	28	160	5.7	117	4.2
S-154 Basin	31,885	37	180	7.8	828	35.8
S-2	28,612	166	160	6.2	194	7.5
S-3	12,087	101	150	2.5	215	3.5
S-4	39,872	66	180	9.7	216	11.7
S65E – S65	348,214	749	113	53.4	200	94.7
S-236		15	90	nd	nd	nd
South Shore/South Bay DD (Culvert 4A)	8,840	7	80	1.0	17	0.2
Nicodemus Slough (Culvert 5)	nd	28	60	1.0	nd	nd
Controllable Totals	1,168,122			242.0	265	420.0
Uncontrollable Sources						
Rainfall	1,893,356				0.03	71.0
S65 (Lake Kissimmee)	993,997				0.08	116.3
Lake Istokpoga (S-68)	344,506				0.04	27.3
S5A Basin	0					0.0
E. Caloosahatchee (S-77)	0					0.0
L-8 Basin (Culv 10A)	48,437				0.1	5.5
Uncontrollable Totals						
Average Total Loadings						641.0
Basin Target						463.0
Vollenweider Target						423.0

PHOSPHORUS LOADING SOURCES IN THE WATERSHED

Human activities occurring within the Lake Okeechobee watershed have contributed to the high external phosphorus loading rates. Sources of pollution to the watershed include both point and nonpoint sources.

Point Sources

Several point sources exist in the Lake Okeechobee watershed; however, none of these discharges directly to the lake, and many of the discharges are through wells to the ground water. Point sources include discharges of effluent from domestic and industrial wastewater treatment facilities (Table 3). These discharges require wastewater permits from FDEP that serve as the National Pollutant Discharge Elimination System (NPDES) permit for the facility if it discharges to surface waters. These permits typically include FDEP approved water quality-based effluent limits (WQBEL) or technology-based effluent limits (TBEL) for surface water discharges.

Nonpoint Sources

Nonpoint sources, which are related to different types of land uses and are driven by rainfall and runoff, are the dominant pollution sources in the Lake Okeechobee watershed (Table 3). Agricultural activities surrounding the lake are the principal land uses in the area and are responsible for discharging large quantities of nutrients to the waters within the watershed through stormwater runoff (Anderson and Flaig 1995). Approximately, 50% of the Lake Okeechobee watershed is used for agriculture (Figure 5). Cattle and dairy pasturelands are the primary agricultural activities north and northwest of the lake, while cropland (sugarcane and vegetables) dominates to the south and east of the lake (SFWMD 1989). The most intensive land use in the watershed is dairy farming, which began in the 1950s (Reddy et al. 1995a).

Residential septic tank systems within the watershed are another source of nonpoint source pollution that delivers contaminants (bacteria and toxic household chemicals) and nutrients to Lake Okeechobee (Environmental Science and Engineering 1993).

Other land uses in the watershed consist of Wetlands (16%), Upland Forests (10%), Water (7%), Rangeland (7%), Urban and Built-up (10%), Barren Land (1%), and Transportation and Utilities

(1%) (Figure 5). While urban land uses make up 10% of total area, they only contribute 3% of the total phosphorus load in the watershed (SFWMD 97). Appendix 1 provides a more detailed distribution of land uses, using Level 2 land use for each of the basins in the Lake Okeechobee watershed.

Table 3. Sources of Pollution in the Lake Okeechobee Watershed (SFWMD 1997)

Sources of Pollution	Type	Total Number Permitted
Industrial Wastewater Facilities	Point	69
Domestic Wastewater Facilities (Municipal and Private)	Point	121
Dairies	Nonpoint	29
Works of the District (Agricultural, Industrial, Commercial, NPS BMPs)	Nonpoint	688
Stormwater Runoff Locations Measured by Surface Water Management (Stormwater Management Systems)	Nonpoint	470
Waste Disposal Systems (landfills)	Nonpoint	16

Out-of-Basin Sources

The importation of phosphorus, as feed, fertilizer and detergents, to support various agricultural activities is a major source of phosphorus to the watershed. Ninety-eight percent of the phosphorus imported to the watershed supports agricultural activities, while the remaining two-percent supports human activities. When this is further broken down, fertilizers account for 73% of the amount imported, dairy feed accounts for 16%, while beef feed supplements, human food and detergents account for the remaining 11% (Fluck et al. 1992). Land use activities that are responsible for the largest percentages of annual phosphorus imports to the watershed include improved pasture (47% of total imports), sugar mills (15%), dairies (14%), sugarcane fields (13%) and truck crops (7%) (Fluck et al. 1992). There is a high correlation between phosphorus imports (animal feed and fertilizers) to the watershed and phosphorus loading to the lake (Boggess et al. 1995). Annually, an average of 8% of the net phosphorus imported to the watershed reaches Lake Okeechobee (Fluck et al. 1992). There are also phosphorus sources

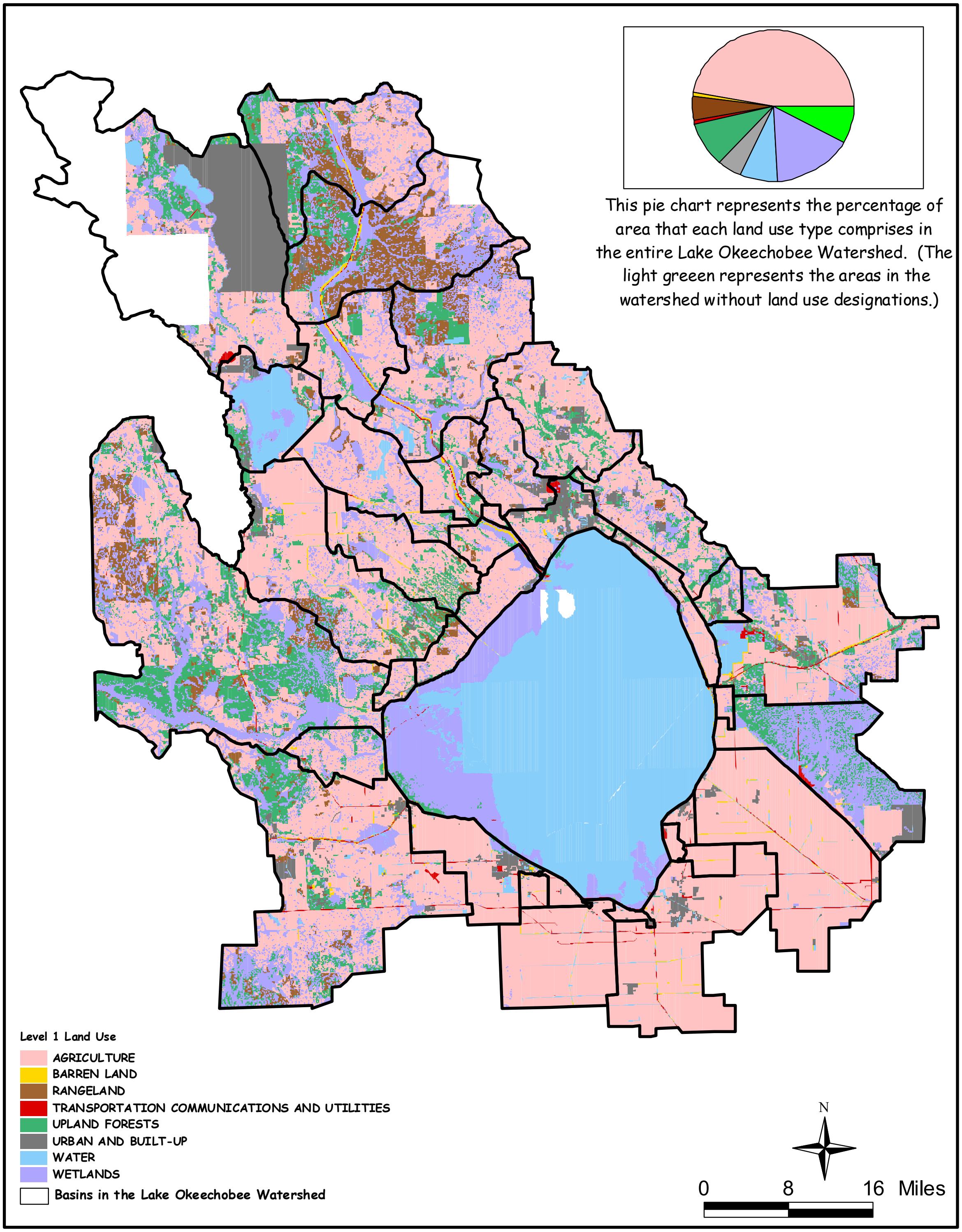


Figure 5. Land Use (Level 1) in the Lake Okeechobee Watershed (SFWMD 1995)

coming into the watershed from the Upper Chain-of-Lakes and Lake Istokpoga. A new phosphorus budget is currently being constructed to reflect more recent trends on phosphorus sources in the watershed; however, it will not be completed for another 18 months.

Atmospheric Loading

Another source of phosphorus loading to Lake Okeechobee is dry and wet atmospheric deposition. Phosphorus loading in South Florida is monitored through the Florida Atmospheric Mercury Study (FAMS). Wet deposition phosphorus loading rates average around 10 mgP/m^2-yr, while dry deposition phosphorus loading rates range from 10 mgP/m^2-yr to 20 mgP/m^2-yr (Pollman 2000). Based on data presented by Curtis Pollman, the Lake Okeechobee Technical Advisory Committee (2000) recommended that 18 mgP/m^2-yr is an appropriate atmospheric loading of phosphorus over the open lake.

FACTORS AFFECTING PHOSPHORUS CONCENTRATIONS IN LAKE OKEECHOBEE

The high phosphorus concentrations in Lake Okeechobee are the result of watershed management activities, lake management activities and in-lake processes (SFWMD 1997). Several of these conditions and activities together exacerbate the phosphorus problems in Lake Okeechobee.

External Loadings

As discussed in previous sections, phosphorus enrichment and the increase in the frequency of high chlorophyll *a* concentrations (algal blooms) are a result of excessive phosphorus loading to Lake Okeechobee from upstream activities in the watershed (Reddy and Flaig 1995). However, reducing external phosphorus loads to the lake according to the SWIM targets will not reduce the in-lake total phosphorus concentration to 40 ppb largely due to the phosphorus currently stored in the lake’s sediments and external sources not controlled under the SFWMD's Works of the District permitting program. In order for the lake to reach the 40 ppb in-lake phosphorus target, additional reductions in phosphorus loading to the lake need to be achieved and/or the phosphorus load in the sediments needs to be controlled in some manner.

High Water Levels

High water levels in the lake have been documented to exacerbate the symptoms of cultural eutrophication (Canfield and Hoyer 1988, Havens 1997). There is a strong correlation between yearly-average total phosphorus concentrations, near-shore algal bloom frequencies, and water levels. Two ecological processes may interactively explain this phenomenon. First, when water levels are high, there is reduced growth of submerged plants in the near-shore zone, and therefore, less competition for phosphorus between plants and phytoplankton. Phytoplankton sequester nearly all of the available nutrients and give rise to blooms. Second, when water levels are high, there is greater transport of phosphorus-rich water from the mid-lake region into the near-shore area by underwater currents. At low lake stages a shallow rock reef that separates the near-shore area from mid-lake prevents this transport. A third mechanism is that littoral flooding results in internal phosphorus loading from dead vegetation. Dierberg (1993) showed this phosphorus load to be of relatively low importance, and that the littoral zone is largely a sink, rather than a source of phosphorus.

Wind Effects

A fourth factor that affects the high total phosphorus concentrations in the water column of the pelagic zone involves wind effects on sediment resuspension. The almost daily wind-driven resuspension of the phosphorus-laden active layer of sediment in the pelagic zone increases phosphorus concentrations in the water column (Havens et al. 1996a). Wind and total phosphorus concentrations have a high correlation (r^2=0.78). The highest sediment resuspension in Lake Okeechobee occurs in the winter (Grimard and Jones 1982, Carrick et al. 1994).

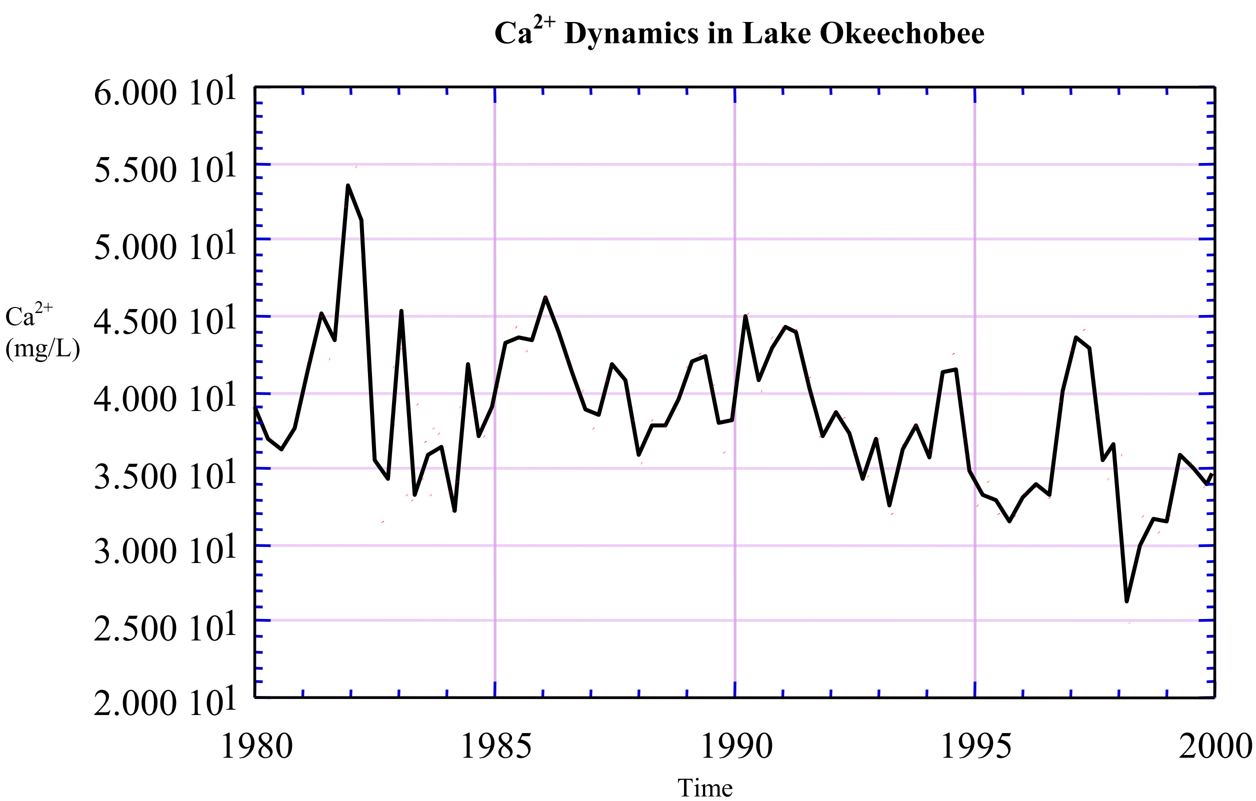
Internal Loadings from Sediment

Another factor involves the internal phosphorus loading from the consolidated organic muds at the center of the lake bottom. Sixty percent of the pelagic bottom is composed of these consolidated organic muds, which store approximately 30,000 metric tons of phosphorus within the upper 10 cm of the mud that have accumulated over the last 75 years. This phosphorus is typically bound to calcium, other organic matter or iron at the sediment surface. The diffusive flux of phosphorus between the sediment surface and water column is controlled by iron solubility (Olila and Reddy 1993). Under reducing conditions (iron is in the form of Fe^{2+}), phosphorus is released at high rates from the sediment active zone into the water column. Under conditions of low dissolved oxygen, the levels of phosphorus in the water column could increase from 50 ppb to over 100 ppb. This condition could contribute to the algal blooms that occur in summer months (Havens et al. 1995). Despite a slight decline in external phosphorus loading in the late 80s and early 90s from the implementation of the FDEP Dairy Rule in 1987, internal phosphorus loading has kept the concentration of total phosphorus in the water column at 90 ppb to 100 ppb since the 1980s (Harvey and Havens 1999). This is a common effect seen in shallow lakes with a long history of excessive external phosphorus inputs (Sas 1989).

Potential Role of Calcium

Over time, Ca^{2+} has been declining in the water column of Lake Okeechobee. From 1980 to 2000, Ca^{2+} has declined by an average of 15 mg/L (Figure 6). Phosphorus tends to bind to calcium forming calcium phosphate (hydroxyapatite), which is a sink for phosphorus. As the amount of Ca^{2+} declines because of the supersaturation of hydroxyapatite, dissolved inorganic phosphorus increases because it is being released back into the water column. Therefore, calcium concentrations are positively correlated with the phosphorus settling rate.

Figure 6. Change in Ca^{2+} over time (Pollman 2000)



Biological Processes

Biological processes also affect the phosphorus dynamics and phosphorus concentrations found in Lake Okeechobee. The biological processes that occur in the lake are complex and produce feedback loops and non-linear responses (Havens and Schelske 2001). Macrophytes affect the phosphorus dynamics by removing phosphorus from the water column through their roots and providing a sink for the phosphorus. The larger the macrophyte population, the larger the sink. Additionally, the roots of macrophytes stabilize the sediments, thereby reducing the resuspension of phosphorus-laden sediments (Vermaat et al. 2000). Lake Okeechobee experiences high levels of turbidity, which are in part a result of a loss of submerged aquatic vegetation from years of high water levels (Havens 1997).

Benthic invertebrates also affect the cycling of phosphorus. Phosphorus can be released into the water column from the sediments through bioturbation and feeding activities of various invertebrates (Van Rees et al. 1996) and benthic feeding fish (Moss et al. 1997). In addition, some macroinvertebrates, such as mussels, are able to remove phosphorus from the watershed through filtration (Nalepa and Fahnenstiel 1995).

Over time, a larger portion of the total phosphorus in the water column has been found in the dissolved form. This dissolved phosphorus is utilized by the phytoplankton. However, from years of high phosphorus loading to the lake, the amount of dissolved phosphorus that is available exceeds the demand, and as a result the dissolved phosphorus in the water column is lost to the sediments. As more phosphorus is incorporated into the sediments, the lake is losing its ability to assimilate phosphorus. Another mechanism of phosphorus loss involves the storage of soluble phosphorus from within the sediment-water interface as polyphosphates in algal cells (Carrick et al. 1993).

HISTORIC AND CURRENT PROGRAMS, GROUPS AND MANAGEMENT PLANS TO ADDRESS WATER QUALITY PROBLEMS IN THE LAKE OKEECHOBEE WATERSHED

Interim Action Plan (IAP)

The Interim Action Plan (IAP) was implemented in 1979 to reduce the nutrient loads coming to Lake Okeechobee from the backpumping of the Everglades Agricultural Area (EAA).

Alternatively, the water from the EAA was to be diverted south into the Water Conservation Areas (WCAs). The goal of IAP was to reduce nitrogen loading to the lake by 90%. The IAP was successful in meeting this goal, which also helped to reduce phosphorus inputs to the lake from the EAA. Water is still occasionally pumped from the EAA to the lake during periods of high rainfall (Harvey and Havens 1999).

Surface Water Improvement and Management (SWIM)

In 1987, the Florida Legislature passed the SWIM Act, Sections 373.451-373.4595, F.S., which required the Water Management Districts (WMDs) to develop plans and programs for the improvement and management of surface waters that have been degraded, altered, or are in danger of being degraded. The SWIM Act required a 40% reduction in phosphorus flowing into Lake Okeechobee to achieve the in-lake phosphorus reduction goal of 40 ppb, based on the South Florida Water Management District's Technical Publication 81-2, by July 1992. According to the 1989 Interim Lake Okeechobee SWIM Plan, all inflows to the lake are required to meet total phosphorus concentrations of 180 ppb or lower. Tables 1 and 2 depict the total phosphorus concentration targets established for each basin.

Lake Okeechobee Technical Advisory Council II (LOTAC II)

LOTAC II was created by the Florida Legislature through the SWIM Act of 1987 with the purpose of investigating the adverse affects of past diversions of water and the potential effects of future diversions on indigenous wildlife and vegetation within the environmentally sensitive areas surrounding Lake Okeechobee. The council reported to the Legislature by March 1, 1988 with findings and recommendations of permanent solutions to eliminate the adverse effects. This investigation included the St. Lucie and Caloosahatchee watersheds and Everglades National Park (LOTAC II 1988).

Works of the District (WOD) Permitting Program

To achieve the reduction goals established in the SWIM Plan, the SFWMD adopted the Works of the District (WOD) Permitting Program (Rule 40E-61). This program established a permitting process for non-dairy land uses within the Lake Okeechobee watershed and established discharge limits for runoff from different land uses based on the in-lake phosphorus target of 40 ppb

(SFWMD 1989). For example, the total phosphorus concentration limit for improved cattle pasture is 350 ppb. The SFWMD works with landowners to help them meet their discharge limits by identifying best management practices (BMPs) or other measures to reduce the total phosphorus concentration in runoff. Figure 7 illustrates the WOD permit locations.

FDEP Dairy Rule and Dairy Buy-Out Program

In 1987, the FDEP adopted Chapter 62-670 to establish treatment requirements to reduce total phosphorus concentrations in runoff coming from animal feeding operations and dairy farms in the Lake Okeechobee watershed. Waste treatment systems were to be constructed to treat runoff and wastewater from barns and high-intesity milk herd holding areas. According to the rule, all 49 dairies in the Lake Okeechobee drainage basin had to sell and remove their cattle or else comply with the rule by 1991. The Dairy Buy-Out Program allowed owners of dairies to sell their dairy if they were unable or unwilling to comply with the FDEP Dairy Rule. In 1997, 23 dairies were eliminated, while 26 came into compliance due to the Dairy Rule, Dairy Buy-Out Program and the Save Our Rivers Program.

Taylor Creek Headwaters Project and Taylor Creek Nubbin Slough (TCNS) Rural Clean Waters Program (RCWP)

A variety of best management practices (BMPs) were implemented to reduce phosphorus loading from the Taylor Creek and Nubbin Slough basins. These BMPs included fencing cows away from streams, animal wastewater disposal on croplands, and utilization of wetlands for nutrient removal. More detailed information on the BMPs is available in Anderson and Flaig (1995).

Lake Okeechobee Action Plan

The Lake Okeechobee Issue Team, formed by the South Florida Ecosystem Restoration Working Group, a multi-agency group working on South Florida environmental issues, was formed in 1998 to develop an Action Plan to protect and enhance the ecological and societal values of Lake

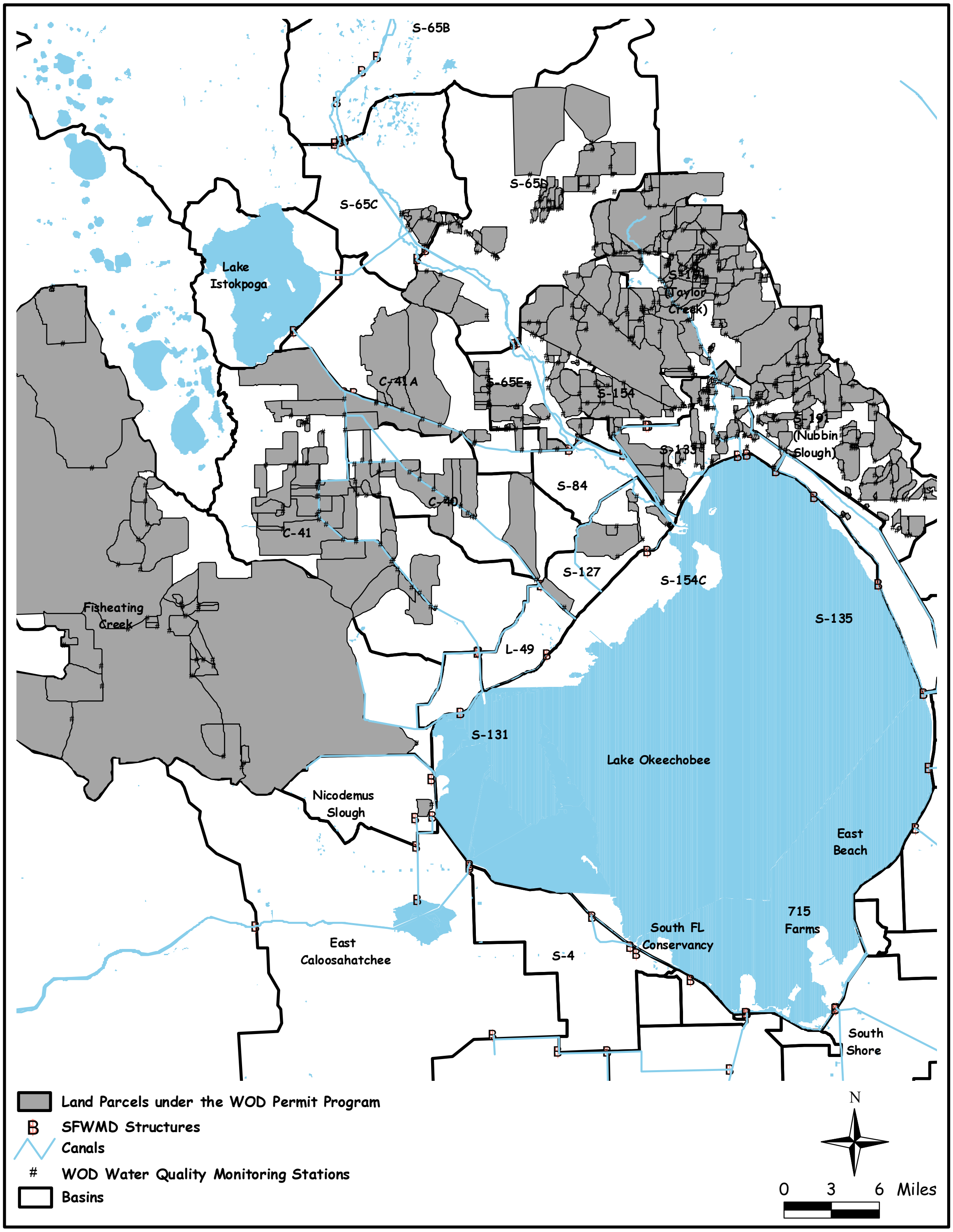


Figure 7. Works of the district (WOD) permits and monitoring locations

Okeechobee. The primary focus of the Action Plan (Harvey and Havens 1999) was to reduce in-lake phosphorus concentrations to 40 ppb (the target established by the SWIM Plan). The Action Plan provides strategies and options for reducing phosphorus inputs to Lake Okeechobee from its surrounding watershed. It also provides a summary of current on-going and projected future projects that could reduce phosphorus loading in the watershed. These projects include the construction of reservoir assisted stormwater treatment areas (RASTAs) to attenuate peak flows, development of a phosphorus budget for the watershed, reclamation of isolated wetlands, elimination of importing residuals into the watershed, analysis for and implementation of additional measures for phosphorus controls, and implementation of a sediment removal feasibility study.

Lake Okeechobee TMDL Technical Advisory Committee

In February of 2000, the department established the Lake Okeechobee TMDL technical advisory committee (TAC) to provide scientific input to assist in the development of a phosphorus TMDL for Lake Okeechobee. Discussion included the appropriate in-lake phosphorus concentration target, biotic responses to phosphorus loading, the in-lake cycling of phosphorus with emphasis on the role of sediments in phosphorus cycling, tools currently available for modeling the Lake Okeechobee system, and the formulation of a method for determining allowable phosphorus loading to the lake. The eight member TAC met seven times over the year. The TAC determined that the restoration target would be 40 ppb for the pelagic zone of the lake. It is assumed that the littoral zone would be protected with this restoration target for the pelagic zone.

Lake Okeechobee Protection Program (Section 373.4595, F.S.)

The Lake Okeechobee Protection Program provides a plan for restoring and protecting Lake Okeechobee using a watershed-based approach to reduce phosphorus loadings to the lake and downstream receiving waters. The Legislature intends for this section and s. 403.067, F.S., to provide a reasonable means of achieving and maintaining compliance with state water quality standards in Lake Okeechobee. The act outlines several plans and projects that are to be implemented to restore Lake Okeechobee. The first is the development and implementation of the Lake Okeechobee Protection Plan by January 1, 2004, which will address the reduction of phosphorus loads to Lake Okeechobee from both internal and external sources using a phased program of implementation. The initial phase of phosphorus load reductions will be based on the South Florida Water Management District's (SFWMD) Technical Publication 81-2 and the SFWMD's WOD program. Subsequent phases of phosphorus load reductions will be based on the TMDL established in accordance with s. 403.067, F.S. Components of the Lake Okeechobee Protection Plan to reduce phosphorus loads to the lake are outlined below.

- <u>Lake Okeechobee Construction Project</u>
  The purpose of the Lake Okeechobee Construction Project is to improve the hydrology and water quality of Lake Okeechobee and downstream receiving waters. Phase I of the construction project includes the design and construction of the Grassy Island Ranch and New Palm Dairy stormwater treatment facilities and two of the isolated wetland restoration projects as components of the Lake Okeechobee Water Retention/Phosphorus Removal Critical Project. Additionally, by January 31, 2002, the SFWMD shall design and complete implementation of the Lake Okeechobee Tributary Sediment Removal Pilot Project. The fourth component of Phase I includes initiating the design process for the Taylor Creek/Nubbin Slough Reservoir Assisted Stormwater Treatment Area. Phase II includes the development of an implementation plan for the Lake Okeechobee Construction Project. The implementation plan will identify the Lake Okeechobee Construction Projects to be constructed, identify size and location, provide a construction schedule, provide a land acquisition schedule, provide a detailed schedule of costs, and identify impacts on wetlands and state-listed species expected to be associated with construction of these projects.
- <u>Lake Okeechobee Watershed Phosphorus Control Program</u>
  The Lake Okeechobee Watershed Phosphorus Control Program is designed to be a multifaceted approach to reducing phosphorus loads by improving the management of phosphorus sources within the Lake Okeechobee watershed through continued implementation of existing regulations and best management practices (BMPs), development and implementation of improved BMPs, improvement and restoration of the hydrologic function of natural and managed systems, and utilization of alternative technologies for nutrient reduction. This section includes the development of an interagency agreement for the development and evaluation of agricultural and nonagricultural BMPs by March of 2001. It also includes rule development by FDACS for interim measures, BMPs, conservation plans, nutrient management plans, or other measures necessary for Lake Okeechobee

phosphorus load reduction. The program also addresses nonagricultural nonpoint source BMPs. By January 2001, FDEP is to develop interim measures, BMPs or other measures necessary for Lake Okeechobee phosphorus load reduction resulting from nonagricultural nonpoint sources. Other components of the program include the development and submission of agricultural use plans from entities disposing domestic wastewater residuals and rulemaking for conservation or nutrient management plans of animal manure application.

- Lake Okeechobee Research and Water Quality Monitoring Program
  By January 2001, the Lake Okeechobee Research and Water Quality Monitoring Program is to be established by the SFWMD. The program requires that all total phosphorus data be evaluated to develop a water quality baseline of existing conditions in Lake Okeechobee. The program also includes 1) the development of a Lake Okeechobee water quality model that represents phosphorus dynamics of the lake, 2) the determination of the relative contribution of phosphorus from all identifiable sources and all primary and secondary land uses, 3) an assessment of the sources of phosphorus from the Upper Kissimmee Chain-of-Lakes and Lake Istokpoga and their relative contribution to the water quality of Lake Okeechobee, 4) an assessment of current water management practices within the Lake Okeechobee watershed and develop recommendations for structural and operational improvements, 5) and an evaluation of the feasibility of alternative nutrient reduction technologies.
- Lake Okeechobee Exotic Species Control Program
  This program requires the coordinating agencies to identify the exotic species that threaten the native flora and fauna within the Lake Okeechobee watershed and develop and implement measures to protect the native flora and fauna by June 1, 2002.
- Lake Okeechobee Internal Phosphorus Management Program
  By July 1, 2003, in cooperation with coordinating agencies and interested parties, the SFWMD is to complete a Lake Okeechobee internal phosphorus load removal feasibility study. If any removal methods are found to be technically and economically feasible, then the SFWMD will immediately pursue the design, funding and permitting for implementing the removal method.

- Annual Progress Report

  Every January 1, beginning on January 1, 2001, the SFWMD shall submit to the Governor, the President of the Senate, and the Speaker of the House of Representatives annual progress reports regarding implementation of this section, s. 373.4595, F.S. The annual progress report will include a summary of water quality and habitat conditions in Lake Okeechobee and its surrounding watershed, and an update on the status of the Lake Okeechobee Construction Project.

- Lake Okeechobee Protection Permits

  This section of the legislation requires that all structures discharging into or from Lake Okeechobee must obtain permits. All permits obtained through the act will be in lieu of other permits under chapter 373 and chapter 403, except for 403.0885, F.S. Owners and operators that have existing structures that discharge into and from the lake are required to apply for 5-year permits to operate and maintain such structures within 90 days of completion of the diversion plans set forth in FDEP's Consent Orders 91-0694, 91-0707, 91-0706, 91-0705, and RT50-205564. As of September 1, 2000, owners or operators of all other existing structures, which discharge into or from the lake are required to apply for 5-year permits from FDEP to operate and maintain the structures. By January 1, 2004, the SFWMD shall submit to FDEP a permit modification to the Lake Okeechobee structure permits to incorporate any changes needed to achieve state water quality standards, including the TMDL established in accordance with s. 403.067, F.S.

Section 403.067, F.S. Establishment and Implementation of Total Maximum Daily Loads (TMDLs)

Section 403.067, F.S. provides the framework for how the state will approach developing TMDLs. The legislation instructs FDEP to adopt by rule a methodology for determining those waters that are impaired and provides guidance for the calculation, allocation and implementation of a TMDL. The total maximum daily load calculations for each water body or water body segment are to be adopted by rule by the secretary pursuant to ss. 120.536(1), 120.54 and 403.805. Section 403.067 recognizes Lake Okeechobee as impaired without using the methodology that the state is going to use to determine impairment. This is significant, as this methodology is currently undergoing rulemaking.

AVAILABLE AMBIENT MONITORING DATA

Since the late 1960s, water quality has been monitored in Lake Okeechobee by many agencies, including the South Florida Water Management District (SFWMD), Florida Department of Environmental Protection (FDEP), United States Army Corps of Engineers (USACE), United States Environmental Protection Agency (USEPA), county governments, universities, and private organizations. The SFWMD has been the primary agency responsible for continuous monitoring in Lake Okeechobee since the early 1970s. The SFWMD monitoring stations are shown in Figure 8. Constituents monitored at these stations vary among physical parameters, nutrients, metals, and select biotic communities. Additionally, monitoring is conducted at most inflows and outflows to the lakes at the structures. Data from near-shore stations were used to establish the in-lake total phosphorus concentration goal of 40 ppb. Stations L001 to L008 within the pelagic zone of the lake are being used to monitor the in-lake phosphorus concentration. The near-shore stations were used in the Walker and Pollman models to develop the TMDL.

TOTAL MAXIMUM DAILY LOAD (TMDL) DEVELOPMENT

In-lake Phosphorus Concentration Target

In order to establish or calculate a Total Maximum Daily Load (TMDL), a waterbody specific concentration target is established, above which the waterbody is unable to meet its designated uses. In the case of Lake Okeechobee, that target was determined to be 40 ppb for total phosphorus in the pelagic zone of the lake. The target was developed using chlorophyll *a* as an indicator of algal biomass, which in turn acts as a surrogate for indicating excessive nutrient concentrations. Based on several published journal articles, algal blooms (chlorophyll *a* concentrations greater than 40 *u*g/l (Havens et al. 1995, Walker and Havens 1995)) occur as a result of excessive phosphorus levels in the lake. These algal blooms pose a significant threat to many of the uses of the lake including drinking water, habitat, nesting, fishing and swimming.

Total phosphorus and chlorophyll *a* concentrations are found to be highly correlated in the near-shore areas to the south and north/west (Walker and Havens 1995). In the south littoral and the pelagic zones, the frequency of algal blooms greatly increased when mean phosphorus

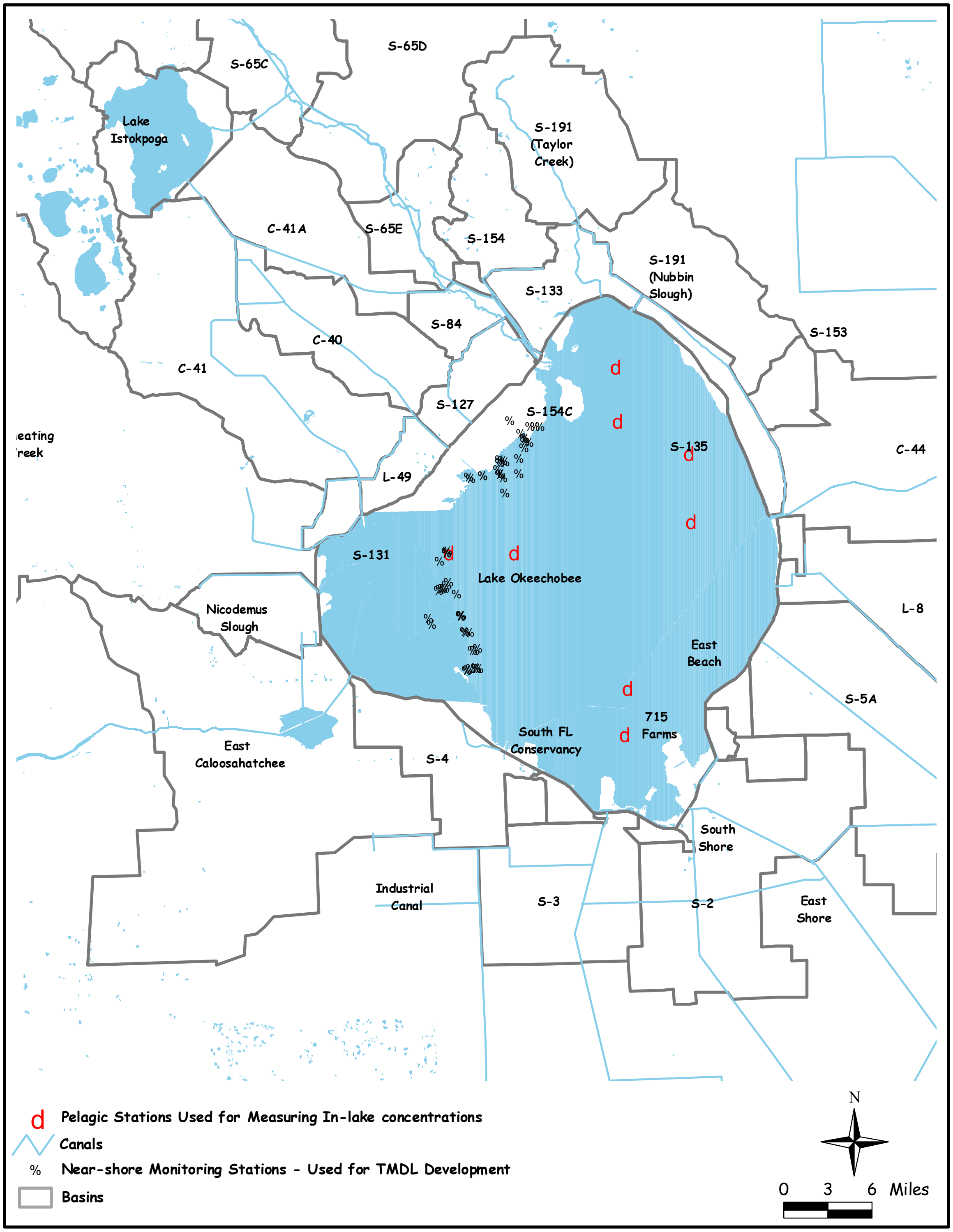


Figure 8. SFWMD Station and Structure Locations in Lake Okeechobee

concentrations exceeded 40 ppb. When total phosphorus is less than 30 ppb, bloom conditions are rare, however, between 30 ppb and 60 ppb total phosphorus, the frequency of blooms steeply increases (Walker and Havens 1995). Figure 9 illustrates the change in algal bloom frequency versus change in mean phosphorus concentrations for three areas of the lake.

Additional studies also suggest a restoration target around 40 ppb. In Havens and James (1997), the existing South Florida Water Management District (SFWMD) concentration target was evaluated considering historical "pre-impact" phosphorus concentration data and the heterogeneity of algal responses to in-lake phosphorus concentrations. Based on this study, the total phosphorus concentration target to return the lake to a less-impacted condition was found to be between 26 ppb and 92 ppb. However, on closer inspection of this range, the Lake Okeechobee Issue Team and the TMDL Technical Advisory Committee noted that values towards the mid-point (30 to 50 ppb) were the most appropriate from a scientific standpoint. In another study, James and Havens (1996) conducted a regression analysis to derive a total phosphorus concentration goal to achieve a desired algal bloom frequency. From this study, the regression model provided a near-littoral zone total phosphorus concentration goal of between 36 ppb and 52 ppb. Another regression model generated by using the historic low chlorophyll *a* concentration produced a total phosphorus concentration goal of between 40 ppb to 75 ppb (r^2=0.88, α<0.05).

The total phosphorus concentration target produced by these different analysis methods all encompass the 40 ppb concentration target. The Lake Okeechobee TMDL Technical Advisory Committee, after considering information regarding the 40 ppb concentration target (including what is discussed above) also supports a phosphorus concentration of 40 ppb in the pelagic zone of the lake. The 40 ppb goal for the entire pelagic region is considered to be a conservative goal that introduces a margin of safety into the TMDL. This reflects the fact that under high lake stage conditions, total phosphorus concentrations are relatively homogeneous across the open-water region, but when lake stages are low, the near-shore area displays considerably lower total phosphorus than the open water zone. Hence, if 40 ppb is met at the eight pelagic stations (which represent the mid-lake) we can expect total phosphorus concentrations of below 40 ppb in the near-shore during certain years.

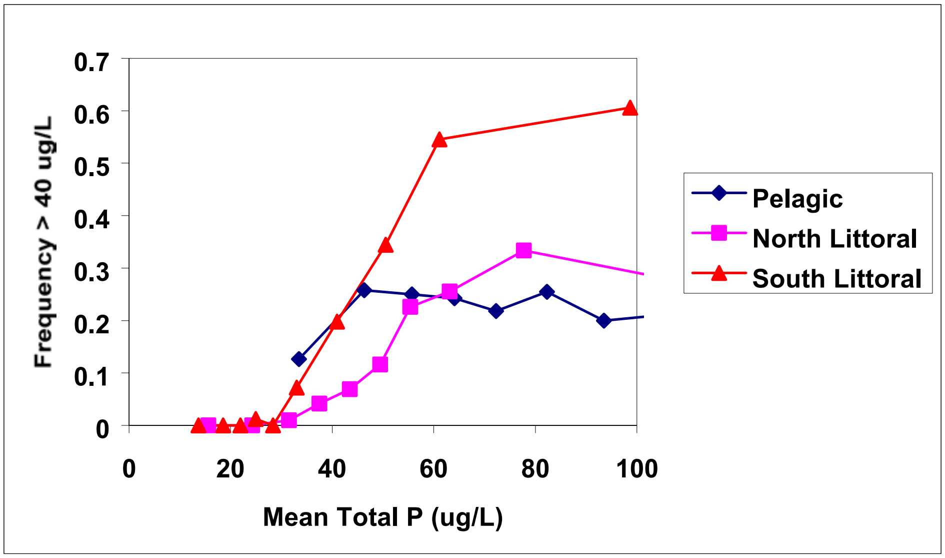


Figure 9. Mean total phosphorus versus of algal blooms over 40 µg/L (Walker and Havens 1995)

Calculation

The total annual phosphorus load to Lake Okeechobee that will meet the in-lake target restoration goal of 40 ppb in the pelagic zone (based on water quality stations L001 – L008) is 140 tonnes, including atmospheric deposition, which accounts for 35 tonnes/yr. The attainment of the TMDL will be calculated using a 5-year rolling average using the monthly loads calculated from measured flow and concentration values. This load was determined using the results from two different models presented to FDEP from the Lake Okeechobee TMDL Technical Advisory Committee. The models are discussed in Appendix 2 and 3. The TMDL is defined as follows:

$$\text{TMDL} = \sum \text{Point Sources} + \sum \text{Nonpoint Sources} + \text{Margin of Safety}$$

$$\text{TMDL} = 140 \text{ metric tons/yr}$$

Load Allocation

This load will be allocated to the sum of all nonpoint sources. For this TMDL, all existing direct inflows into Lake Okeechobee are considered to be nonpoint sources (Figure 10). This includes the phosphorus load from atmospheric deposition, which is currently estimated at 35 metric tons/year. No portion of the TMDL will be allocated to point sources. Currently, there are no point sources to the lake. See Appendix 2 for more information on phosphorus loads from rainfall. Future allocations may be revised based on new research and data as they become available (refer to the implementation section). From the equation above:

∑Point Sources = 0

∑Nonpoint Sources = 140 (atmospheric deposition will be accounted for in this section)

Margin of Safety = implicit by using conservative parameters

Critical Condition Determination

This TMDL establishes the maximum annual load for phosphorus for Lake Okeechobee. The models include and represent critical conditions by utilizing a 26-year data set. Using a broad time frame as in this case allows the range of flow and meteorological conditions that can occur in Lake Okeechobee to be considered.

Margin of Safety (MOS)

A margin of safety (MOS) is required as part of a TMDL in recognition that there are many uncertainties in scientific and technical understanding of the chemical and biological processes that occur in Lake Okeechobee. The MOS is intended to account for such uncertainties in a conservative manner that protects the environment. According to EPA's guidance, a MOS can be achieved through reserving a portion of the load for the future, or using conservative assumptions in calculating the load. In the case of Lake Okeechobee, the MOS is accounted for by using a conservative estimate for the in-lake total phosphorus concentration target of 40 ppb. A specific load is not reserved for the margin of safety (See Section on In-lake Phosphorus Concentration Target).

Seasonal Variation

Long-term (26 year) data for flow and total phosphorus concentrations used in the modeling process account for interannual and long-term variations that have occurred within Lake Okeechobee. Also, variations in flow are accounted for in the expression of the TMDL as an annual flow weighted average over several years.

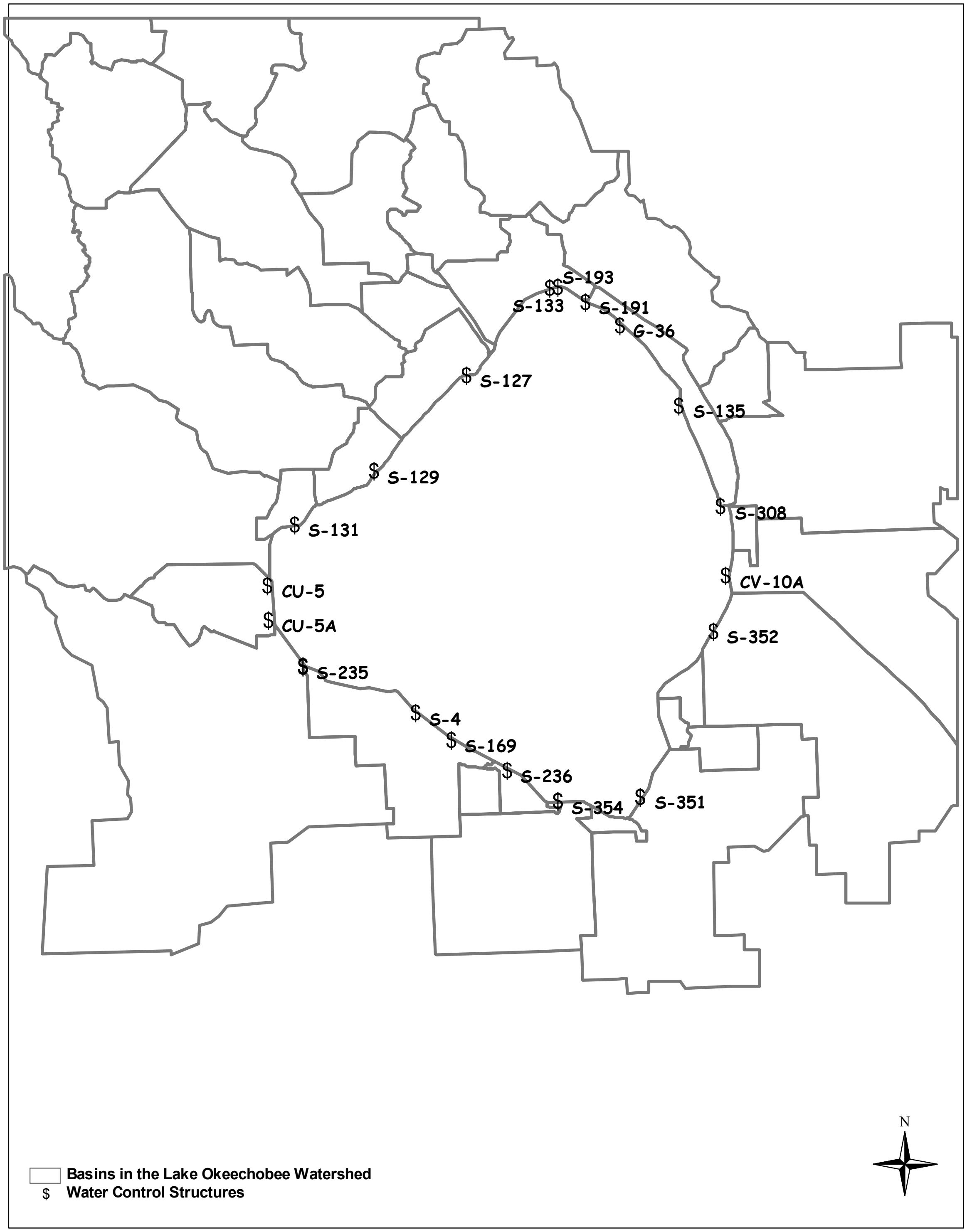


Figure 10. Location of Structures in the Lake Okeechobee Watershed

IMPLEMENTATION PLAN

In order to achieve phosphorus reductions necessary to meet the TMDL for Lake Okeechobee, the state will implement a phased approach. Phased implementation is necessary because the processes involving phosphorus cycling in Lake Okeechobee and the surrounding watershed are not fully understood. The phosphorus dynamics within Lake Okeechobee sediments are also not fully understood, except that the contribution of phosphorus from the sediments to the water column is significant. As a result, predictive modeling for the recovery of the lake uses conservative assumptions because the degree of uncertainty cannot be precisely quantified until more data become available. Additionally, limited information exists on the nature of nonpoint source stormwater runoff, including the performance of phosphorus removal techniques based on Best Management Practices (BMPs) and Reservoir Assisted Storage Treatment Areas (RASTAs), and thus only estimates of phosphorus removal can be made. Even with the above uncertainties, it is imperative that the state moves forward with phased water quality management activities to restore the water quality and ecology of Lake Okeechobee. The phased TMDL allows progress to be checked against measurable interim targets. This process will include monitoring and re-assessing the TMDL within five years, as more information becomes available to ensure attainment of water quality standards (USEPA 1991). For example, we may observe a faster recovery of the lake than anticipated, and perhaps an increase in phosphorus assimilative capacity, if past biological trends associated with eutrophication (e.g., blue-green and oligochaete dominance) are reversed. This might lead to adjustment of the TMDL. This phased implementation will be consistent with the phased management activities outlined in section 373.4595, F.S., relating to the restoration of Lake Okeechobee.

The implementation of the Lake Okeechobee TMDL will occur in three phases.

<u>Phase I</u>

The first phase includes immediately initiating activities within the Lake Okeechobee watershed to achieve the phosphorus load reductions as set forth in the South Florida Water Management District's Technical Pub 81-2, which is consistent with recommendations from the Legislature. Technical Pub 81-2 and the SWIM plan, recommends a 40 ppb in-lake phosphorus goal, which was then used to calculate, based on a simplified flow-based water quality model (modified Vollenweider (1975)), an acceptable load of phosphorus to the lake. This first phase will include identifying agricultural and nonagricultural nonpoint sources, evaluating existing program, controls and strategies, developing interim measures and BMPs, and implementing BMPs as part of the Lake Okeechobee Watershed Phosphorus Control Program. Additionally, this phase will be a planning and data gathering period for the construction of large RASTAs and isolated wetlands restoration projects, which are projects being conducted in conjunction with the Comprehensive Everglades Restoration Program (CERP). The design goal of the RASTAs is to treat inflows to an effluent phosphorus concentration of 40 ppb. The priority basins targeted for these construction projects include S-191 (Taylor Creek/Nubbin Slough), S-154, and Pools D and E of the Lower Kissimmee River (Figure 11). These basins are considered the priority basins because they are contributing some of the highest loads of phosphorus to Lake Okeechobee and they have particularly high concentrations of phosphorus in their waters. Using this phased approach allows time for construction, designs, water quality evaluations, feasibility studies and other studies described in the legislation.

<u>Phase II</u>

In 2004, the phosphorus reductions achieved in Phase I will be evaluated. Additional phosphorus reduction in the watershed will follow management activities outlined in the Lake Okeechobee Protection Plan that is to be completed by 2004 (section 373.4595, F.S.) to achieve the phosphorus TMDL for the lake of 140 metric tons. At this point, the initial assessment and planning of the Lake Okeechobee Construction Project and the Lake Okeechobee Watershed Phosphorus Control Program should be completed. The information from the assessment and planning activities will guide future management activities, including the actual construction of large-scale construction projects (RASTAs and other treatment wetlands) and implementation of additional BMPs. In addition, the TMDL will be reevaluated by 2006.

<u>Phase III</u>

In 2010 - 2020, the current planned construction projects and management activities will have been completed and implemented. Phosphorus reductions and monitoring will be evaluated and compared to the water quality target (40 ppb in-lake concentration target in the pelagic zone). The TMDL numeric target will be re-calculated if the current phosphorus reduction target is not adequate to meet the water quality restoration goal (40 ppb in-lake total phosphorus concentration). Future construction projects and other management activities will be determined from the results of the construction projects, BMPs implemented and other management activities that have been implemented.

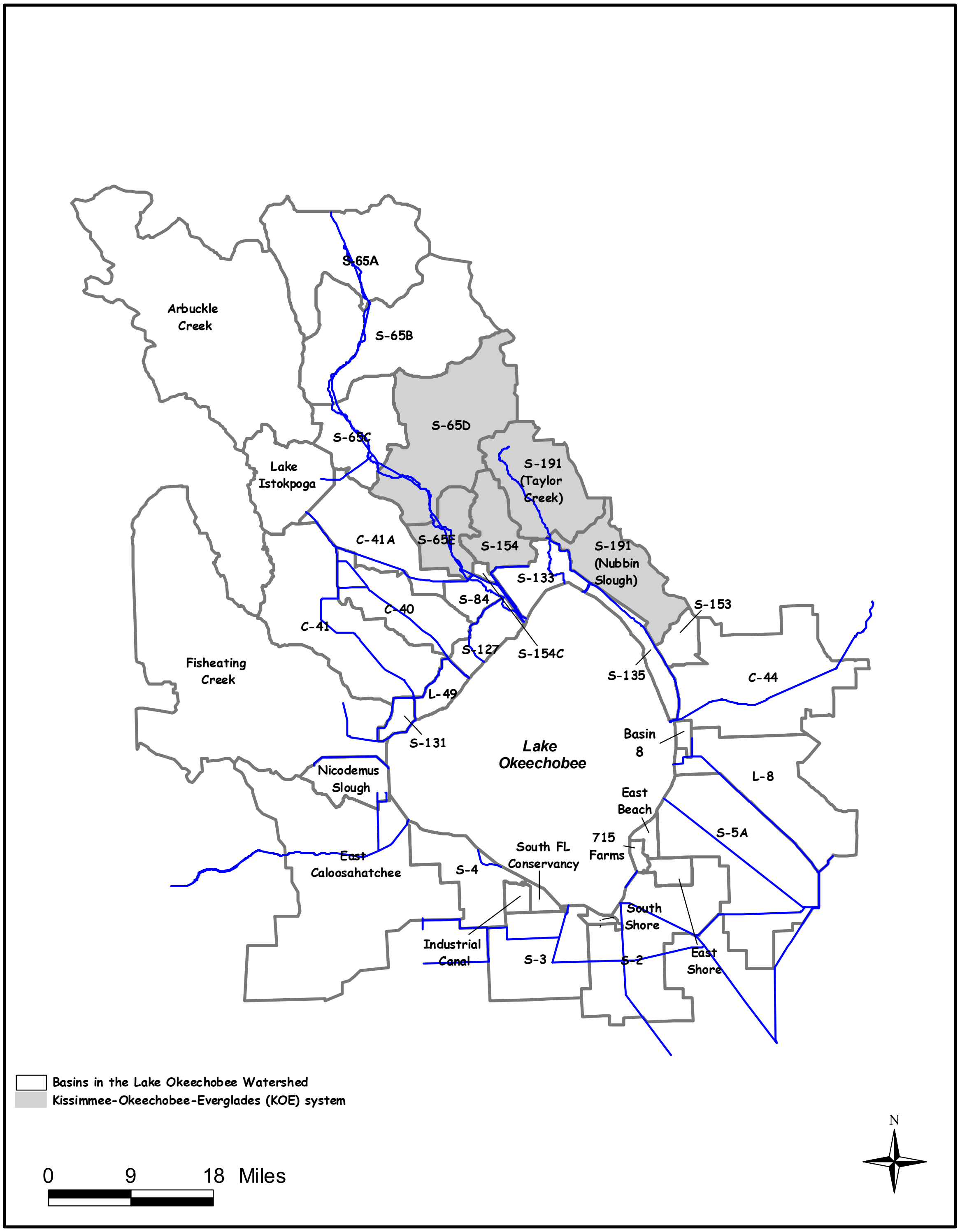


Figure 11. Priority Basins within the Lake Okeechobee Watershed

PUBLIC PARTICIPATION

Public participation was a major focus in the development of the Lake Okeechobee phosphorus TMDL. Within the Lake Okeechobee watershed, there is growing consensus among the stakeholders for immediate implementation of effective control measures. This kind of agreement and cooperation, directed at expeditious action, is essential if Lake Okeechobee is to be restored. Restoration of Lake Okeechobee will require unprecedented cooperation between the public and private sector. The FDEP felt that this cooperation should begin in the initial stages of TMDL development.

During the TMDL development process, eight technical advisory committee (TAC) meetings were held, in which the public was invited to provide input. These meetings were held on 2/15/00, 3/15/00-3/16/00, 4/6/00, 5/3/00, 5/31/00, 6/22/00, 8/1/00, and 10/7/00. The minutes to these minutes are provided in Appendix 4. Additionally, FDEP solicited comments on the Draft TMDL document during September of 2000. These comments are provided in Appendix 5.

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