White Paper

Caloosahatchee River/Estuary Nutrient Issues

Prepared for the

South Florida Water Management District

3301 Gun Club Road
West Palm Beach, Florida 33406

October 10, 2005

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Executive Summary

The Caloosahatchee River/Estuary drains a watershed in southwest Florida extending from Lake Okeechobee on the east to the Gulf of Mexico on the west. The river/estuary system has been altered by agricultural and urban development during the past 120 years and is challenged by a variety of water quality problems, including altered salinity, elevated nutrients, and seasonal flow shifts. These altered conditions result in an increasingly visible impact on the natural flora and fauna of the aquatic ecosystems and have affected traditional human uses of the river and estuary. This white paper briefly summarizes the large body of existing information about the Caloosahatchee River/Estuary with a particular focus on nutrient issues. The purpose of this summarization is to provide a convenient reference document for decision-makers who will be convening over the next year to help resolve some of the most pressing environmental problems in the basin.

Water quality and quantity have been altered in the Caloosahatchee Basin since historic times. Canalization of the Caloosahatchee River (C-43 Canal) has increased flood events and reduced dry season flows. Regulatory releases from Lake Okeechobee upstream periodically dump large freshwater volumes and associated nutrients into the Caloosahatchee River and Estuary. As human land uses in the watershed become more intense, both in agricultural production and for urban development, there are concerns that ambient concentrations and mass loads of both nitrogen and phosphorus have been increasing. Algal blooms in the estuary, massive accumulations of drift algae, and the geographic extent of red tides off shore have all apparently increased in recent years. Salinity changes have displaced key submerged aquatic plant species and the fauna those plants typically support.

Decreased flows during the wet season and increased freshwater flows during the dry season are the target of the proposed C-43 Basin Storage Reservoir project as part of the Comprehensive Everglades Restoration Plan (CERP). Nutrient load reductions resulting from the project will be accomplished through flow reductions. Historically, nutrient load reductions have been accomplished through control of point sources with relatively high concentrations and low discharge volume. Here the reduction is accomplished primarily by decreasing loads that are primarily a function of high discharge with a low concentration. However, existing research has indicated that additional nutrient controls are needed in addition to control of timing of fresh water flows to help fully restore the Caloosahatchee aquatic ecosystem. A variety of agricultural and urban best management practices (BMPs) are potentially available to help reverse the apparent increasing nutrient loading rate trends. In addition point sources (stormwater and municipal wastewater) can be further polished to reduce their contributions to anthropogenic nutrient loads to the estuary. It will take a variety of technical solutions as well as serious political and economic will power to reverse the increasingly-evident nutrient associated impacts to the Caloosahatchee ecosystem.

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Acknowledgements

This Caloosahatchee River / Estuary Nutrient Issues White Paper was prepared by Wetland Solutions, Inc. for the South Florida Water Management District. Robert Knight, Ph.D. and Jessica Steele, M.A. of Wetland Solutions, Inc. co-authored the White Paper. Carla N. Palmer, P.E., Stormwater Management Division Director for the South Florida Water Management District, managed and co-edited the project. Gary Goforth, Ph. D., P.E., edited and collaborated on the White Paper. Special thanks to Peter Doering, Ph.D., Robert Chamberlain, Ph.D., and Darren Rumbold, Ph.D., of the SFWMD for providing guidance and assistance for scientific references for the White Paper.

Introduction

The Caloosahatchee River (C-43 Canal) and Caloosahatchee Estuary are located on the southwest coast of Florida and provide drainage from about 3,625 square kilometers [km^2] (1,400 square miles, mi^2), extending from Lake Okeechobee at the northeast extent of the watershed to the Gulf of Mexico on the southwest (**Figure 1**).

In pre-development times, the Caloosahatchee River was a smaller, meandering river originating at the west end of Lake Flirt and extending to Beautiful Island in Ft. Myers. East of Lake Flirt, there was only sawgrass marsh extending to Lake Okeechobee with evidence of Indian canoe trails. The area was subject to prolonged flooding, and cattle ranching was the primary human land use in the basin. Intensive agriculture was not a major land use in the watershed until large scale drainage projects were constructed, beginning with the Disston Canal in the 1880's; additional channelization and construction of the combination lock and dam structures at Moore Haven (S-77) and Ortona (S-78) in 1937; and continuing with final widening and construction of the C-43 Canal in the 1950's and completion of the Franklin Lock and Dam (S-79) in 1966 (Flaig and Capece 1998).

The Caloosahatchee River (C-43 Canal) currently extends about 68 kilometers [km] (42 miles) from Lake Okeechobee to S-79. The final downstream structure on C-43, S-79, defines the beginning of the Caloosahatchee Estuary. The Caloosahatchee Estuary extends for about 42 km (26 miles) to Shell Point, adjacent to San Carlos Bay, Pine Island Sound, Charlotte Harbor to the northwest, and Estero Bay to the southeast. The open waters of the Gulf of Mexico are located just outside of San Carlos Bay south and west of Sanibel Island.

Construction of the C-43 Canal, agricultural development of the watershed enhanced by the availability of irrigation water from the C-43 Canal, urban development in the Ft. Myers/Cape Coral area, and regulatory releases of freshwater from Lake Okeechobee have been linked to significant water quality changes in the Caloosahatchee Estuary (Flaig and Capece 1998; Chamberlain and Doering 1998; Barnes *et al.* 2004; ERD 2003; FDEP 2003). Water quality parameters of concern in the Caloosahatchee Estuary include salinity, nutrients, turbidity, trace organics, and metals.

Problems associated with water quality and quantity changes in the Caloosahatchee River/Estuary have become a focus of environmental restoration efforts in southwest Florida. Timing and delivery of freshwater releases from Lake Okeechobee have been implicated in a variety of salinity-related stresses in the Caloosahatchee Estuary. Anomalous salinity conditions have resulted in changes in populations of submerged aquatic vegetation, oysters, and other estuarine life forms. Nutrient load increases to the river and estuary have been associated with excessive growth of floating aquatic plants, planktonic algae, and marine algae. Off-shore impacts have even been noted with claims of increased occurrences of red tide toxic algae.

Numerous projects, initiatives, and programs have been instituted with the express purpose of achieving this environmental restoration. The Comprehensive Everglades Restoration Plan (CERP) has focused a significant amount of attention on the Caloosahatchee

River/Estuary through the C-43 Basin Storage Reservoir project (USACE and SFWMD, in prep). Non-CERP programs will also be important to achieve eventual reductions in salinity and nutrient impacts. Representative projects include: 1) USACE & SFWMD Revised Lake Okeechobee Regulation Schedule (SFWMD, USACE, and FDEP no date); 2) SFWMD Lake Okeechobee Protection Plan; 3) FDEP Lake Okeechobee Total Maximum Daily Loads (TMDLs); 4) SFWMD Caloosahatchee Minimum Flows and levels (MFLs); 5) SFWMD Caloosahatchee River Water Management Plan; 6) FDEP Caloosahatchee Basin TMDL; 7) Florida Department of Agriculture and Consumer Services (FDACS)/FDEP Agricultural BMP Program for the Caloosahatchee Basin; 8) SFWMD Urban Irrigation and Landscape BMP Implementation Projects; 9) SFWMD Stormwater Management Regulations; and 10) Lee and Hendry Counties Stormwater Management Projects. Many of those programs have been developed through exhaustive studies of the Caloosahatchee River/Estuary and many of these studies were reviewed and summarized to prepare this white paper (**Appendix A**). Additional studies that describe the effects of nutrients in similar water bodies were also reviewed and are described in **Appendix B**.

The process of ecosystem recovery is slow and some metrics of ecosystem health in the Caloosahatchee River and Estuary continue to decline. For this reason a new overarching initiative to unite scientific, technical, and political efforts into a comprehensive plan of ecosystem recovery is needed for this system. This document has been prepared to help accelerate this effort by providing planners, decision makers, and other stakeholders with a succinct summary of the scope of the nutrient issues that face the Caloosahatchee River/Estuary and the types of options that are potentially available to address those issues. This white paper will provide background information for a workshop to be held in Ft. Myers on September 22, 2005.

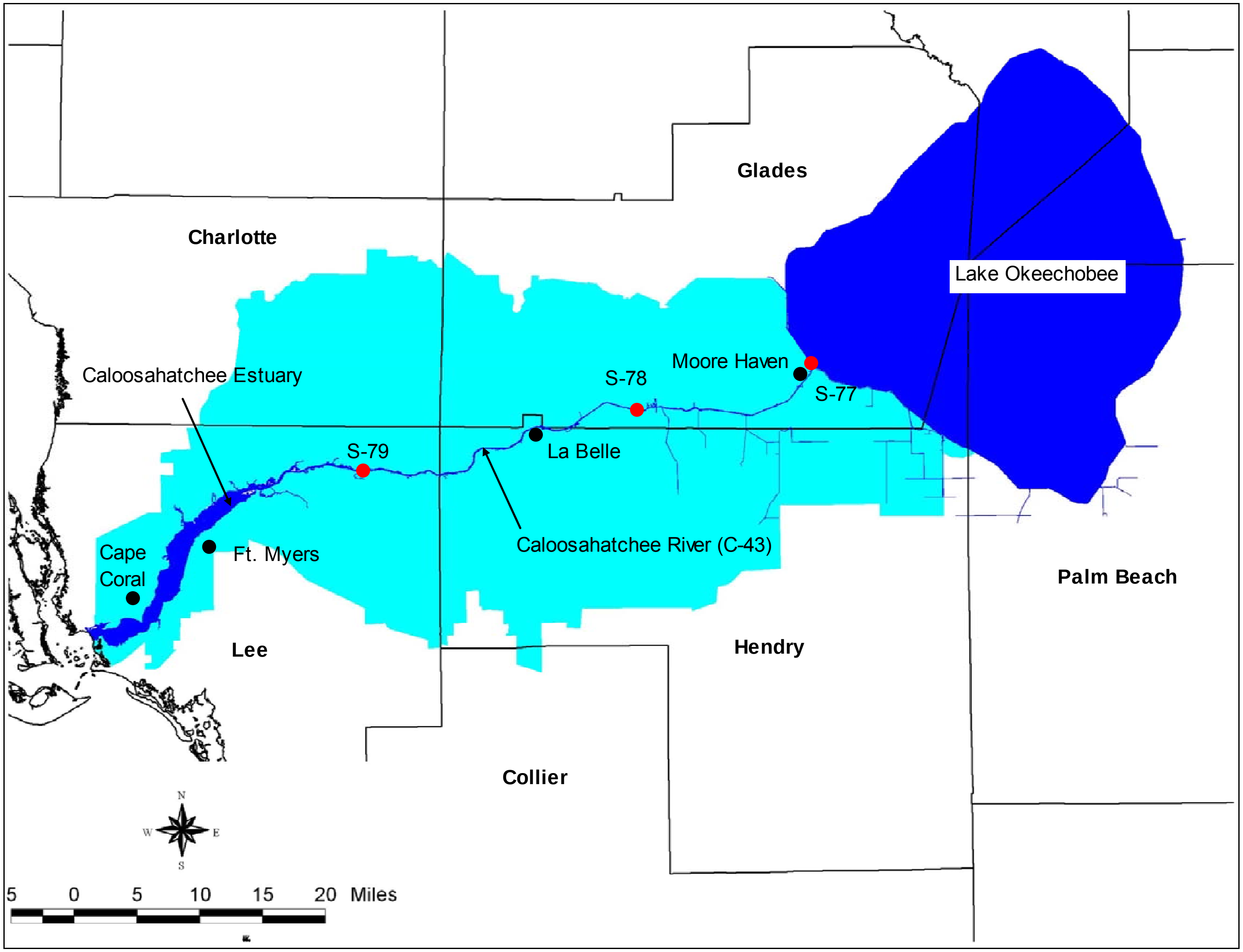


FIGURE 1
Caloosahatchee River Watershed

Nutrient Issues

All plants and animals require certain chemical compounds to grow and flourish. These essential chemicals are called nutrients. While there are many different chemicals that are essential for growth, the two elements in these compounds that are most frequently required in the greatest proportions and that most frequently limit growth of plants and animals are nitrogen (N) and phosphorus (P). This section briefly describes the chemical forms of these elements and their importance to the Caloosahatchee River/Estuary ecosystem. Detailed information about the importance of these elements in aquatic, wetland, and estuarine environments can be found in standard textbooks such as Wetzel (2001), Mitsch and Gosselink (2000), and Reid and Wood (1976).

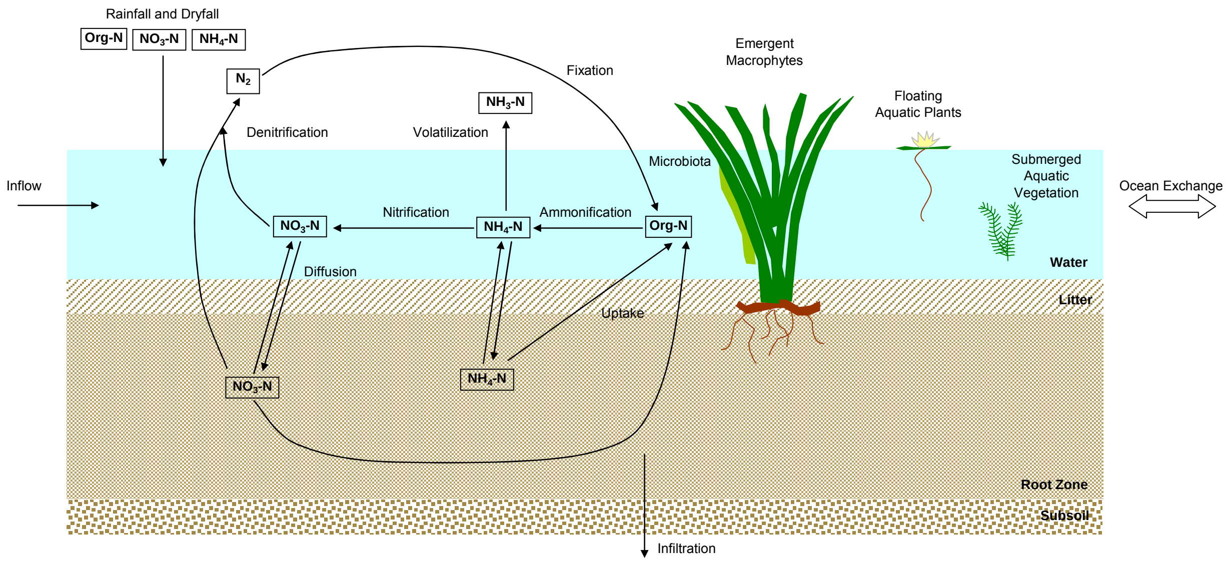
Nitrogen Cycle

Nitrogen (N) compounds are primary constituents of concern in surface waters due to their limiting role for plant growth, potential for negative effects on dissolved oxygen (DO) content, and potential toxicity to aquatic invertebrate and vertebrate species. The most important forms of inorganic N in surface waters are ammonium ion (NH_4), nitrite (NO_2), and nitrate (NO_3). Organic nitrogen (org N) is also an important constituent of surface waters in Florida and occurs in both dissolved forms and in particulate organic matter. Nitrogen concentrations in surface water are generally reported as the mass of N in the compound and written as: NO_3-N, NO_2+NO_3-N [NO_x-N = NO_2-N + NO_3-N], NH_4-N, total inorganic N (TIN) [TIN = NO_2+NO_3-N + NH_4-N], total kjeldahl N (TKN) [TKN = org N + NH_4-N], and total nitrogen (TN) [TN = TKN + NO_2+NO_3-N]. **Figure 2** illustrates the basic N cycle in aquatic systems, both freshwater and saltwater. All of the N forms can be transformed through natural oxidation and reduction processes.

Nitrogen is the critical element required for protein synthesis and, hence, is critical to life. All plants and animals require N to grow, but when present in excessive amounts in surface waters, N can contribute to a condition known as eutrophication in which excessive algal and/or aquatic plant growth can create ecological imbalances and aesthetic nuisances. Algal blooms may result in excessively high DO concentrations (super-saturation) and elevated pH conditions. A secondary or indirect effect of these nutrient imbalances is the periodic die-off of excess plant biomass followed by a depletion of available DO as organic compounds are digested by aquatic microbial populations. Lowered DO concentrations in turn can lead to die-offs of important aquatic invertebrates and fish.

When living organisms die or excrete waste products, a fraction of the org-N that was incorporated in organic molecules is converted to NH_4-N by bacteria and fungi through the process of mineralization. In the highly colored waters rich in dissolved organic tannins and lignins typical of south Florida, there is frequently a significant fraction of the org-N that is not available for mineralization and that does not readily enter into the biogeochemical cycle. This recalcitrant org-N is ultimately transported downstream and eventually diluted and dissipated as a slow-release form of N in estuarine and off-shore waters.

FIGURE 2
Simplified Diagram of the Nitrogen Cycle in Aquatic Environments



For this reason neither the measured concentration of org-N nor the concentration of TN in the water column are good predictors of eutrophication in downstream receiving waters. Concentrations of NH_4-N and NO_x-N are generally better correlated with measurable indicators of eutrophication such as algal biomass or chlorophyll *a* concentrations.

The concentration of NH_4-N in surface waters is important because it stimulates plant growth (this is the preferred N compound for plant uptake), is toxic in the un-ionized ammonia form (NH_3-N), and requires the consumption of oxygen during the aerobic transformation process of nitrification to NO_x-N. Nitrate can also serve as an essential nutrient for plant growth, and also contributes to eutrophication of surface waters when present in excess concentrations.

Atmospheric nitrogen exists principally in its molecular form (N_2). In this form, it is unusable by plants and must first be transformed by the process of fixation into either ammonia or nitrate. Certain bacteria, blue-green algae, and higher plants are capable of fixing nitrogen directly from the atmosphere. Nitrogen fixation also occurs during electrical storms when N_2 oxidizes, combines with water, and is rained out as nitric acid (HNO_3). Under anaerobic conditions, bacteria are capable of transforming NO_3-N back to N_2 through the process of denitrification, completing the nitrogen cycle (Masters 1998).

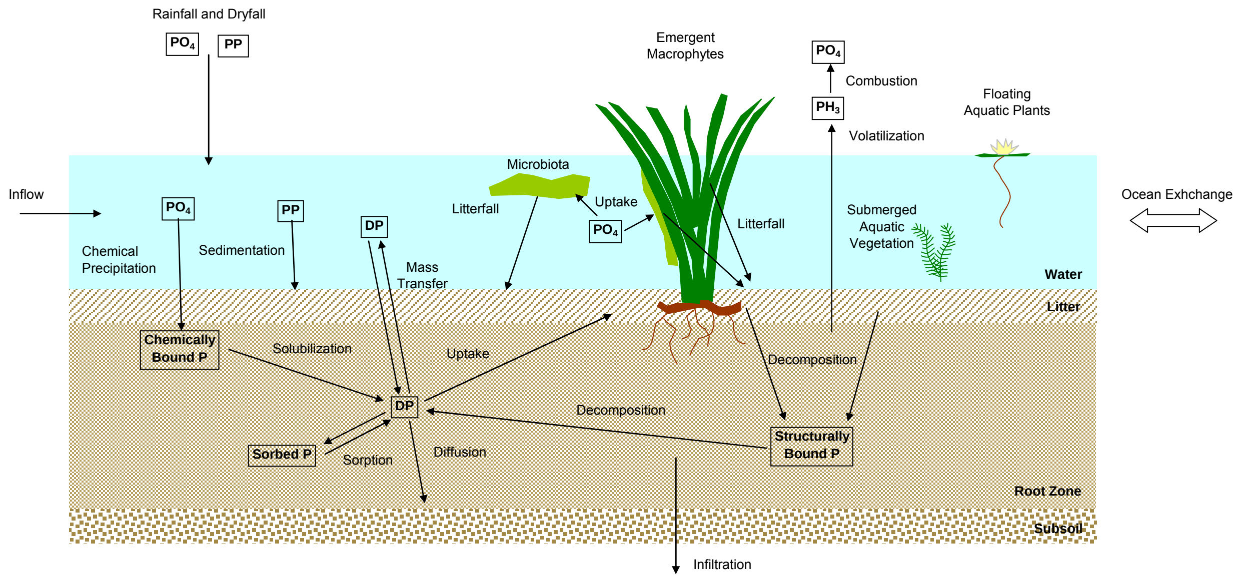
Phosphorus Cycle

Phosphorus (P) occurs as soluble and insoluble complexes in both organic and inorganic forms in aquatic systems. The principal inorganic form is ortho-phosphate (PO_4) and is the preferred form for plant (macrophyte) growth. Dissolved P (DP) includes both PO_4 and dissolved organic P. Particulate P (PP) includes biological matter such as planktonic algae (microbiota) and P sorbed on biotic and abiotic suspended particles. Dissolve organic P and insoluble forms of organic and inorganic phosphorus are generally not biologically available until they are transformed into soluble inorganic forms. Phosphorus may be permanently or semi-permanently lost from aquatic ecosystems to the sediments and to a lesser extent as phosphine gas (PH_3) to the atmosphere. Because the organic P can be transformed and used by plants, it is generally sufficient to consider the ambient concentrations of total phosphorus (TP) in natural water bodies to anticipate ecological effects.

The biogeochemical cycle for P in surface waters is illustrated in **Figure 3**. Naturally-occurring inputs of phosphorus originate from surface inflows, groundwater inflows, leaching from soils, and atmospheric deposition. Anthropogenic inputs are typically from the use of inorganic phosphorus fertilizers for agriculture and landscaping, the use of animal feeds rich in P, and from discharges of P in wastewaters and stormwaters. A variety of transformation processes occur within the phosphorus cycle. Sediment and soil accumulation provides phosphorus storage that can alternate between storage and release on a short-term basis (Kadlec and Knight 1996).

Due to the general scarcity of phosphorus in most natural environments and the lack of a major atmospheric source, ecosystems have many adaptations to trap and recycle this essential element. Phosphorus cycling is extensive in aquatic systems. Organisms require phosphorus for growth and incorporate it into their tissues. The most rapid uptake is by bacteria, fungi, algae, and macroinvertebrates. The uptake of phosphorus by plants increases their size and, in turn, generates more litter when the plants decompose, returning phosphorus back into the system. Plant roots are an important part of the biomass compartment and comprise a significant fraction of active phosphorus storage. Phosphorus retention is considered one of the most important attributes of wetlands, particularly those that receive nonpoint source pollution (Mitsch and Gooselink 2000; Kadlec and Knight 1996). Due to the inherently higher ionic characteristic of saltwater, phosphorus is generally more mobile in estuarine and marine environments, further complicating the complex nutrient processes.

FIGURE 3
Simplified Diagram of the Phosphorus Cycle in Aquatic Environments



Light and Nutrient Limitation of Primary Productivity

In surface waters, the most limiting factor for aquatic plant growth is typically light. Macro-nutrients such as N and P typically come next in the list of critical plant growth factors. For this reason, other factors that affect light availability may obscure the effects of nutrient concentrations on plant growth and occurrence in some environments. Natural surface waters in the Caloosahatchee River have elevated concentrations of dissolved color. High color attenuates the transmission of sunlight into the water column. In many cases available sunlight may be fully absorbed to the point that there is no light available for growth of rooted plants in waters more than about 0.5 to 1.0 meters [m] (3 to 5 feet) deep. Although light availability might regulate growth of rooted aquatic plants under these conditions, some species of floating plants such as duckweed (*Lemna* spp.) and floating or planktonic algae are adapted to grow at or near the surface of the water column and can overcome light limitations.

Light and nutrients do not necessarily act independently of each other. A well know effect of over-fertilization with nutrients is excessive growth of phytoplankton. This can lead limitation of further growth by self-shading, as well as reducing light availability for submerged aquatic plants.

Aquatic species require a variety of factors for growth, but from a water quality perspective the most important nutrients are carbon (C), N, and P. Plants require relatively large amounts of these nutrients and unless all are readily available, growth will be limited. The nutrient that is least available relative to a plant's needs is called the limiting nutrient. In terms of water quality, nutrients are considered pollutants when their concentrations are sufficient enough to allow excessive growth of aquatic plants, particularly algae. Carbon is usually available in adequate quantities from the atmosphere as carbon dioxide (CO_2). Freshwater systems are most frequently phosphorus-limited while saltwater systems are often nitrogen-limited. In some instances, nutrient limitations are highly variable between differing plant species and assemblages of species. Co-limitation by multiple factors including both N and P, as well as light and micro-nutrients is sometimes important in predicting the dynamics of aquatic ecosystems.

Estuaries represent a transition zone between phosphorus limited fresh water and nitrogen limited ocean water. Shifts in limiting nutrient occur both temporally and spatially. The extent to which these shifts are simply a function of the mixing fresh and salt water or whether processes specific to estuaries are important has been a key issue in accounting for differences in nutrient limitation between salt and freshwater systems. Further research is needed on how the estuarine processes contribute to the transition from generally P-limited freshwater to generally N-limited marine waters.

Environmental Setting

Watershed Basins

The Caloosahatchee River (C-43 Canal) Watershed Basin extends about 110 km (68 miles) from Lake Okeechobee in the east to the downstream end of the Caloosahatchee Estuary on the Gulf coast at San Carlos Bay. The Caloosahatchee (C-43) Basin lies in parts of Charlotte, Collier, Glades, Hendry, Lee, and Palm Beach Counties (**Figure 4**).

The freshwater Caloosahatchee River (C-43 Canal) can be functionally divided into East and West segments. The East Caloosahatchee Basin includes 982 km^2 (379 mi^2) and extends from Moore Haven (S-77) upstream to Ortona (S-78) downstream (**Figure 5**). This area includes the 160-km^2 S-4 Basin (62 mi^2) and the 43 km^2 S-236 Basin (16.5 mi^2). The West Caloosahatchee Basin includes 1,445 km^2 (558 mi^2) and extends from Ortona (S-78) to the Franklin Lock and Dam structure (S-79) downstream (**Figure 5**). The Telegraph Swamp Basin includes an additional 228 km^2 (88 mi^2), its outfall just downstream of S-79. The freshwater portion of the Caloosahatchee River (C-43 Canal) ranges from about 50 to 130 m in width and 6 to 9 m deep. Many of the original oxbows still exist outside the footprint of the C-43 Canal.

The Tidal Caloosahatchee Basin includes approximately 792 km^2 (306 mi^2) around the Caloosahatchee Estuary between S-79 and Shell Point **(Figure 6**). The estuary can be conveniently divided into three segments: the Upper Estuary from S-79 to I-75, the Middle Estuary from I-75 to the US 41 bridge, and the Lower Estuary from US 41 to Shell Point. The estuary width between S-79 and Shell Point is irregular, ranging from 160 m in the channelized upper portion of the estuary to 2,500 m downstream (Chamberlain and Doering 1998). The surface area of the Caloosahatchee Estuary is about 62 km^2 (24 mi^2).

Existing and Historic Land Use

Land use in the Caloosahatchee watershed has changed from a pre-development mosaic of sloughs, wet prairies, and pine flatwoods to agriculture and urban land. Current land use within the inland, upper portions of the C-43 Basin is dominated by rangeland and agriculture, particularly in the upper (freshwater) part of the basin. **Table 1** provides a summary of major Florida Land and Cover Classification System (FLUCCS) land use areas in the Caloosahatchee Basin for 2000. Detailed land use data for this watershed are provided in **Appendix C**. **Figure 7** shows 2000 land use mapping data.

Within the watershed, land use is dominated by agriculture (42% of the watershed area). Sugarcane farming, ranching, and citrus production are prevalent in the eastern and southern portions of the watershed. In the northern half of the East Caloosahatchee basin and in the Telegraph Swamp basin, the dominant land uses are split between upland forests and agriculture. Urban development began in the 1870's in Ft. Myers and progressed slowly until the later quarter of the 1900's. Today, dense urban land uses are concentrated in the western part of the watershed around Ft. Myers and Cape Coral, but the process of urbanization is accelerating throughout the entire Caloosahatchee (C-43) Basin (Flaig and Capece 1998; USACE, 2004b; Janicki, 2002). Based on mapping data compiled in 2000, urban land use comprises about 15% of the watershed area.

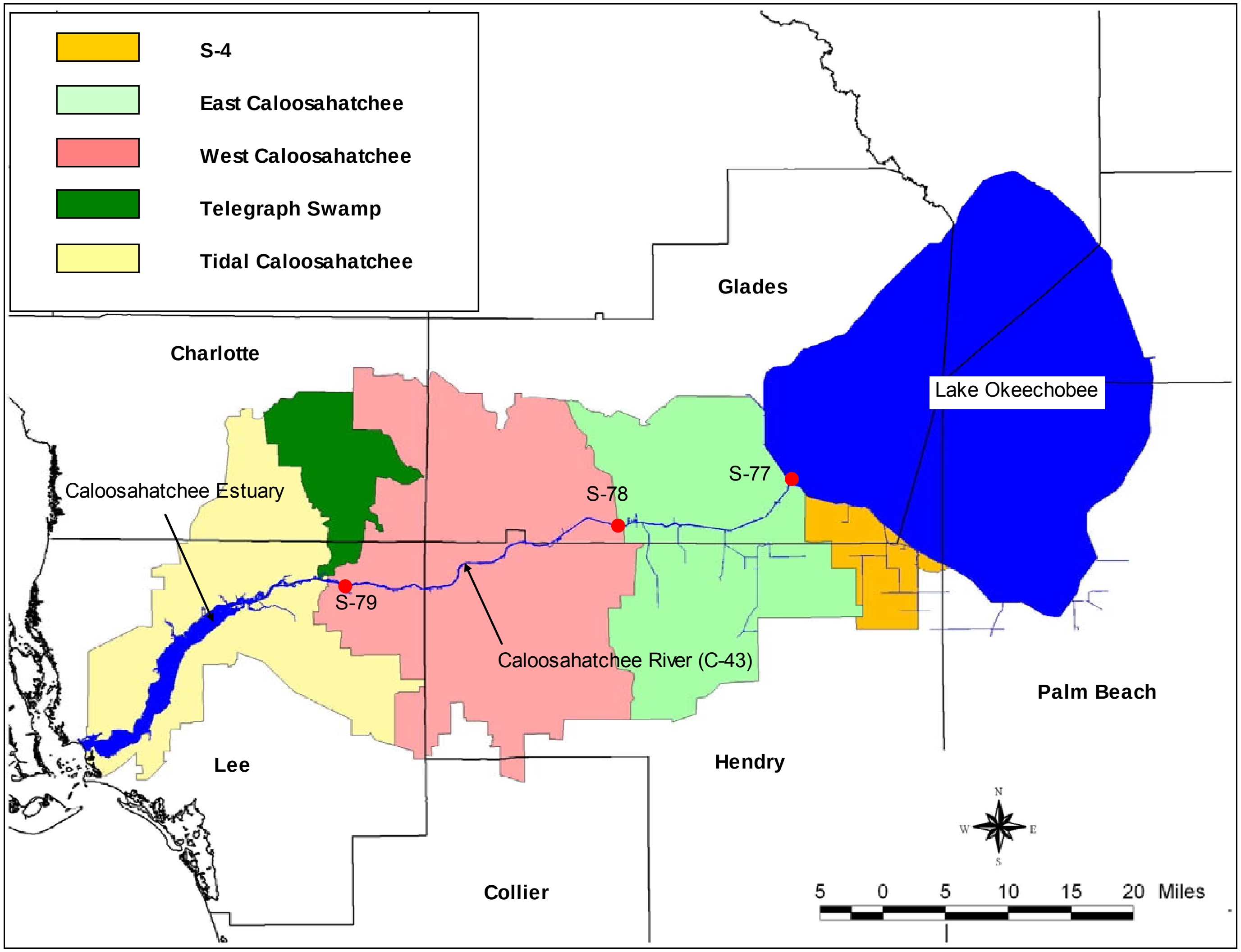


FIGURE 4
Primary Basins of the Caloosahatchee Watershed

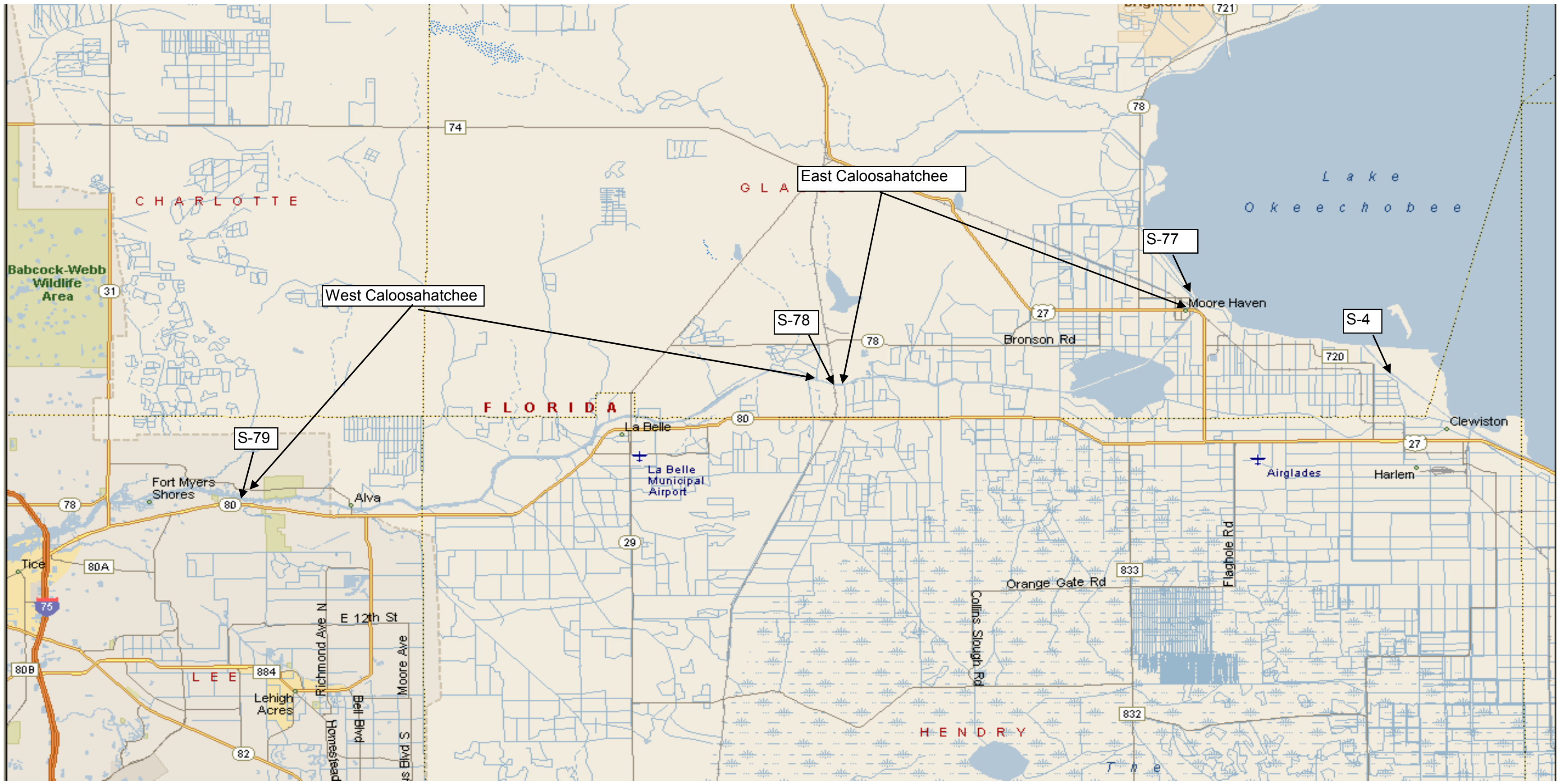


FIGURE 5
East and West segments of the Caloosahatchee River

FIGURE 6
Upper, Middle, and Lower Segments of the Caloosahatchee Estuary

TABLE 1
Summary of 2000 Land Use in the Caloosahatchee Watershed

2000 Land Use	FLUCCS	S-4	East Caloosahatchee	West Caloosahatchee	Telegraph Swamp	Tidal Caloosahatchee	Caloosahatchee Estuary	Watershed Total	% of Total
Urban and Built-up	1000	3,251	5,961	32,260	154	89,484	84	131,194	15%
Agriculture	2000	32,376	145,242	157,830	11,055	23,995	11	370,509	42%
Rangeland	3000	27	7,815	25,707	2,583	10,703	0	46,835	5%
Upland Forests	4000	452	27,177	70,256	28,077	32,523	1	158,485	18%
Water	5000	1,373	2,191	1,760	18	3,548	14,401	23,291	3%
Wetlands	6000	977	33,894	63,843	14,187	25,786	429	139,116	16%
Barren Land	7000	617	2,119	3,085	331	3,449	34	9,634	1%
Transportation	8000	601	2,233	2,187	68	6,652	416	12,158	1%
Total Area by Basin		39,673	226,632	356,927	56,474	196,140	15,376	891,223	100%

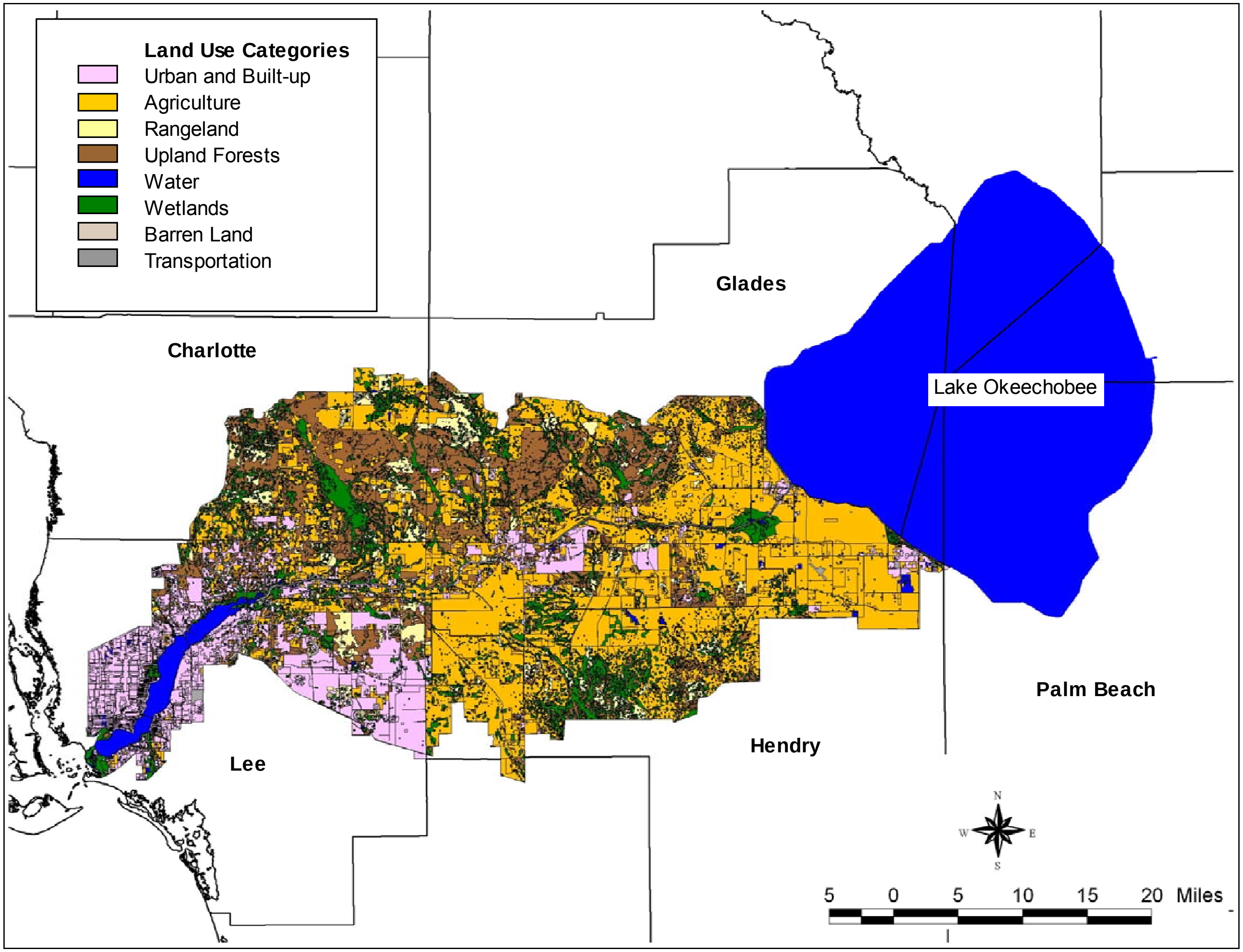


FIGURE 7
2000 Land Use

Much of the urban land use/cover change occurring within southwest Florida within the past several years can be characterized as either the creation of new developments in previously undeveloped or agricultural areas, or as the change in types of agriculture practiced on a particular segment of land. The Caloosahatchee (C-43) Basin continues to experience growth in irrigated agricultural acreage, especially citrus. Much of the new urban development includes golf course/ residential development along the Interstate 75 corridor in Lee County (USACE 2004b, Flaig and Capece 1998).

Population within the C-43 study area has increased significantly during the period 1990-2000 (**Table 2**). Charlotte County increased by 27.6%; Lee by 31.6%; Glades by 39.3%; and Hendry by 40.5%. For comparison, the population of Florida and the United States increased 23.5% and 13.1%, respectively over the same decade.

TABLE 2
Historic and estimated human population in Counties included in the Caloosahatchee River Basin

County	1990	2000	2010	2020	2030
Charlotte	110,975	141,627	174,700	206,000	234,200
Lee	335,113	440,888	592,700	728,000	852,200
Glades	7,591	10,576	12,000	13,600	15,000
Hendry	25,773	36,210	43,400	51,400	58,700
Total	479,452	629,301	822,800	999,000	1,160,100

Source: Southwest Florida Regional Planning Council (2005)

Hydrology

Rainfall averages about 52 in/yr (132 cm/yr) in the Caloosahatchee Basin (**Figure 8**). Yearly rainfall was highly variable, ranging from about 30 to 80 in/yr (75 to 200 cm/yr) during the period of record from 1931 to 2001. Rainfall is also seasonal with a dry season typically extending from November through April and a wet season extending from May through October. Tropical storms and hurricanes may contribute record rainfall amounts during late summer and early fall periods.

Annual runoff from the Caloosahatchee Basin was estimated as about 20% of average annual rainfall over a 10-year period from 1970 to 1979 (USGS 1983). Annual average and maximum daily gauged flows at the three principal lock and dam structures on the Caloosahatchee River are summarized in **Figure 9**. Average flows increase with travel distance downstream from S-77 at Moore Haven (734 cfs or 20.8 m^3/s) to S-79 just upstream of Ft. Myers (1,730 cfs or 49.0 m^3/s) primarily in response to non-point source inputs from the surrounding watershed. Annual flow variation at these stations is great in response to rainfall within the watershed and due to regulatory releases from Lake Okeechobee at S-77. Peak annual average discharges range from about 2,600 cfs (74 m^3/s) at S-77 to about 4,700 cfs (133 m^3/s) at S-79. Maximum daily discharges at the three structures ranged from 8,816 cfs (250 m^3/s) at S-77 to 21,400 cfs (606 m^3/s) at S-79.

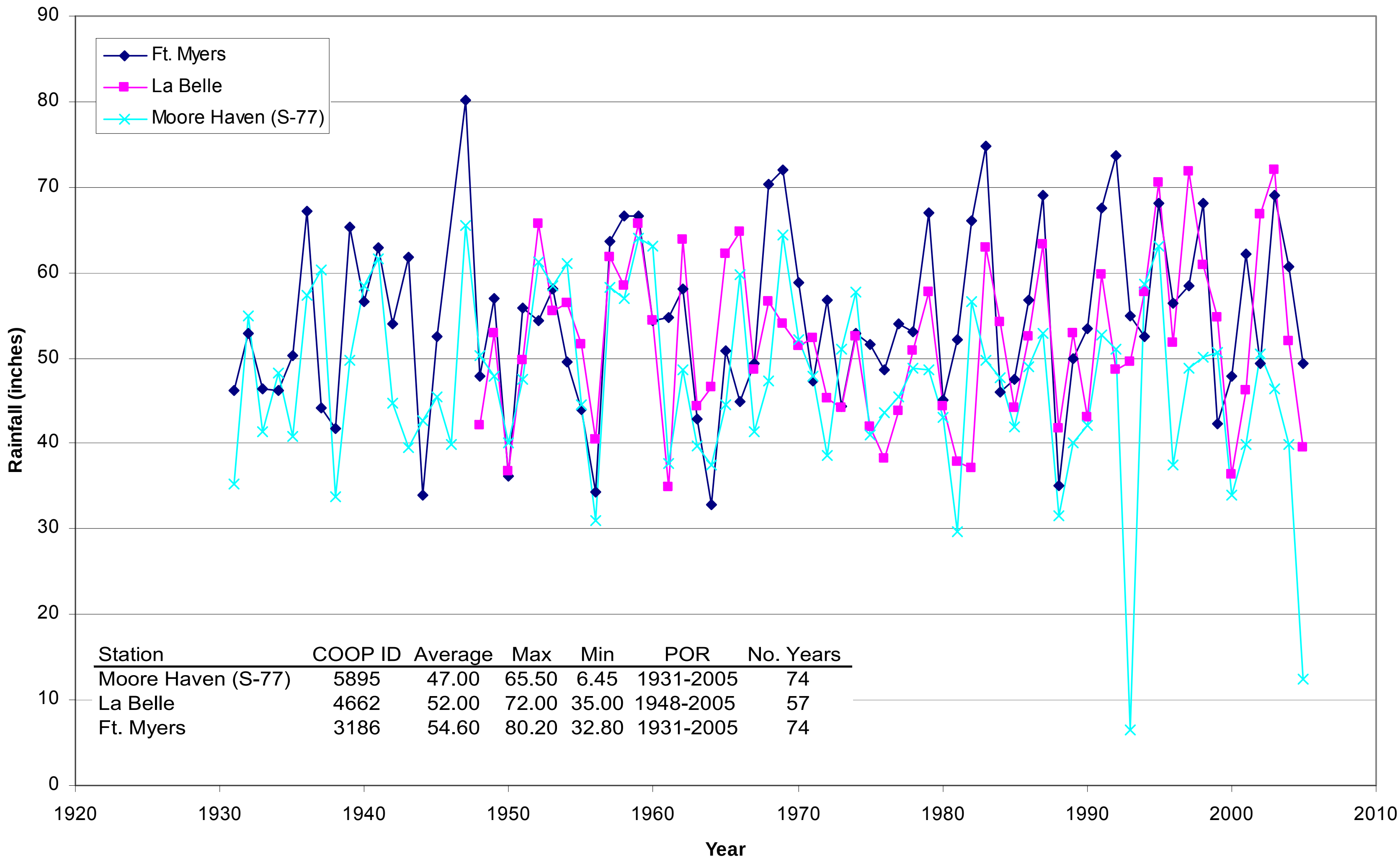


FIGURE 8
Historic rainfall data for the period-of-record (POR) for the Caloosahatchee River (C-43) Watershed Basin (source: NOAA , DBHYDRO database)

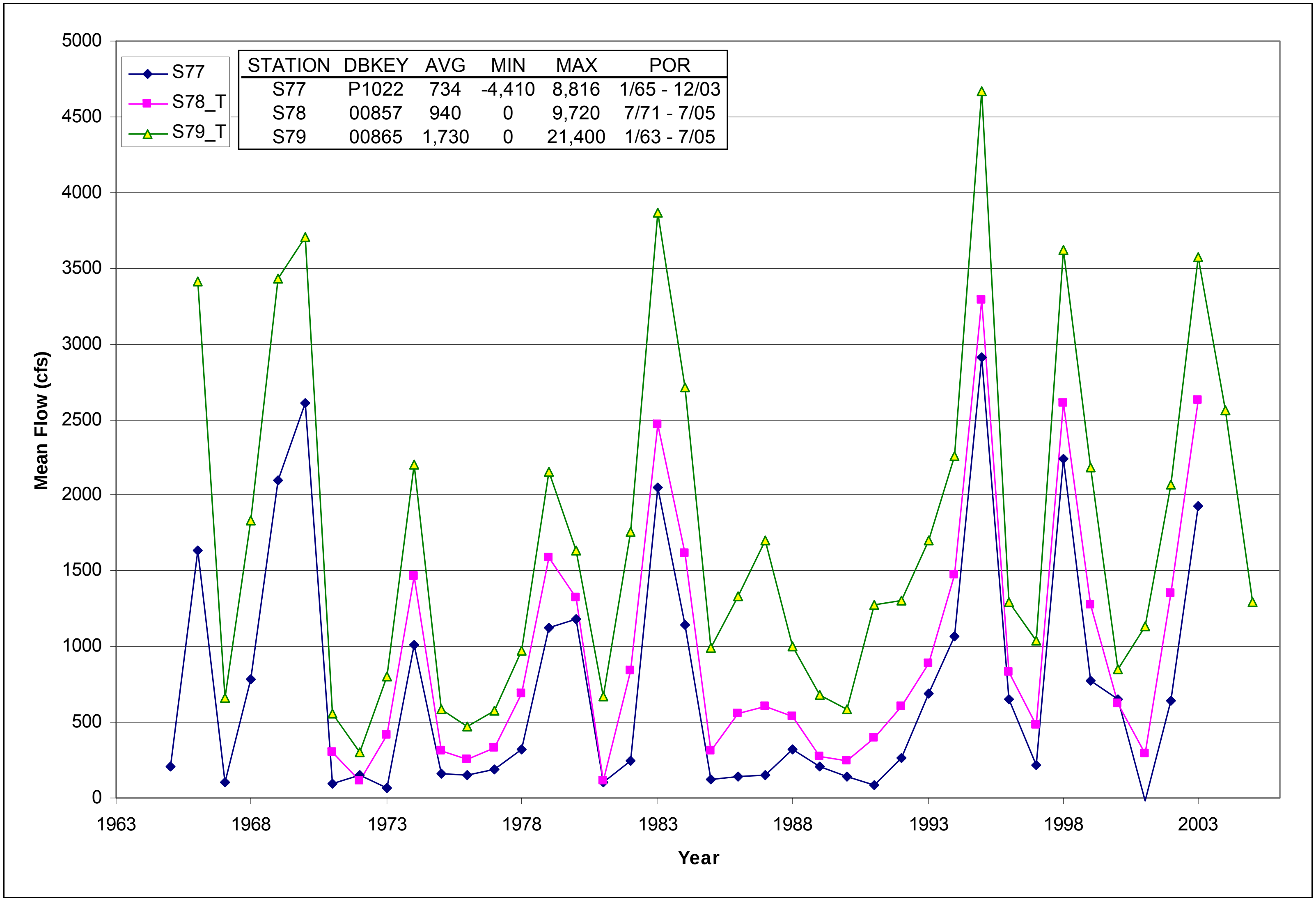


FIGURE 9
Caloosahatchee (C-43) Basin gauged flows (source: SFWMD, DBHYDRO database)

The Caloosahatchee Basin is underlain by three aquifer systems: the Surficial Aquifer System (SAS), the Intermediate Aquifer System (IAS), and the Floridan Aquifer System (FAS). Surface water storage in the numerous wetlands provides for groundwater recharge of the underlying SAS and provides surface runoff to the Caloosahatchee River (USACE 2004b, Flaig and Capece 1998).

With increased development in the watershed, consumptive water use has become a significant issue. Water use demand for 1990 was 94 million m^3/yr for the 2-in-10 dry year, which is the expected volume of water required two out of every ten years (Flaig and Capece 1998). Water for both urban and agricultural uses within the basin is provided by groundwater and surface water from the Caloosahatchee (C-43) basin. Surface water is used for agricultural irrigation and for potable supply in Lee County. Ground water is utilized in agricultural areas that do not have direct access to the river or its tributary canals. In recent years, some potable water suppliers have shifted from surface water withdrawals to Floridan Aquifer withdrawals to meet demand and minimize impacts to the Caloosahatchee River/Estuary. The City of Ft. Meyers upgrades the quality of their potable groundwater by reverse osmosis prior to distribution.

Water Quality

Numerous investigators have compiled and analyzed water quality data in the Caloosahatchee River/Estuary system (SFWMD 2000, Doering 2005, Janicki Environmental, Inc. 2002). Existing and historic water quality conditions in the East and West Caloosahatchee River segments are summarized in **Table 3**. Means and extremes, spatial variability, and the data period-of-record are presented in detailed summary data tables in **Appendix D**. Non-nutrient parameters are summarized first. While these synoptic statistics are an important first step in characterizing the Caloosahatchee system, it should be noted that more rigorous analyses are required to identify and evaluate sub-basin specific nutrient control programs. Additional analyses could include detrending, evaluating specific time frames with full consideration of varying meteorological conditions, and distinguishing between loading and concentration trends at the sub-basin level. Regarding nutrient loading to the estuary, rigorous quantification of the nutrient budget, analysis of trends in loading and better understanding of the effects of nutrient inputs on water quality and resident biota are central to effectively managing eutrophication problems.

Dissolved oxygen (DO) concentrations averaged about 5.25 mg/L at the S-77 structure, 5.91 mg/L at the S-78 structure, and 6.45 at the S-79 structure. Minimum DO concentrations were about 0.260 mg/L at S-77, 1.70 mg/L at S-78, and 2.30 mg/L at S-79. Color averaged 95 cobalt-platinum units (CPU) at S-77, 101 CPU at S-78, and 89.3 CPU at S-79. The maximum recorded value of color was 644 CPU at S-78. pH was approximately neutral in the freshwater portion of the river. Turbidity levels were typically low (less than 5 NTUs) and secchi depth was limited more by color to about 1 m. This water is moderately hard with a chloride concentration of about 68.3 mg/L at S-77, 61.3 mg/L at S-78, and 162 mg/L at S-79; a calcium concentration of about 45.3 mg/L at S-77, 54.5 mg/L at S-78, and 60.4 mg/L at S-79; and a sulfate concentration of about 39.9 mg/L at S-77, 31.4 mg/L at S-78, and 48.1 mg/L at S-79. Total and dissolved organic carbon is associated with the high color and averaged about 20 to 30 mg/L.

Water quality in the estuarine portion of the Caloosahatchee is also summarized in **Table 3**. Means and extremes and spatial variability are illustrated in detailed summary data tables in **Appendix D**. DO was lowest in the Upper Estuary with an average of about 5.45 mg/L and increased downstream to about 6.73 mg/L in the Lower Estuary. Minimum DO concentrations were as low as 0.2 mg/L in the Upper Estuary and have not been recorded below 0.36 mg/L in the Middle and Lower Estuaries. Color was highest in the Upper Estuary. Secchi disk depth was lowest in the Lower Estuary. Average turbidity decreased slightly downstream in the Lower Estuary. The entire portion of the Caloosahatchee Estuary downstream of S-79 is subject to tidal saline waters.

TABLE 3
Summary of Key Water Quality Parameters in the Caloosahatchee Basin (source SFWMD DBHYDRO)

		Subbasin					
Parameter	**Units**	**S-77**	**S-78**	**S-79**	**Upper Estuary**	**Middle Esturary**	**Lower Estuary**
Temperature	Deg C	25.3	25.5	26.0	26.2	26.4	26.3
pH	UNITS	7.42	7.43	7.52	7.45	7.58	7.84
Secchi Desk Depth	METERS	0.630	ND	ND	1.16	0.955	1.26
Dissolved Oxygen	mg/L	5.25	5.91	6.45	5.45	5.80	6.73
Specific Conductance	uS/cm	525	537	640	1,896	4,435	15,465
Calcium	mg/L	45.3	54.5	60.4	ND	112	134
Hardness	mg/L	169	180	228	ND	1,156	1,519
Chloride	mg/L	68.3	61.3	162	ND	ND	ND
Sulfate	mg/L	39.9	31.4	48.1	ND	429	573
Color	PCU	95.1	101	89.3	106	98.0	67.8
Turbidity	NTU	6.59	3.49	2.72	2.56	3.56	2.78
Total Nitrogen	mg/L	ND	ND	ND	1.26	1.19	1.01
Ammonium N	mg/L	0.077	0.058	0.045	0.086	0.059	0.035
Nitrate+Nitrite N	mg/L	0.129	0.273	0.396	0.174	0.146	0.084
Total Phosphorus	mg/L	0.094	0.131	0.138	0.104	0.107	0.097
Ortho-P	mg/L	0.040	0.083	0.094	0.075	0.070	0.054
Chlorophyll a	mg/M3	17.2	13.1	3.48	14.0	8.75	10.5
Fecal Coliform	CFU/100m	ND	ND	ND	45.0	5.00	6.88

Source: South Florida Water Management District (2005)
ND= no data

Nutrients

Total nitrogen (TN) in the freshwater portion of the Caloosahatchee River decreased slightly from east to west from an average of 1.8 to 1.7 mg/L. This nitrogen was primarily in the organic form (likely associated with dissolved organic matter in the colored water). Average concentrations of ammonium nitrogen (NH_4-N) decreased from about 0.077 mg/L at S-77 to about 0.045 mg/L at S-79. Oxidized nitrogen (nitrite + nitrate nitrogen or NO_x-N) average concentrations increased from east to west from about 0.129 to 0.396 mg/L. Average concentrations of total phosphorus (TP) increased slightly from east to west from about 94 to 138 µg/L. Maximum recorded TP concentrations are generally less than 1 mg/L. Average concentrations of trace metals in the freshwater portion of the Caloosahatchee River are typical of south Florida surface waters.

Average TN concentrations declined from 1.26 mg N/L in the Upper Caloosahatchee Estuary to 1.01 mg N/L in the Lower Estuary. Organic N accounted for the majority of this TN (about 90%). The average concentration of NH_4-N decreased downstream through the estuary from about 0.09 mg/L in the Upper Estuary to about 0.04 mg/L in the Lower Estuary. The average concentration of NOx-N also generally decreased downstream from 0.174 mg/L in the Upper Estuary to 0.084 mg/L in the Lower Estuary. The average TP concentration was highest in the Middle Estuary with a concentration of 107 µg/L.

Preliminary analysis of estuary nutrient conditions were summarized by Doering (2005). **Table 4** is a synthesis of that analysis. No concentration trends for TN or TP are apparent in the Caloosahatchee Estuary, partly due to the relative absence of historic data at key stations.

Nutrient Loads

Table 5 summarizes the period-of-record (SFWMD DBHYDRO) average nutrient loads at the S-77, S-78, and S-79 structures. Nutrient loads increased in the downstream direction. Annual average TN loads increased from about 1,090 metric tons per year (mT/yr) at S-77 to 2,640 mT/yr at S-79. Annual average TP loads increased from about 45 mT/yr at S-77 to 236 mT/yr at S-79.

Figure 10 provides an historical summary of estimated monthly TN and TP nutrient loads with distance in the main channel of the Caloosahatchee River (C-43 Canal) during the most recent decade of data (1993 – 2003). No apparent increasing or decreasing trend in these loading rates is evident for this most recent period.

TABLE 4
Median values for water quality parameters during three time periods in four regions of the Caloosahatchee estuarine system. Letters indicate statistical significances between periods at the 95% confidence level. Medians with the same letter are not significantly different

Region	**Period**	**Water Quality Parameter**			
		Salinity	**TN**	**TP**	**Chlorophyll a**
		Parts per 1000	**mg/L**	**mg/L**	**ug/L**
Upper Estuary	1985 - 1989	4.1 a	1.43 a	0.14 a	10.3
(6-14 km from S-79)	1994 - 1996	0.3 b	1.31 a	0.09 b	3.5
	1999 - 2003	1.0 a	1.13 b	0.13 a	8.6
Mid Estuary	1985 - 1989	13.9 a	1.30 a	0.12 a	8.1
(14-28 km from S-79)	1994 - 1996	1.0 b	1.29 a	0.08 b	7.3
	1999 - 2003	8.8 a	0.91 b	0.13 a	10.5
Lower Estuary	1985 - 1989	25.3 a	0.95 a	0.07 a	4.7
(28-41 km from S-79)	1994 - 1996	15.3 b	0.99 a	0.06 b	5.5
	1999 - 2003	26.8 a	0.33 b	0.09 a	3.6
San Carlos Bay	1985 - 1989	30.7	0.83 a	0.05	3.1
(41 – 49 km from S-79)	1994 - 1996	27.9	0.83 a	0.05	3.4
	1999 - 2003	31.8	0.25 b	0.04	3.4

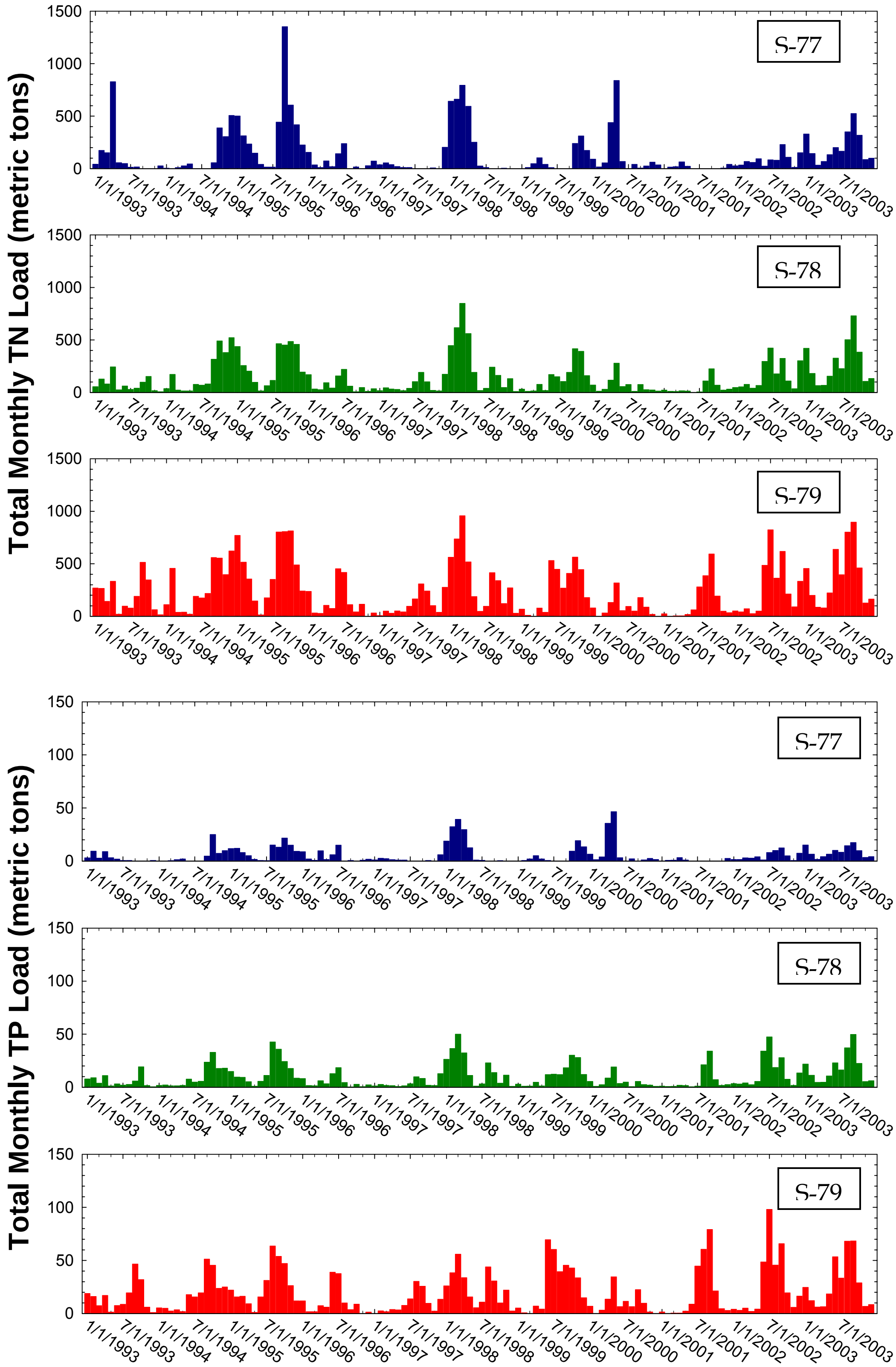


FIGURE 10
Temporal Trends in TN and TP Monthly Mass Loads in the Caloosahatchee River (C-43 Canal).

TABLE 5

Average Nutrient Loads (metric tons/year) at S-77, S-78, S-79 in the Caloosahatchee (C-43) Basin (SFWMD DBHYDRO).

Parameter	S-77	S-78	Increase (metric tons/yr)	Loading rate (kg/km2/yr)	S-79	Increase (metric tons/yr)	Loading Rate (kg/km2/yr)
Ammonia	38.5	86.0			95.3		
Nitrate-Nitrite	56.8	133			435		
TKN	1,031	1,164			2,199		
TN	1,087	1,297	210	214	2,635	1,338	926
TP	44.8	91.6	46.8	47.7	236	144.4	99.9
Period-of-Record	1973-2003	1998-2003			1981-2003		

Table 6 is provided to summarize the estimated year 2000 average basin nutrient loads for the entire Caloosahatchee River/Estuary basin as assessed in the C-43 Basin Storage Reservoir CERP plan (USACE and SFWMD, in prep). These loads are estimated based on actual existing land use conditions and typical nutrient mass loading rates for southwest Florida land use conditions. Of the total annual flow of 2.2 million m^3 in the basin, Lake Okeechobee contributes about 31%, the freshwater Caloosahatchee River basin contributes 46%, and the estuary basin contributes 23%. Lake Okeechobee discharges contribute about 28% of the annual average TN loads (3,965 mt/yr), while the remainder of the annual TN load is contributed from the freshwater basin (50%) and the estuarine basin (21%). Of the estimated average total load of TP to the watershed (448 mt/yr), Lake Okeechobee contributes 11%, the freshwater basin contributes 63%, and the estuarine basin contributes 26%. Estimated water and nutrient loads are summarized further in **Table 6** by subbasin for the freshwater and estuarine portions of the watershed. Agricultural land uses contribute the greatest share of water and nutrients in the freshwater Caloosahatchee River while urban and built-up land uses predominate in the Caloosahatchee Estuary basin.

TABLE 6
Estimated 2000 Existing Water and Nutrient Loads within the Caloosahatchee River/Estuary Watershed Basin (from USACE and SFWMD, in prep)

Watershed Source	Flow (hm3/yr)	Load (MT/yr)	
		TN	TP
Lake Okeechobee	680	1,127	48
Caloosahatchee - Fresh	988	2,002	284
Agriculture	640	1,469	218
Urban/Disturbed	129	260	39
Upland Forest	89	97	4
Wetland/Water	130	176	23
Caloosahatchee - Brackish	493	836	116
Agriculture	101	187	25
Urban/Disturbed	270	503	77
Upland Forest	57	63	3
Wetland/Water	65	83	11
Total Watershed	2,161	3,965	448

Doering and Chamberlain (2004) reported that 88-92% of TN loading into the downstream estuary from surface waters was from the discharge at S-79. CERP suggests marked changes in the volume and timing of delivery of freshwater at S-79, as nutrient loading is primarily a function of discharge rather than concentration (Doering and Chamberlain, 2004).

Doering and Chamberlain (1999) also found that when the river basin was the major source of water in the discharges, the concentrations of nutrients and color in the estuary were relatively higher than when the lake was the major source. Their analysis indicated that water quality in the downstream estuary changes as a function of both the total discharge and the source of discharge.

Environmental Research and Design, Inc. (2003) presented a summary of years 1 – 3 of the Caloosahatchee Water Quality Data Collection Program. This study was a three-year project funded by the South Florida Water Management District (District) to quantify external loadings entering the Caloosahatchee Estuary from the Caloosahatchee River, Orange River, wastewater treatment facilities, and eight major rivers and creeks.

Field monitoring and sampling were performed at 15 estuary sites and 14 nutrient monitoring sites during both wet season and dry season conditions over a three-year period from 2000–2002. Eight of the 14 monitoring sites are located in significant tributaries, based on the magnitude of freshwater discharge, which discharge directly into the Caloosahatchee Estuary between the S-79 structure and Shell Point. These eight tributaries include Trout Creek, Telegraph Creek, Popash Creek, Daughtrey Creek, Powell Creek, Hancock Creek, Billy Creek, and Whiskey Creek. Monitoring sites were also established upstream of the S-79 structure and in the Orange River. Four wastewater treatment facilities that discharge directly into the Caloosahatchee Estuary were monitored, including: Waterway Estates STP; Ft. Myers South STP; Fiesta Village STP; and Ft Myers Central STP.

The most dominant impact on the estuary is clearly inflow from the S-79 Structure followed by the Orange River, Telegraph Creek, Daughtrey Creek, Trout Creek, Popash Creek, and the Ft. Myers South STP. A graphical comparison of dry season and wet season inflow to the Caloosahatchee Estuary is given in **Figure 11**. Under dry season conditions, inflow from the S-79 Structure, Orange River, FT. Myers South STP, Ft. Myers Central STP, and Telegraph Creek represent the most significant volumetric inputs to the system. However, under wet season conditions, inflow from the Orange River becomes more significant, though discharges through S-79 still represent the vast majority of the inflow into the estuary system.

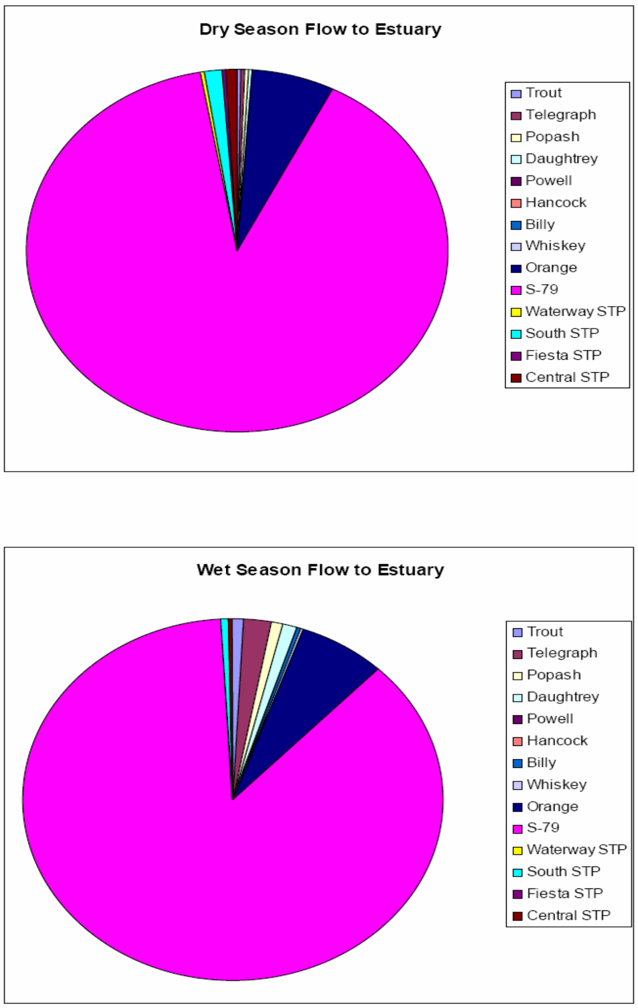
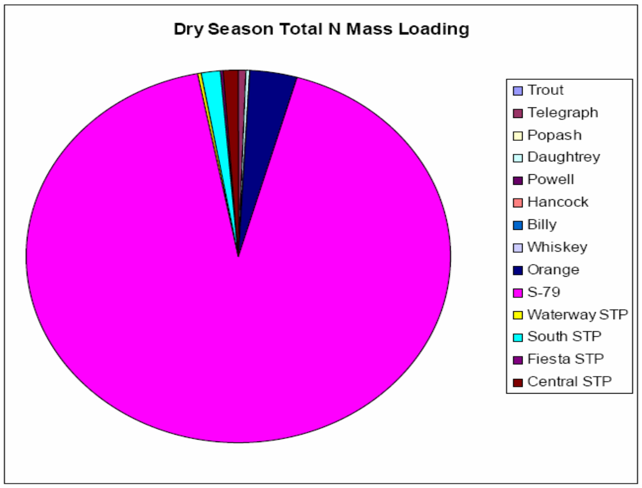


FIGURE 11
Comparison of Wet Season and Dry Season Inflow to the Caloosahatchee Estuary

Estimates of mass loadings into the Caloosahatchee Estuary were calculated for each of the measured laboratory parameters at the 14 nutrient monitoring sites. Mass loadings were calculated utilizing the mean measured flow data and the mean measured laboratory characteristics of nutrient inputs. A summary of calculated mean daily mass loadings of measured parameters discharging to the Caloosahatchee Estuary under dry season conditions and under wet season conditions are given in **Table A12** and **Table A13**, respectively (see **Appendix A**). **Figure 12** and **Figure 13** show the estimated seasonal mass inputs of TN and TP into the Caloosahatchee Estuary.



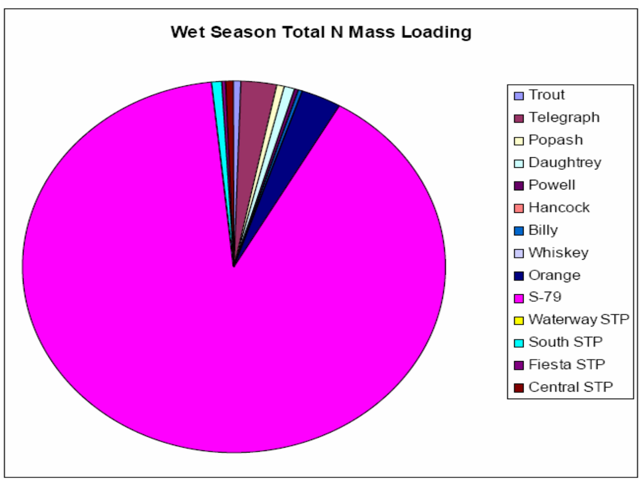
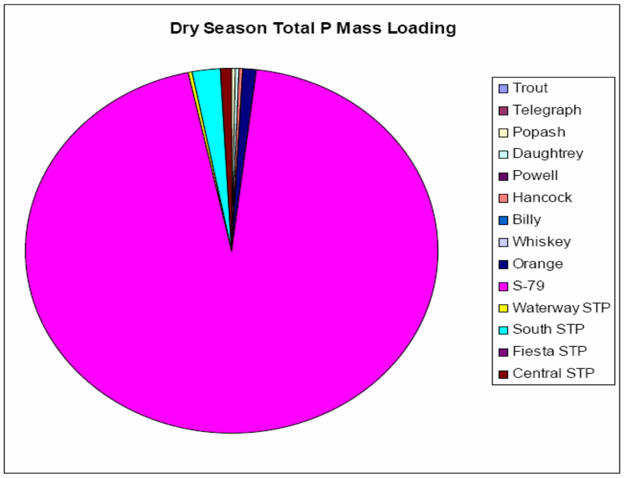


FIGURE 12
Comparison of Seasonal Mass Inputs of Total Nitrogen into the Caloosahatchee Estuary



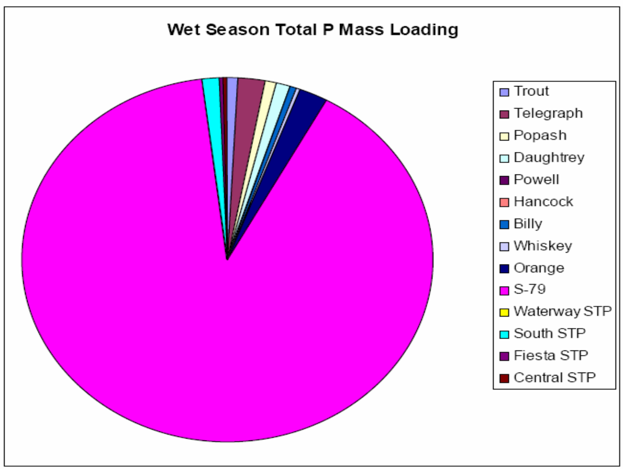


FIGURE 13
Comparison of Seasonal Mass Inputs of Total Phosphorus into the Caloosahatchee Estuary

Impaired (303d) Waters List

The Florida Department of Environmental Protection (FDEP) has reviewed water quality data from the project area and prepared a list of waters that are potentially impaired by natural and man-induced pollution (FDEP 1998). This list has recently been updated for waters that are verified as being impaired (FDEP 2005). FDEP has identified impaired and potentially impaired waters throughout the Caloosahatchee Basin.

There are seventeen permitted nonsurface water discharges and one permitted surface water discharge within the East Caloosahatchee Basin. The East Caloosahatchee contains zero Superfund sites. There are also two active and one inactive Class I solid waste landfills within the basin (FDEP 2003). The major water quality problems in the area are low dissolved oxygen and elevated metals. This is likely due to agricultural activity. The FDEP waterbodies 3237A and 3237D are included within the East Caloosahatchee Basin (**Figure 14**). Based on an FDEP June 2005 Verified Impaired Waters List, 3237A is impaired based on iron. It is also listed on the 1998 303(d) Potentially Impaired Waters List as potentially impaired for nutrients, dissolved oxygen, and biological oxygen demand. The 2005 list records 3237D as impaired based on fecal coliform and lead. The 1998 303(d) Parameters of Concern List records it as potentially impaired for nutrients, dissolved oxygen, and biological oxygen demand in addition to the aforementioned two parameters (FDEP 2003, 2005) (**Table 7**).

TABLE 7
Summary of FDEP status for the East Caloosahatchee River by parameter.

FDEP waterbody	June 2005 Verified Impaired Waters	1998 303(d) Parameters of Concern
3237A	Iron	Nutrients, DO, BOD
3237D	Fecal coliform, Lead	Nutrients, DO, BOD, Fecal coliform, Lead

There are twenty-one permitted nonsurface water discharges and zero permitted surface water discharges within the West Caloosahatchee Basin, including seventeen sewage treatment plants, three citrus processing plants, and one reverse osmosis water treatment plant. There are also two inactive Class I solid waste landfills (FDEP, 2003). The major water quality problem in the western section of the river is low DO. There are also impairments as far as metals and chlorophyll-a are concerned. This is also likely due to agricultural activity. The FDEP waterbodies 3235A, 3235D, and 3235K, are included within the West Caloosahatchee Basin (**Figure 15**). Based on the FDEP June 2005 Verified Impaired Waters List, 3235A is impaired based on iron and lead. 3235D is impaired based on nutrients (chl-a), and 3235K is impaired based on lead. 3235A also appears on the 1998 303(d) Parameters of Concern List as potentially impaired for chlorophyll-a, dissolved oxygen, and mercury. 3235D and 3235K are potentially impaired based on dissolved oxygen (FDEP 2003, 2005) (**Table 8**).

TABLE 8
Summary of FDEP status for the West Caloosahatchee River by parameter.

FDEP waterbody	June 2005 Verified Impaired Waters	1998 303(d) Parameters of Concern
3235A	Iron, Lead	Chlorophyll-a, DO, Mercury
3235D	Nutrients (chl-a)	DO
3235K	Lead	DO

There are thirty-one permitted nonsurface water discharges and eight permitted surface water discharges within the Caloosahatchee Estuary Basin. Also, one closed Class I solid waste landfill and one brownfield exist within this region. The Caloosahatchee Estuary has water quality problems due to its own sources of pollution, in addition to the pollution that is transported downstream from the Caloosahatchee River and water releases from Lake Okeechobee. Documented water quality problems include low DO; high metals, coliform bacteria and chlorophyll-a; and diminished biological integrity. This is likely due to urban land development, poorly flushed residential canals, and the migration of pollutants from upstream basins (FDEP, 2003).

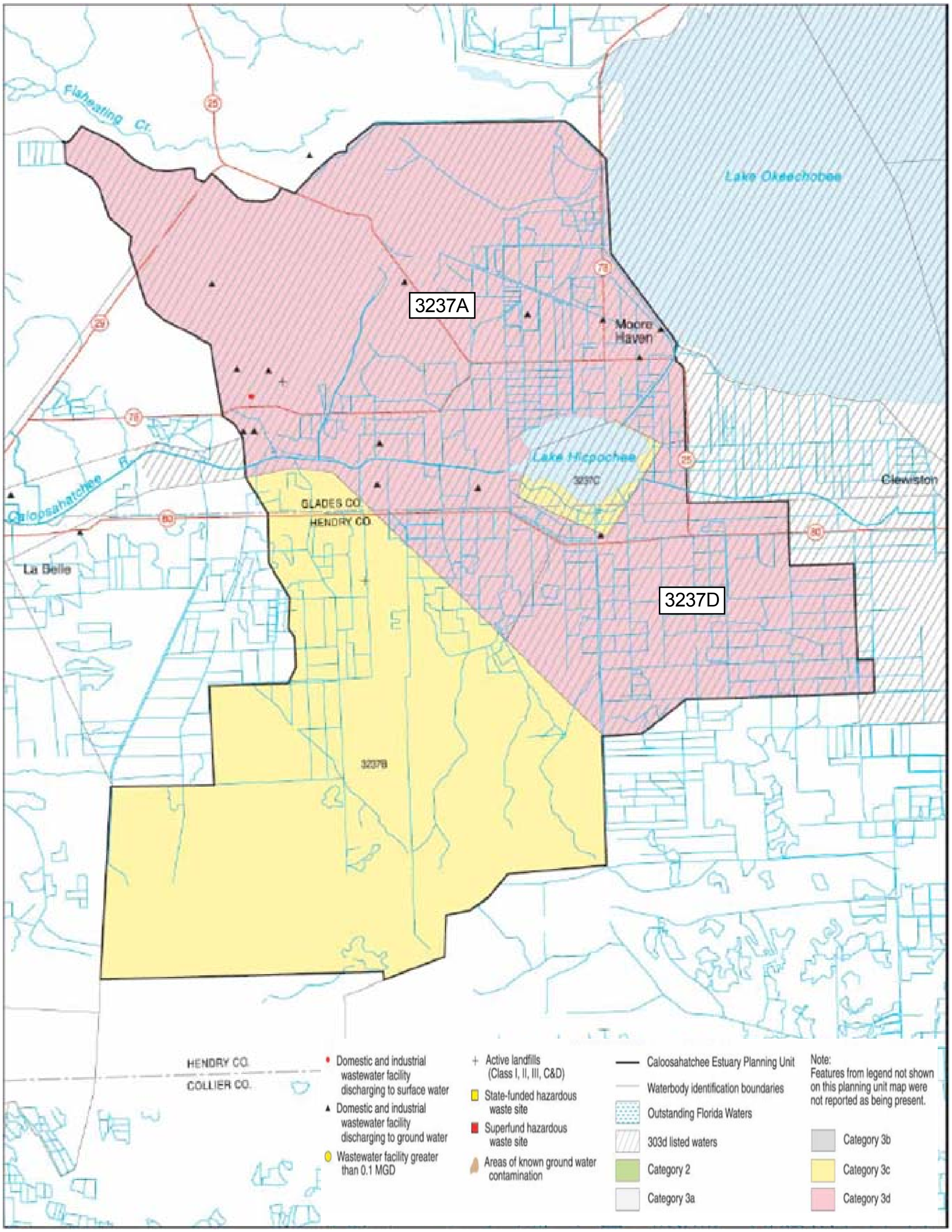


FIGURE 14
East Caloosahatchee (C-43) watershed sub-basins (FDEP)

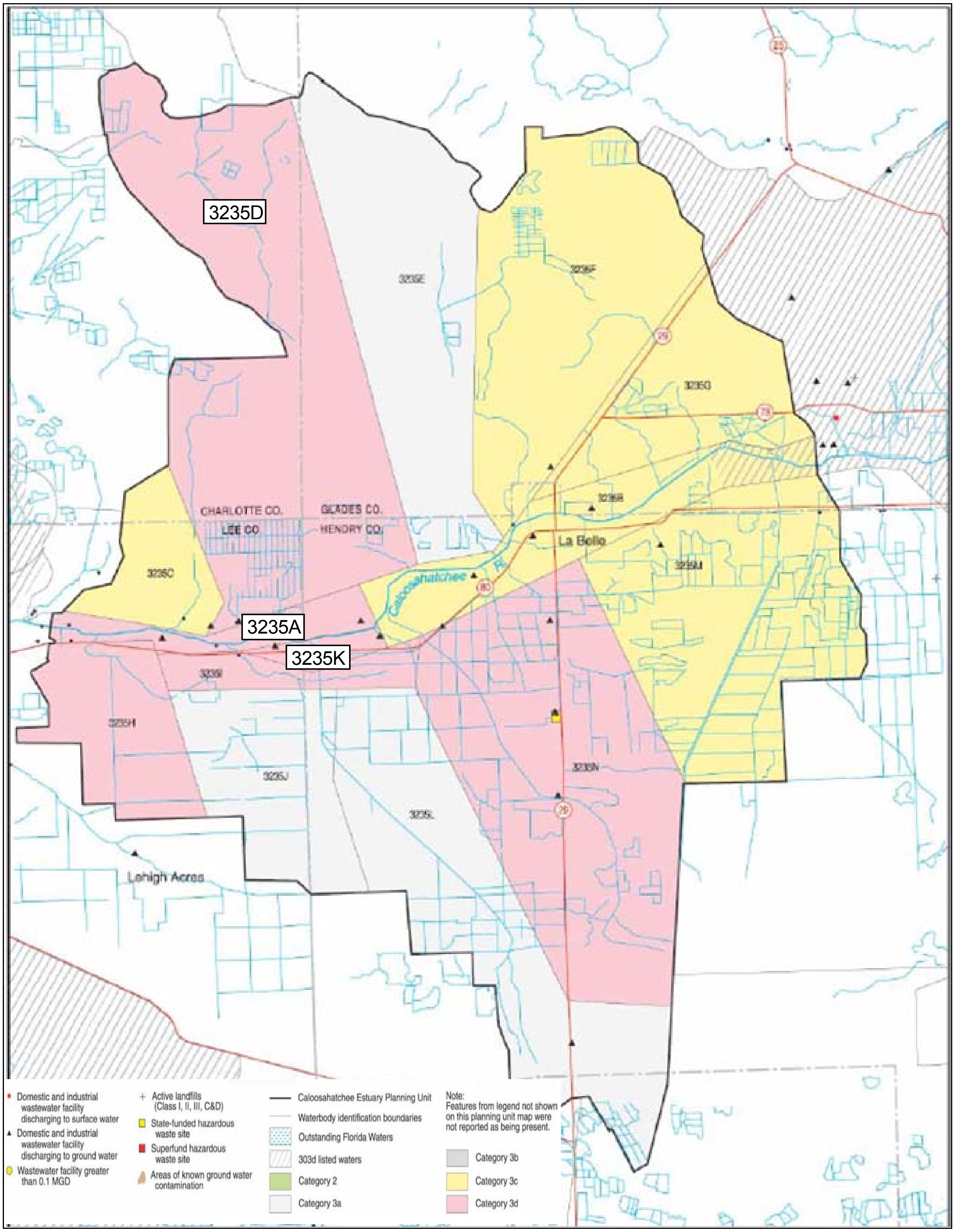


FIGURE 15
West Caloosahatchee (C-43) watershed sub-basins (FDEP)

Included in the Caloosahatchee Estuary and on the FDEP June 2005 Verified Impaired Waters List are waterbodies 3240A, 3240B, 3240C, 3240E, 3240E1, 3240F, 3240G, 3240H, 3240I, 3240L, 3240M, 3240N, and 3240Q (see **Figure 16**). Several of these waterbodies are verified as impaired for the following parameters: copper, DO, fecal coliforms, nutrients as judged by chlorophyll a concentrations, and specific conductance (FDEP, 2005) (**Table 9**).

TABLE 9
Summary of FDEP status for the Caloosahatchee Estuary by parameter.

FDEP Waterbody	June 2005 Verified Impaired Waters	1998 303(d) Parameters of Concern
3240A	Copper, DO, Fecal coliform, nutrients (chl-a)	
3240B	DO, Fecal coliform, nutrients (chl-a)	
3240C	DO, Fecal coliform, nutrients (chl-a)	
3240E	Fecal coliform	DO
3240E1	DO, Fecal coliform, nutrients (chl-a)	
3240F	Fecal coliform	Nutrients, DO
3240G	Conductance, Fecal coliform	Coliform, BOD, DO
3240H	Fecal coliform	
3240I	Copper, Fecal coliform, Lead, Total coliform	Nutrients, DO
3240L	DO, Fecal coliform, nutrients (chl-a)	
3240M	Fecal coliform, Nutrients (chl-a)	
3240N	Fecal coliform	
3240Q	DO, Fecal coliform, nutrients (chl-a)	

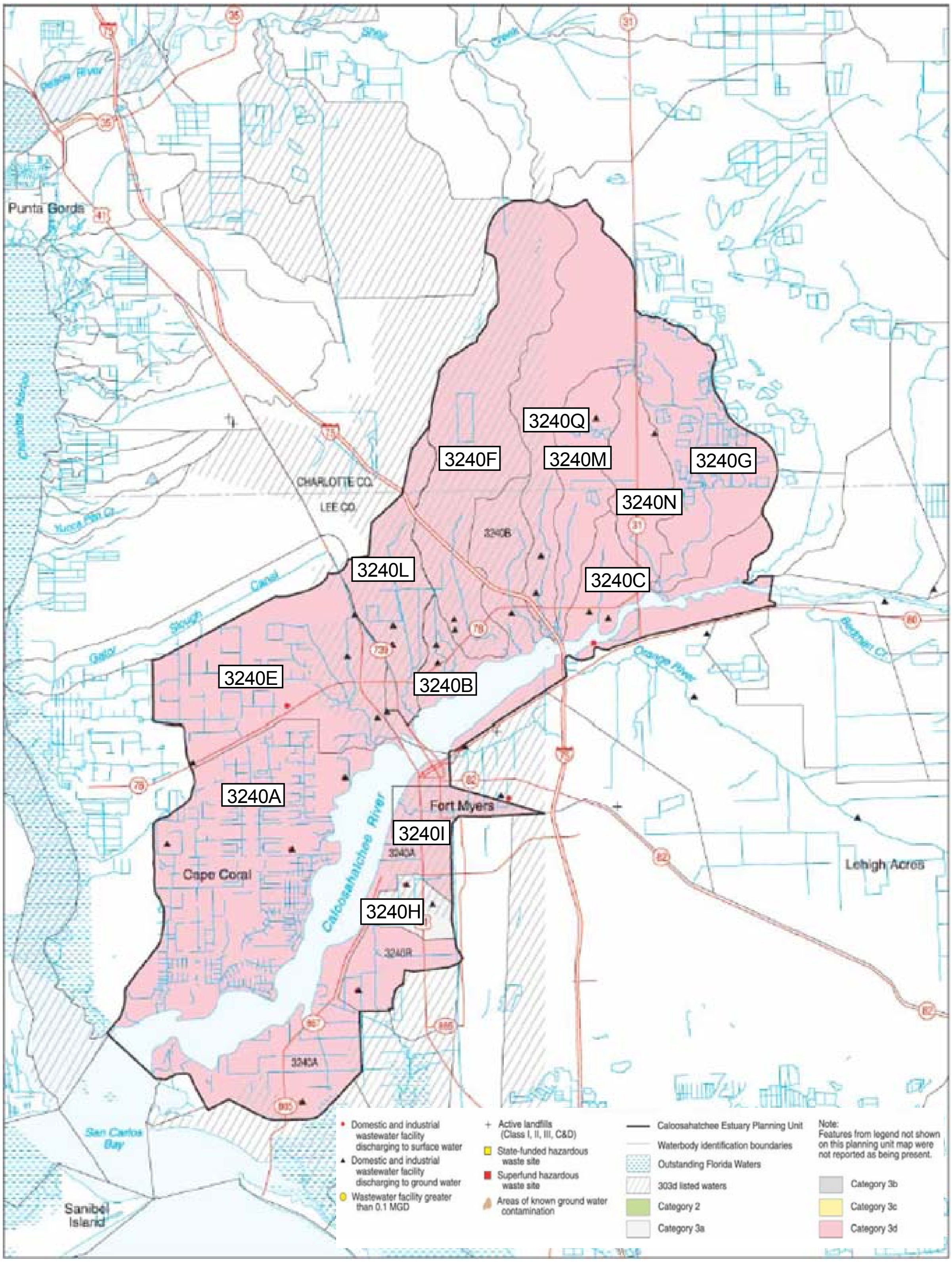


FIGURE 16
Caloosahatchee River Estuary watershed sub-basins (FDEP)

Biology

The Caloosahatchee River upstream of S-79 is primarily freshwater. Although historically salt water could influence populations of plants and animals living in the West Caloosahatchee Basin, this has not been the case since installation of the lock and dam structure. Freshwater plants that occur in the Caloosahatchee River include a variety of floating and submerged aquatic species such as water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*), hydrilla (*Hydrilla verticillata*), southern naiad (*Najas guadalupensis*), and coontail (*Ceratophyllum demersum*). Emergent wetland plant species line the banks of the C-43 canal including sawgrass (*Cladium jamaicense*) and cattails (*Typha* spp.). Freshwater fauna that utilze this canal include native and exotic fish species as well as a large variety of wetland-dependent wading and diving birds.

The Caloosahatchee Estuary is characterized by populations of ecologically important submerged aquatic vegetation with increasing salinity tolerance including: tape grass (*Vallisneria americana*), shoal grass (*Halodule wrightii*), turtle grass (*Thalassia testudinum*), and manatee grass (*Syringodium filiforme*). Populations of these species have been adversely affected by discharges of high volumes of freshwater from the upstream Caloosahatchee River. Portions of the Caloosahatchee Estuary have been historically important for recreational and commercial fishing (*e.g.*, redfish, seatrout, grouper, snook), harvesting of blue crabs and oysters, and as critical manatee habitat (USACE 2004b; SFWMD 2003).

Freshwater inflow and salinity have a significant effect on submerged aquatic vegetation (SAV) and other estuarine species. Freshwater is necessary to support tape grass which is associated with a greater density of benthic invertebrates, fish, and invertebrates (Chamberlain and Doering 1999). Enhancing and maintaining the biological and physical habitats of key species should lead to a generally healthy and diverse ecosystem.

Examples of key biological habitat are oyster bars and grass beds, with prominent species being the American oyster and the SAVs, *Vallisneria americana, Halodule wrightii,* and *Thalassia testudinum* (SFWMD 2002a). Historical accounts of the river suggest that oysters were once a more prominent feature in this area. The freshwater discharge ranges used to assess the condition of the Caloosahatchee Estuary are based on the salinities that these discharges produce in the downstream estuary, and the effects these salinities have on beds of SAV located there (Doering *et al*. 2002, Chamberlain and Doering 1999).

Oyster bars provide several important functions, including habitat and food for other species. Further, individual oysters filter 4 – 34 liters of water per hour, removing phytoplankton, particulate organic carbon, sediments, pollutants, and microorganisms from the water column. This results in greater light penetration and promotes SAV growth just downstream of oyster bars (SFWMD 2003).

Oysters are sensitive to salinity and siltation. They require salinities of at least 4 – 5 ppt. with an optimal salinity range between 14 and 28 ppt (SFWMD 2003). They usually live in brackish waters or in areas of unstable salinity that are unsuitable for marine predators. Salinities above 7 ppt are required for spawning. Embryos develop normally at salinities of 16 – 30 ppt. Larvae can tolerate salinities of 3 – 31 ppt., but grow fastest and survive best at salinities above 12 ppt. Adults tolerate salinities of 5 – 32 ppt. Outside this range of salinity, they discontinue feeding and reproducing (Stanley and Sellers 1986). Increased freshwater conditions have limited the distribution of oysters in the Caloosahatchee Estuary.

Submerged aquatic vegetation plays several roles in maintaining an estuary's health. They provide habitat and nursery grounds for many fish and invertebrate communities and are especially important in benthic based primary productivity. SAV and the organisms that live on them are important food sources in the estuarine system. Manatees, waterfowl and wading birds rely heavily on seagrass systems as forage areas. Further, SAV help maintain water clarity by trapping fine sediments; they improve water quality by talking up large quantities of nutrients that would otherwise accelerate the eutrophication of the estuary (SFWMD 2003).

All species of SAV have a preferred and tolerable salinity range; they respond unfavorably when these ranges are exceeded through salinity alterations. Beds of *Vallisneria americana*, in the upper estuary serve as the key ecosystem component upon which the minimum freshwater flow and level is based. At flows below 300 cfs, saltwater can intrude into the upper estuary and damage beds of *V. americana*. Flows greater than 2800 cfs will cause salinity to decline in the lower estuary and damage beds of *H. wrightii*. In addition, flows greater than 4500 cfs will lower salinity further downstream in San Carlos Bay, endangering *T. testudinum* (SFWMD 2002a, 2003).

Open bottoms in the Caloosahatchee Estuary are composed of sand, mud, shell, and bedrock. Macroinvertebrates, including mollusks, are dominant elements of the Caloosahatchee estuarine and tidal river ecosystems. *Rangia cuneata* and *Polymesoda carolineata* are mollusks commonly associated with the mud and sandy bottoms of the Caloosahatchee Estuary. They require lower salinities and thus can be used as indicators of estuarine condition. As well, mollusks leave behind their shells upon death and assembling these shells can provide insight into historical salinity regimes. If sampled along with the live community, the death assemblage can be used as an indicator of conditions prior to system alterations and also as a target for comparing current conditions (SFWMD, 2003).

Nineteen federally listed species exist within the Caloosahatchee (C-43) area. Three of these species have a portion of their designated critical habitat within or adjacent to the study area. Threatened and endangered species with critical habitat present within the study area include the piping plover, Everglades snail kite, and beautiful pawpaw (USACE 2004b).

Further, strategic habitat conservation areas exist for the red cockaded woodpecker, wood stork, and Florida scrub jay. The Florida panther and eastern indigo snake are also species that depend on critical habitat areas within the Caloosahatchee (C-43) Basin (SFWMD 2000).

Summary of Critical Issues

This section briefly describes some of the most critical water quality issues in the Caloosahatchee River/Estuary. These issues are inter-related and can best be resolved through development of an integrated, inter-governmental strategy to be called the Caloosahatchee Restoration Initiative. Ongoing projects discussed elsewhere in this white paper such as the Southwest Florida Feasibility Study, CERP, development of stormwater regulations, TMDLS, and MFLs can ultimately restore some of the historic quality to the Caloosahatchee system as long as they can be applied strategically.

Freshwater Loads and Salinity

Many researchers emphasize freshwater supply to estuaries as the significant influence on the composition, abundance, productivity, and distribution of estuarine flora and fauna. Doering and Chamberlain (2004) note that because the amount of freshwater discharge at S-79 directly affects the water quality parameters in the estuary, nutrient and material loading is a secondary concern to the volume of flows. Rapid and unnatural fluctuations in salinity have contributed to major impacts on submerged plant abundance and distribution, including a loss of the natural gradient of grass species between downtown Fort Myers and the mouth of the river (SFWMD 2003).

The Caloosahatchee River (C-43 Canal) is the predominant source of freshwater to the Caloosahatchee Estuary. High daily and monthly inflows from the watershed basin including Lake Okeechobee (especially if prolonged) can push freshwater as far as Pine Island Sound and the Gulf of Mexico. This impacts ecologically and commercially significant estuarine resources that are dependent on a high salinity environment. Alternatively, during the dry season, reduced flows of freshwater resulting from upstream allocation to satisfy human demands can upset the salinity balance in the upper estuary and threaten species that rely on a lower salinity environment.

Altered estuarine salinity has resulted from the man-made hydrological modifications to the system. These modifications have altered the natural quantity, quality, timing, and distribution of flows into the estuary, often occurring without regard to the biological integrity of the estuary. For example, rainfall runoff that was historically retained within the undeveloped watershed now reaches the river in greater volume and less time. Furthermore, the construction of S-79 has confined the estuary by restricting freshwater flows from the upper reaches of the estuary during the dry season (SFWMD 2003). Freshwater faunal species that previously could flee upstream into the Caloosahatchee River during low flow/high salinity periods are now confronted with a significant barrier at S-79.

The volume of freshwater passing through S-79 from the watershed and Lake Okeechobee overwhelms any other source. In 1985, the SFWMD initiated a research project to address impacts of (basin and lake) water management on the estuary and establish freshwater inflow limits and water quality targets for the estuary. The proper water quantity was determined by the optimum range of freshwater inflow that protects key species. For example, at 500 cfs a desirable salinity exists somewhere for all organisms within the estuary. The maximum mean monthly discharge was determined to provide a range of salinities to accommodate organisms along the estuary based on their tolerance limits (Chamberlain and Doering 1998). When there is not a need to discharge water from the lake for flood control purposes, opportunities for meeting Minimum Flow and Levels (MFLs) can be considered. The adopted MFL criteria for the Caloosahatchee Estuary indicates a flow of approximately 300 cfs at S-79, in combination with downstream runoff, that is expected to maintain a 30-day average salinity concentration of 10 ppt or less during the year at the Ft. Myers salinity station (SFWMD 2002). The long term solution to meeting MFLs for the estuary is CERP.

SFWMD (2000) reports that the inflows to the estuary at S-79 should have mean monthly values between 300 and 2,800 cfs. In addition to the immediate impacts associated with dramatic changes in freshwater inflows, long-term cumulative changes in water quality constituents or water clarity may also negatively affect the estuarine community.

Nutrients and Eutrophication

Nutrients and dissolved organics enter the system as a result of anthropogenic activities in the watershed. The greatest loadings come from agricultural runoff facilitated by water management practices, urban runoff, and point source discharges to the estuary from sewage treatment plants (SFWMD 2003). **Table 10** lists many of the principal anthropogenic external nutrient sources, point and non-point. The contribution of these types of sources is dependent upon local human population densities and land use.

TABLE 10
Likely sources of anthropogenic point and non-point pollutant inputs to the Caloosahatchee River/Estuary (modified from Carpenter *et al.* 1998 and Novotny and Olem 1994)

Point Sources
Wastewater effluent (municipal and industrial)
Runoff and leachate from waste disposal sites
Runoff and infiltration from animal feedlots
Runoff from mines, oil fields, and unsewered industrial sites
Storm sewer outfalls from cities with populations > 100,000
Overflows of combined storm and sanitary sewers
Runoff from construction sites with an area > 2 ha
Nonpoint sources
Runoff from agriculture (including return flows from irrigated agriculture)
Runoff from pastures and rangelends
Urban runoff from unsewered areas and sewered areas with populations < 100,000
Septic tank leachate and runoff from failed septic systems
Runoff from construction sites with an area < 2 ha
Runoff from abandoned mines
Atmospheric deposition over a water surface
Activities on land that generate contaminants, such as logging, wetland conversion, construction, and development of land or waterways

This process of nutrient enrichment, eutrophication, is the most widespread water quality problem in the US and many other nations (Masters 1998, Smith *et al*. 1999). In terms of water quality, nutrients are considered pollutants when their concentrations are sufficient enough to allow excessive growth of aquatic plants, particularly algae. Initial conceptual models of eutrophication emphasized the link between increased nutrient inputs and blooms of algae, which eventually die and decompose. Their decomposition removes oxygen from the water, potentially leading to levels of dissolved oxygen that are insufficient to sustain normal life forms (Ryther and Dunstan 1971). In the intervening decades it has become apparent that there is no generic response of coastal estuaries to nutrient enrichment. Factors such as tidal range, hydraulic residence time, suspended sediments, or dense populations of filter feeders can determine how the primary producers in a particular estuary will respond (Cloern 2001).

Nutrient availability is a key factor regulating primary productivity in estuarine and coastal waters. Recycled nutrients sustain much of the productivity in these waters. Basin runoff adds nutrients and contributes to the relatively high estuarine productivity compared with that of off-shore waters. Increased loadings of nutrients related to human development have been implicated in estuarine enrichment; increased phytoplankton productivity and biomass; and declines in seagrass communities.

The concept of nutrient limitation can be considered the keystone of eutrophication research. In effect it implies (1) that one key nutrient should be the primary limiting factor on plant growth in a given ecosystem; (2) that the growth of plants in a given ecosystem should be proportional to the rate of supply of this nutrient; and (3) that the control of eutrophication should be accomplished by restricting the loading of this key nutrient to the ecosystem (Smith *et al.* 1999).

High external nutrient loadings and the resulting eutrophication process can have three directly measurable impacts on the DO of an estuarine system: 1) a BOD exerted by the oxidation of NH_4-N; 2) a BOD in the water column created by the conversion of inorganic carbon to organic carbon; and 3) a significant increase in total organic carbon of the system and its secondary impacts, such as benthic oxygen demand. There also can be an impact on the DO demand due to photosynthesis and concurrent respiration (Jaworski 1981).

McPherson *et al.* (1990) note that freshwater runoff in southwest Florida coastal areas is a major source of new N that stimulates phytoplankton productivity and chlorophyll *a* biomass in the mid-salinity regions of the estuary. Urban population growth is expected to increase N loading by more than 18% by the year 2020. Although nutrient enrichment and reduced freshwater runoff could affect multiple processes in unpredictable ways, projected basin changes would favor algal growth by increasing N availability and increasing the availability of light due to reduced inflows of freshwater (McPherson *et al.* 1990).

Effects on Primary Productivity

McPherson and Miller (1990) found that relatively low concentrations of inorganic nitrogen likely limit plant growth in the estuary at times. They link phytoplankton productivity to N availability, suggesting that significantly more N is needed in the system than is available from rainfall and runoff.

Generally, phytoplankton productivity and the peak biomass of dependent aquatic flora and fauna occur during the warmer seasons of the year and are usually controlled by either nutrient or light availability (McPherson *et al.* 1990).

It is usually N or P that controls algal growth rates. In general, seawater is most often limited by N, while freshwater lakes are most often limited by P (Masters 1998). Studies of nutrient data from the sea surface reveals that as the two elements are utilized, N compounds become depleted more rapidly and more completely than does P (Ryther and Dunstan 1971).

In addition to the concentration of nutrients required for growth, the availability of sunlight to power photosynthetic reactions controls rates of production. The amount of light available is related to the transparency of the water which is, in part, a function of the level of eutrophication (Masters 1998). The minimal light requirement of a particular species determines the maximum water depth at which it can survive (Dennison *et al.* 1993).

Freshwater inputs to the Caloosahatchee Estuary, in effect, add both color nutrients to the water and this color shades the estuary vertically. In low salinity waters, productivity may be limited by highly colored freshwater that greatly restricts light penetrating in the water column. The nutrient-rich, colored river water is diluted by seawater at mid-salinities and the availability of light increases. Availability of light may be more important than availability of nutrients for aquatic plant growth in parts of the estuary (McPherson and Miller 1990).

In regions of the system that are more distant from the source of freshwater (S-79) such as San Carlos Bay and Pine Island Sound, accumulation of phytoplankton biomass may be sufficient to contribute significantly to light attenuation (Doering and Chamberlain 1999). Thus in other parts of the system, nutrient availability may play an important role in controlling light availability to seagrasses and other benthic flora.

Tilman and Nekola (1999) found that load reductions of N and P in Hillsborough Bay, Florida were almost immediately followed by significant reductions in phytoplankton biomass, and increases in water transparency and DO concentrations in the bay. Nutrient availability is a key factor regulating primary productivity in estuarine and coastal waters. Recycled nutrients sustain much of the productivity in these waters. Basin runoff adds nutrients and contributes to the relatively high estuarine productivity compared with that of off-shore waters. In general, macroalgae growing in estuaries with increased nutrient supply show elevated nutrient uptake rates, tissue nutrient contents, maximum photosynthetic rates, and macroalgal growth rates. In studying two estuaries in Massachusetts (Waquoit Bay), Valiela et al (1997) found that macroalgal biomass was consistently greater in the estuary that received the largest N load. Where nutrient supply increases, seagrasses are replaced by macroalgae, which in turn can be replaced by phytoplankton as the dominant producers. Even at modest increases in nitrogen loadings from watersheds, the macroalgae bloom and replace seagrasses as the dominant producers (Valiela et al, 1997).

It is possible that as N loads increase and nutrient concentrations rise, N uptake by phytoplankton increase and cells divide faster. Further, in such N-enriched situations, phytoplankton biomass may increase sufficiently to shade and eventually replace bottom-dwelling SAV and macroalgae that support desirable fauna. In estuaries with longer residence times, phytoplankton may become the dominant producers at much lower rates of N loading.

Macroalgal blooms uncouple biogeochemical cycles in sediments from those in water columns to a significant degree. Macroalgae that uptake nutrients from water replace plants that “mine” nutrients from sediments using roots. The presence of macroalgal canopies seems likely to sequester nutrients that otherwise may have entered the water column and may enhance recycling of nutrients near the sediment surface. Furthermore, macroalgal dominated canopies are likely to increase the delivery of labile carbon compounds to estuarine waters. The released carbon may be sufficient to enter the microbial food web; microbes cause aggregation of the DOC into amorphous particles that resemble marine snow in appearance, and the aggregates may be ingested and assimilated by larger animals. The released DOC may be sufficient to increase biological oxygen demand and is perhaps involved in the increased frequency of anoxic events found in enriched waters (Valiela *et al.* 1997).

Continuing growth and development in coastal southwest Florida without a zero net gain in nutrient enrichment will increase nutrient loadings in rivers and streams that flow into the Caloosahatchee Estuary and result in continuing increases in eutrophication and related ecological and aesthetic problems for the region. In this connection it is again worth noting that there is no generic response of estuaries to nutrient enrichment. In order to predict and manage nutrient problems in the Caloosahatchee, a full accounting of the factors that govern nutrient utilization and cycling will be required.

Red Tides

One of the consequences of increased algal productivity in coastal waters is the increased occurrence and density of red tide or harmful algal bloom (HAB) conditions (Steidenger *et al.* 1998; Tester and Steidenger 1997; Steidenger 1975). Red tides are visible discoloration of the surface water resulting from a bloom of certain marine, phytoplanktonic algal species in the dinoflagellate phylum. Some of these species produce conservative toxins that may accumulate in affected organisms, such as shellfish, fish, and sea turtles. Ingestion of toxin laden fish and shellfish can cause severe illness in humans. Through the year 2003, HABs had occurred in the western waters off of Florida for the past 26 out of 27 years that records have been kept (Steidenger, pers. comm.). Also, the observed geographic extent of these algal blooms has increased during the most recent years of observation. There is a suspicion in the scientific community that the apparent increased prevalence of red tides globally may be due to transport of increasing nutrient loads from coastal rivers. Both nitrogen, in the form of ammonia and/or dissolved organic N, and P have been implicated. Florida red tides appear to form well offshore and their initiation has not been linked to cultural eutrophication (Cindy Heil, personal communication); however, nearshore nutrient conditions and converging circulation patterns associated with coastal rivers may contribute to the maintenance of HABs once they do form (Schofield and von Alt 2003).

Stormwater Management

Stormwater runoff is a significant source of nutrient loading to the Caloosahatchee River and Estuary. Runoff from agricultural development contains particulates (soil and plant matter) that contain associated nutrients. Dissolved nutrients are often released from agricultural lands during rain events and wet season pumping activities. While best management practices (BMPs) are important for some agricultural uses such as dairies and citrus groves, controls are generally not sufficient to reduce nutrient discharges to pre-development levels. Urban development creates impervious surfaces, creating a medium that transports and heats water much faster than undeveloped land. It is imperative that this runoff water be managed properly in order to decrease nutrient concentrations and water temperature, and slow down the rate at which the runoff reaches receiving waters. Further, regulatory flows from Lake Okeechobee for flood control introduce significant amounts of stormwater contaminants to the estuary (SFWMD 2000).

Many of the older urban and residential land uses are exempt from current stormwater regulations (see Chapter 403, Florida Statutes and Title 62, Florida Administrative Code) and as such are not subject to any stormwater controls. Stormwaters from these areas are discharged directly into the Caloosahatchee River and Estuary. Newer developments are subject to strict stormwater management principles and send lower nutrient loads to adjacent and downstream waters. However, all developments, old and new will be subject to greater stormwater controls due to the promulgation of Total Maximum Daily Loads (TMDLs) for the river and estuary. The state of Florida is currently considering writing a proposed unified stormwater management rule that will hold new development to higher water quality discharge standards.

Wastewater Discharges

Point source discharges to the Caloosahatchee River/Estuary contribute a significant proportion of the nutrient loads (SFWMD 2003). There are six sewage treatment plants (STPs) that are permitted to discharge directly to the Caloosahatchee River/Estuary watershed (**Table 11**). The total permitted discharge capacity from these systems is about 44 million gallons per day (mgd) [1.9 m^3/s]. The quality of this water is generally high with typical permit standards requiring a minimum of advanced secondary (nitrification) and some nutrient removal (tertiary treatment).

TABLE 11
Permitted wastewater treatment facilities in the Caloosahatchee Basin (FDEP web site).

Name of Facility	*Permitted Capacity (mgd)*
Lee Co. Fiesta Village WWTP	5
Lee Co. Waterway Estates	1.25
Ft. Myers Central	11
Ft. Myers South	12
Cape Coral Everest Parkway	8.5
Cape Coral Southwest	6.6

Potential Nutrient Load Reduction Opportunities

Nutrient loading rates within the Caloosahatchee Basin have been well documented by a number of researchers as summarized above. Some of these nutrient loads are controllable through normal water management/treatment activities (*e.g.*, runoff from citrus or urban stormwater) while others are not within the immediate control of society (*e.g.*, N and P in direct rainfall). Controllable nutrient loads typically include those arising from manmade non-point sources (stormwater) and those resulting from point sources such as agricultural and municipal wastewater treatment systems. Various opportunities to control these abatable nutrient sources are briefly summarized below.

Stormwater Best Management Practices

Current stormwater management regulations in southwest Florida require a fairly high level of water quality control for new urban developments. Additional nutrient controls that require post-development nutrient loads leaving a newly developed piece of land to not exceed pre-development loads have been required for some projects. This type of "no net loss" for maintaining watershed basin nutrient loading rates is often attainable through judicious conservation of on-site wetlands and other undeveloped areas and implementation of stormwater best management practices (BMPs) in the more intensely developed areas. A broad variety of stormwater BMPs are available. Many of these BMPs are described in greater detail for Lee County (Johnson Engineering 2005) and by the SFWMD (SFWMD 2002b).

Fertilizer Minimization

The use of fertilizers in large and small scale applications is generally aimed at faster growth or improved appearance of cultivated plants. Incorrectly applying fertilizers (in timing or volume) results in the transport of excess nutrients into surface waters through runoff. Any reduction of fertilizer runoff will be a positive contribution to water quality and nutrient load reduction. The kinds of fertilizer used by managers of large areas will differ from those used by private individuals on home lawns and gardens. Individuals need to be educated on the proper timing and amount of fertilizer for applications at home. Homeowners should have their soil tested to avoid the application of unnecessary nutrients. Large-area fertilizer users – institutional, business, industrial, and governmental – should obtain guidance on fertilizer management from specialists such as those of the Florida Cooperative Extension Service and USDA, Soil Conservation Service, or private firms (Florida Green Industries 2002).

The SFWMD (2002b) recommends BMPs specific to choosing a fertilizer and applying a fertilizer. The BMPs for choosing a fertilizer include selecting slow release fertilizer with the proper N-P-K proportions and following label instructions application procedures. Application BMPs focus of the timing of applications in relation to frequency and weather, and care in application procedures heeding waterways and impervious surfaces.

Fertilizer minimization is targeted toward reducing nitrogen and phosphorus in runoff. Soils in Florida are typically not lacking in phosphorus, so it is particularly important to look at the phosphorus content of soils and only add more as necessary.

Livestock Fencing

Livestock fences are installed to allow for rotation, deferment, and resting of grazing lands. To reduce erosion and avoid water quality degradation through the improved distribution of grazing animals and wildlife, fences need to be strategically placed. Any areas that receive periodic standing surface water such as swamps and marshes should be avoided (Florida Cattleman's Association 1999). Livestock wastes deposited in or near wetlands and waterbodies within a watershed contribute excess nutrients to surface waters. Fencing livestock away from wetlands and waterbodies also creates a buffer to filter wastes from runoff before it reaches surface waters.

Manure Management

Farm advisers and resource planners are recommending that the nutrient content of manure and soil be determined by soil test laboratories before land application of manure. Without such determinations, farmers and their advisers tend to underestimate the nutritive value of manure. Soil test results can also demonstrate the positive and negative long-term effects of manure use and the time required to build up or deplete soil nutrients. Soil tests can help a farmer identify the soils in need of P fertilization, those where moderate manure applications may be made, and fields where no manure applications need to be made for crop yield response (Sharpley *et al*. 2003).

Erosion Control

The use of erosion control blankets, mulches, and mats involve the application of organic materials to form a temporary, protective soil cover (Barr 2001). When selected and applied correctly, they are effective, practical means of controlling runoff and erosion on disturbed land prior to vegetation establishment. The timely establishment of a good stand of vegetation is critical for limiting soil erosion and for the effectiveness of most BMP's (Barr 2001). The State of Florida Department of Environmental Protection notes the most cost effective, environmentally friendly, and aesthetically pleasing form of erosion prevention is through the use of vegetation. Vegetative BMPs include surface roughening, topsoiling, mulching, vegetative streambank stabilization, and more. Vegetation protects soil from erosion from raindrops, runoff, water currents, and wind. Vegetated areas decrease runoff volume and runoff velocities. Further, vegetation will increase soil strength and stability.

There are also several structural methods that can be used to provide permanent and temporary erosion protection. For example, riprap is heavy stone placed around inlets and outlets of pipes or paved channels to provide protection against erosion. Riprap is a permanent, erosion-resistant protective layer intended to prevent soil erosion in areas of concentrated flow, turbulence, or wave energy (Barr 2001).

Buffer Strips

Buffer strips (**Figure 17)** are small areas or strips of land with permanent vegetation designed to intercept pollutants, reduce sediment, and manage other environmental concerns (SFWMD 2002b). Buffer strips work to reduce nutrient loads to receiving waters by removing sediment, fertilizers, pesticides, pathogens, and other potential contaminants from runoff. Buffer strips slow water runoff, trap sediment, and enhance infiltration within the buffer (NRCS website). Recommended areas of use are for agriculture and low density development. Vegetated buffer strips are often used as pretreatment for other structural practices, such as detention ponds and exfiltration trenches. Grassed buffer strips may develop a berm of sediment at the upper edge that must be periodically removed. Mowing will maintain a thicker vegetative cover, providing better sediment retention. Buffer strips are designed to target suspended sediments, total phosphorus, total nitrogen, heavy metals, trace metals, and oxygen demanding substances. They provide little treatment for concentrated flows (SFWMD 2002b).

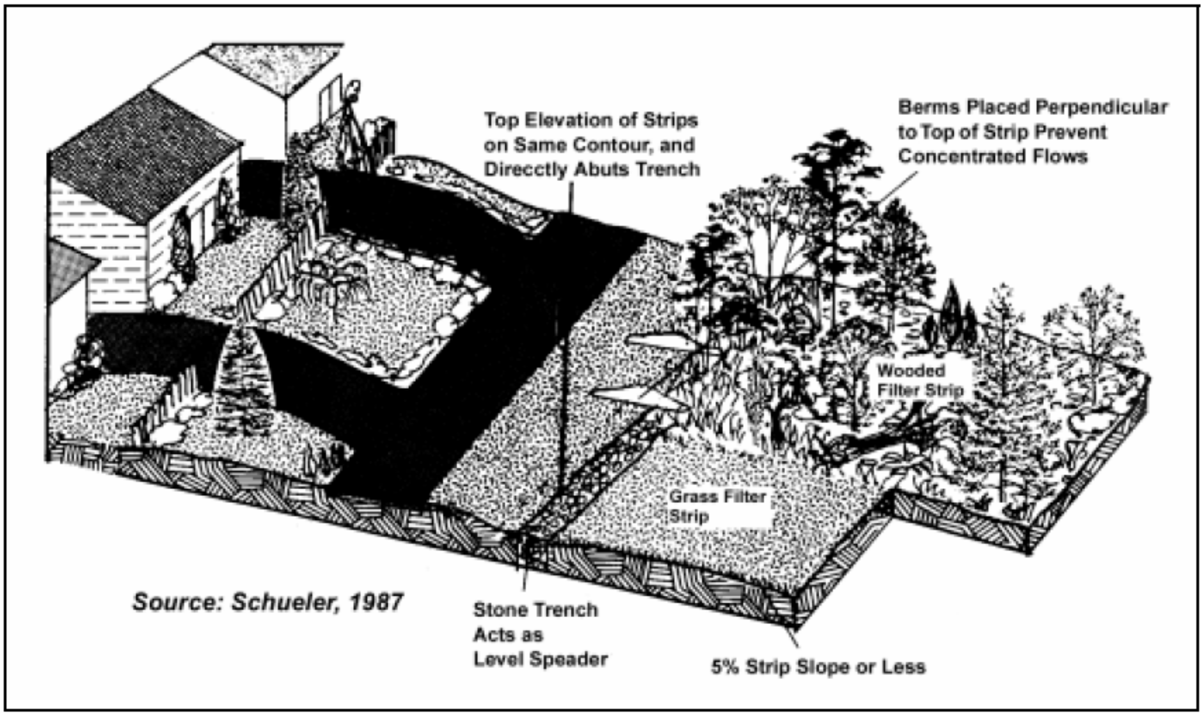


FIGURE 17
Buffer strip design (SFWMD 2002b)

Wet Detention Ponds

A wet detention pond (**Figure 18**) is a constructed stormwater pond that retains a permanent pool of water (SFWMD 2002b). They are designed to temporarily store urban runoff until it is released at a controlled rate. Hydraulic holding times are relatively short, such as hours or days. The primary pollutant removal mechanism in a wet pond is sedimentation. Significant loads of suspended pollutants, such as metals, nutrients, sediments, and organics can be removed by sedimentation. Dissolved contaminants are removed by a combination of processes: physical adsorption to bottom sediments and suspended fine sediments; natural chemical flocculation; bacterial decomposition; and uptake by aquatic plants and algae. Wet ponds have a moderate to high capacity for removing pollutants depending on how large the volume of the wet pond is in relation to the runoff from the surrounding watershed (SFWMD 2002b).

Wet detention ponds are designed to target suspended sediments, total phosphorus, total nitrogen, heavy metals, trace metals, and oxygen demanding substances (SFWMD 2002b). Wet detention ponds with short hydraulic residence times are generally less effective for reducing dissolved nitrogen forms.

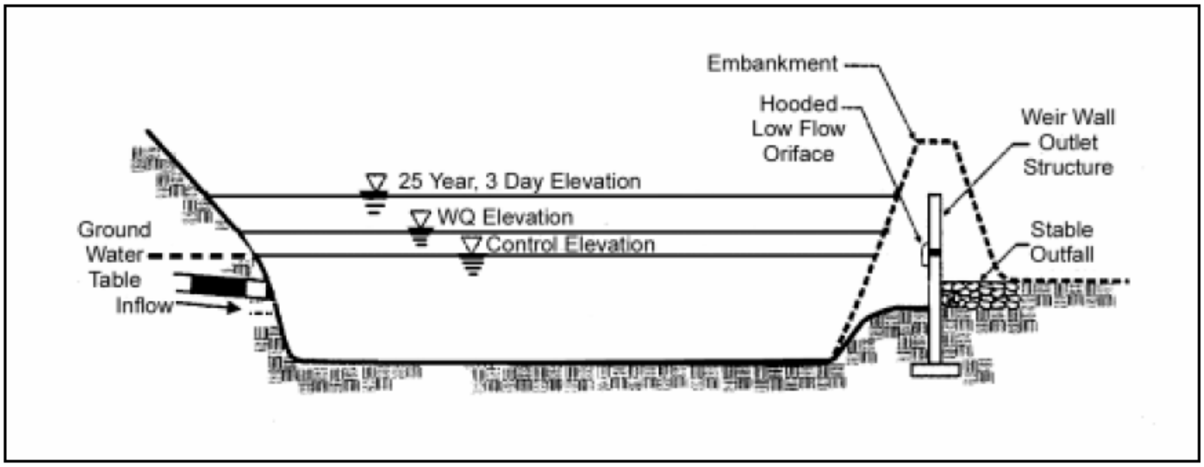


FIGURE 18
Wet detention pond design (SFWMD 2002b)

Retention Basins

Retention basins (**Figure 19**) are depressed areas where incoming urban runoff is temporarily stored until it gradually infiltrates into the surrounding soil (SFWMD 2002b). They are recommended for moderate to large drainage areas with moderate to large amounts of available open area. They may not be appropriate where ground water requires protection. For example, restrictions may apply to systems located above sole source (drinking water) aquifers. Retention basins are designed to target suspended sediments, TP, TN, heavy metals, oxygen demanding substances, and trace metals. Retention is an effective BMP for controlling nutrients, but often cannot be used in South Florida due to the very high groundwater tables (SFWMD 2002b).

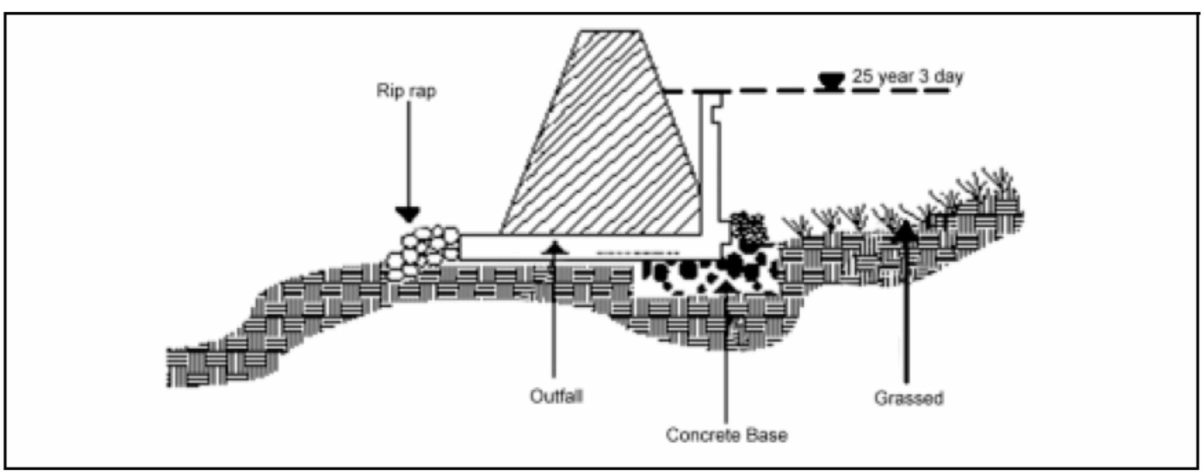


FIGURE 19
Retention basin design (SFWMD 2002b)

Grassed Swales

Grassed swales (**Figure 20**) are filtration and conveyance mechanisms that are generally used to provide pretreatment before runoff is discharged to treatment systems (SFWMD 2002b). They are ideal for low density, small drainage areas. They are designed to target suspended sediments, total phosphorus, total nitrogen, heavy metals, and oxygen demanding substances. If flows pass through rapidly and limited soil infiltration occurs, minimal pollutant removal can be expected. Further, the soil must have good infiltration rates (at least 0.5 inch per hour).

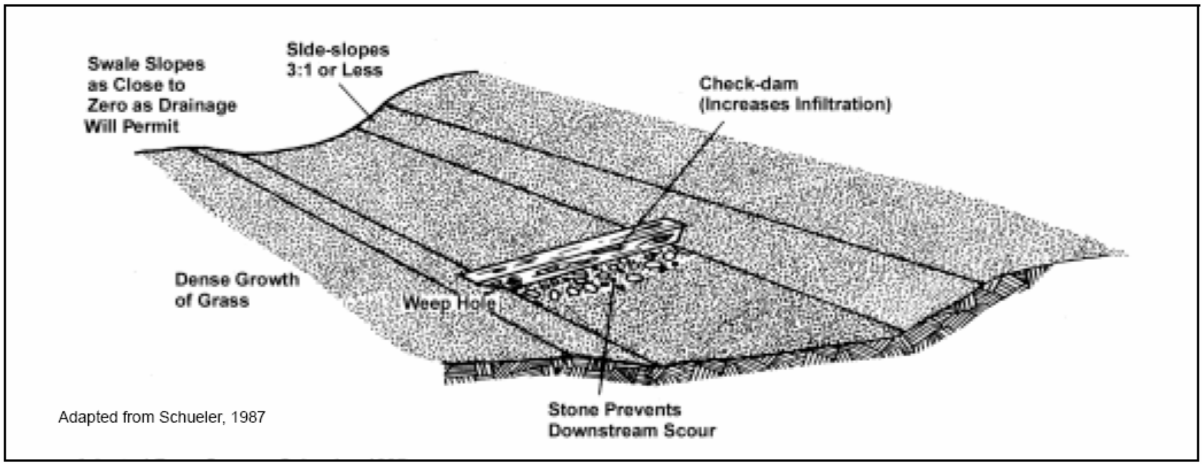


FIGURE 20
Grassed swale design (SFWMD 2002b)

Florida Lawns

Due to environmental considerations, many assume that less fertilizer is best, but studies have shown that fewer nutrients are lost from the surface or leached through healthy, maintained turfgrass and lawns. Turfgrass that receives the appropriate levels of fertilizer will produce a dense root and shoot system capable of filtering out impurities or other components of runoff. The importance of proper irrigation during fertilization cannot be overemphasized. Excessive irrigation after fertilization may cause leaching, and a lack of irrigation may result in fertilization inefficiency (Florida Green Industries 2002, Kelly-Begazo and McNair 2003).

Exfiltration Trenches

Exfiltration trenches are perforated pipes buried in trenches that have been backfilled with stone or sand/aggregate (SFWMD 2002b). Urban runoff diverted into the pipe gradually infiltrates from the pipe into the trench and into the subsoil, eventually reaching the ground water. Exfiltration trenches are recommended for high density development with deep permeable soils and small drainage areas. They provide little to no nutrient treatment for high flows and are not to be considered toward flood attenuation requirements. Again, restrictions may apply to systems located above sole source (drinking water) aquifers (SFWMD 2002b).

Temporary Sedimentation Basins/Traps

A temporary sedimentation basin is a controlled stormwater release structure formed by constructing an embankment of compacted soil across a drainageway and installing an outlet structure and outlet pipe. The purpose of the basin is to detain the sediment-laden runoff from disturbed areas long enough for the majority of the sediment to settle out in the basin. This reduces sediment transport off-site. Sediment traps are temporary settling ponds having a simple spill-way outlet structure stabilized with geotextile and riprap. Sediment traps do not include an outlet structure and pipe. Both are reliable measures used for treating sediment-laden runoff from construction sites. They are usually placed near the perimeter of construction sites and are recommended as a principal sediment control practice for construction sites (Barr 2001).

Treatment Wetlands

Treatment wetlands (**Figure 21**) are designed to maximize the removal of pollutants from stormwater runoff via several mechanisms: microbial breakdown of pollutants, plant uptake, retention, settling, and adsorption. They are designed to simulate the water quality improvement functions of natural wetlands to treat and contain surface water runoff pollutants and decrease loadings (SFWMD 2002b; Kadlec and Knight 1996).

For this reason and due to their relatively low capital and operational costs, treatment wetlands have been constructed throughout central and south Florida for the express purpose of TP retention and protection of downstream sensitive environmental resources. For example, over 45,000 acres (18,000 ha) of Stormwater Treatment Areas filter marshes have been built in the Everglades Agricultural Area alone for reduction of TP inputs to the Everglades protection Area (Goforth *et al.* 2005)

Treatment wetlands are effective in reducing most anthropogenic pollutants including nutrients, sediments, heavy metals, and trace organics (Kadlec and Knight 1996).

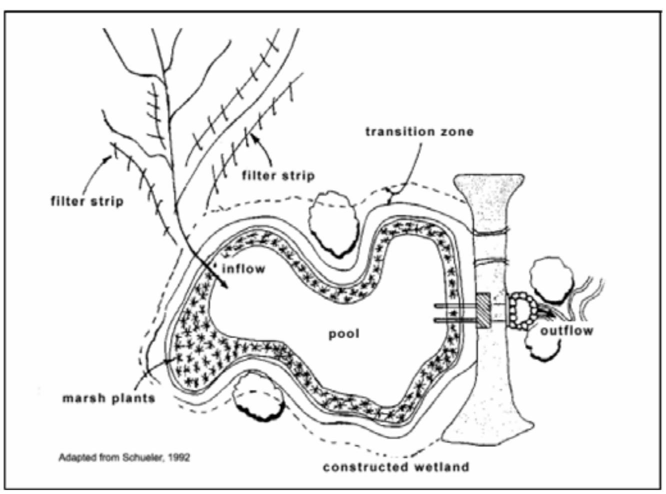


FIGURE 21
Treatment wetland design (SFWMD 2002b)

Enhanced Municipal Wastewater Treatment for Onsite and Point Source Discharges

A primary emphasis of wastewater treatment and disposal in Florida over the past three decades has been the reduction and elimination of point-source discharges to surface waters. This focus has been dictated by a well established realization that most of Florida's surface waters have limited assimilative capacity for biochemical oxygen demanding (BOD) substances and nutrients. Addition of BOD typically exacerbates naturally low DO concentrations in many of Florida's surface waters and low-gradient, high residence time systems such as meandering coastal rivers and estuaries are particularly susceptible to algal blooms due to increased nutrient concentrations and loads. Unfortunately, due to the typical climatic conditions in Florida of high seasonal humidity and rainfall, true zero-discharge wastewater disposal systems are frequently not feasible. This condition results either in some portion of the nutrients in land-disposed water entering surface waters through underground pathways or in failed land application systems that have considerable documented or undetected surface runoff to adjacent waters. Where nutrients are just being transferred from one point to another, there may be established technologies that are preferable to existing wastewater management methods. Some of these are described briefly below.

Replacement of Septic Systems

As urban development expands into areas that rely on septic systems for sewage treatment, these areas need to be connected to centralized wastewater treatment plants. Centralized water treatment plants are generally more reliable and effective in treating wastewater and at reducing nutrient loads to adjacent water bodies. The cumulative number of septic system installations between 1970 and 2004 in Charlotte, Collier, Glades, Hendry, Lee, and Palm Beach Counties are presented in **Table 12**. These totals do not reflect systems that are removed from septic services.

TABLE 12
Septic system installations (1970 – 2004) by county (Florida Department of Health)

County	Septic system Installations (1970 - 2004)
Charlotte	39,234
Collier	39,497
Glades	4,769
Hendry	9,307
Lee	98,938
Palm Beach	77,391

Tertiary Treatment

Secondary treatment is the minimal level of municipal and industrial treatment that is required in the U.S. before discharge to most surface receiving waters. Advanced biological treatment processes are available for varying levels of nitrogen transformation and phosphorus concentration reductions. Reductions of biochemical oxygen demand, total suspended solids, nitrogen, and phosphorus beyond those typically accomplished by secondary treatment are tertiary or advanced treatment.

Advanced wastewater treatment accomplishes nitrification. Nitrification alone does not reduce the total mass of nitrogen; however the process of denitrification microbially transforms NO_x-N into nitrogen gas, which is lost to the atmosphere. This process is anoxic and occurs to a limited extent in conventional aerated treatment processes such as activated sludge or trickling filter units. Wastewater treatment systems can be designed for denitrification by including an anaerobic process after effluent nitrification (Kadlec and Knight 1996).

Biological phosphorus removal relies on an uptake of phosphorus that occurs in microbial populations during growth under vigorously aerated conditions. With higher uptake rates and increased sludge wastage, a higher percentage of dissolved phosphorus can be removed from wastewater. Phosphorus removal from wastewaters is also frequently accomplished through several conventional chemical and physical processes. Chemical processes typically use aluminum or iron salts to chemically precipitate dissolved phosphorus and remove it in a solid (sludge) form. Total phosphorus removal efficiency through chemical precipitation can exceed 90 percent in municipal effluents (Kadlec and Knight 1996).

Combinations of advanced wastewater treatment technologies can also reduce concentrations of biochemical oxygen demand and total suspended solids below the typical secondary treatment level.

Treatment Wetlands

Constructed and natural wetland treatment systems are widely used in Florida for nutrient reduction of municipal effluents. Treatment wetlands use rooted, water-tolerant plant species and shallow, flooded, or saturated soil conditions to provide various types of wastewater treatment. Treatment wetlands mimic the optimal treatment conditions found in natural wetlands, but provide the flexibility of being constructible at almost any location. They can be used for treatment of primary and secondary wastewaters, but are most often used in tertiary treatment and advanced polishing. Treatment wetlands have been found to be effective in treating biochemical oxygen demand, suspended solids, nitrogen, and phosphorus, as well as for reducing metals, organics, and pathogens. Effective wetland performance relies on adequate pretreatment, conservative constituent and hydraulic loading rates, collection of monitoring information to assess system performance, and knowledge of successful operation strategies (Kadlec and Knight 1996).

Comprehensive Everglades Restoration Plan (CERP)

Decreased flows during the wet season and increased freshwater flows during the dry season are the target of the proposed C-43 Basin Storage Reservoir project as part of the Comprehensive Everglades Restoration Plan (CERP). The discharge of freshwater from S-79 controls the downstream water quality based on the overwhelming dominance of the Caloosahatchee River as a source of nutrients and other materials to the downstream estuary (Doering and Chamberlain 2004). Changes in discharges are likely to alter nutrient loading. In support of the CERP Water Quality Team efforts, Doering and Chamberlain (2004) analyzed total nitrogen loading at the Franklin Lock and Dam (S-79). The discharge at S-79 accounts for 88%-92% of TN loading from surface waters during the wet and dry seasons, respectively. Janicki Environmental (2003) estimated that TN loads exceeding 350 English tons/month in the wet season and 190 tons/month in the dry season (or annual loads greater than 3000 tons/year) result in chlorophyll-*a* concentrations exceeding a potential target value of 11 ug/l. CERP suggests marked changes in the volume and timing of delivery of freshwater at S-79, as nutrient loading into the Caloosahatchee is primarily a function of discharge (rather than concentration). Thus, changes in discharges are likely to alter nutrient loading. This analysis suggests that reductions in flow projected to occur as a result of CERP will decrease nutrient loading to the Caloosahatchee Estuary. However, the TN loading estimates calculated for each model output scenario assume that concentrations in the future remain on average as they have for the past 22 years. This conclusion is rendered suspect by the lack of reliable estimates of future TN concentrations in water released at S-79. These future concentrations will be influenced by population growth, land use in the C-43 basin, impoundment of runoff in reservoirs, and use of Aquifer Storage and Retrieval wells. The volume weighted impact of each of these factors requires evaluation. Additional details of this analysis are provided in **Appendix A**.

Summary

Numerous projects, initiatives, and programs have been instituted with the express purpose of addressing environmental problems associated with water quality and quantity changes in the Caloosahatchee River/Estuary. Nutrient load reductions resulting from the C-43 CERP project will be accomplished through flow reductions. Historically, nutrient load reductions have been accomplished through control of point sources with relatively high concentrations and low discharge volume. Here the reduction is accomplished primarily by decreasing loads that are primarily a function of high discharge with a low concentration.

Additional nutrient controls are needed in addition to control of timing of fresh water flows to help fully restore the Caloosahatchee aquatic ecosystem. A variety of agricultural and urban best management practices (BMPs) are potentially available to help reverse the apparent increasing nutrient loading rate trends. In addition point sources (stormwater and municipal wastewater) can be further polished to reduce their contributions to anthropogenic nutrient loads to the estuary. It will take a variety of technical solutions as well as serious political and economic will power to reverse the increasingly-evident nutrient associated impacts to the Caloosahatchee ecosystem.

References

Barnes, T., Rumbold, D., and M. Salvato. 2003. Caloosahatchee Estuary and Charlotte Harbor Conceptual Model. Draft.

Barr Engineering Company. 2001. Minnesota Urban Small Sites BMP Manual. Metropolitan Council Environmental Services, St. Paul, MN.

Bricker, S.B., and J.C. Stevenson. 1996. Nutrients in Coastal Waters: A Chronology and Synopsis of Research. *Estuaries*. 19(2B): 337-341

Charlotte Harbor Estuary Program. Technical Report No. 98-02. South Florida Water Management District, West Palm Beach, Florida.

Chamberlain, R. and D. Hayward. 1996. Evaluation of water quality monitoring in the St. Lucie Estuary, Florida. Water Resources Bulletin 32(4).

Chamberlain , R.H. and P. H. Doering. 1998. Freshwater Inflow to the Caloosahatchee Estuary and the Resource-Based Method for Evaluation. Pp. 81-90 in: S.F. Treat (ed.) Proceedings of the Charlotte Harbor Public Conference and Technical Symposium.

Chamberlain , R.H. and P. H. Doering. 1998. Preliminary Estimate of Optimum Freshwater Inflow to the Caloosahatchee Estuary: A Resource-based Approach. Pp. 121-130 in: S.F. Treat (ed.) Proceedings of the Charlotte Harbor Public Conference and Technical Symposium. Charlotte Harbor Estuary Program. Technical Report No. 98-02. South Florida Water Management District, West Palm Beach, Florida.

Dennison et al. 1993. Assessing Water Quality with Submersed Aquatic Vegetation. *BioScience* 43(2): 86-94

Doering, P.H. 2005. The Caloosahatchee Estuary: Status and Trends in Water Quality in the Estuary and Nutrient Loading at the Franklin Lock and Dam (Draft).

Doering, P.H. 1996. Temporal variability of water quality in the St. Lucie Estuary, south Florida. Water Resources Bulletin 32(6).

Doering, P.H., and R. H. Chamberlain. 2004. Total Nitrogen Loading to the Caloosahatchee Estuary at the Franklin Lock and Dam (S-79): Interim CERP Water Quality Update. South Florida Water Management District, Coastal Ecosystem Division, Unpublished Technical Analysis for CERP WQT ICU.

Doering, P.H., and R. H. Chamberlain. 1999. Water Quality and Source of Freshwater Discharge to the Caloosahatchee Estuary, Florida. *Journal of the American Water Resources Associations*, 35(4): 793-806.

Doering, P.H., and R. H. Chamberlain. 1998. Freshwater Inflow to the Caloosahatchee Estuary and the Resource-Based Method for Evaluation. Pp. 81-90 in: S.F. Treat (ed.) Proceedings of the Charlotte Harbor Public Conference and Technical Symposium.

Doering, P.H., and R. H. Chamberlain. 1998. Preliminary Estimate of Optimum Freshwater Inflow to the Caloosahatchee Estuary: A Resource-based Approach. Pp. 121-130 in: S.F. Treat (ed.) Proceedings of the Charlotte Harbor Public Conference and Technical Symposium. Charlotte Harbor Estuary Program. Technical Report No. 98-02. South Florida Water Management District, West Palm Beach, Florida.

Doering, P.H., and R. H. Chamberlain. 1998. Water Quality in the Caloosahatchee Estuary, San Carlos Bay and Pine Island Sound, Florida. Pp. 229-240 in: S.F. Treat (ed.) Proceedings of the Charlotte Harbor Public Conference and Technical Symposium. Charlotte Harbor Estuary Program. Technical Report No. 98-02. South Florida Water Management District, West Palm Beach, Florida.

Doering, P.H., R.H. Chamberlain and D. E. Haunert. 2002. Using submerged aquatic vegetation to establish minimum freshwater inflows to the Caloosahatchee estuary, Florida. Estuaries 25 (6B): 1343-1354.

Environmental Research & Design, Inc. (ERD). 2003. Caloosahatchee Water Quality Data Collection Program. Final Interpretive Report for Years 1-3. Prepared for the South Florida Water Management District. Orlando, FL.

Fernandez Jr. M., M. Marot, and C. Holmes. 1998. Reconnaissance of Chemical and Physical Characteristics of Selected Bottom Sediments of the Caloosahatchee River and Estuary, Tributaries, and Contiguous Bays, Lee County, Florida, July 20-30, 1998.

Flaig, E. G. and J. C. Capece. 1998. Water use and runoff in the Caloosahatchee watershed. Pp. 73-80 in: S.F. Treat (ed.) Proceedings of the Charlotte Harbor Public Conference and Technical Symposium. Charlotte Harbor Estuary Program. Technical Report No. 98-02. South Florida Water Management District, West Palm Beach, Florida.

Florida Cattleman's Association. 1999. Water Quality Best Management Practices for Cow/calf Operations in Florida. Kissimmee, FL.

Florida Department of Environmental Protection. 2003. Basin Status Report Caloosahatchee. South District Division of Water Resources Management, Tallahassee, Florida.

Florida Department of Environmental Protection. 1999. Preliminary findings of the St. Lucie Monitoring Program. Southeast District Water Quality Assessment Program, Port St. Lucie, Florida.

Florida Green Industries. 2002. Best Management Practices for Protection of Water Resources in Florida.

Goforth, G., K. Pietro, M. Chimney, J. Newman, T. Bechtel, G. Germain, and N. Iracanin. 2005. STA Performance, Compliance, and Optimization. Chapter 4 in 2005 South Florida Environmental Report. SFWMD, West Palm Beach, FL.

Janicki Environmental, Inc. 2003. Development of Critical Loads for the C-43 Basin, Caloosahatchee River. Prepared for: Florida Department of Environmental Protection, Tallahassee, FL. Prepared by: Janicki Environmental, Inc., St. Petersburg, FL.

Janicki Environmental, Inc. 2002. Development of Water Quality Targets for the C-43 Basin, Caloosahatchee River. Prepared for: Florida Department of Environmental Protection, Tallahassee, FL. Prepared by: Janicki Environmental, Inc., St. Petersburg, FL.

Janicki, A., D.Wade, J. R. Pribble, and A. Squires. 1999. St. Lucie Watershed Assessment. Task A. Watershed Characterization. Prepared for South Florida Water Management District. Final Report. Tampa, Florida.

Jaworski, N.A. 1981. Sources of Nutrients and the Scale of Eutrophication Problems in Estuaries, p. 83-110. *In*: B.J Neilson and E.J Cronin (Eds.), Nutrients and Estuaries. Humana, Clifton, New Jersey.

Johnson Engineering. 2005. Literature Review of Stormwater Treatment Best Management Practices Research in Florida. Prepared for Lee County Board of County Commissioners, Ft. Myers, FL.

Kadlec, R.H. and R.L. Knight. 1996. Treatment Wetlands. CRC Press-Lewis Publishers, Boca Raton, FL.

Kelly-Begazo, C., and R. McNair. 2003. A Guide to Environmentally Friendly Landscaping, Florida Yards and Neighborhoods Handbook, Second Edition. University of Florida IFAS Extension.

Masters, G.M. 1998. Introduction to Environmental Engineering and Science. Second Edition, Prentice Hall Inc., Upper Saddle River, New Jersey.

McPherson, B.F., Montgomery, R.T., and E. E. Emmons. 1990. Phytoplankton Productivity and Biomass in the Charlotte Harbor Estuarine System, Florida. *Journal of the American Water Resources Associations*, 26(5): 787-800.

McPherson, B.F., and R.L. Miller. 1990. Nutrient Distribution and Variability in the Charlotte Harbor Estuarine System, Florida. *Journal of the American Water Resources Associations*, 26(1): 67-80.

Mitsch, W.J. and J.G. Gooselink. 2000. Wetlands. Third Edition, John Wiley and Sons Inc., New York, New York.

Murdock, J.F. 1954. A Preliminary Survey of the Effects of Releasing Water from Lake Okeechobee through the St. Lucie and Caloosahatchee Estuaries. Final Report to U.S. Army Corps of Engineers. Coral Gables, Florida, June, 1954.

National Resources Conservation Service Website: http://www.nrcs.usda.gov/

Reid, G.K. and R.D. Wood. 1976. Ecology of Inland Waters and Estuaries. Second Edition. D. Van Nostrand Co., new York. 485 pp.

Ryther, J.H., and W.M. Dunstan. 1971. Nitrogen, Phosphorus, and Eutrophication in the Coastal Marine Environment. *In*: B.J Neilson and E.J Cronin (Eds.), Nutrients and Estuaries. 1981. Humana, Clifton, New Jersey.

Schofield, O. and C. von Alt. 2003. Making Progress on Harmful Algal Blooms: Lessons from the Gulf of Mexico. Case Study, pp. 33-34 in: ALPS Autonomous and Lagrangian

Platforms and Sensors. A Report of the Workshop Held March 31-April 2, 2003 in La Jolla, California.

Sharpley, A.N., T. Daniel, T. Sims, J. Lemunyon, R. Stevens, and R. Parry. 2003. Agricultural Phosphorus and Eutrophication, Second Edition. U.S. Department of Agriculture, Agriculture Research Service, ARS-149, 44 pp.

Smith, V.H., Tilman, G.D., and J.C. Nekola. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environmental Pollution* 100 (1999): 179-196

South Florida Water Management District (SFWMD) no date. Adaptive Protocols for Lake Okeechobee Operations. Ecosystem Restoration, Water Supply, and Operations Control and Maintenance Engineering Departments. Final Draft.

South Florida Water Management District (SFWMD). 2003. Draft CERP Monitoring and Assessment Plan A-137. Draft.

South Florida Water Management District (SFWMD). 2002a. Adaptive Protocol for Lake Okeechobee Operations. Ecosystem Restoration, Water Supply, and Operations Control and Maintenance Engineering Departments. Final Draft.

South Florida Water Management District (SFWMD). 2002b. Best Management Practices for South Florida Urban Stormwater Management Systems. Technical Pub. REG-004. Everglades Stormwater Program, South Florida Water Management District, West Palm Beach, FL.

South Florida Water Management District (SFWMD). 2000. Caloosahatchee Water Management Plan – Support Document.

South Florida Water Management District (SFWMD) DBHydro Website: http://glades.sfwmd.gov/pls/dbhydro_pro_plsql/show_dbkey_info.main_page

South Florida Water Management District (SFWMD) GIS Website: http://www.sfwmd.gov/org/gisit/index

Southwest Florida Regional Planning Council (SWFRPC) 2005. http://www.swfrpc.org/Economic Data/popul.htm

Stanley, J.G., and M.A. Sellers. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic)—American oyster. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.65). U.S. Army Corps of Engineers, TR EL-82-4. 25 pp.

Steidenger, K.A. 1975. Basic Factors Influencing Red Tides. Pp. 153-162 in: V.R. LoCicero (ed.) proceedings of the first International Conference on Toxic Dinoflagellate Blooms. Mass. Sci. & Tech. Found.

Steidenger, K.V., G.A. Vargo, P.A. Tester, C.R. Tomas. 1998. Bloom dynamics and Physiology of *Gymnodinium breve* with Emphasis on the Gulf of Mexico. Pp. 133-153 in: D.M. Anderson, A.D. Cembella, and G.M. Hallegraeff (eds.) Physiological Ecology of Harmful Algal Blooms. Heidelberg, Springer-Verlag NATO – Advanced Study Institute Series, Vol. 41.

Tester, P.A. and K.A. Steidinger. 1997. *Gymnodinium breve* red tide blooms: Initiation, transport, and consequences of surface circulation. *Limnol. Oceanogr.* 42(5.part 2): 1039-1051.

Tetra Tech Inc. and Janicki Environmental Inc. 2004. Compilation, Evaluation, and Archiving of Existing Water Quality Data for Southwest Florida. Final Report to Department of the Army Corps of Engineers, Jacksonville, Florida, May 5, 2004. Contract No. DACW 17-02-D-0009.

Tomasko, D.A., Dawes, C.J., and M.O. Hall. 1996. The Effects of Anthropogenic Enrichment on Turtle Grass (*Thalassia testudinum*) in Sarasota Bay, Florida. *Estuaries* 19(2B): 448-456.

U.S. Army Corps of Engineers (USACE) and South Florida Water Management District (SFWMD), in prep. C-43 Basin Storage Reservoir. Draft Project Implementation Report. Central and Southern Florida Project. Scheduled to be released late 2006 or early 2007.

U.S. Army Corps of Engineers (USACE) and South Florida Water Management District (SFWMD) 2004a. Integrated project Implementation Report Environmental Impact Statement. Final. Central and Southern Florida Project Indian River lagoon – South. Jacksonville District and West Palm Beach, Florida.

U.S Army Corps of Engineers (USACE) and South Florida Water Management District (SFWMD). 2004b. C-43 Basin Storage Reservoir Project Part I. Comprehensive Everglades Restoration Plan Existing Conditions, August 24, 2004.

U.S. Environmental protection Agency (USEPA) STORET Website:
http://www.epa.gov/storet

U.S. Geological Survey (USGS). 1983. Chemical and Hydrological Assessment of the Caloosahatchee River Basin, Lake Okeechobee to Franklin Lock, Florida. Water Resources Investigation Report 83-4126. Tallahassee, Florida. 63 pp.

U.S. Geological Survey (USGS) Water Resources Data Website:

http://www.waterdata.usgs.gov/nwis

Valiela, I. et al. 1997. Macroalgal blooms in shallow estuaries: Controls and ecophysiological ecosystem consequences. *Limnol. Oceanogr.* 42(5.part 2): 1105-1118

Wetzel, R. 2001. Limnology. Lakes and River Ecosystems. Third Edition, Academic Press, Orlando, FL

Woodward-Clyde Consultants. 1994. Loadings Assessment of the Indian River Lagoon. Indian River lagoon National Estuary Program, Melbourne, Florida. Prepared for the Indian River Lagoon National Estuary Program. Tampa, Florida.

Appendix A - Review of Research Studies Specific to the Caloosahatchee River/Estuary

Murdock, J.F. 1954. A Preliminary Survey of the Effects of Releasing Water from Lake Okeechobee through the St. Lucie and Caloosahatchee Estuaries. Final Report to U.S. Army Corps of Engineers. Coral Gables, Florida, June, 1954.

The effects of releasing water from Lake Okeechobee through the Caloosahatchee Estuary have been documented since the mid-fifties. This document is an observation of changes in the Caloosahatchee Estuary. Evidence is presented that the release of water from Lake Okeechobee caused changes in salinity, oxygen content, hydrogen ion concentration and turbidity of the estuarine waters. These conditions are severe enough at or near maximum release to cause temporary movements of marine life from the lower river, the southern part of Matlacha Pass, and sections of San Carlos Bay. The sports fishery is hampered in the aforementioned areas. Sediments are being deposited in the Caloosahatchee River but do not affect the fisheries of the estuary. The continuing high rate of water release from the Caloosahatchee River may be a contributing cause of Red Tide outbreaks; it is possible that the contributions of the Peace River and other drainage systems are sufficiently greater toward that end. It is recommended that control measures be taken to minimize the water hyacinth damage.

McPherson, B.F., and R.L. Miller. 1990. Nutrient Distribution and Variability in the Charlotte Harbor Estuarine System, Florida. ***Journal of the American Water Resources Associations*****, 26(1): 67-80.**

The Charlotte Harbor estuarine system examined in this study includes the Caloosahatchee Estuary. The sources and distribution of nutrients in the Charlotte Harbor estuarine system were evaluated using nutrient dilution curve models. With the exception of ammonia, nutrient concentrations were highest and most variable in the rivers and generally decreased with increasing salinity. Concentrations of nitrite + nitrate were well below conservative dilution curves, probably due to phytoplankton uptake. At salinities greater than 20 parts per thousand (ppt), nitrite + nitrate concentrations were usually at or below the detection limit and may limit phytoplankton productivity. Projected increased nitrogen loadings from urban development in the basin would favor undesirable increases in phytoplankton and benthic algal growth in waters where sufficient light is available.

This evaluation is based on data collected in the estuary from 1982- 1985 and on long-term data collected in the major rivers. The sampling locations and nutrient transects for this study are depicted in **Figure A1**.

Annual and seasonal variability in nutrient concentrations in the Caloosahatchee River is presented in **Figure A2**. At S-79, concentrations of TP, orthophosphate, TN, and nitrite + nitrate increased over the last 15 years and were higher after 1981 than for the period of record (**Figure A2**, **Table A1**).

Observed values of nutrient concentrations as compared to the theoretical dilution curve are shown in **Figure A4**. Observed curves that deviate from the theoretical dilution curves suggest nonconservative behavior or river source variation. In contrast, observed curves that were occasionally close to their theoretical mixing curves suggest conservative behavior. More frequently, the observed curves deviated from the theoretical curves, suggesting river source variability.

The relatively low concentrations of inorganic nitrogen may, at times, limit plant growth in the estuary. Concentrations of nitrite plus nitrate and ammonia were inversely related to phytoplankton chlorophyll-a (**Figure A3**). This suggests that phytoplankton are a major sink for these forms of nitrogen. Estimates of phytoplankton productivity in the Charlotte Harbor estuary indicate that significantly more nitrogen is needed than is available from rainfall and runoff. Recycling processes in the estuary are likely a major source of nitrogen and these processes may largely control phytoplankton productivity during much of the year.

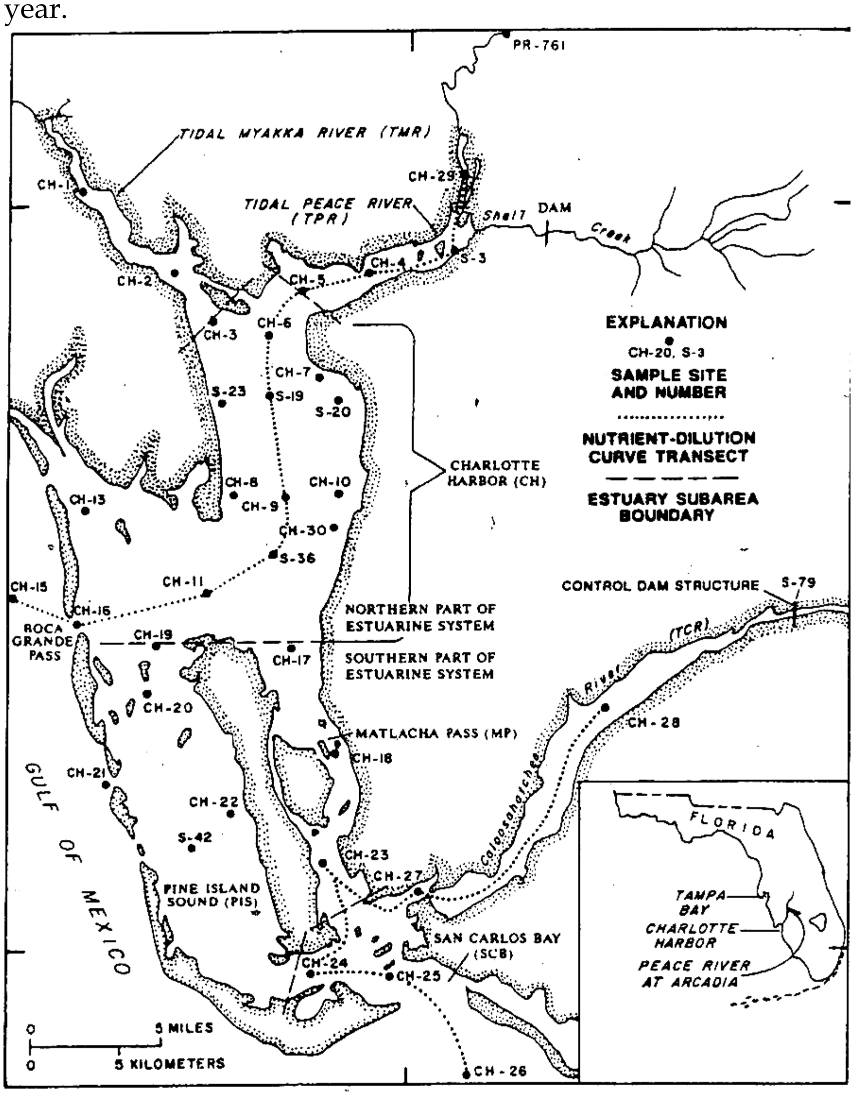


FIGURE A1
Charlotte Harbor Estuary, Sampling Locations, and Nutrient Transects.

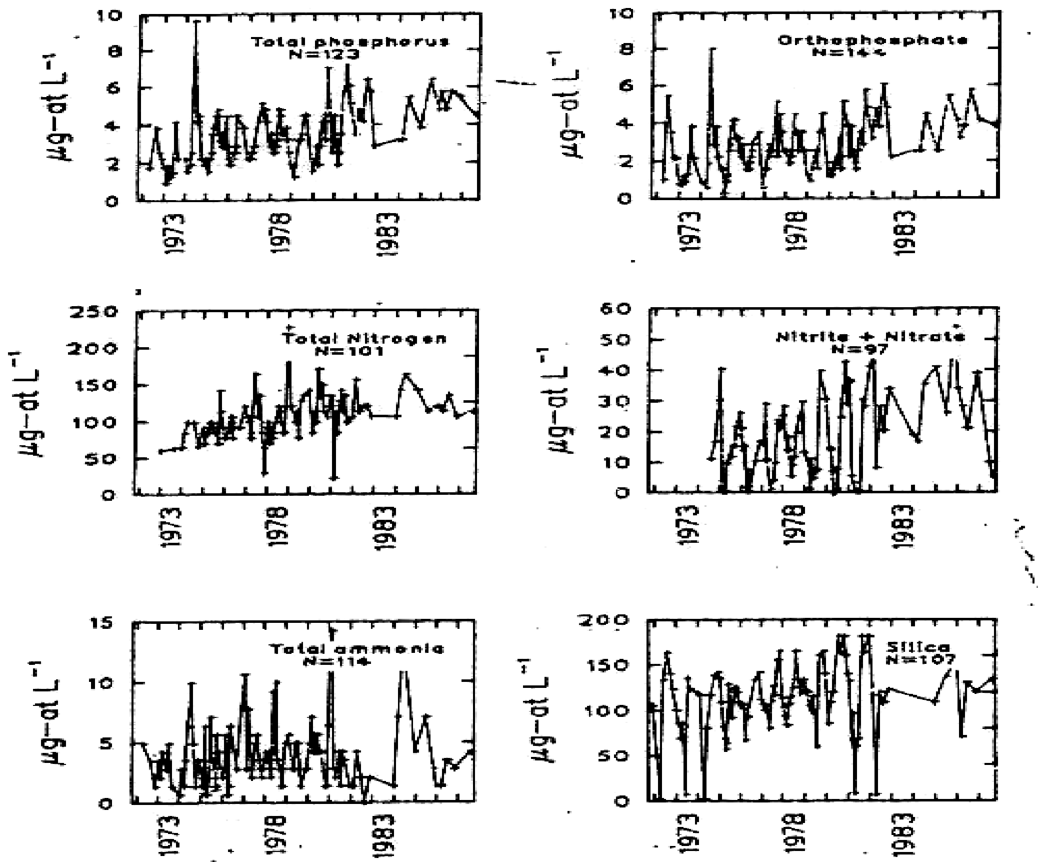


FIGURE A2
Concentrations of Selected Nutrients in the Caloosahatchee River at S-79, 1973-87

Freshwater runoff from the basin is a major source of new nitrogen to the estuarine system, stimulating phytoplankton productivity. Peak productivity and chlorophyll-a concentration occur in the estuary during late summer when freshwater runoff and nutrient loading are greatest.

Although inorganic nitrogen is in abundant supply in the low salinity waters of the tidal rivers, productivity may be limited by highly colored water that greatly restricts light penetrating in the water column. The nutrient-rich, colored river water is diluted by seawater at mid-salinities (near the river mouths) and availability of light increases. Enough inorganic nitrogen remains available from the runoff to stimulate productivity and growth.

Availability of light may be more important than availability of nutrients for aquatic plant growth in parts of the estuary. Nevertheless, increased nitrogen input would favor phytoplankton and benthic algal growth. Also, benthic algae also could increase undesirably in extensive areas of shallow water where sufficient light is available for growth.

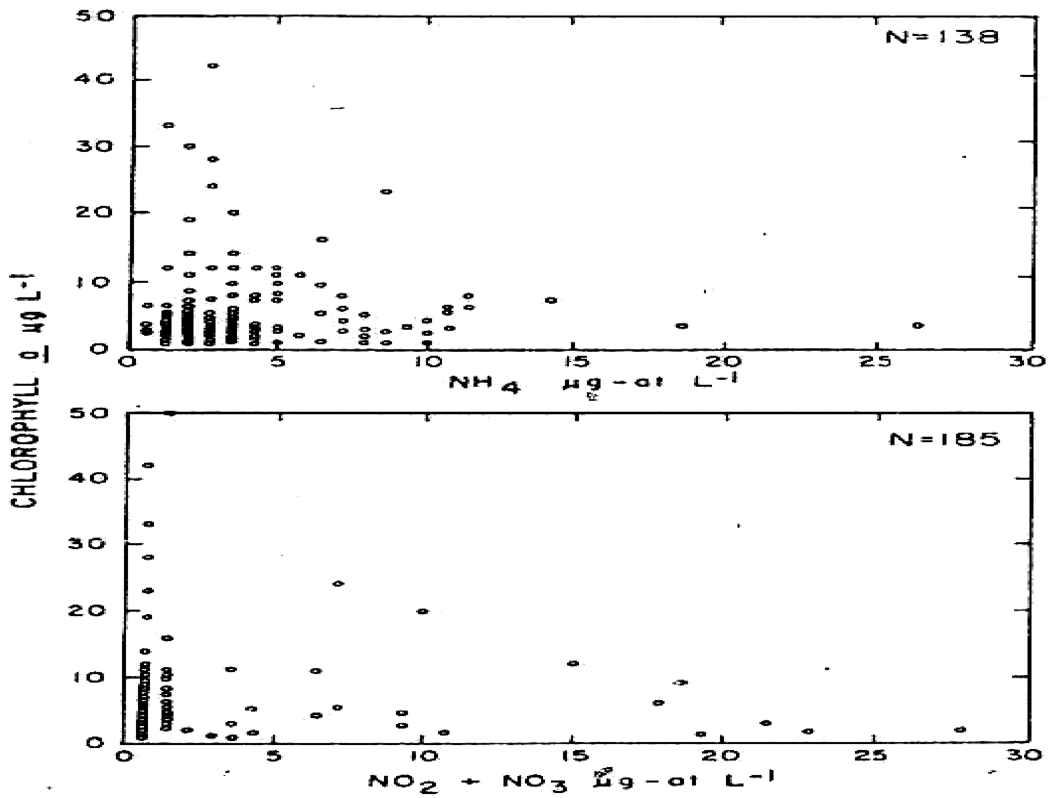


FIGURE A3
Concentrations of Ammonia and Nitrite Plus Nitrate Nitrogen versus Chlorophyll-a in the Charlotte Harbor Estuary, 1982-85

TABLE A1
Average Concentration of Nutrients in the Peace River at Arcadia, Caloosahatchee River at S-79, and the Gulf of Mexico. [Values are in µg-at L^{-1} unless otherwise indicated. N = number of samples; SD = standard deviation.]

	Period of Record			After 1981		
	N	Mean	SD	N	Mean	SD
Peace River at Arcadia						
Conductance (µS cm^{-1})	498	301	124	36	324	119
Total-N	86	133.8	60.1	13	124.7	24.3
NO_2+NO_3	80	53.2	34.3	13	42.2	17.6
NH_4	122	5.54	4.85	22	4.1	2.75
Total-P	145	79.3	46.6	38	46.0	24.4
Ortho-P	107	75.9	43.4	14	35.9	13.4
SiO_2	496	137.3	61.6	34	98.2	59.1
Caloosahatchee River at S-79						
Conductance (µS cm^{-1})	131	770	544	14	747	297
Total-N	103	117.3	84.8	17	124	17.9
NO_2+NO_3	97	17.5	12.8	17	29.7	13.4
NH_4	114	3.98	2.67	17	3.57	3.12
Total-P	113	3.54	1.49	17	4.79	1.14
Ortho-P	114	2.82	1.36	17	4.01	1.18
SiO_2	142	107.6	39.4	14	119.7	40.9
Gulf of Mexico, CH-15						
Salinity (‰)	--	--	--	8	33.3	2.47
Total-N	--	--	--	1	55.7	0
NO_2+NO_3	--	--	--	7	<0.7	0
NH_4	--	--	--	7	2.65	1.35
Total-P	--	--	--	8	2.02	0.54
Ortho-P	--	--	--	8	1.17	0.34
SiO_2	--	--	--	3	6.66	4.4

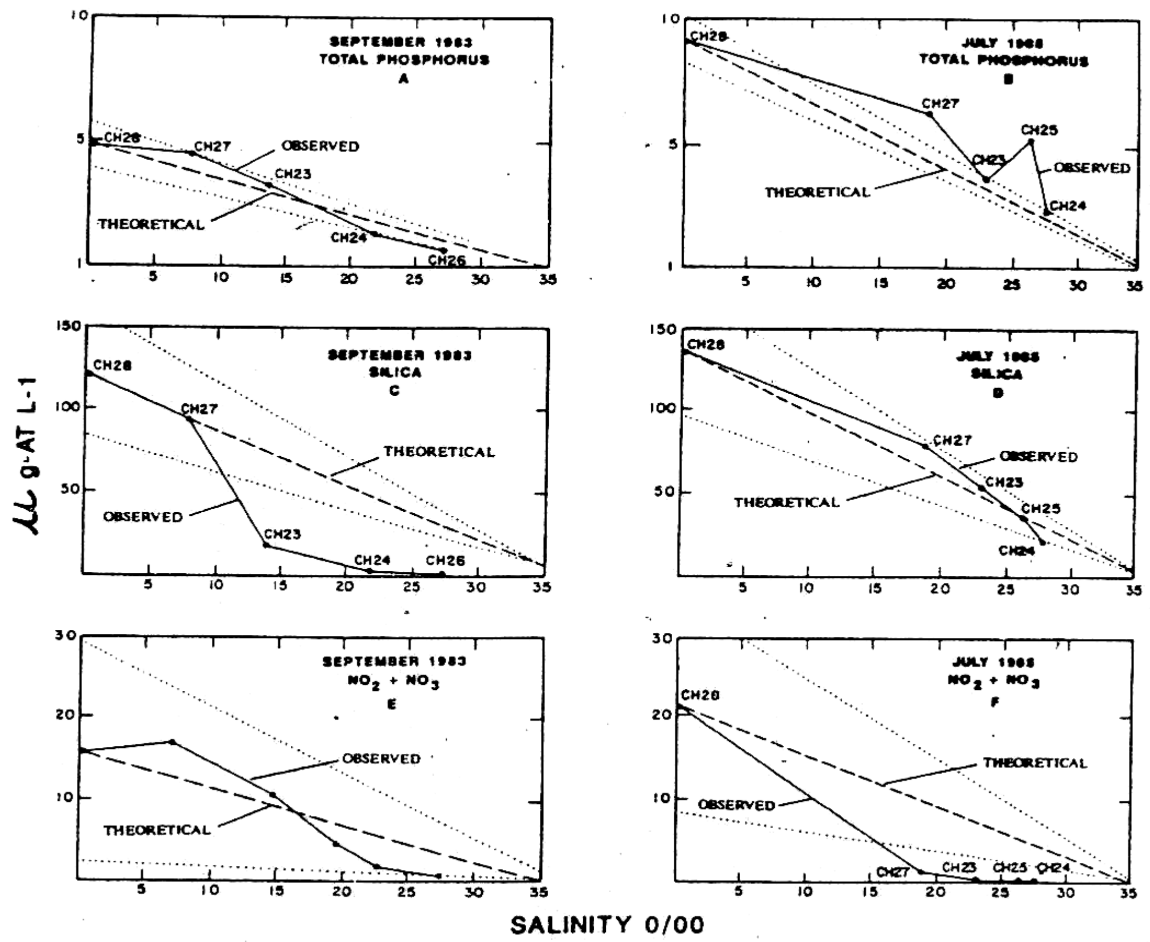


FIGURE A4
Selected Nutrient Dilution Curves for Southern Charlotte Harbor. Dotted lines indicate one standard deviation from the theoretical curve, based on the variability of nutrient concentrations in freshwater in the Caloosahatchee River at S-79, 1982-96

McPherson, B.F., Montgomery, R.T., and E. E. Emmons. 1990. Phytoplankton Productivity and Biomass in the Charlotte Harbor Estuarine System, Florida. ***Journal of the American Water Resources Associations*****, 26(5): 787-800.**

The Charlotte Harbor estuarine system is adjacent to the Caloosahatchee Estuary. Freshwater inputs from the surrounding basin are causing phytoplankton productivity and an increase in phytoplankton biomass. Generally, phytoplankton productivity and biomass maxima occur during the warmer seasons of the year and are usually controlled by either nutrient or light availability. For this study the authors looked at measurements of phytoplankton carbon-14 productivity at a depth of 50% of surface light, and chlorophyll-a concentrations, every other month, from November 1985 through September 1986 at 12 stations in the Charlotte Harbor estuarine system.

The variability in light-normalized productivity and chlorophyll-a was attributed to two factors – seasonal variability and spatial variability. The seasonal factor incorporated the interaction of temperature and nutrients. The spatial factor incorporated the interaction of salinity, nutrients, and water color that results from the mixing of freshwater inflow and seawater.

Although freshwater inflow increased the availability of nutrients in low salinity waters, the highly colored freshwater restricted light penetration and phytoplankton productivity. Maximum productivity occurred where the color associated with freshwater inflow had been diluted by seawater so that light and nutrients were both available. Concentrations of inorganic nitrogen were often at or below detection limit throughout most of the high salinity waters of the estuary and were probably the most critical nutrient in limiting phytoplankton productivity.

The control on phytoplankton biomass may differ from that on productivity. In the Chesapeake Bay, seasonal variations in phytoplankton biomass were correlated with riverine nitrate input, while variations in productivity were correlated with light and temperature. Of the macronutrients, nitrogen availability is most frequently cited as the controlling factor.

Average monthly carbon-14 productivity and chlorophyll data for the 12 stations in Charlotte Harbor are presented in **Table A2**.

TABLE A2
The average monthly Carbon-14 Productivity and Chlorophyll-a Biomass at 12 Stations in the Charlotte Harbor Estuary

	Chlorophyll *a*	**Carbon-14 Productivity**	
	mg m^{-3}	**mg C m^{-3} (Em^{-2})$^{-1}$**	**mg C m^{-3} hr^{-1}**
November 1985	11	18	68
January 1986	3	5	19
March 1986	7	8	45
May 1986	6	8	40
July 1986	13	16	89
September 1986	12	19	100

The composition of the phytoplankton community in varied with location and season. At intermediate and high salinity locations, the small size fraction was often dominated by Cryptophyceae. Diatoms usually characterized the large size fraction. Non-flagellated green cells and phytoflagellates were abundant components of the small size fraction in low salinity waters. The large size fraction at low salinities was usually characterized by a mixture of Chlorophyceae, diatoms, and blue-green algae.

For this study, an intermediate Factor I score corresponds to a location where nutrient-rich colored water has been diluted by seawater so that the availability of light has increased and stimulated phytoplankton productivity and growth. At lower Factor I scores the phytoplankton population may be limited by availability of nutrients; at higher Factor I scores limitation may be due to availability of light (color). A high Factor II score corresponds to seasonally high water temperatures and sunlight (summer). High light-normalized productivity at this time may be attributed to the high water temperature. The relatively low concentrations of nitrate and orthophosphate at high Factor II scores were probably due to biological uptake (nitrate) and river dilution (orthophosphate) during summer. Results are illustrated in **Figure A5**.

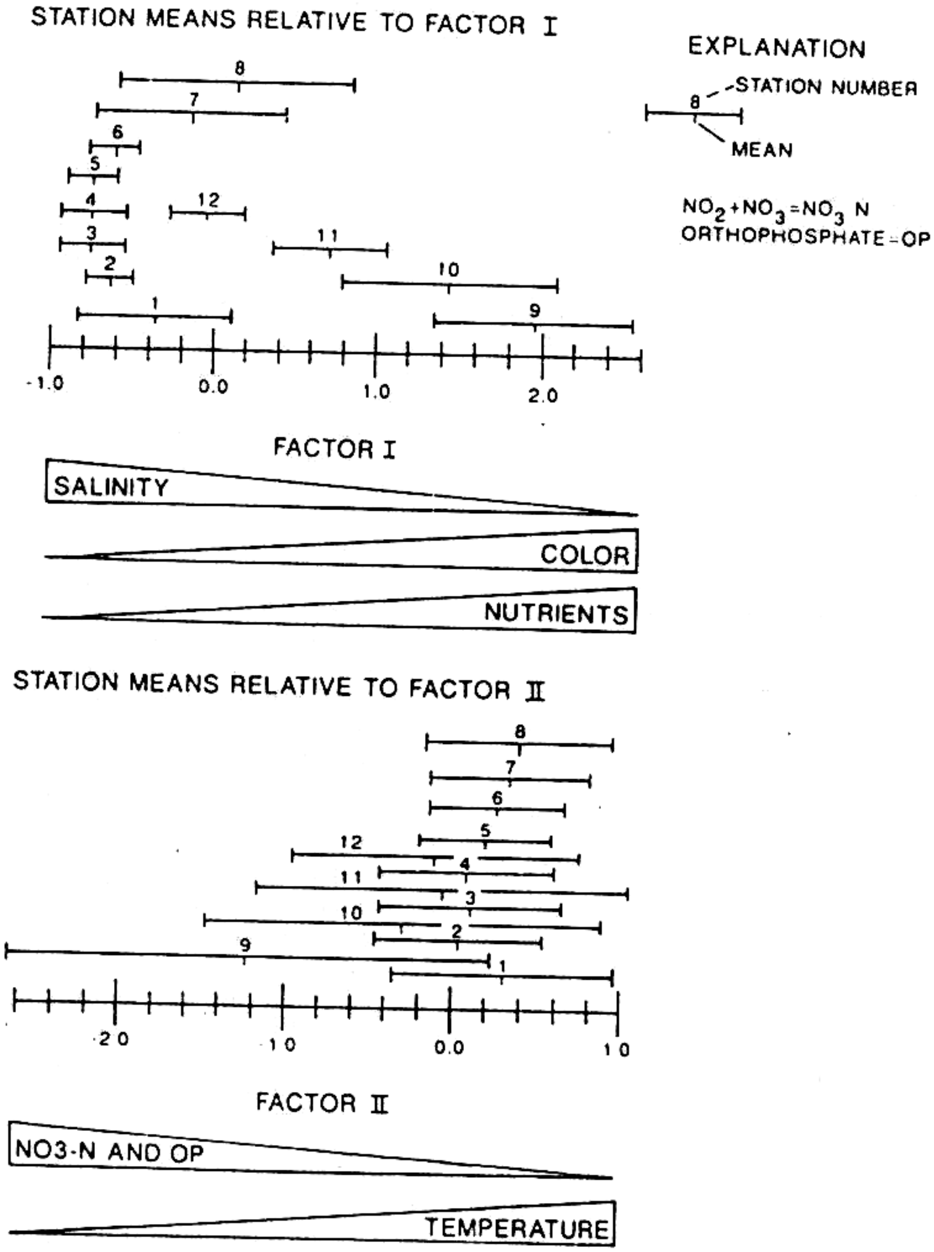


FIGURE A5
Mean score for Each Station on Factor I and Factor II With 92% Confidence Intervals Around the Mean. (Major factor loadings and correlations are shown below the axis with relative magnitude associated with the loading.)

Freshwater runoff from the Charlotte Harbor basin is a major source of new nitrogen that stimulates phytoplankton productivity and chlorophyll-a biomass in the mid salinity regions of the estuary. Urban population growth in the basin is expected to increase nitrogen loading by more than 2.7 X 10^6 mg d^{-1} by the year 2020. Although nutrient enrichment and reduced freshwater runoff could affect multiple processes (nutrient cycling, etc.) in unpredictable ways, the projected basin changes would favor phytoplanktonic and benthic algal growth by increasing the availability of nitrogen and by increasing the availability of light due to the reduced inflow of colored freshwater.

Doering, P.H., and R. H. Chamberlain. 1998. Freshwater Inflow to the Caloosahatchee Estuary and the Resource-Based Method for Evaluation. Okeechobee Systems Research Division, Ecosystem Restoration Department, South Florida Water Management District. West Palm Beach, Florida.

The volume of freshwater flow into the Caloosahatchee Estuary affects many species' ability to proliferate. Freshwater is necessary to support tape grass which is associated with a greater density of benthic invertebrates, fish, invertebrates, and possibly manatees. The last substantial oyster reef also exists near the mouth at Shell Point. Historical accounts of the river suggest that oysters were once a more prominent feature in this area. The reduction in oyster coverage in this portion of the estuary was largely due to shell mining, altered freshwater inflow, and changes in hydrodynamics.

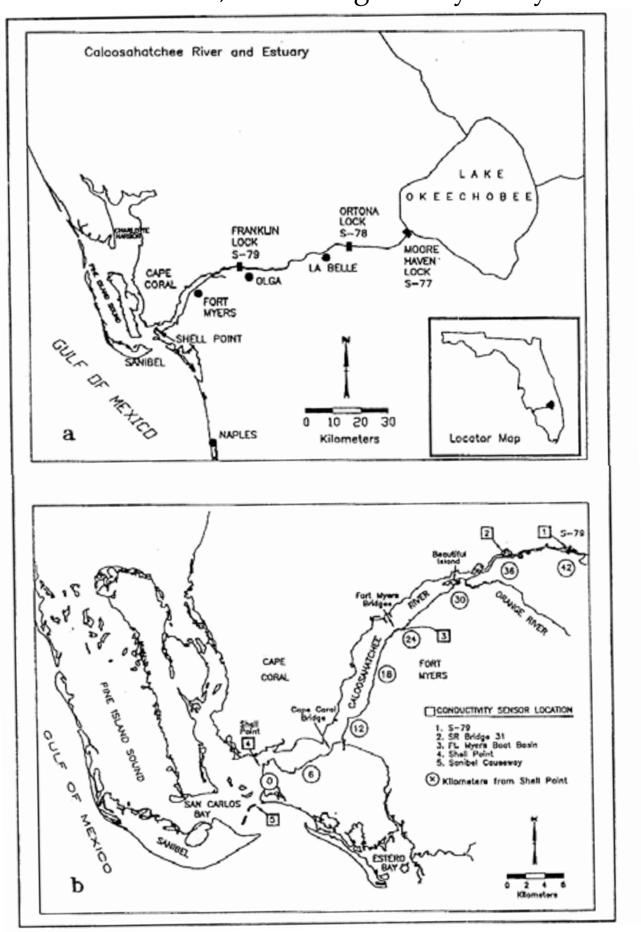


FIGURE A6
a) Caloosahatchee River and Estuary system. (b) Caloosahatchee Estuary and location of five conductivity (salinity) sensors

San Carlos Bay's dominant biological features are its numerous mangrove islands and many kilometers of mangrove shoreline. Small oyster bars are also plentiful. Future water management policies need to balance agriculture and other upland interests with the biotic richness and aesthetic appeal of San Carlos Bay, including a wide variety of recreational and fishery activities with noteworthy economic value.

For the period 1966-1990, the greatest frequency of mean monthly inflows of freshwater entering the estuary through S-79 from both the basin and Lake Okeechobee are in the 0-300 cfs range (**Figure A7**). The overall mean monthly inflow was in the 900-1200 cfs range for this period of record. Since 1990, there has been an increase in the frequency of mean monthly flows in the high flow categories.

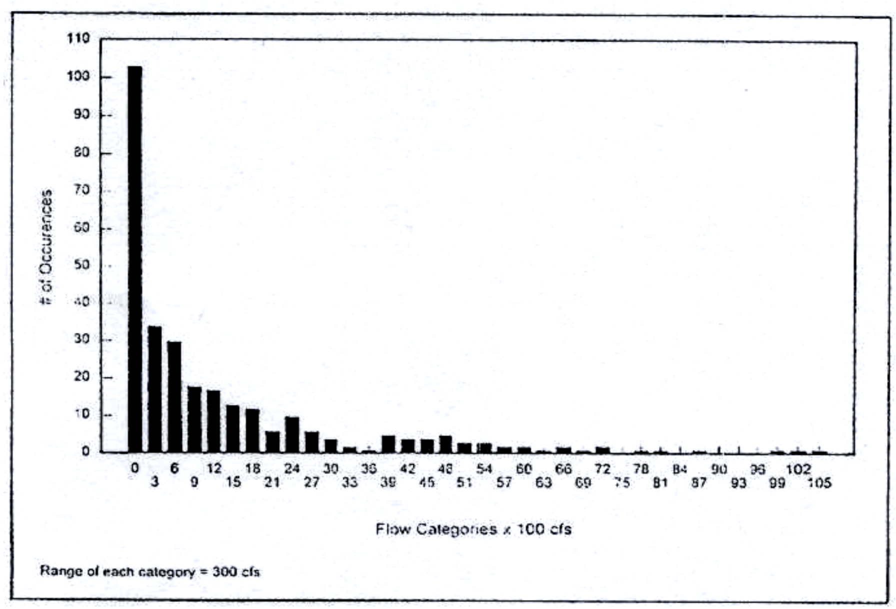


FIGURE A7
Frequency of mean monthly flow (cubic feet per second) from S-79 during the period 1966-1990

The long term (1966-1994) mean daily discharge through S-79 (from the watershed only, as well as from all sources combined) usually falls between 300 cfs and ≈ 3000 cfs, with lower discharge occurring in the dry season. There are high and low flow periods within each of the two seasons; this is related to the source of the water. The majority of freshwater input (75% of total discharge though S-79 in the wet season) is rainfall runoff from the basin. The percent contribution in the dry season of basin-only discharge is lower due to reduced rainfall runoff and the regulatory discharges from Lake Okeechobee in effort to lower the lake by the beginning of the wet season. Daily and monthly average flows are highly variable. To illustrate this variability, **Figure A8** compares daily wet season inflow in 1995 with the 1966-1994 average.

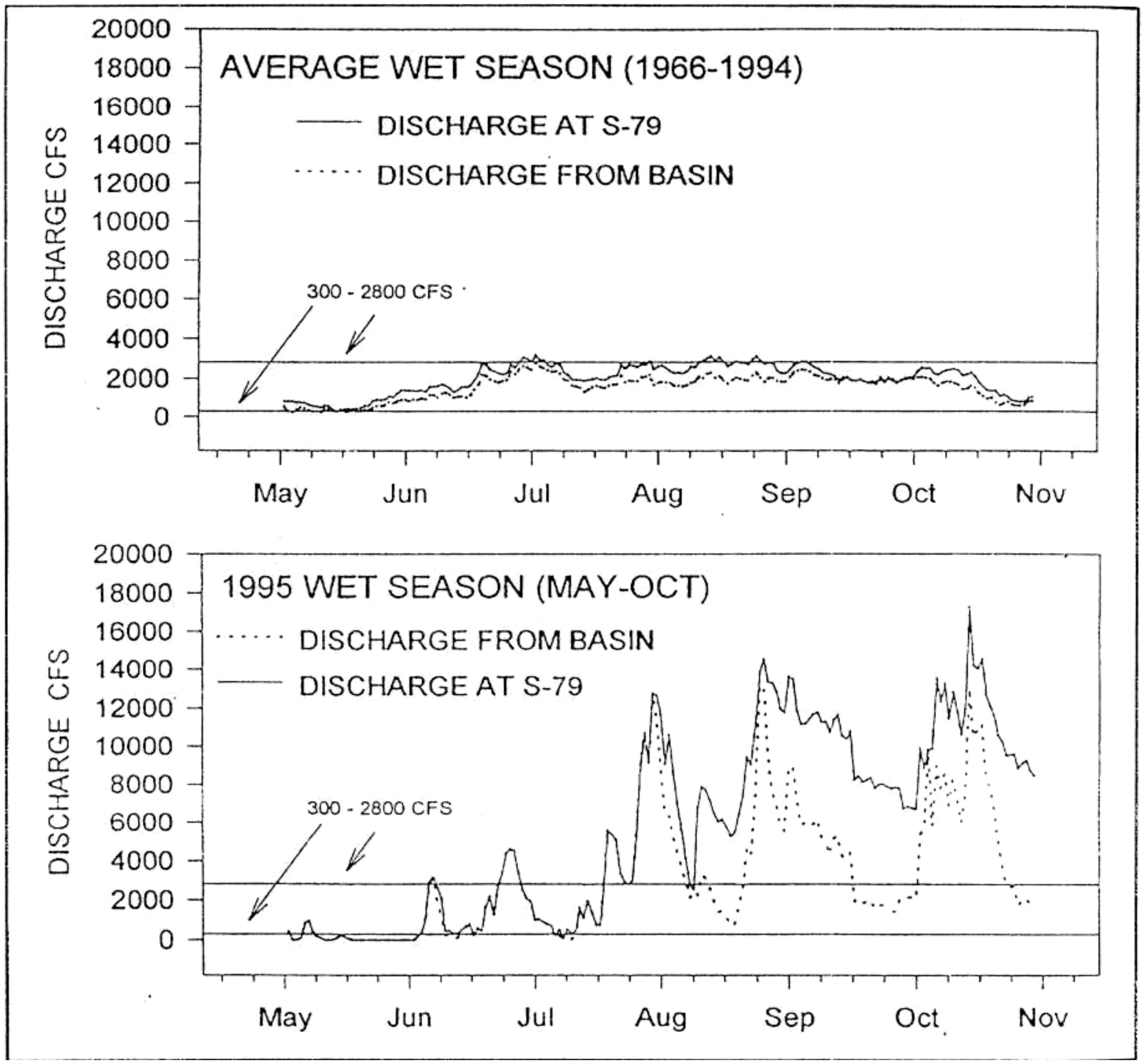


FIGURE A8

Average daily freshwater discharge (cubic feet per second) to the Caloosahatchee Estuary through S-79 during the average wet season (May-October) 1966-1994 (n=29; top), and 1995 only (bottom). Both total (discharge at S-79: Lake Okeechobee plus the basin) and basin only discharge depicted

The volume of freshwater passing through S-79 from the watershed and Lake Okeechobee overwhelms any other source. In 1985, the SFWMD initiated an ongoing research project to address impacts of (basin and lake) water management on the estuary and establish freshwater inflow limits and water quality targets for the estuary. The proper water quantity will be determined by the optimum range of freshwater inflow that protects key species – i.e. tape grass and oysters. Predictive modeling seeks to show the full range of salinity represented at various discharges (**Figure A9**). For example, at 500 cfs a desirable salinity exists somewhere for all organisms within the estuary. The maximum mean monthly discharge can be controlled to provide a range of salinity to accommodate organisms along the estuary based on their tolerance limits.

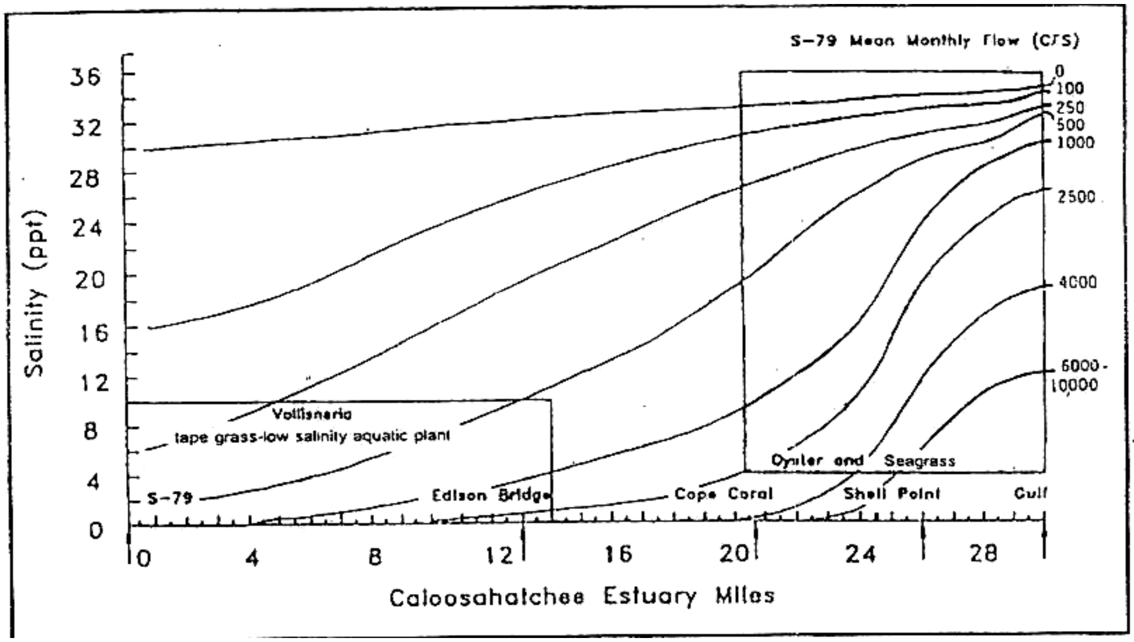


FIGURE A9
Projected longitudinal salinity distribution in the Caloosahatchee Estuary for selected mean monthly inflow volumes from S-79. Literature reported tolerance limits for Vallisneria americana, Halodule wrightii, and oysters indicated with estimated current spatial distribution

Doering, P.H., and R. H. Chamberlain. 1998. Preliminary Estimate of Optimum Freshwater Inflow to the Caloosahatchee Estuary: a Resource-based Approach.

Establishing a suitable salinity environment is the most basic prerequisite for promoting estuarine biota within the Caloosahatchee Estuary. SFWMD implemented a strategy based on the salinity tolerance range of key estuarine species to prescribe an acceptable freshwater discharge distribution. The purpose of this paper is to report the preliminary results of the relationship between freshwater inflow, salinity, submerged aquatic vegetation, and other estuarine species.

The model results indicate that more than half of the estuary upstream of Shell Point will become nearly freshwater and salinity will be reduced downstream during even moderate mean monthly discharges of 2000 cfs (**Figure A10**). Inflows greater than 4000 cfs will cause most of the estuary upstream of Shell Point to become freshwater and depress salinity in portions of San Carlos Bay. The other extreme – prolonged low to no flow, less than 100 cfs, result in salinity conditions near S-79 that exceed 15 ppt, eliminating any tidal freshwater zone within the estuary.

Table A3 recommends provisional inflow ranges and timing for maintaining the health of important taxa. A distribution of inflows that has the greatest frequency range from 300 to < 1500 cfs, with a peak of 300-800 cfs, should be generally beneficial to all biota evaluated. Percent violations were defined for upper and lower flow limits to account for freshwater inflow as a natural function of rainfall.

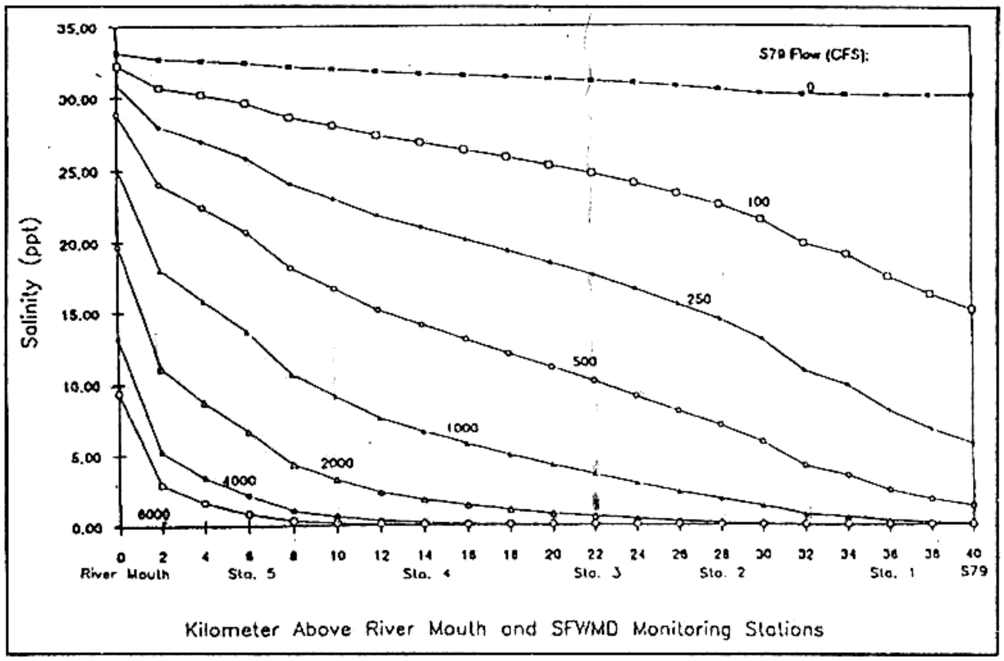


FIGURE A10
Projected steady-state longitudinal salinity distribution in the Caloosahatchee Estuary for a range of freshwater inflows. The x-axis corresponds to distance from Shell Point (km).

TABLE A3
Short-term recommended inflows (cubic feet/second) for taxa health in the Caloosahatchee Estuary

SPECIES	LOWER INFLOW LIMIT (LIL)	PREFERRED INFLOW RANGE (PIR)	UPPER INFLOW LIMIT (UIL)	IMPORTANT MONTHS
Vallisneria	300	>400		dry season (Nov–May) LIL, PIR
Halodule, *Thalassia*		<800	3,000 *Halodule* 4,500 *Thalassia*	all year — UIL
Fish (general)	300	300–1,300	3,000	dry season — PIR; all year — UIL
Bay anchovy	300	300–800	3,000	dry season — PIR; all year (esp. spring) — UIL
Silver perch	300	300–800	3,000	dry season — PIR; all year (esp. Jan–early summer) — UIL
Redfish	300	300–800	3,000	dry season (esp. Nov–Mar) — PIR; all year (esp. Jul–Dec) — UIL
Snook	300	300–1,500	3,000	late dry season — PIR; all year (esp. late dry season) — UIL
Larval fish		300–600	2,500	dry season (esp. spring–early summer)
Fish eggs		150–600	2,500	all year
Pink shrimp	300	300–800	3,000	all year
Blue crabs	300	300–800	3,000	all year (esp. Feb–Jul)
Zooplankton		300–600:<1,500	2,500	all year
Shrimp and crab larvae		<1,300	2,500	all year (esp. spring–Jul)
Benthic macro-invertebrates		300–800	3,000	all year
Oysters		300–800	3,000	all year

Fernandez Jr. M., M. Marot, and C. Holmes. 1998. Reconnaissance of Chemical and Physical Characteristics of Selected Bottom Sediments of the Caloosahatchee River and Estuary, Tributaries, and Contiguous Bays, Lee County, Florida, July 20-30, 1998.

The South Florida Water Management District (District) is developing a Caloosahatchee River Water Management Plan to address environmental and water-supply needs of the Caloosahatchee watershed. As part of this plan, the District will evaluate potential toxic substances in the sediments of the study area. For this report, the study area includes the Caloosahatchee River and Estuary, and the contiguous waterbodies of Matlacha Pass, San Carlos Bay, Estero Bay, Tarpon Bay, and Pine Island Sound, in Lee County.

The toxic substances include anthropogenic organic compounds and trace elements. The data in this report provide chemical and physical characterization of sediments at selected sites in the study area.

A technical advisory group consisting of USGS and District personnel selected 60 sampling sites, 58 of which were located in the estuary, tributaries, and the bays; two sites were located upstream of Franklin Lock.

Bottom samples from 59 sites were analyzed for Beryllium activity; 31 had detectable Be; 19 in the river/estuary, and 12 in the bays and tributaries. Scans for trace elements were used to identify the presence of trace elements above Natural Range. Cadmium, chromium, copper, lead, and zinc were above Natural Range at some sites in the estuary and bays.

Total organic carbon analyses were used to identify the locations of carbonaceous sediments. TOC concentrations in the bays and tributaries ranged between 4,290 ppm at Matlacha Pass and 142,000 ppm at Daughtrey Creek. TOC from sediments in 18 sites in the river and estuary ranged between 4,600 and 164,000 ppm.

Laboratory analysis for toxic organic compounds and selected trace elements was performed on samples from 10 of the sites. The toxic organic compounds included the organochlorine and organophosphorus pesticides, PCBs, and PAHs. The selected trace elements included arsenic, cadmium, chromium, copper, lead, iron, mercury, and zinc. There were 3 organochlorine pesticide compounds detected in sediment samples from four sites. There were no organophosphorus pesticides or PCBs reported for the 10 sediment samples.

Flaig, E. G. and J. C. Capece. 1998. Water use and runoff in the Caloosahatchee watershed. South Florida Water Management District. West Palm Beach, Florida.

Identifying the sources of runoff in the Caloosahatchee watershed along with water use demand is necessary for continual development and sustainable ecosystem health. This paper describes the important features of the Caloosahatchee watershed, the water budget for the Caloosahatchee estuary from the watershed, and the potential impact of future land use on the discharge to the estuary.

The watershed receives ≈ 130 cm of rain annually (**Table A4**). Annual rainfall ranges from 60-200 cm. The groundwater resources in the watershed are limited. The watershed is underlain by three aquifer systems: the Surficial Aquifer System (SUS), Intermediate Aquifer System (IAS), and the Floridan Aquifer System (FAS). The SUS provides usable water in the region east of LaBelle. Several municipal well fields in Lee County draw water from the IAS. Urban wells along the coast obtain water from the Floridan; this groundwater requires reverse osmosis for use.

TABLE A4
Annual rainfall, runoff, and water use demand in the Caloosahatchee River watershed

	MEDIAN	2-IN-10 DRY	2-IN-10 WET
Rain (cm)	120	95	140
Lake Okeechobee Discharge			
Regulatory ($10^6 m^3$)	69	3	830
Water Supply ($10^6 m^3$)	94	66	124
Watershed Runoff			
S-78 discharge ($10^6 m^3$)	350	225	475
ECAL Basin runoff (cm)	36	21	46
S-79 discharge ($10^6 m^3$)	870	500	1050
WCAL Basin runoff (cm)	38	22	45
Water Use Demand			
Urban			
1990 estimation ($10^6 m^3$)	17	---	---
2010 projection ($10^6 m^3$)	33	---	---
Agriculture			
1990 estimation ($10^6 m^3$)	76	---	---
2010 projection ($10^6 m^3$)	110	---	---
Estuary (Chamberlain *et al*. 1997)			
Minimum flow ($10^6 m^3$)	270	---	---

With increased development in the watershed, water use has become a significant issue. Urban Lee County, agriculture, and the environment are the three major water users. Water use demand for 1990 was $94X10^6$ m^3 yr^{-1} for the 2-in-10 dry year, which is the expected volume of water required two out of every ten years.

The urban users are located primarily in the lower end of the watershed, associated with the cities of Ft. Myers, Cape Coral, and urban Lee County. These cities obtain their water from a combination of surface water and groundwater, which is recharged from the river.

Land use in the Caloosahatchee watershed has changed from a pre-development mosaic of sloughs, wet prairies, and pine flatwoods to agriculture and urban land (**Figure A11**). Urban land has developed along the estuary shoreline at Ft. Myers and along the river since the 1870's. In 1950, less than 1% of the watershed was urban; urban land now occupies 25% of the total area. The eastern portion of the Caloosahatchee watershed was a sawgrass marsh extending from Lake Flirt to Lake Okeechobee with wet prairie to the south and pine flatwoods to the north. The area was subjected to prolonged flooding pre-development and intensive agriculture was not a major land use until large-scale drainage projects were constructed. Lake Okeechobee is used to provide 40% of irrigation water to the watershed.

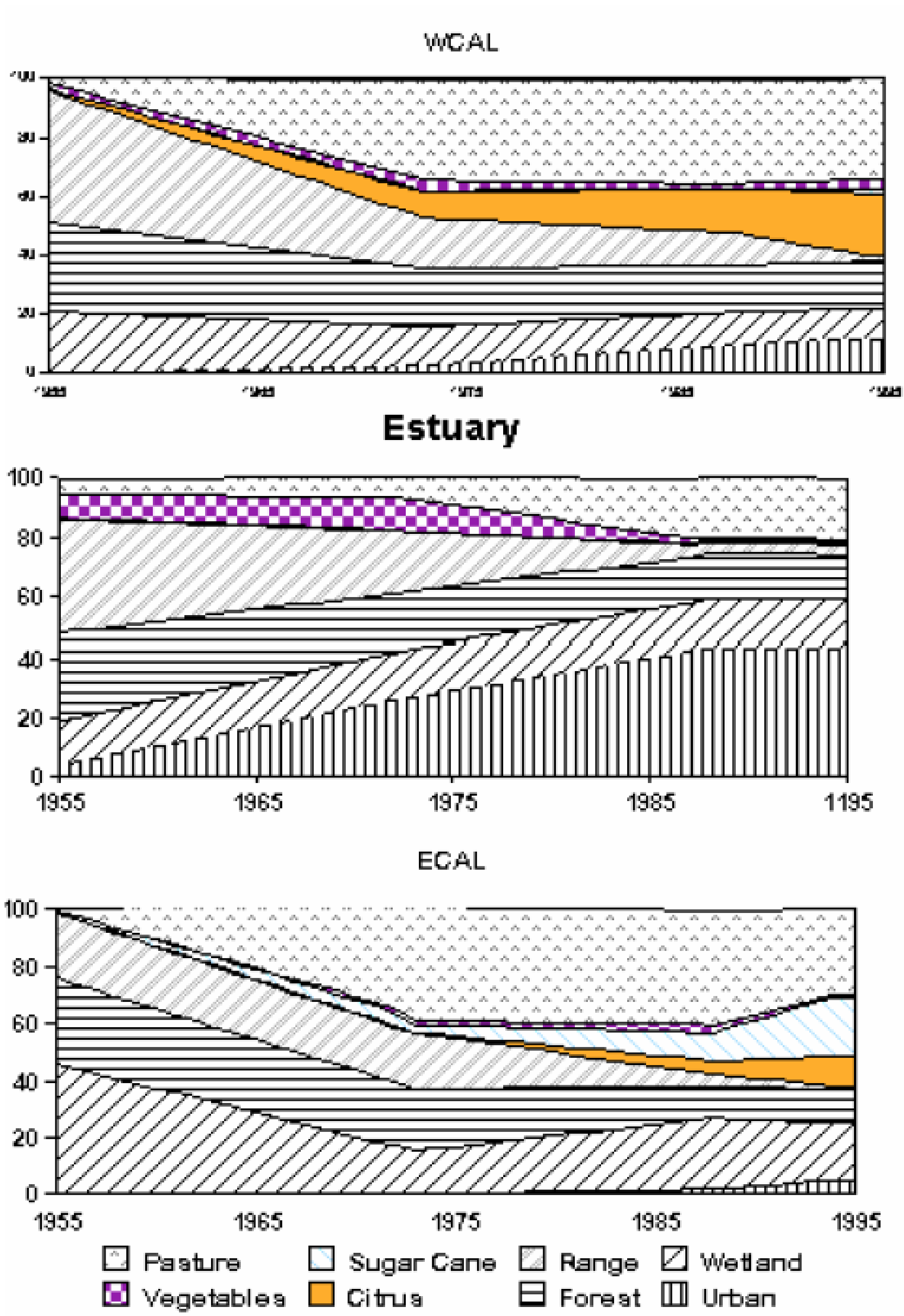


FIGURE A11
Major land use types, by percentage, in the east Caloosahatchee basin (ECAL), the west Caloosahatchee basin (WCAL) and the direct Caloosahatchee estuary watershed (Estuary)

Native ecosystems (upland ecosystems and the estuary) are the other major users of water in the watershed. There are four sources that discharge into the Caloosahatchee Estuary:

Lake Okeechobee; Everglades Agricultural Area (EAA); Caloosahatchee River watershed; and the Estuary watershed. The Caloosahatchee Canal receives discharge from Lake Okeechobee for flood control and water supply. The estuary also receives runoff from the adjacent watershed with ≈ 1/3 of the watershed discharges to the estuary downstream of S-79.

Determining the native runoff is difficult; however, in comparison with runoff rates from less altered watersheds, annual runoff is 20% higher in the Caloosahatchee. This increased runoff is likely an impact of canal construction.

In 1994, SFWMD completed the Lower West Coast Water Supply Plan, proposing a strategy for groundwater management in the Caloosahatchee watershed. Based on unmet future water supply needs, development of new sources, particularly deep ground water and water reuse for urban areas was recommended. In addition, the SFWMD is developing a regional water supply plan for the lower east coast that includes allocation of water from Lake Okeechobee. It is likely that regulatory discharges will decrease and there will be less water available from Lake Okeechobee for water supply. When water is unavailable from the lake, water users will have to depend on local supplies, i.e. surface water and shallow groundwater reservoirs.

Doering, P.H., and R. H. Chamberlain. 1999. Water Quality and Source of Freshwater Discharge to the Caloosahatchee Estuary, Florida. ***Journal of the American Water Resources Associations*****, 35(4): 793-806.**

In looking at water quality in the Caloosahatchee Estuary, it is important to examine the effects of total river discharge into the estuary as well as the source of the discharge (river basin, lake). By looking at routine monitoring data, the effects on water quality in the downstream estuary were analyzed based on source. Parameters examined were: color, total suspended solids, light attenuation, chlorophyll-a, and total and dissolved inorganic nitrogen and phosphorus. In general, as total discharge increased, the concentrations of color, TN, and DIN increased and TSS decreased. When the river basin was the major source, the concentrations of nutrients (excepting ammonia) and color in the estuary were relatively higher than when the lake was the major source. Light attenuation was greater when the river basin dominated discharge to the estuary. The analysis indicates that water quality in the downstream estuary changes as a function of both total discharge and source of discharge. Relative to discharge from the river basin, releases from Lake Okeechobee do not detectably increase concentrations of nutrients, color, or TSS in the estuary.

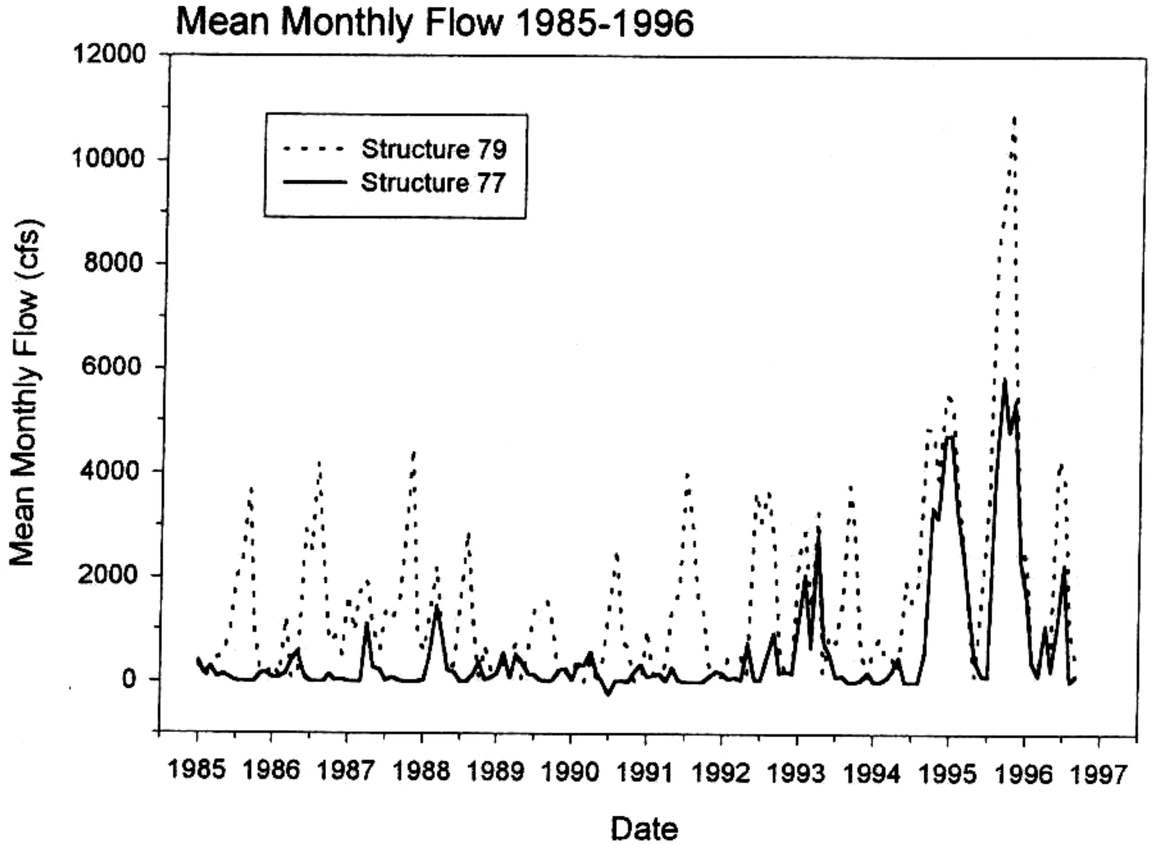


FIGURE A12
Average Monthly Discharge at the Franklin Lock and Dam (S-79) and at Moore Haven (S-77) from 1985 to 1996

The average monthly discharge from Lake Okeechobee at S-77 and to the estuary at S-79 is shown for the period, January 1985 to September 1996, in **Figure A12**. The difference between the two lines represents an estimate of the freshwater discharge at S-79 that is due to runoff from the Caloosahatchee River basin. Runoff from the basin comprised more than half of the total discharge in 62% of the 141 months, while the lake dominated in 38%.

Of 64 samples of water quality in the estuary, runoff from the basin dominated discharge at S-79 in 34 samples and at least one time during each month of the year; Lake Okeechobee dominated in 30 samples. For the basin-dominated cases, discharge at S-79 was 187 cfs – 11024 cfs. For the Lake-dominated cases, discharge ranged from 62 cfs – 9300 cfs.

Most water quality parameters at S-79 did not vary as a function of total discharge. Only the concentrations of color and ammonium increased with increasing discharge. Further, the magnitude of discharge at S-79 did not affect the concentrations of TN, NO_x, or TSS. For both TP and TIP, results showed that when total discharge was dominated by the basin, all concentrations were similar at all discharges. However, when the lake dominated the discharge, concentrations were higher at low discharge (< 1000 cfs) than at the two higher discharges (**Table A5**). Concentrations of TN and color were higher by 26 and 64 percent, respectively, when the river basin dominated the discharge (**Table A5**).

TABLE A5
Water Quality as a Function of Source (River Basin or Lake Okeechobee) at the Franklin Lock and Dam (S-79). Arithmetic means (+ std) are shown. Statistical analyses conducted on transformed (log + 1) data. Means for discharge classes shown were discharge classes shown where discharge x source interaction was significant. n=32-33 for River Basin, n=26 for Lake Okeechobee. * indicates statistical difference between sources. Letters indicate statistical difference between discharge classes when the lake was the major source

Parameter	Discharge (cfs)	Basin	Lake
Color (cu)*	---	105 (48)	64(20)
TN (mg/l)*	---	1.8 (0.75)	1.42(0.40)
Nox (mg/l)	---	0.31 (0.18)	0.25 (0.20)
NH4 (mg/l)	---	0.04 (0.04)	0.04 (0.03)
TSS (mg/l)	---	3.6 (2.4)	3.8 (2.3)
TP (mg/l)	< 1000	0.15 (0.07)	0.12 (0.01)a
	1000-4000*	0.16 (0.05)	0.07 (0.01)b
	> 4000*	0.22 (0.12)	0.06 (0.01)b
DIP (mg/l)	<1000	0.09 (0.04)	0.08 (0.03)a
	1000-4000*	0.09 (0.04)	0.08 (0.03)a
	> 4000*	0.12 (0.05)	0.03 (0.01)b

Correlation analysis (**Table A6**) indicated that every water quality parameter examined was correlated with freshwater discharge in some region of the estuary. As discharge at S-79 increases, the percentage of freshwater in any given region of the estuary also increases. TN, NO_x, NH_4, and K were positively correlated with discharge. TSS was negatively correlated with discharge. TP and chlorophyll-a were negatively correlated with discharge at the head of the estuary but positively correlated farther downstream. The effects of discharge could be detected up to 59 km from S-79 in Pine Island Sound for some parameters, while others could only be detected in the upstream regions.

TABLE A6
Spearman's Rank Correlation (r) Between Mean Daily Discharge (cfs) at the Franklin Lock and Dam (S-79), Calculated for the 30 Days Prior to Sampling and Water Quality in Five Regions of the Caloosahatchee Estuary. Kilometers are distance downstream from S-79. Correlation coefficients calculated using transformed (log + 1) data. All r statistically significant except where noted by ns = not statistically significant. n = 21-36 for k

	Head (0 - 14 km)	Upper Estuary (14 - 28 km)	Lower Estuary (28 - 41 km)	San Carlos Bay (41-49 km)	Pine Island Sound (59 km)
Salinity	-0.939	-0.968	-0.889	-0.901	-0.832
Color	0.844	0.902	0.880	0.776	0.449
TN	0.133 ns	0.439	0.532	0.286	-0.035 ns
Nox	0.506	0.724	0.434	0.355	0.196 ns
NH4	0.487	0.282	0.231 ns	0.208 ns	0.118 ns
TP	-0.538	-0.050 ns	0.251 ns	0.297	0.002 ns
DIP	-0.328	-0.061 ns	0.084 ns	0.183 ns	0.131 ns
TSS	-0.748	-0.660	-0.244	-0.111 ns	-0.047 ns
Chlorophyll a	-0.525	0.041 ns	0.470	0.442	0.136 ns
K	0.071 ns	0.668	0.743	0.820	0.423 ns
n	55 - 62	56 - 62	56 - 62	57 - 60	37 - 40

An interaction between region and total discharge may indicate that the effect of discharge on concentration is different in different regions. Alternatively, the interaction may indicate that the spatial gradient of concentration varies as a function of discharge. The effect of discharge on concentration gradients in the estuary is most clearly exemplified by salinity (**Figure A13**). Most parameters behaved much like salinity; TN provides a good example. At a low discharge, there were distinct spatial gradients of decreasing concentration with increasing distance from S-79. As the discharge increased, the concentration gradient in the head and upper estuary disappeared and significant differences occurred further downstream. At the highest discharges, gradients became less distinct and even statistically non-detectable.

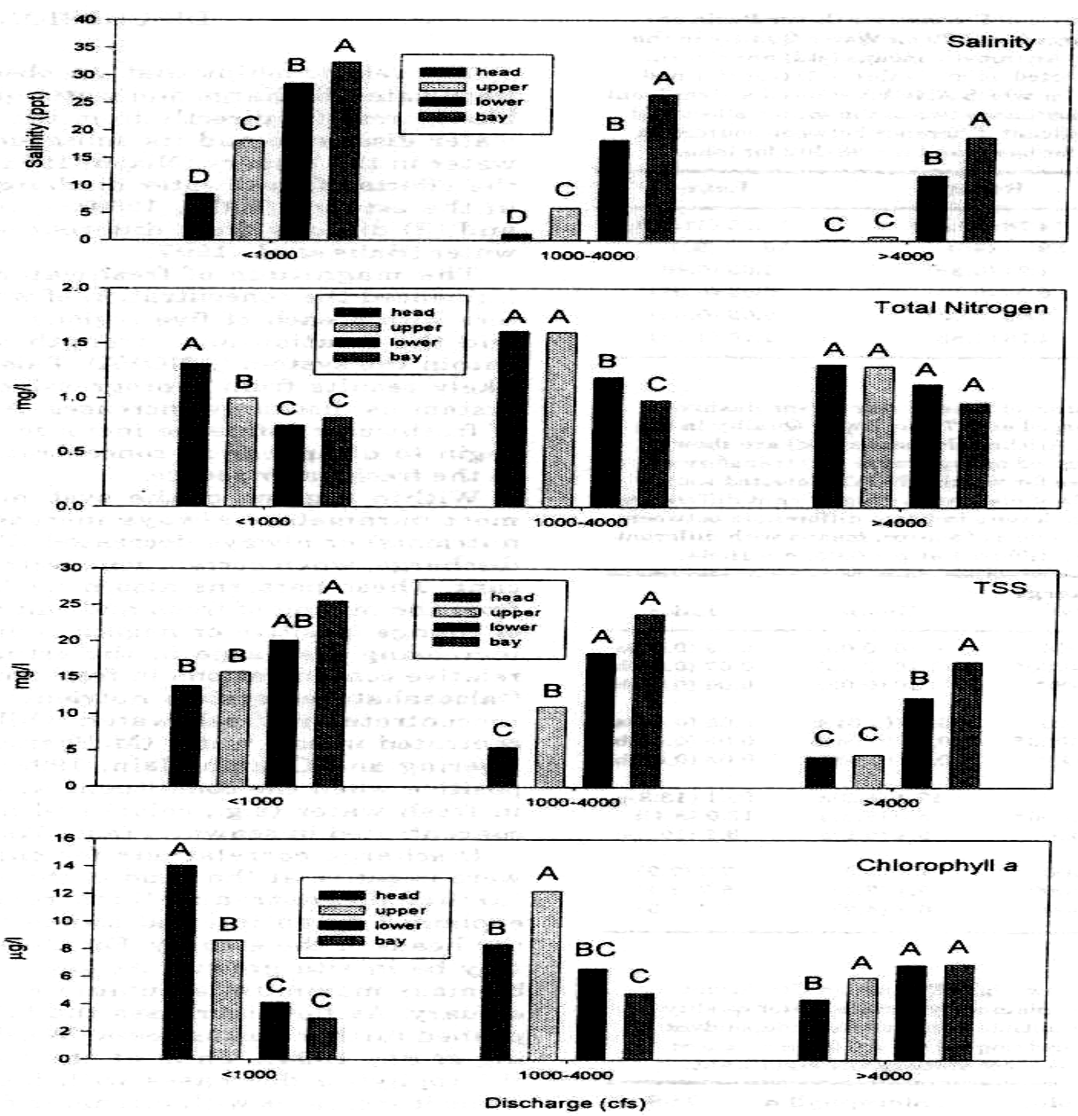


FIGURE A13
Effect of Freshwater Discharge at Structure S-79 on Spatial Gradients of Water Quality in the Downstream Estuary. Letters summarize results of the SNK-Test examining potential differences between regions at each level of discharge. Bars with different letters are significantly different.

The results of the statistical analysis demonstrate that both the magnitude of freshwater discharge and the source of discharge have an important impact on water quality in the downstream estuary. When the two sources are compared, the lower concentrations associated with discharges from Lake Okeechobee suggest that the effects of discharges from the lake are less severe on estuarine water quality than discharges from the basin. Improving the water quality of water discharged from the basin would have the greatest effect on downstream conditions in the estuary.

Doering, P.H., and R. H. Chamberlain. 1999. Water Quality in the Caloosahatchee Estuary, San Carlos Bay and Pine Island Sound, Florida.

Water quality parameters in the lower Caloosahatchee Estuary are different from those in the upper Estuary. These concentrations vary as a function of distance from S-79. Concentrations of nutrients and other water quality parameters were sampled monthly at 17 stations in the Caloosahatchee Estuary-Pine Island Sound region of the Charlotte Harbor system from 1985-1989. Many stations were revisited monthly from November 1994 to December 1995. **Figure A14** shows a map of the 17 water quality sampling stations. All sites

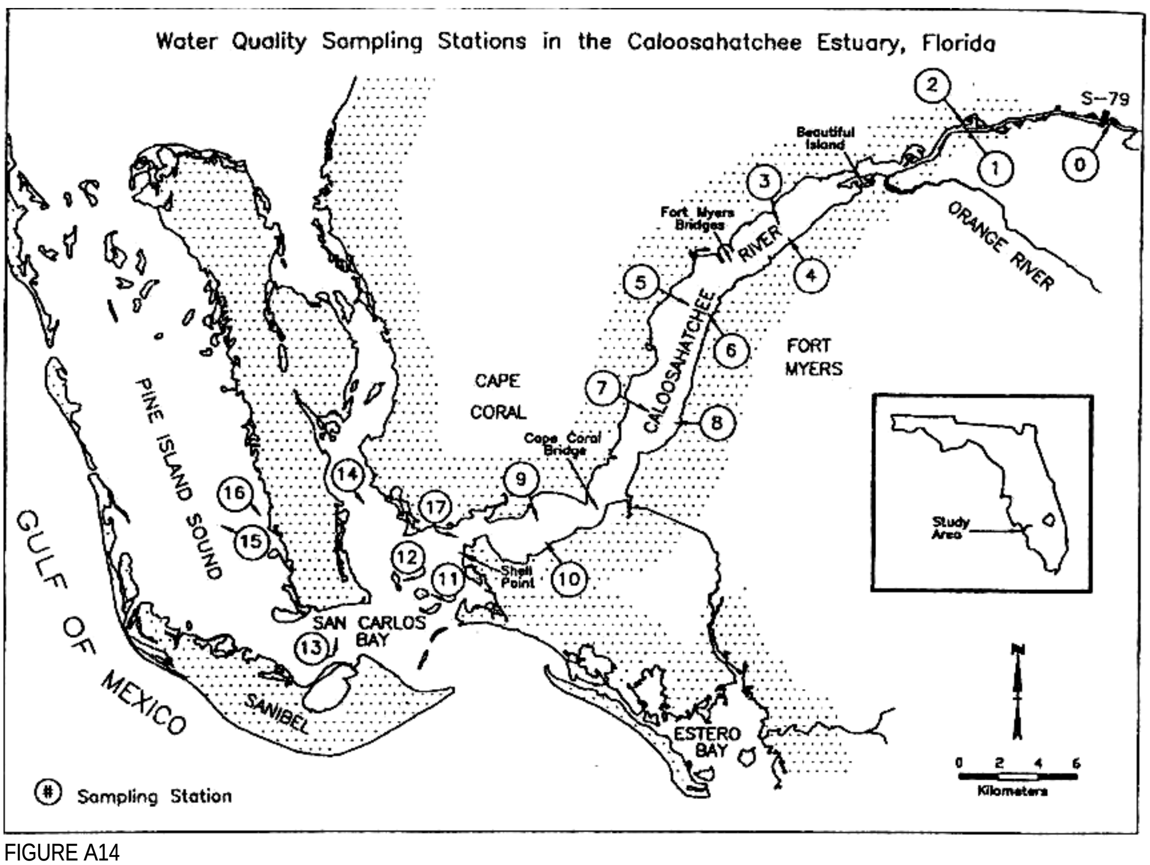


FIGURE A14
Map of Southern Charlotte Harbor showing water quality sampling stations in the Caloosahatchee Estuary, San Carlos Bay and Pine Island Sound

were sampled during phase one (1985-1989), and a reduced number (0, 2,4,8,10,17,11,12,16) were sampled in the second phase (1994-1995).

All water quality parameters varied as a function of distance from S-79 in the wet and dry seasons, except turbidity. All other parameters, except TSS, decreased in magnitude as the distance from S-79 increased; TSS increased with distance (suggesting that the ocean is a major source). All water quality parameters showed statistically significant differences between wet and dry seasons (**Table A7**). In general, concentrations were higher in the wet season than in the dry season.

TABLE A7
Average seasonal concentrations of water quality parameters in southern Charlotte Harbor including the Caloosahatchee Estuary, San Carlos Bay, and Pine Island Sound. All units are mg/l except for turbidity (NTU), color (CU), and chlorophyll (µg/l). For the wet season, n= 421-489 depending on the parameter

PARAMETER	WET SEASON	DRY SEASON
Color	50.4	39.4
Total Suspended Solids (TSS)	18	15.8
Total Nitrogen (TN)	1.08	1.14
Turbidity (TURB)	5.3	4.9
Total Phosphorus (TP)	0.1	0.08
Chlorophyll a	9.8	6.5
Dissolved Inorganic Nitrogen (DIN)	0.1	0.07
Dissolved Inorganic Phosphorus (DIP)	0.06	0.04

Statistically, significant interactions between distance and season were detected for dissolved inorganic phosphorus (DIP), TP, and turbidity. Concentrations at each distance were always higher in the wet season than in the dry season. The variation in water quality as a function of distance from S-79 indicates that freshwater discharge at this structure may be a primary determinant of water quality in the southern portion of Charlotte Harbor. To quantify the degree of influence, simple linear correlations between freshwater discharge and water quality were calculated for each transect. Examples are given in **Figure A15** and show that correlation coefficients tend to be lower in Pine Island Sound were still significant for some parameters, even at this most distant transect.

TABLE A8
Median values of water quality parameters in different regions of Southern Charlotte Harbor compared with median values for Florida estuaries. Upper estuary – stations 1-6; Lower estuary – stations 7-10; San Carlos Bay – stations 11-14; and Pine Island Sound – Stations 15, 16

	Upper Estuary	Lower Estuary	San Carlos Bay	Pine Island Sound	Florida Median
Chlorophyll a (µg/l)	7.1	4.5	3.4	5	8.5
Color (CU)	46	21	14	11	20
Dissolved Oxygen (mg/l)	7.3	7.3	8	8.5	6.8
Total Nitrogen (mg/l)	1.3	0.9	0.85	0.88	0.8
Total Phosphorus (mg/l)	0.12	0.07	0.05	0.04	0.1
Total Suspended Solids (mg/l)	10	18	21	26	17.5
Turbidity (NTU)	3.7	5.8	5.2	3.7	5

Compared to other Florida estuaries, median concentrations of chlorophyll-a and TSS were relatively low, while median concentrations of DO, TN, and color were relatively high. Turbidity and TP were close to median values for other Florida estuaries (**Table A8**). Concentrations of most parameters were higher in the Caloosahatchee Estuary than in San Carlos Bay or Pine Island Sound. TSS showed an opposite pattern – higher in the Sound and Bay than in the Estuary. Although DO concentrations generally were high in the overall system, hypoxic (<2 mg/l) conditions were observed at the head of the Caloosahatchee Estuary – occurring between May and October.

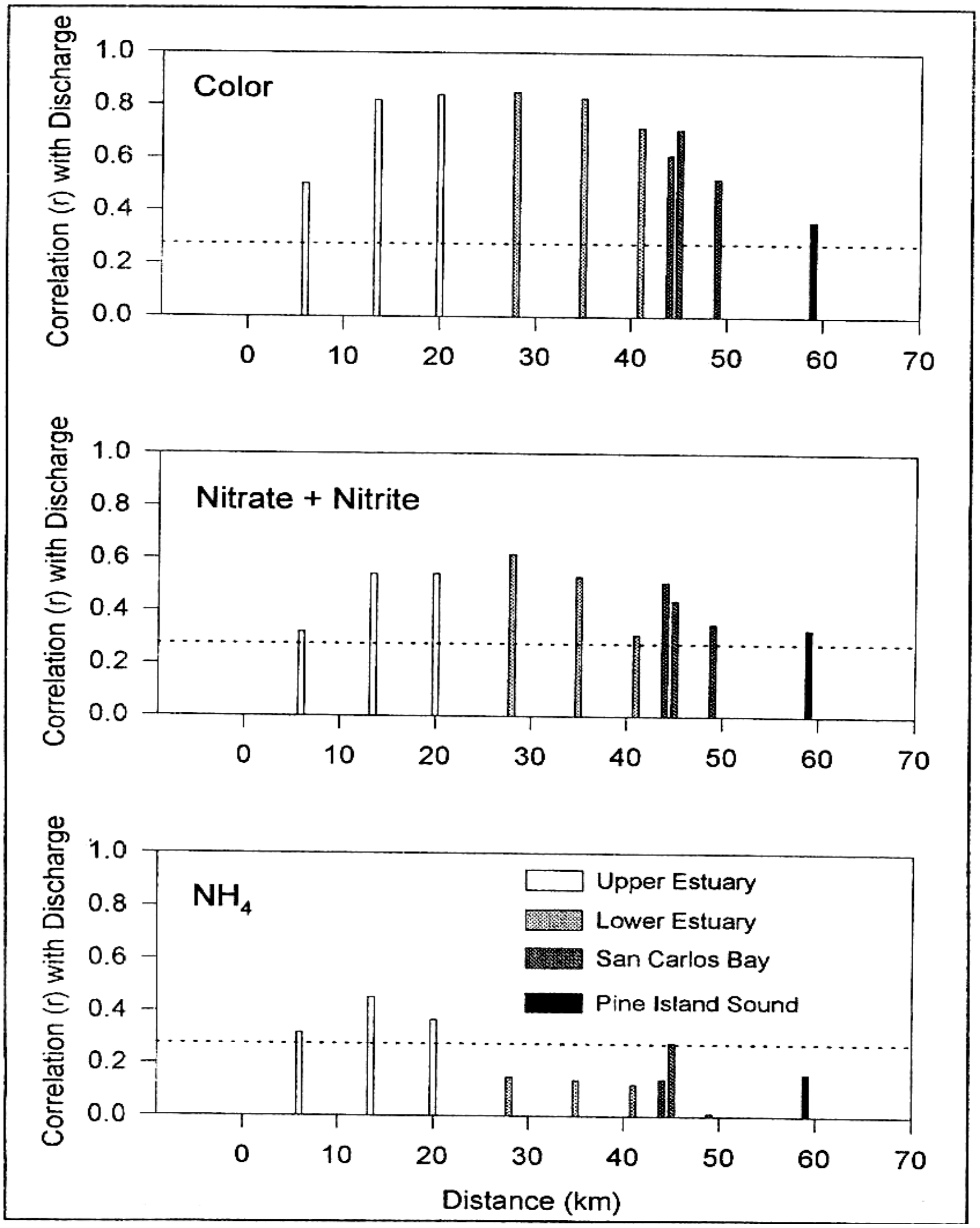


FIGURE A15
Linear Correlation between water quality parameters and the average freshwater discharge at S-79 for the 30 days prior to sampling. Correlation coefficients above the dotted reference line are statistically significant. Correlations calculated using log transformed (log [value+1]) data

Compared with other estuaries in Florida, Southern Charlotte Harbor is rich in TN, while TP concentrations are close to the State median. Lowest DO, highest chlorophyll-a, and highest nutrient concentrations were found in the upper Caloosahatchee Estuary (**Figure A16**, **Figure A17**). Judging by these parameters, the upper estuary has relatively poorer water quality than areas nearer to the ocean.

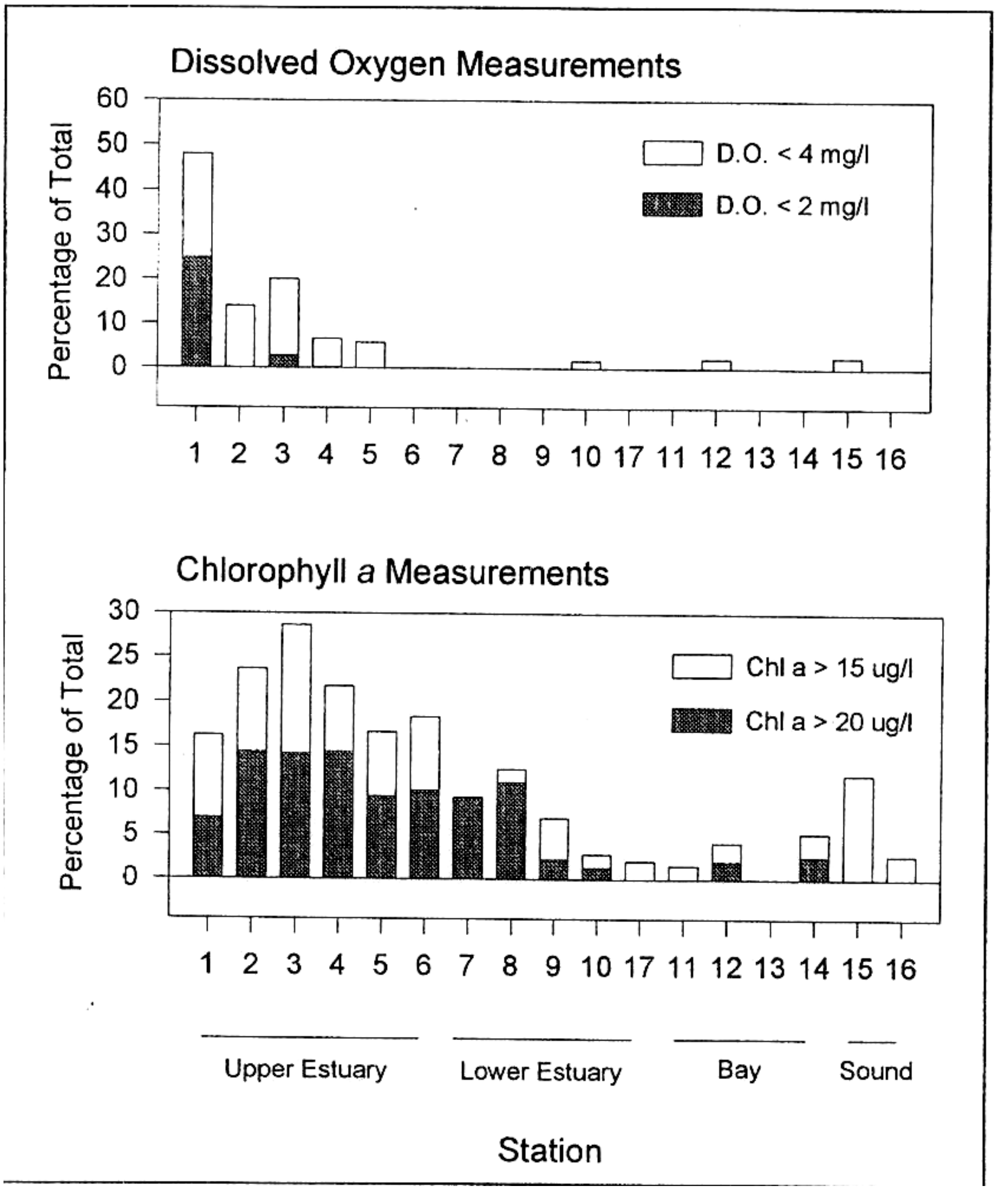


FIGURE A16
Summary of dissolved oxygen and chlorophyll-a measurements at each station. For dissolved oxygen, bars represent the percentage of sampling dates on which the minimum concentration measured at each station fell below the values given in the legend. For chlorophyll-a, bars represent the percentage of total number of measurements taken at each station that exceeded values given in the legends

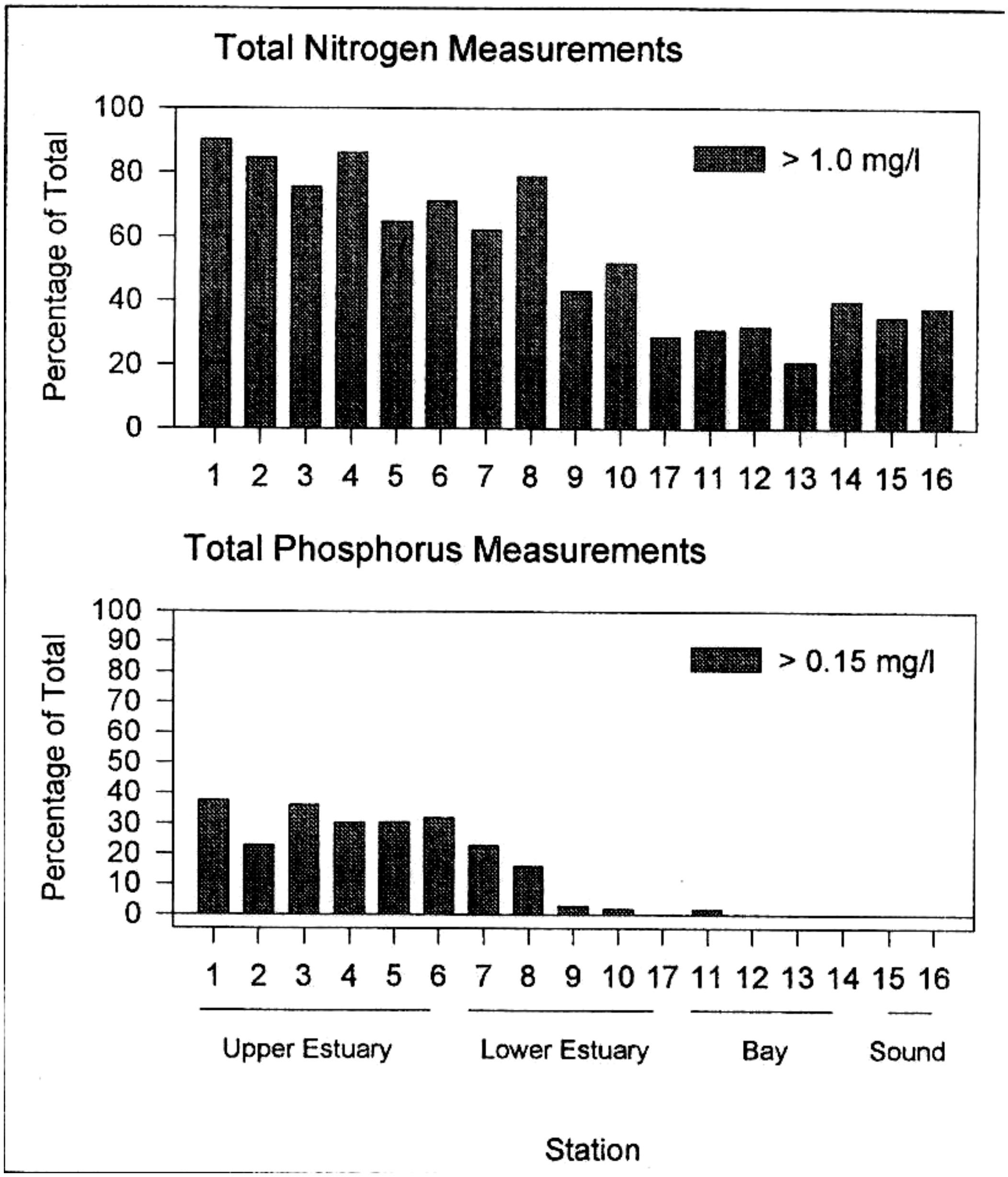


FIGURE A17

Summary of total nitrogen and total phosphorus measurements at each station. Bars represent percentage of total number of measurements taken at each station that were above 1.0 mg/l for total nitrogen or above 0.15 mg/l for total phosphorus

Janicki Environmental, Inc. 2002. Development of Water Quality Targets for the C-43 Basin, Caloosahatchee River. Prepared for: Florida Department of Environmental Protection, Tallahassee, FL. Prepared by: Janicki Environmental, Inc., St. Petersburg, FL.

This document describes the development and evaluation of potential water quality targets for the C-43 Basin and the tidal portions of the Caloosahatchee River estuary. This evaluation is one component of a broader FDEP project entitled *Pollutant Loading and Abatement Analysis for the C-43 Basin*. The specific objective of the work for this report was to identify potential water quality targets in both the freshwater portion of the study area above S-79 and in the estuarine portion of the study area below S-79. The recommended water quality targets for the waterbodies of the C-43 Basin and tidal Caloosahatchee River estuary were developed by combining lines of evidence from three independent approaches (Historical Data, Reference Condition, and Standards/Rule).

Water quality targets are set identified for the following parameters: chlorophyll-a concentration, dissolved oxygen concentration, total nitrogen concentration, total phosphorus concentration, turbidity, and Secchi disk depth.

Ambient water quality data for surface waters in the C-43 Basin were compiled from available historical databases. The approach of the historical-based target is to compare the earliest historical data available and current condition data, and establish the historical conditions as water quality targets if conditions have worsened over time. An inherent constraint in this type of approach is that the relatively recent historical time period for which data are available may represent watershed and water quality conditions for which significant impacts have already occurred.

Of the 37 waterbodies in the study, the available data were sufficient to identify historical data periods for parameters as follows: 2 waterbodies for chlorophyll-a; 15 for DO; 4 waterbodies for Secchi disk depth; 3 waterbodies for TN, 7 waterbodies for TP; and 7 waterbodies for turbidity. Total periods of record for the historical data are generally 20 years before the current period and representative of a time of much less watershed disturbance.

Potential water quality targets were defined as waterbodies and water quality parameters for which a historical and current data set were selected and for which current water quality conditions did not meet or exceed historical conditions. Potential targets were defined for DO for 8 waterbodies, TP for 4 waterbodies, Secchi disk depth for 2 waterbodies, and turbidity for 6 waterbodies.

For the Reference Approach, waterbodies and water quality parameters for which a reference data set and current data set were selected, and for which current water quality conditions did not meet or exceed reference conditions were defined as having a potential water quality target. Potential targets were defined for DO for 7 waterbodies; for chlorophyll-a for 4 waterbodies; TP for 7 waterbodies; TN for 7 waterbodies.
For this project, potential water quality targets based on the Standards/Rule approach were defined for each waterbody for DO and chlorophyll-a based on an application of the methods used to compute the FDEP Impaired Waters. Several waterbodies were identified as having potential standards/rule-based water quality targets for DO or chlorophyll-a. Sufficient data existed to evaluate the potential for standards/rules-based water quality targets for 21 waterbodies for DO and 25 waterbodies for chlorophyll-a.

The recommended target is defined for each waterbody and water quality parameter as Meeting the Historical-Based Target OR Meeting the Reference System-Based Target (if data are insufficient to define a historical-based target) AND Meeting the Standards/Rule-Based Target. These results are presented in a Weight of Evidence Matrix based on individual parameter targets.

For the three water segments in the tidal Caloosahatchee River (3240A, 3240B, 3240C), potential water quality targets were developed for chlorophyll-a concentration. The current period reference site approach potential target was a median of 3.2 µg/L for each water segment, which corresponds to a mean value of 3.8 µg. The standards/rule-based approach potential target was 11 µg for each water segment.

Florida Department of Environmental Protection. 2003. Basin Status Report Caloosahatchee. South District Division of Water Resources Management, Tallahassee, Florida.

The Status Report for the Caloosahatchee Basin was developed in the first phase of the Florida Department of Environmental Protection's (Department) watershed management approach for restoring and protecting water resources and addressing Total Maximum Daily Load (TMDL) Program requirements. This report provides a preliminary identification of impaired waters in the Caloosahatchee Basin that may require the establishment of TMDLs. Further, the information in this report is being used to identify waterbodies and parameters for which additional data are needed to verify water quality impairments.

This report describes the environmental setting of the Caloosahatchee Basin including population, land use, and economic activity. It classifies surface water resources, including special designations, and ground water resources within the area. The report further summarized watershed management activities and processes, including ongoing issues such as CERP and SWFFS.

For its preliminary surface water quality assessment, the following planning units are identified and assessed: East Caloosahatchee; West Caloosahatchee; Telegraph Swamp; Orange River; and Caloosahatchee Estuary. Each planning unit assessment includes a general description, water quality summary, summary of permitted discharges and land uses, ecological summary, and fish consumption advisories.

Janicki Environmental, Inc. 2003. Development of Critical Loads for the C-43 Basin, Caloosahatchee River. Prepared for: Florida Department of Environmental Protection, Tallahassee, FL. Prepared by: Janicki Environmental, Inc., St. Petersburg, FL.

This paper describes the development of potential critical nutrient loads from the C-43 Basin to the tidal portion of the Caloosahatchee River commensurate with water quality targets. This evaluation is one component of a broader FDEP project entitled, *Pollutant Loading and Abatement Analysis for the C-43 Basin*. Specifically, the objective of the work for this report was to develop a tool that will allow estimation of the critical nutrient load from S-79 consistent with any chosen chlorophyll-a target in the estuarine portion of the C-43 Basin below S-79.

Analysis of nutrient loading estimates indicates a high correlation between nitrogen and phosphorus load from the C-43 Basin. The current month total nitrogen (TN) load was identified as the independent variable that explains the greatest degree of variation in mean monthly chlorophyll observed in the tidal Caloosahatchee River.

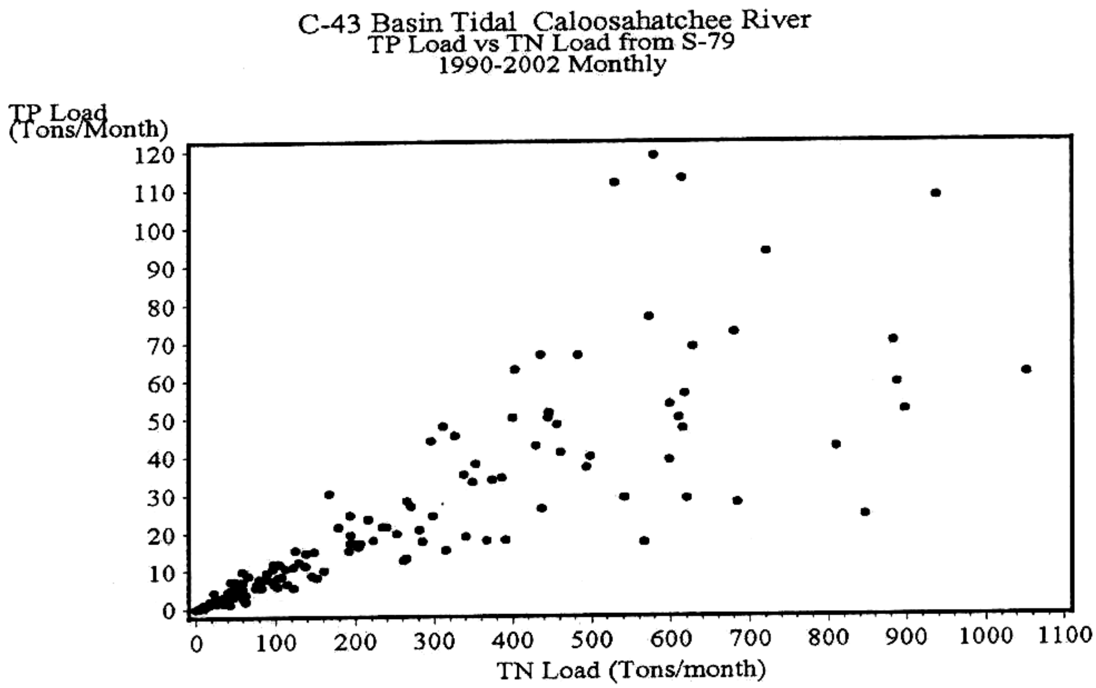


FIGURE A18.
Monthly TP loads against monthly TN loads from S-79, 1990-2002

The estimated daily nutrient concentrations at S-79 were derived from observed data. These daily concentrations were multiplied by the observed daily flow at S-79 to provide the estimated daily loads of nitrogen and phosphorus to the tidal river. Monthly loads were summed from the estimated daily loads from S-79. TN loads and TP loads from S-79 are highly correlated (**Figure A18**); therefore, care must be taken in the selection of the variable that best explain the variation in chlorophyll-a concentrations.

Figures A19 and **A20** display the 1990-2002 time series of monthly TN loading and chlorophyll-a concentration. Higher chlorophyll-a values typically occur when higher TN loads enter the tidal river from S-79. However, this relationship does not hold true at extremely high TN loads.

Figure A21 graphically represents the relationship between TN load and chlorophyll-a concentration on an annual time scale. Given a mean annual chlorophyll-a target, the associated critical load can be estimated from this relationship.

The relationships shown in **Figure A22** can be used similarly to that described above if management of TN loads from S-79 is desired on a shorter time scale.

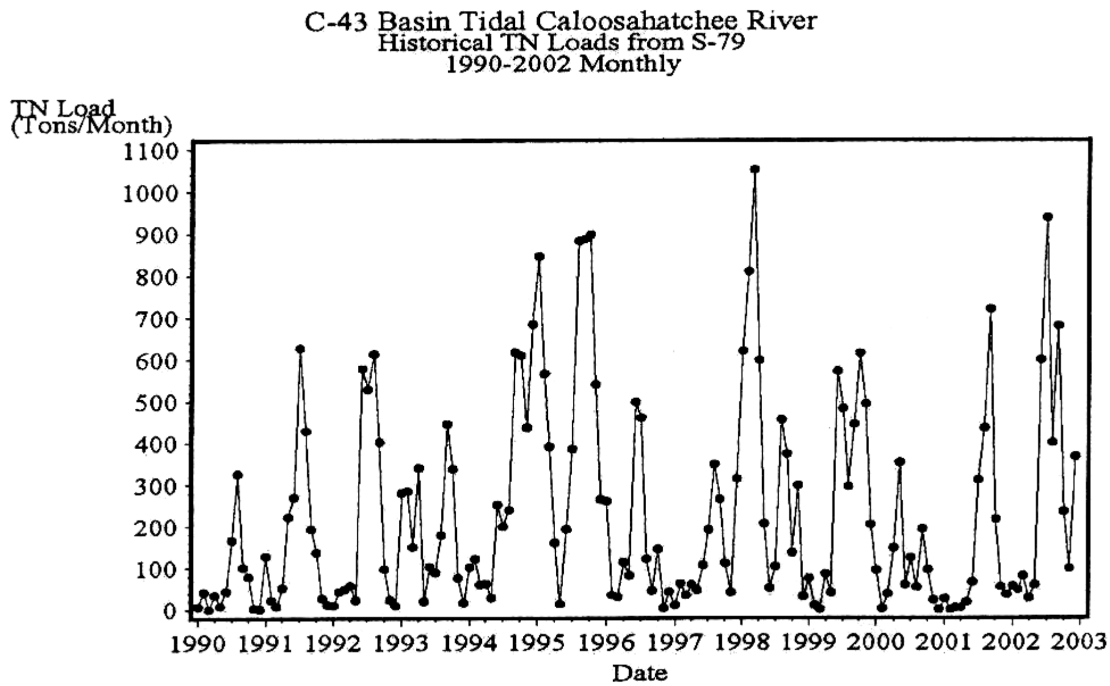


FIGURE A19
Monthly TN loads from S-79, 1990-2002

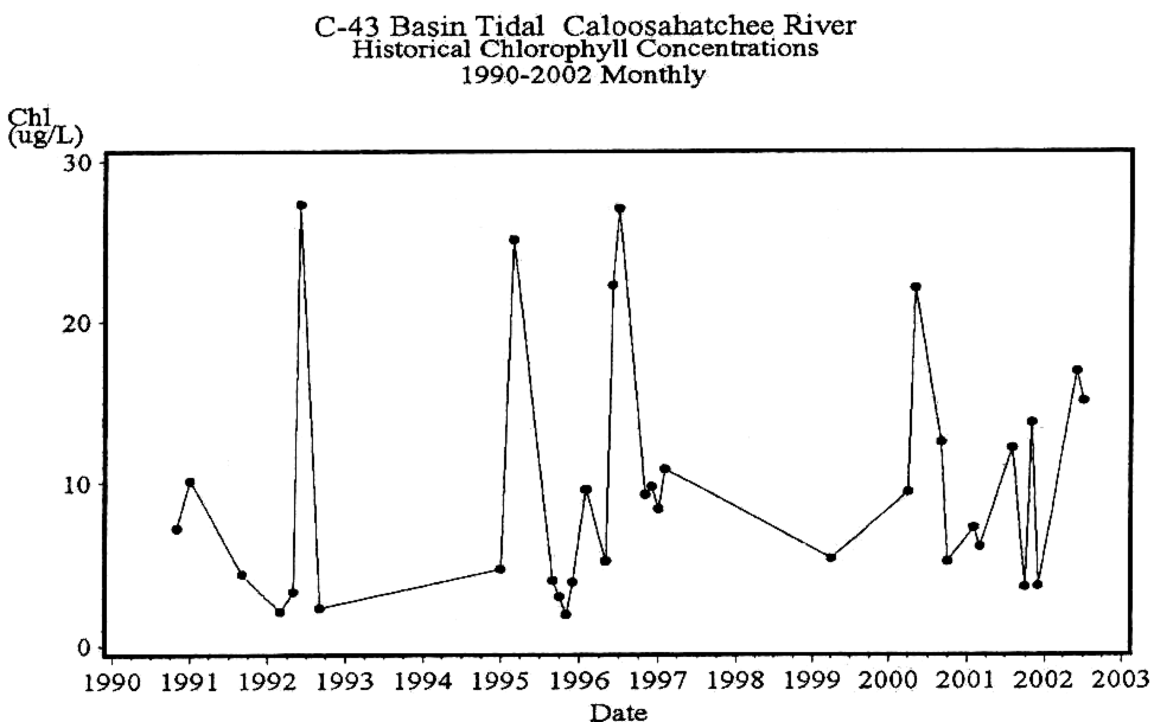


FIGURE A20
Monthly mean chlorophyll-a concentrations in the tidal Caloosahatchee River, 1990-2002

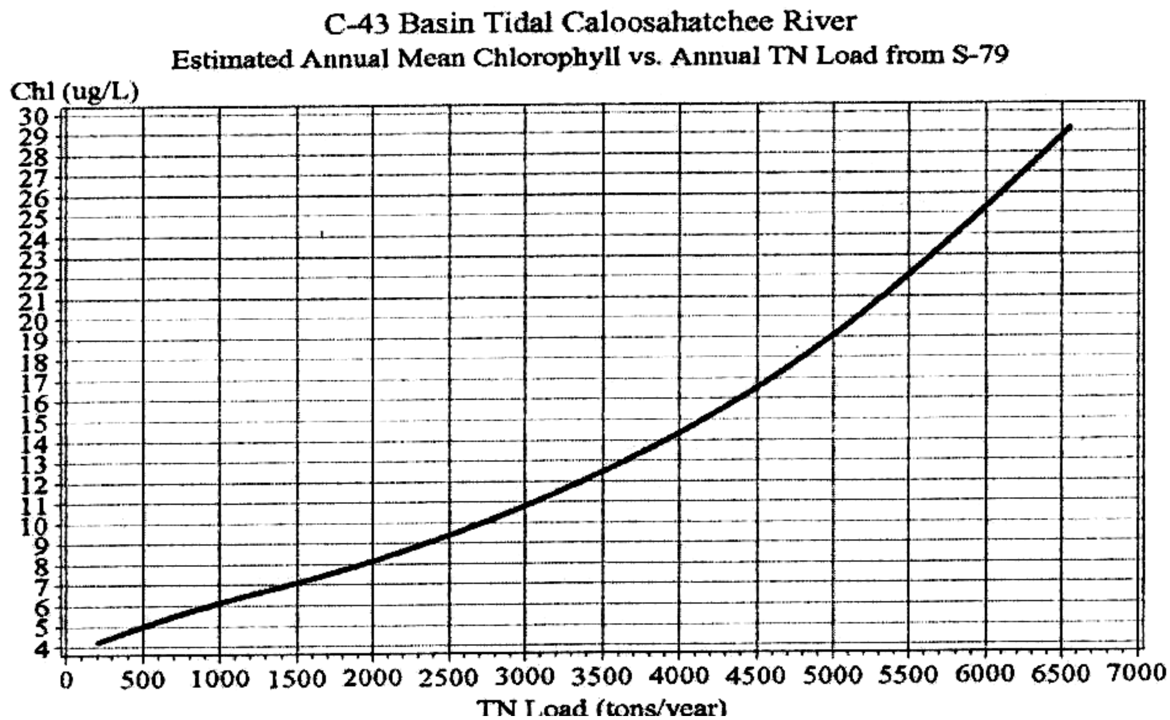


FIGURE A21
The estimated relationship between mean annual chlorophyll-a concentration in the tidal Caloosahatchee River and annual TN load from S-79

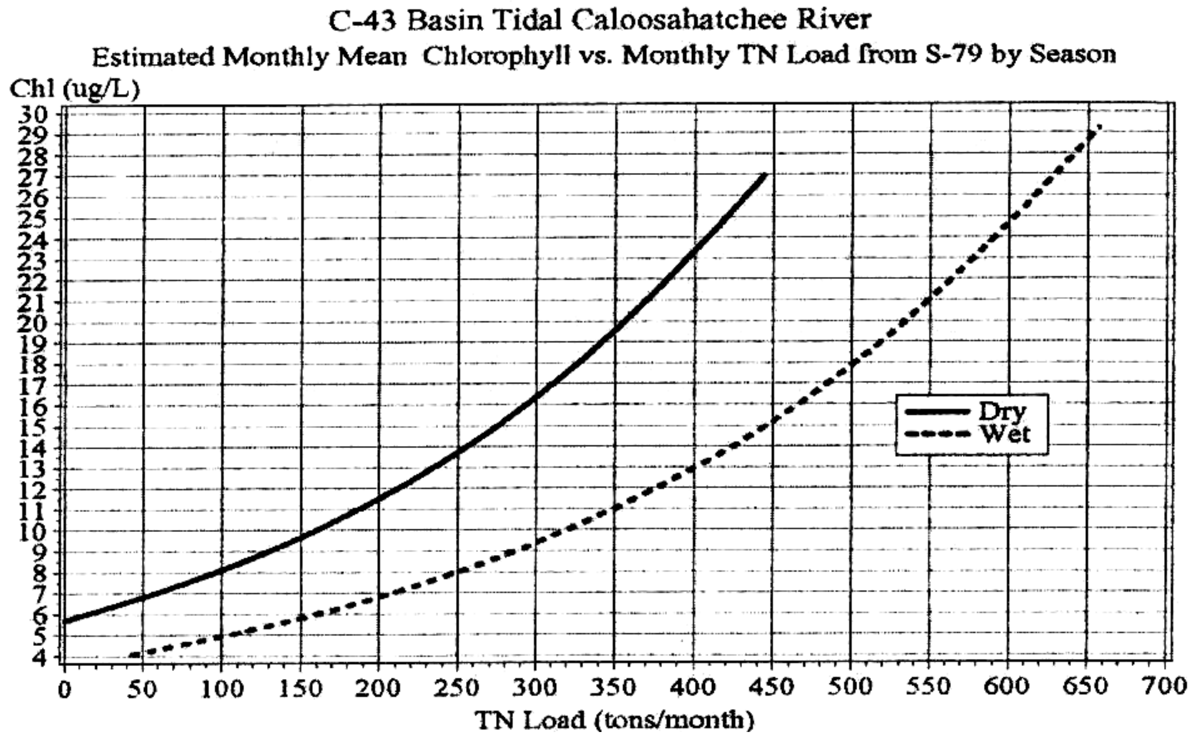


FIGURE A22
The estimated seasonal relationship between mean monthly chlorophyll-a concentration in the tidal Caloosahatchee River and monthly TN load from S-79

Doering, P.H., and R. H. Chamberlain. 2004. Total Nitrogen Loading to the Caloosahatchee Estuary at the Franklin Lock and Dam (S-79): Interim CERP Water Quality Update. South Florida Water Management District, Coastal Ecosystem Division, Unpublished Technical Analysis for CERP WQT ICU.

The discharge of freshwater from S-79 controls the downstream water quality based on the overwhelming dominance of the Caloosahatchee River as a source of nutrients and other materials to the downstream estuary. Changes in discharges are likely to alter nutrient loading. The discharge at S-79 accounts for 88%-92% of TN loading from surface waters during the wet and dry seasons, respectively. Janicki Environmental (2003) estimated that TN loads exceeding 350 English tons/month in the wet season and 190 tons/month in the dry season (or annual loads greater than 3000 tons/year) result in chlorophyll-a concentrations exceeding a potential target value of 11 ug/l. The Comprehensive Everglades Restoration Plan (CERP) suggests marked changes in the volume and timing of delivery of freshwater at S-79, as nutrient loading into the Caloosahatchee is primarily a function of discharge (rather than concentration). Thus, changes in discharges are likely to alter nutrient loading. This analysis is to estimate changes in nutrient loading that might accompany the implementation of CERP. The study focuses on nitrogen because 1.) Nitrogen likely limits primary production, and 2.) Potential critical nitrogen loads have been identified.

The loading of material from the S-79 structure is equal to the freshwater discharge multiplied by the material concentration. The daily loads are thus the concentration multiplied by the total daily discharge. For the period of record Jan 1981 – Jun 2003, a mean concentration of TN was calculated for each month of the year. For each model scenario, this average 12 month year was repeated 36 times and paired with total monthly discharge for each month. As a result, loading was calculated for each month of each 36 year scenario. Seasonal and annual loads were calculated and compared to the critical loads identified by Janicki Environmental (2003).

The South Florida Water Management Model produces hydrologic output based on hypothetical conditions of land use and water management. Water quality is not in the model output. While discharge is estimated by the model, no nutrient concentrations are available to use in a loading calculation. TN concentrations are estimated from existing data at S-79.

The same annual pattern of TN concentrations was used for each year in each model scenario – differences between scenarios are entirely a function of discharge differences. The potential water quality benefit of any scenario is a function of discharge and not a function of any TN concentration change that may accompany CERP. The analysis compares TN loading estimates to potential WQ performance measures based on Janicki 2003 report.

The concentration of TN in freshwater at S-79 generally fluctuated between 1.0 and 2.5 mg/l and exceeded the concentration (1.0 mg/l) recommended for downstream estuarine waters in most of the samples taken between 1981 and 2003 (**Figure A23**).

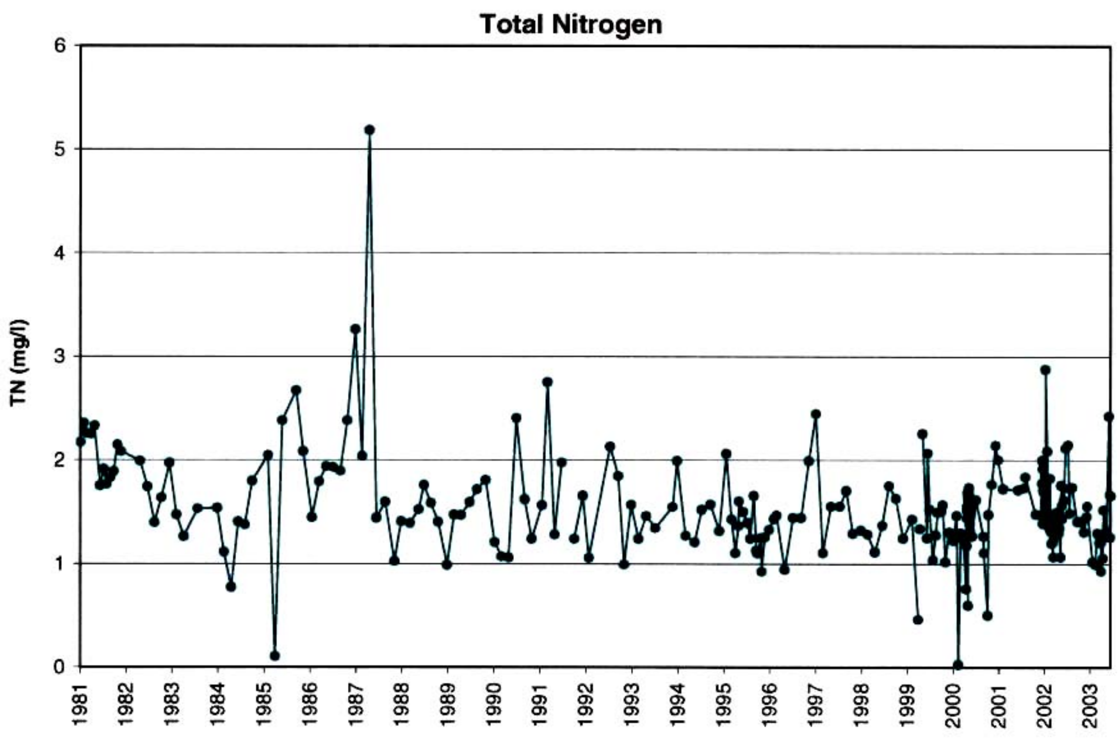


FIGURE A23
Concentration of Total Nitrogen (TN) in the freshwater discharge at S-79

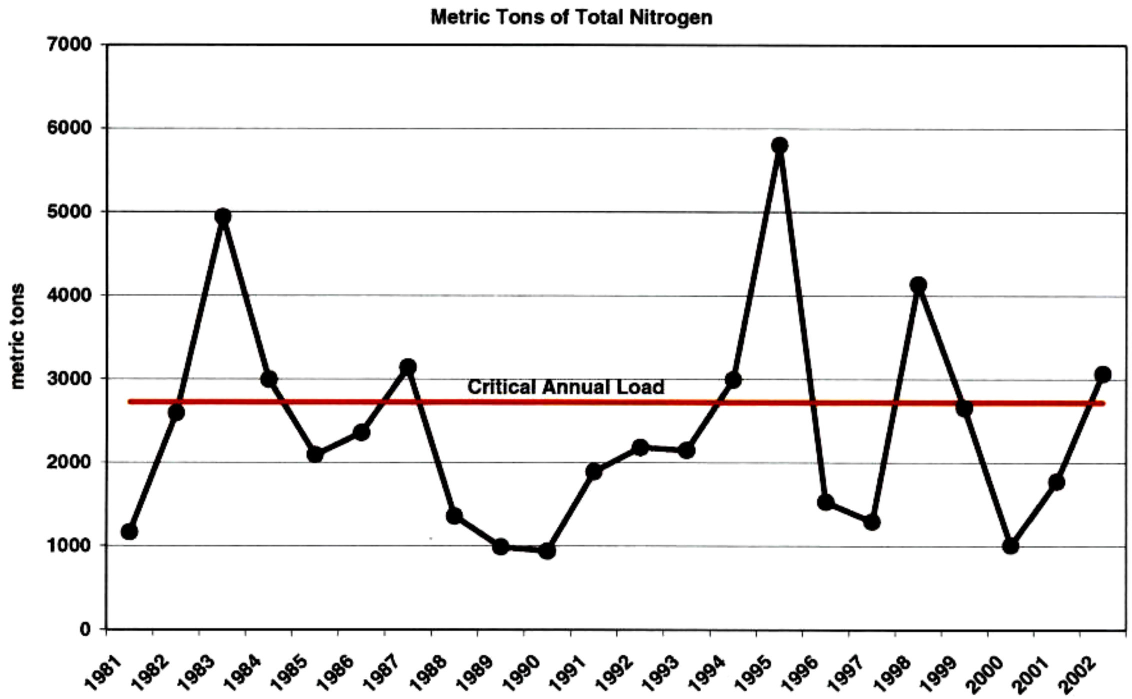


FIGURE A24
Annual load in metric tons of Total Nitrogen (TN) to the Caloosahatchee Estuary at S-79. The reference line marks the critical annual load of 3000 English tons identified by Janicki Environmental (2003)

The annual load of TN showed no trend (**Figure A24**) and exceeded the critical load of 3000 English tons (~ 2700 metric tons) in only 7 of the 22 years of record.

As compared to the two base cases (2000 and 2050), the total annual and seasonal discharges to the Caloosahatchee were reduced in the two CERP modeling scenarios. As compared to the two base cases, the CERP scenarios showed a lesser number of years in which the annual TN load at S-79 exceeded critical loads. Most of the reduction in flow occurred in the wet season. The results of modeling scenarios are depicted in **Table A9**.

TABLE A9
Annual and seasonal discharge to the Caloosahatchee Estuary at S-79 for the modeling scenarios

Discharge at S-79 in acre-ft/year				
Season	2000 base	2050 base	CERP 0	CERP 1
Dry	350,880	320,156	227,888	227,102
Wet	7,000,257	6,312,002	339,304	341,827
Annual	1,051,137	951,358	567,192	568,929

Looking at consecutive months that exceed the loading target, the CERP scenarios showed less consecutive months in which loads were exceeded. This analysis suggests that reductions in flow projected to occur as a result of CERP will decrease nutrient loading to the Caloosahatchee Estuary. However, the TN loading estimates calculated for each model output scenario assume that concentrations in the future remain on average as they have for the past 22 years. This conclusion is rendered suspect by the lack of reliable estimates of future TN concentrations in water released at S-79. These future concentrations will be influenced by population growth, land use in the C-43 basin, impoundment of runoff in reservoirs, and use of Aquifer Storage and Retrieval wells. The volume weighted impact of each of these factors requires evaluation.

The highest frequency of flows in the CERP scenarios fall in the 301-660 cfs range. The relative absence of flows above 4500 cfs should improve water quality in San Carlos Bay.

Tetra Tech Inc. and Janicki Environmental Inc. 2004. Compilation, Evaluation, and Archiving of Existing Water Quality Data for Southwest Florida. Final Report to Department of the Army Corps of Engineers, Jacksonville, Florida, May 5, 2004. Contract No. DACW 17-02-D-0009.

The purpose of this project was to develop a baseline water quality data set for the Southwest Florida region to serve as a tool for quantifying and qualifying responses to alternative plans. This data set can be used in identifying opportunities for water quality improvement within the SWFFS area. Most of the trends that indicated a decline in water quality were found in the northwest region of the study area, near Fort Myers and Fort Myers Beach.

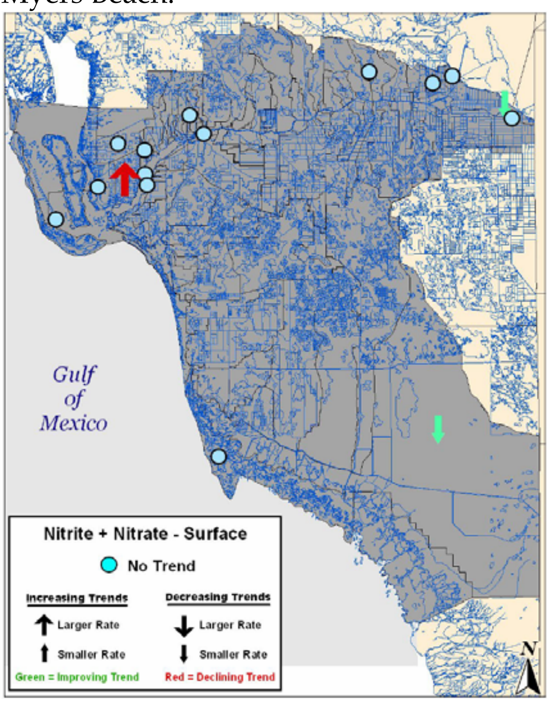


FIGURE A25
Trends in Nitrite + Nitrate for surface waters of the Southwest Florida region

No significant trends were found in ammonia. Nitrite along the northwestern coast and near Fort Myers was steeply decreasing or showing no trend. 4 waterbodies, all in the San Carlos Bay area, exhibited steep increasing trends in nitrate (declining water quality). Organic nitrogen trends in water bodies in the Fort Myers area were not significant. In general TKN (the total concentration of organic and ammonia nitrogen) trends near the Fort Myers area were either increasing or not significant. Trends for nitrogen are shown in **Figure A25** and **Figure A26**. The trends in total phosphorus showed that several water bodies had increasing (declining) trends just north of the Caloosahatchee Estuary. TP trends are represented in **Figure A27**. Further, dissolved oxygen trends in surface water in the northwest region of the study, from Fort Myers to Naples, were observed as being either steep or shallow decreases (declining condition). Results are illustrated in **Figure A28**.

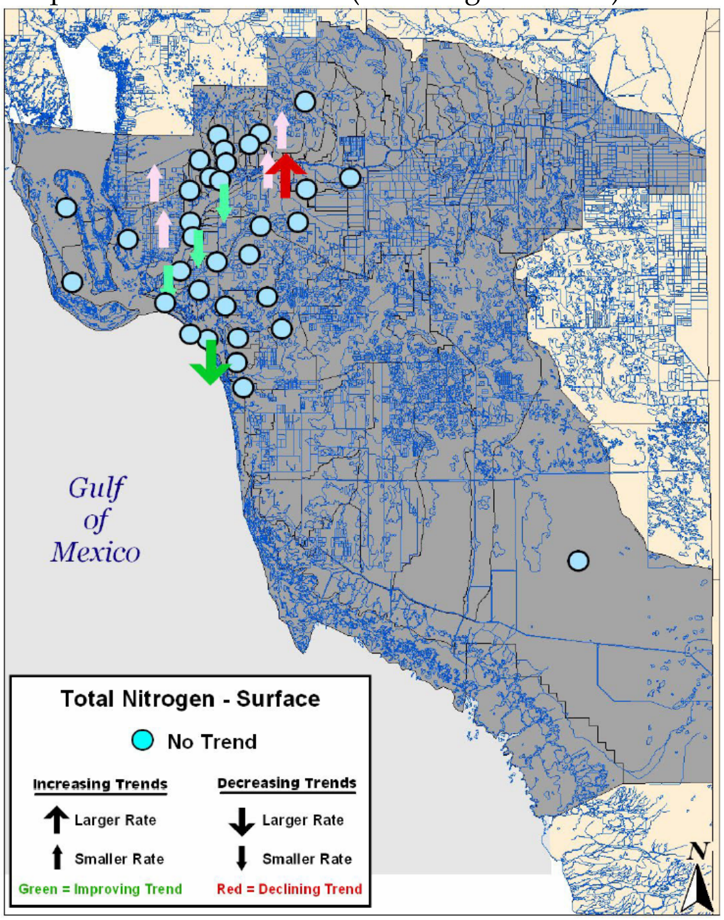


FIGURE A26
Trends in total nitrogen for surface waters of the Southwest Florida region

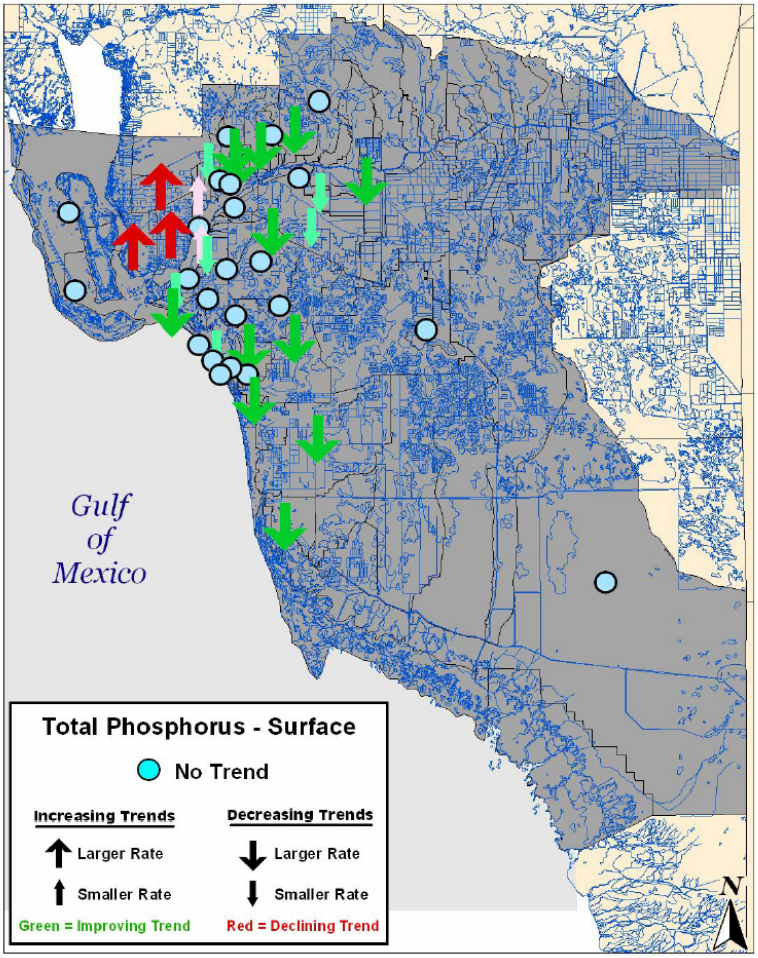


FIGURE A27
Trends in total phosphorus for surface waters of the Southwest Florida region

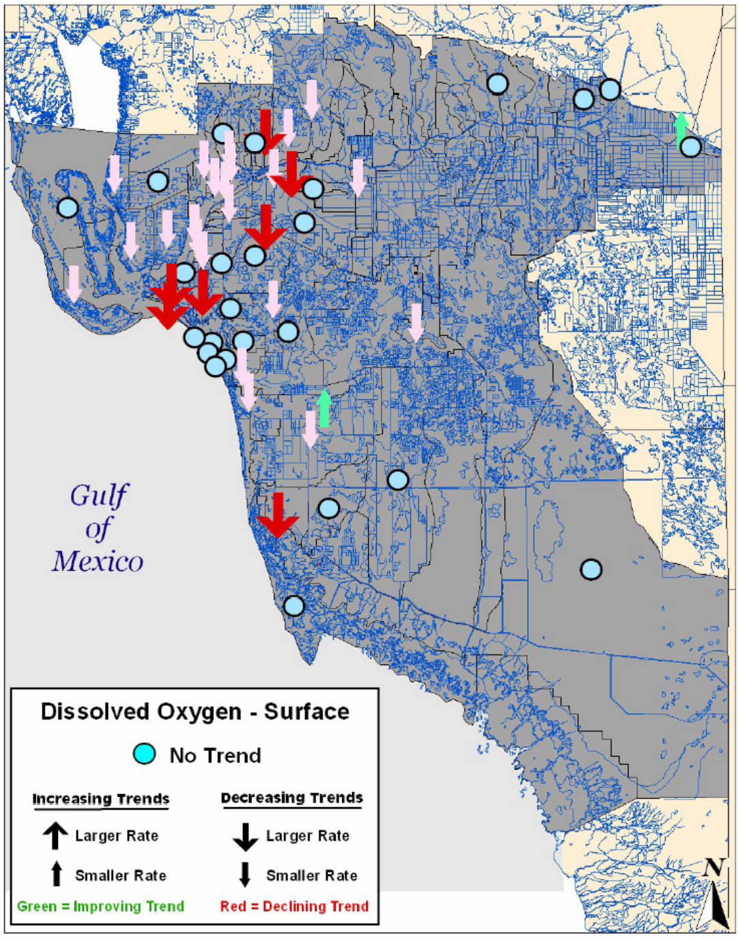


FIGURE A28
Trends in dissolved oxygen for surface waters of the Southwest Florida region

As far as bottom waters are concerned, all of the waterbodies in the northwest part of the study area showed no trend. TKN and TN in the northwest showed one small rate increase and the remaining showed no trend. All of the sites tested for trends in orthophosphate and total phosphate were located in the northwest portion of the study area and ¾ showed large declining trends in orthophosphate (improving water quality). Similarly, all of the sites tested for trends in TSS and turbidity were located in the NW portion of the study area. Mixed results were seen for trends in TSS, while increasing trends were observed in bottom turbidity, indicating a decline in water quality. DO in bottom waters was observed as having no significant trend, with the exception of one decreasing trend, again in the northwest portion of the study area near Fort Myers. Many of the waterbodies in the northwest exhibited no significant trends in pH with one small decreasing trend in the vicinity of Fort Myers.

The authors note that only FDEP has the authority to identify waterbodies that have been determined to have a water quality problem or have been determined to need more attention and data collection. However, Tetra Tech has developed a Waters of Concern Calculator to identify Waters of Potential Concern and Waters of Verified Concern.

Waters are placed on the planning list if:
1.) Exceed applicable aquatic life-based water quality criteria (62-303.320)
2.) Does not meet biological assessment thresholds (62-303.330)
3.) Acutely/Chronically toxic (62-303.340)
4.) Exceeds nutrient thresholds (62-303.350)

Based on these considerations, there are 318 parameter-specific Waters of Potential Concern in the SWFFS area. Results are summarized in **Table A10**. The most frequent parameter of concern was fecal coliform bacteria, followed by DO, un-ionized ammonia, nutrients, iron, copper, and total coliform.

TABLE A10
Parameter-specific Waters of Potential Concern in the SWFFS area

Parameter	Count of Basins
Fecal coliform bacteria	72
Dissolved Oxygen	71
Un-ionized Ammonia	51
Nutrients	45
Iron	32
Copper	15
Total coliform bacteria	15
Conductance, specific	13
pH	3
Turbidity	1
Grand Total	318

There are 296 Waters of Verified Concern in the SWFSS area. Results of the related parameters of concern are summarized in **Table A11**.

Table A11
Parameter-specific Waters of Verified Concern in the SWFFS area

Parameter	Count of Basins
Fecal coliform bacteria	70
Dissolved Oxygen	68
Un-ionized Ammonia	44
Nutrients	39
Iron	32
Total coliform bacteria	14
Conductance, specific	13
Copper	11
Lead	1
pH	2
Turbidity	2
Grand Total	296

Johnson Engineering. 2005. Literature Review of Stormwater Treatment Best Management Practices Research in Florida. Prepared for Lee County Board of County Commissioners, Ft. Myers, FL.

This report provides the results of a literature review of ongoing and completed research on stormwater treatment best management practices (BMPs) in Florida. The State of Florida's stormwater rule was adopted in 1982 and required all new development and redevelopment projects to include site appropriate BMPs to treat stormwater. The program established a performance standard of removing at least 80% of the average annual post-development loading of total suspended solids for stormwater discharged to most waters and a reduction of pollutant loadings by 95% for discharges to Outstanding Florida Waters.

In brief, a stormwater treatment BMP is a technique, measure, or control that is used for a given set of conditions to manage the quantity and/or improve the quality of stormwater runoff in the most cost effective manner. BMPs can be engineered and constructed systems ("structural systems") that improve the quality and/or control the quantity of runoff such as detention ponds and constructed wetlands. Institutional, educational or pollution prevention practices designed to limit the generation of stormwater runoff or reduce the amounts of pollutants contained in the runoff are considered "non-structural" BMPs.

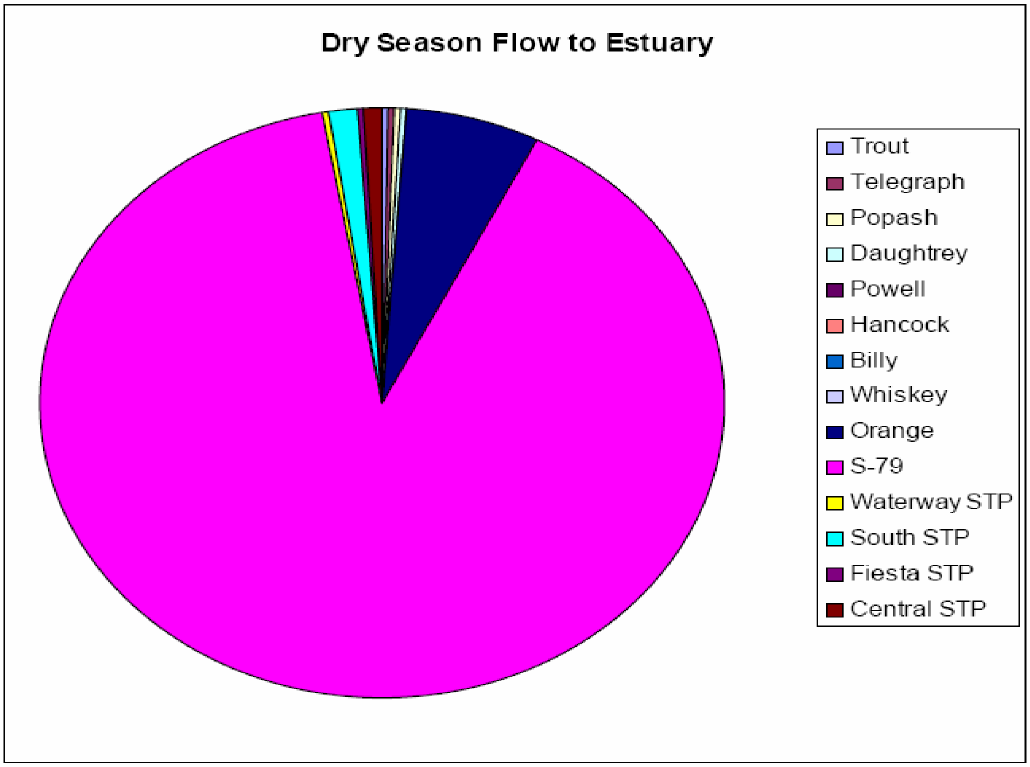
Environmental Research and Design, Inc. 2003. Caloosahatchee Water Quality Data Collection Program. Final Interpretive Report for Years 1-3. Prepared for the SFWMD. Orlando, FL. January 2003.

This report summarizes the results of years 1 – 3 of the Caloosahatchee Water Quality Data Collection Program. This study was a three-year project funded by the South Florida Water Management District (District) to quantify external loadings entering the Caloosahatchee Estuary from the Caloosahatchee River, Orange River, wastewater treatment facilities, and eight major rivers and creeks.

Field monitoring and sampling were performed at 15 estuary sites during both wet season and dry season conditions over a three-year period from 2000–2002. Water quality samples were collected at the majority of these sites at a depth of 0.5 m from the surface and 0.5 m from the bottom (a fraction of the sites were only sampled at 0.5 m from the surface). Mean vertical profiles of temperature, pH, dissolved oxygen, and salinity under wet and dry season conditions were obtained by averaging all dry season and wet season field data at a given monitoring site. Also, changes in longitudinal water quality characteristics throughout the Caloosahatchee Estuary were evaluated by examining the characteristics of the surface samples collected at each of the monitoring sites along the main channel of the estuary.

As well, field monitoring and sample collection were performed at 14 nutrient monitoring sites during both wet season and dry season conditions over a three-year period from 2000–2002. Each monitoring event involved the collection of water quality samples and volumetric flow measurements. Eight of the 14 monitoring sites are located in significant tributaries, based on the magnitude of freshwater discharge, which discharge directly into the Caloosahatchee Estuary between the S-79 structure and Shell Point. These eight tributaries include Trout Creek, Telegraph Creek, Popash Creek, Daughtrey Creek, Powell Creek, Hancock Creek, Billy Creek, and Whiskey Creek. Monitoring sites were also established upstream of the S-79 structure and in the Orange River. Four wastewater treatment facilities that discharge directly into the Caloosahatchee Estuary were monitored, including: Waterway Estates STP; Ft. Myers South STP; Fiesta Village STP; and Ft Myers Central STP. At each monitoring site, field measurements of pH, conductivity, salinity, and temperature were performed. Flow measurements were obtained by direct field measurement (tributaries), District records (S-79), operational reports (wastewater plants).

The most dominant impact on the estuary is clearly inflow from the S-79 Structure followed by the Orange River, Telegraph Creek, Daughtrey Creek, Trout Creek, Popash Creek, and the Ft. Myers South STP. A graphical comparison of dry season and wet season inflow to the Caloosahatchee Estuary is given in **Figure A29**. Under dry season conditions, inflow from the S-79 Structure, Orange River, FT. Myers South STP, Ft. Myers Central STP, and Telegraph Creek represent the most significant volumetric inputs to the system. However, under wet season conditions, inflow from the Orange River becomes more significant, though discharges through S-79 still represent the vast majority of the inflow into the estuary system.



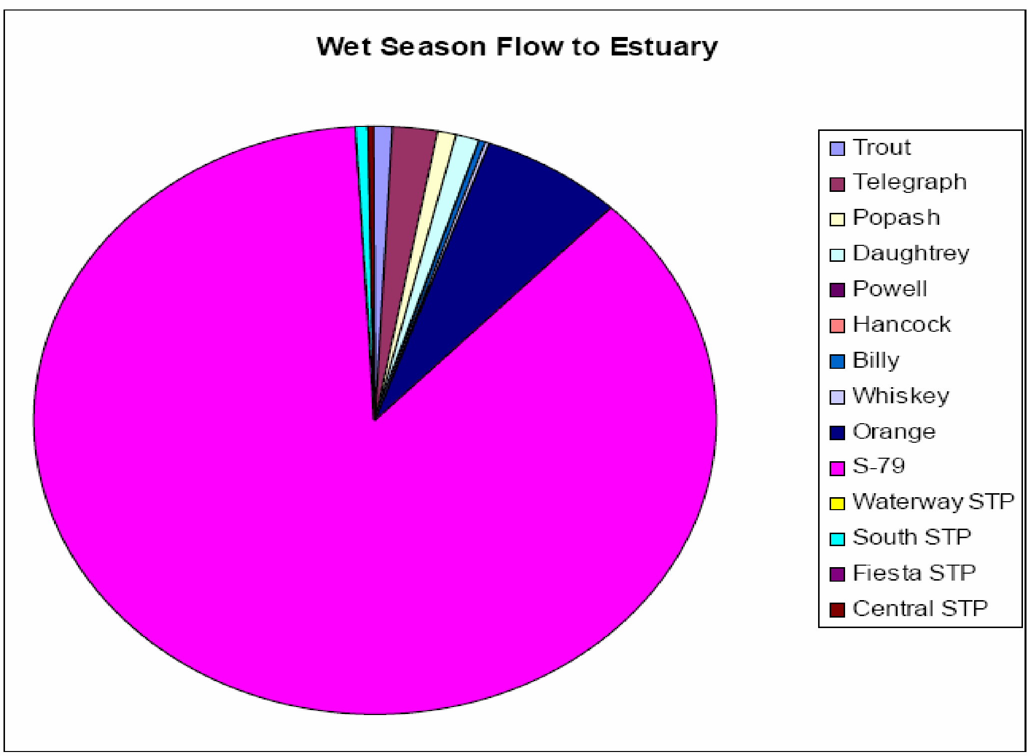


FIGURE A29.
Comparison of Wet Season and Dry Season Inflow to the Caloosahatchee Estuary

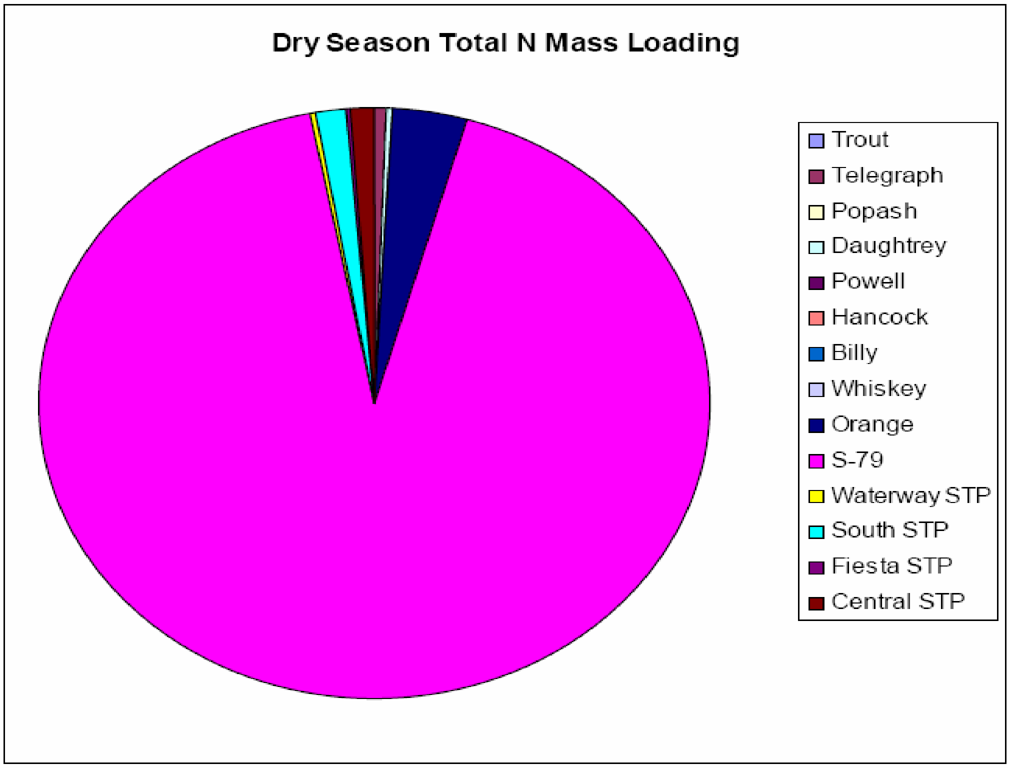
Estimates of mass loadings into the Caloosahatchee Estuary were calculated for each of the measured laboratory parameters at the 14 nutrient monitoring sites. Mass loadings were calculated utilizing the mean measured flow data and the mean measured laboratory characteristics of nutrient inputs. A summary of calculated mean daily mass loadings of measured parameters discharging to the Caloosahatchee Estuary under dry season conditions and under wet season conditions are given in **Table A12** and **Table A13**, respectively. A comparison of wet and dry seasonal mass inputs into the Caloosahatchee estuary are represented graphically for ammonia, nitrite, nitrate, TKN, TN, orthophosphorus, TP, TSS, and VSS. **Figure A30** and **Figure A31** show the seasonal mass inputs of TN and TP into the Caloosahatchee Estuary.

TABLE A12
Calculated Mean Daily Mass Loadings of Measured Parameters Discharging to the Caloosahatchee Estuary under Dry Season Conditions

SITE	PARAMETER									
	Ammonia (kg/day)	Nitrite (kg/day)	Nitrate (kg/day)	TKN (kg/day)	Total N (kg/day)	Ortho-P (kg/day)	Total P (kg/day)	TSS (kg/day)	VSS (kg/day)	Flow Rate (cfs)
Trout Creek	0.13	0.02	1.29	1.48	2.80	0.07	0.15	5.63	3.30	1.33
Telegraph Creek	0.26	0.03	0.24	8.24	8.51	0.07	0.29	9.86	8.86	3.33
Popash Creek	0.11	0.02	0.49	2.88	3.39	0.25	0.82	18.7	10.0	1.06
Daughtrey Creek	0.13	0.02	0.27	3.88	4.18	0.77	1.31	17.8	13.5	2.22
Powell Creek	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hancock Creek	0.08	0.00	0.01	0.51	0.52	0.11	0.25	4.44	2.51	0.21
Billy Creek	-0.09	0.00	0.04	-0.32	-0.29	-0.01	-0.10	-1.36	-0.86	-0.19
Whiskey Creek	0.00	0.01	0.08	0.21	0.30	0.00	0.02	0.70	0.31	0.13
Orange River	3.62	0.22	5.72	91.9	97.9	0.98	4.18	162	98.0	45.4
S-79 Structure	182	51.5	374	2010	2408	211	355	5943	4412	647
Waterway Estates STP	0.23	0.07	1.11	2.59	3.73	0.08	0.19	3.76	2.41	1.23
Ft. Myers South STP	3.46	0.07	7.12	32.8	40.0	0.95	8.33	111	82.0	9.97
Fiesta Village STP	0.64	0.01	0.59	4.39	4.98	0.22	0.32	4.05	2.75	1.52
Ft. Myers Central STP	1.69	0.08	3.64	25.0	28.7	0.47	3.19	75.8	52.4	6.86

TABLE A13
Calculated Mean Daily Mass Loadings of Measured Parameters Discharging to the Caloosahatchee Estuary under Wet Season Conditions

SITE	PARAMETER									
	Ammonia (kg/day)	Nitrite (kg/day)	Nitrate (kg/day)	TKN (kg/day)	Total N (kg/day)	Ortho-P (kg/day)	Total P (kg/day)	TSS (kg/day)	VSS (kg/day)	Flow Rate (cfs)
Trout Creek	8.86	0.82	9.60	70.0	80.0	3.97	9.68	233	113	25.0
Telegraph Creek	24.2	2.39	13.11	315	329	13.9	24.1	645	349	80.0
Popash Creek	5.73	0.54	5.18	69.0	75.0	6.03	12.1	204	121	22.3
Daughtrey Creek	10.0	0.55	5.93	105	111	4.91	10.8	261	137	35.2
Powell Creek	1.32	0.06	0.55	12.2	12.8	0.46	1.94	54.9	29.2	5.63
Hancock Creek	0.33	0.01	0.12	2.18	2.31	0.13	0.41	12.5	7.54	0.71
Billy Creek	1.67	0.33	2.89	22.3	25.3	3.60	5.48	67.0	41.6	9.07
Whiskey Creek	5.16	0.43	2.47	16.2	19.0	0.72	2.43	70.0	47.4	3.42
Orange River	32.7	5.19	42.2	310	356	9.11	26.2	2597	1040	225
S-79 Structure	249	66.9	2160	8838	11,051	474	1040	34,519	25,365	2892
Waterway Estates STP	0.98	0.05	1.26	4.17	5.48	0.18	0.31	4.44	3.72	1.71
Ft. Myers South STP	41.7	0.25	5.78	102	108	0.88	15.8	210	160	14.3
Fiesta Village STP	0.45	0.01	1.17	6.49	7.67	0.43	0.70	8.03	7.22	3.14
Ft. Myers Central STP	27.8	0.30	5.49	75.9	81.6	0.45	4.76	106	75.6	10.0



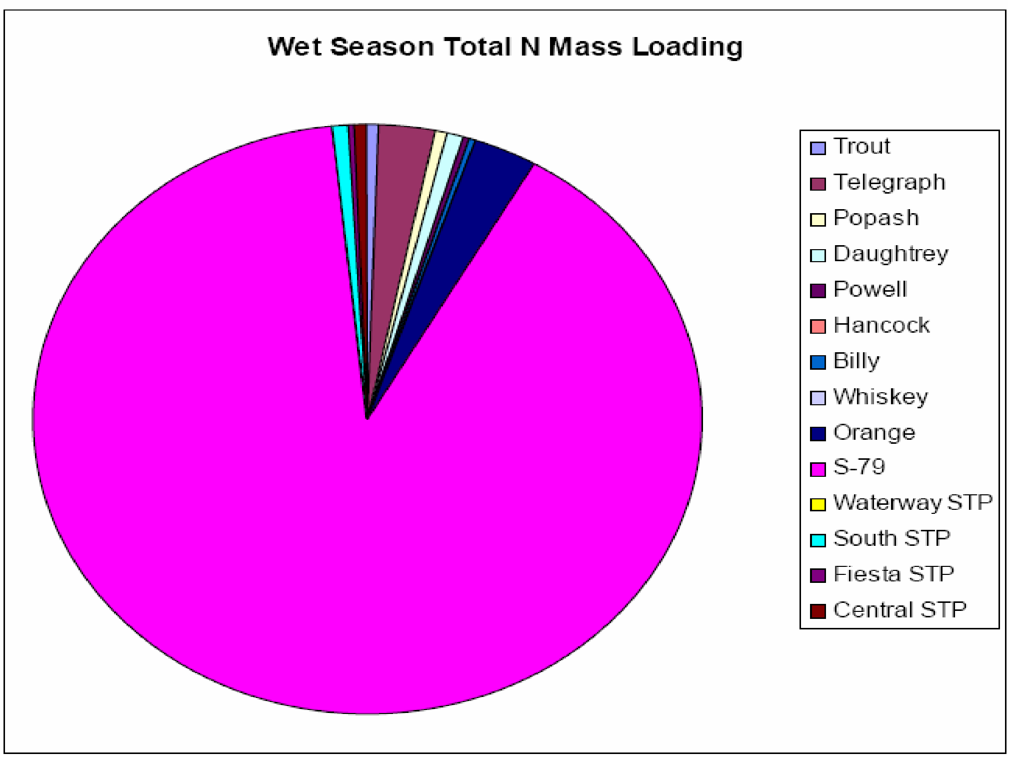
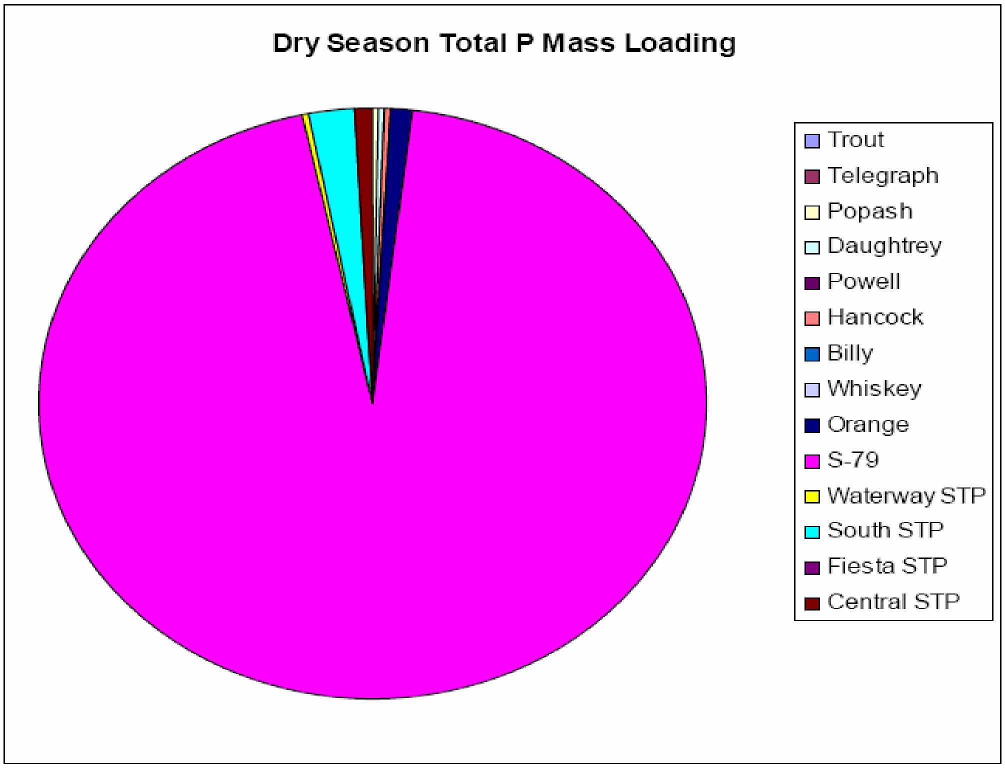


FIGURE A30
Comparison of Seasonal Mass Inputs of Total Nitrogen into the Caloosahatchee Estuary



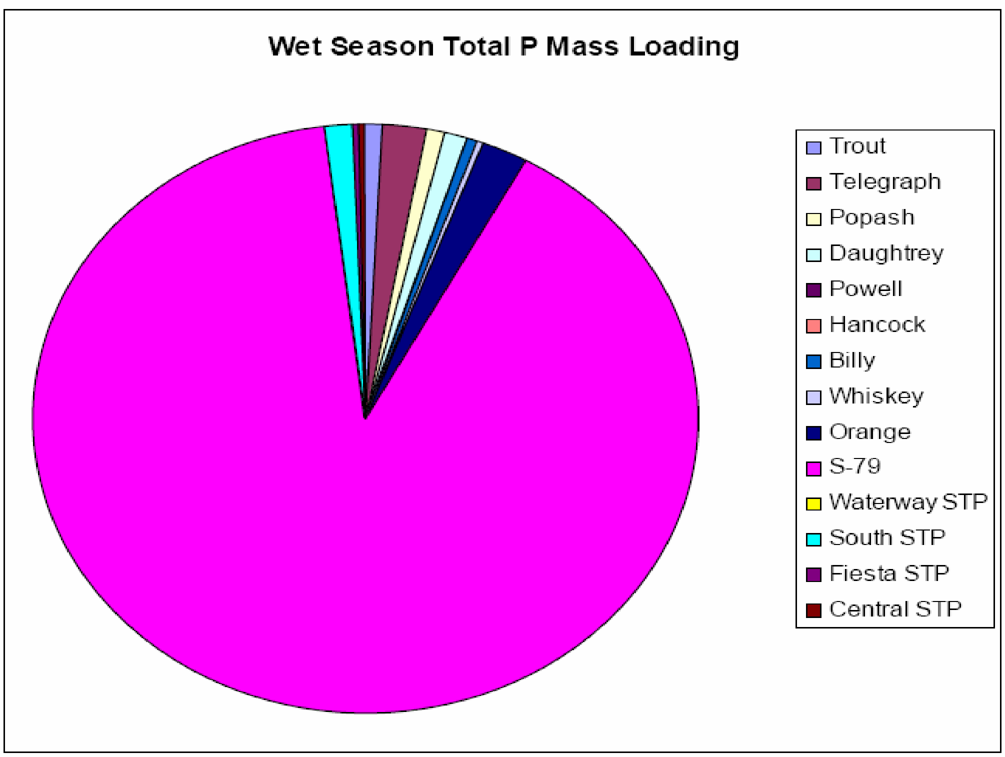


FIGURE A31
Comparison of Seasonal Mass Inputs of Total Phosphorus into the Caloosahatchee Estuary

Doering, P.H. 2005. The Caloosahatchee Estuary: Status and Trends in Water Quality in the Estuary and Nutrient Loading at the Franklin Lock and Dam (Draft). Deliverable Number 1 Water Quality Report Florida Coastal Management Program Grant CZ515.

Nutrient loads delivered to the Caloosahatchee Estuary at the Franklin Lock and Dam (S-79) were calculated on an annual basis from 1982 – 2002. Monthly nutrient loads were also calculated and related to synoptic water quality samples taken in four different regions of the downstream estuary. Trends and status of estuarine water quality were also evaluated. Water quality data collection in the estuary has not been continuous. Three sampling periods were compared to establish trends (1985-1989, 1994-1996, 1999-2003). **There were no trends in annual nutrient loads at S-79**, although loads ranged from 938 to 5,801 metric tons/yr for TN and 101 to 403 tons per year for TP. In the downstream estuary color increased while TN and dissolved inorganic phosphorus decreased over time. The molar ratio of dissolved inorganic nitrogen to dissolved inorganic phosphorus decreased. There was also evidence that the concentration of dissolved oxygen in bottom waters declined in the upper and mid estuarine regions. Chlorophyll *a* may be an acceptable indicator of eutrophication in the Caloosahatchee system. In the lower estuary and San Carlos Bay, the concentration of chlorophyll *a* increased with increasing loading of TN at S-79. In the Caloosahatchee Estuary, high concentrations of chlorophyll *a* were associated with low concentrations of dissolved oxygen at lags of one or two months. In San Carlos Bay chlorophyll *a* explained nearly 70% of the variability in light attenuation, suggesting that increased nutrient loading could reduce light availability to seagrasses. Empirical relationships between (1) nutrient loading at S-79 and chlorophyll *a* concentrations in San Carlos Bay and (2) light extinction and chlorophyll *a* in San Carlos Bay in combination with assumptions about light requirements for seagrass were used to calculate nutrient loads at S-79 that were commensurate with growth of seagrass at various depths.

Appendix B - Review of Selected Research Studies Relevant to the Effects of Nutrients in River/Estuary Environments

Ryther, J.H., and W.M. Dunstan. 1971. Nitrogen, Phosphorus, and Eutrophication in the Coastal Marine Environment. *In*: B.J Neilson and E.J Cronin (Eds.), Nutrients and Estuaries. 1981. Humana, Clifton, New Jersey.

This study looks at nitrogen and phosphorus as contributors to eutrophication in coastal environments. The freshwater loads to the Caloosahatchee Estuary and the nutrient loading that accompanies these loads are of primary concern in the estuarine water quality. The photosynthetic production of organic matter by phytoplankton in the surface layers of the sea is made possible by the assimilation of inorganic nutrients from the surrounding water.

Most of these substances are present at concentrations in excess of a plant's needs, but some, like N and P, occur at minute levels and may be utilized by algae to the point of exhaustion. It is the availability of these nutrients that most frequently controls and limits the rate of organic production in the sea. Detailed examination of the nutrient data from the sea surface reveals that, as the two elements are utilized, nitrogen compounds become depleted more rapidly and more completely than does phosphate.

The surplus of phosphate in coastal waters and estuaries may be quite large and its source is unquestionably the land (detergents, human excreta, agricultural runoff, industrial wastes). This article shows through enriched water laboratory studies that it is nitrogen that limits and controls algal growth and eutrophication. Figure B1 shows the results of algal growth in unenriched, ammonium-enriched, and phosphate-enriched water from New York bight – a location where sewage sludge and dredging spoils from NYC are routinely dumped – as well as from up the Raritan and Hudson rivers.

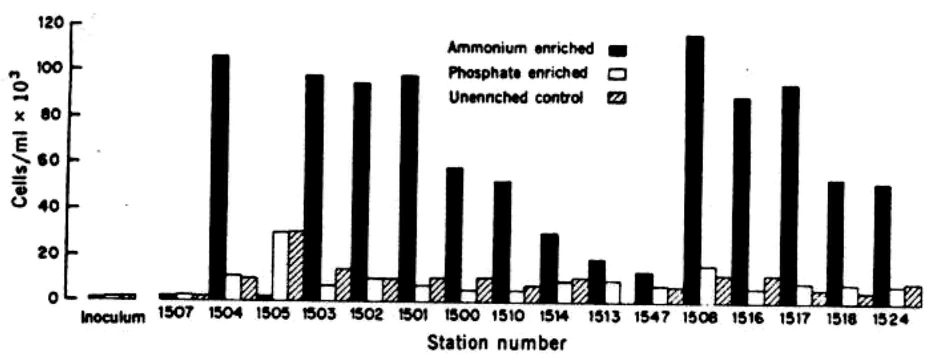


FIGURE B1
Growth of Skeletonema costatum in unenriched, ammonium-enriched, and phosphate-enriched water from the New York bight

If the phosphate in detergents is replaced with nitrogenous compounds, the net effect could be an acceleration and enhancement of eutrophication processes. Further, coastal waters receive the sewage of roughly half the population of the U.S. To replace a portion of the phosphate in this sewage with a nitrogenous compound and then discharge it into an environment in which eutrophication is nitrogen-limited may be adding fuel to a fire.

Jaworski, N.A. 1981. Sources of Nutrients and the Scale of Eutrophication Problems in Estuaries, p. 83-110. *In*: B.J Neilson and E.J Cronin (Eds.), Nutrients and Estuaries. Humana, Clifton, New Jersey.

Almost half of the FDEP waterbodies in the Caloosahatchee Estuary are verified as impaired for dissolved oxygen. High external nutrient loadings and the resulting eutrophication process can have three directly measurable impacts on the dissolved oxygen of an estuarine system: (1) a BOD exerted by the oxidation of ammonia nitrogen, (2) a BOD in the water column created by the conversion of inorganic carbon to organic carbon, and (3) a significant increase in total organic carbon of the system and its secondary impacts, such as benthic oxygen demand. There also can be an impact on the dissolved oxygen demand due to photosynthesis and respiration.

The impact of high nutrient enrichment is focused on over the concentration of nutrients because many estuaries which are highly enriched can be light limited, thus having no major eutrophication problems.

For estuarine ecosystems that are nitrogen limited (N/P ratio less than 16), the data are somewhat conflicting with regard to suggesting permissible loading for nitrogen. Estuaries that exhibited nitrogen loadings above the "permissible" level were nitrogen limited.

The studies suggest that use of the nutrient loading concept can yield insights as to the success of advanced wastewater treatment to prevent excessive eutrophic conditions in many estuaries. For estuarine systems with short hydrologic retention times and highly varying external loadings, seasonal or monthly analysis may be required.

Dennison et al. 1993. Assessing Water Quality with Submersed Aquatic Vegetation. *BioScience* 43(2): 86-94.

Chesapeake Bay has experienced water quality deterioration from nutrient enrichment, sediment inputs, and high levels of contaminants, resulting in anoxic or hypoxic conditions and declines in living resources. Water quality issues in the Caloosahatchee Estuary have been noted to be similar. The authors use habitat requirements for submersed aquatic vegetation to characterize the water quality of Chesapeake Bay because of their wide-spread distribution, sensitivity to water quality parameters, and important ecological role in the bay. Submersed aquatic vegetation is also important to the health of the Caloosahatchee Estuary.

Submersed aquatic vegetation (SAV) provides food for waterfowl and critical habitat for shellfish and fin fish. This vegetation also affects nutrient cycling, sediment stability, and water turbidity. The decline of SAV was related to increasing amounts of nutrients and sediments in Chesapeake Bay resulting from development of the bay's shoreline and watershed.

The generic nature of submersed aquatic vegetation/ light interactions leads to a potential for wider application of SAV habitat requirements. Establishment of minimal light requirements for various SAV species coupled with water quality monitoring data could be used to establish water clarity and nutrient standards in a variety of coastal environments with the goal of preventing further vegetation declines. The minimal light requirement of a particular species of SAV determines the maximum water depth at which it can survive.

Habitat requirements for DIN and DIP varied substantially between salinity regimes. In tidal freshwater and oligohaline regions, established SAV beds survive both episodically and chronically high DIN; consequently habitat requirements for DIN were not determined for these regions. Maximal DIN concentrations of 10 µM were established for mesohaline and polyhaline regions.

Water-quality conditions sufficient to support survival, growth, and reproduction of submersed aquatic vegetation to water depths of one meter below MLW were used as habitat requirements (**Table B1**).

TABLE B1
Chesapeake Bay submersed aquatic vegetation habitat requirements. For each parameter, the maximal growing season median value that correlated with plant survival is given for each salinity regime. Growing season defined as April-October, except for polyhaline (March-November). Salinity regimes are defined as tidal fresh = 0-0.5 o/oo; oligohaline = 0.5-5 o/oo; mesohaline = 5-18 o/oo; polyhaline = more than 18 o/oo

Salinity regime	Light attenuation coefficient (K_d; m^{-1})	Total suspended solids (mg/l)	Chlorophyll a (µg/l)	Dissolved inorganic nitrogen (µM)	Dissolved inorganic phosphorus (µM)
Tidal freshwater	2.0	15	15	—	0.67
Oligohaline	2.0	15	15	—	0.67
Mesohaline	1.5	15	15	10 0.1 mg/l	0.33
Polyhaline	1.5	15	15	10	0.67

The various water quality parameters had differing abilities to predict SAV distributions: chlorophyll-a (99%), dissolved inorganic phosphorus (95%), light attenuation coefficient (90%), TSS (84%), and DIN (83%); however, the overall average (90%) for all parameters is fairly high and indicates the utility of this approach. The habitat requirements represent the absolute minimal water-quality characteristics necessary to sustain plants in shallow water.

Because habitat requirements for nutrient concentrations depended on location, nutrient reduction strategies could vary depending on the salinity regime. However, nutrient loading in freshwater or oligohaline regions of the estuary affects nutrient concentrations of other salinity regimes, and nutrient reduction strategies may need to be baywide to achieve habitat requirements in each salinity regime.

Bricker, S.B., and J.C. Stevenson. 1996. Nutrients in Coastal Waters: A Chronology and Synopsis of Research. *Estuaries*. 19(2B): 337-341

This paper reviews the history of eutrophication studies in shallow-water estuaries and then presents some of the latest research: how far have we come in 40 years? The results of studies in this issue are consistent with the conclusions of early investigators. Both phosphorus and nitrogen can be limiting in large estuaries depending on temporal and spatial considerations.

Staver et al. investigates temporal and spatial patterns of nutrient inputs to a tributary of the Chesapeake. Nitrogen inputs were dominated by diffuse sources that are highly correlated to freshwater discharge.

Staver and Brinsfield examine subsurface nitrogen sources at the estuarine/groundwater interface. They report that groundwater discharge from agricultural fields is primarily driven by seasonal changes in groundwater recharge rages.

Malone et al. report that phytoplankton growth in the Chesapeake is limited by dissolved inorganic phosphorus during spring when ample nitrate flows into the Chesapeake. However dissolved inorganic nitrogen is often limiting by summer. Nonetheless, the magnitude of the spring bloom is governed by dissolved silica.

Lapointe and Matzie report that stormwater discharges of groundwater contaminated by septic tank effluent are a major source of land-based nutrients accelerating coastal eutrophication in subtropical waters of the Florida Keys.

Further, the studies that investigate sources of nutrients to Chesapeake systems suggest that nitrogen reductions will require the modification of agricultural practice within the agricultural drainage basin, rather than edge of field interception. Diffuse source phosphorus loads will require long-term management of phosphorus levels in upper soil horizons. The implication to management in Florida, where groundwater is contaminated with septic wastes, are equally daunting, suggesting nutrient removal with advanced wastewater treatment is required if nutrient reductions are to be achieved.

Tomasko, D.A., Dawes, C.J., and M.O. Hall. 1996. The Effects of Anthropogenic Enrichment on Turtle Grass (*Thalassia testudinum*) in Sarasota Bay, Florida. *Estuaries* 19(2B): 448-456.

Sea grasses are important species in estuarine environments, including the Caloosahatchee Estuary. Worldwide, the most often-cited cause of seagrass decline and disappearance is anthropogenic nutrient enrichment of nearshore waters. In most estuaries in Florida, seagrass loss is due to a combination of both direct and indirect impacts, from removal during dredge and fill operations to degraded water quality.

Five nitrogen nutrient sources were modeled in the nutrient loading analysis for Sarasota Bay: stormwater runoff, baseflow, point sources, septic tanks, and rainfall. There was no clear relationship between nitrogen loads and chlorophyll-a concentrations.

In Sarasota Bay, water-column nutrient concentrations do not reflect differences in modeled watershed nitrogen loads. Even with greater intensity of bi-weekly sampling, Chlorophyll-a concentrations off Siesta Key were only 26% higher than Leffis Key, despite a 12-fold higher value for modeled nitrogen loads.

The sparsest and least productive seagrass meadow, off of Siesta Key, was in waters that received the greatest nitrogen input. The authors recommend that water monitoring programs include the use of seagrasses as "bio-indicators" of system health along with traditional water quality parameters.

Tester, P.A. and K.A. Steidinger. 1997. *Gymnodinium breve* red tide blooms: Initiation, transport, and consequences of surface circulation. *Limnol. Oceanogr.* 42(5.part 2): 1039-1051.

Episodic increases in microalgal organisms, such as *Gymnodinium breve,* have a direct chemically-based toxic effect on animal or human health. Researchers have been stymied by the occurrence of red tides and are trying to understand these organisms and the conditions under which they thrive.

Gymnodinium breve have a high photosynthetic capacity at low light and are light-adapted at varying intensities. Once growth occurs, it takes 2-8 weeks to develop into a bloom of fish-killing proportions (1-2X10^5 cells liter $^{-1}$) depending on physical, chemical, and biological conditions. Further, *Gymnodinium breve* has advantages in nutrient dynamics; *G. breve* assimilates nitrogen at low light and is able to utilize organic as well as inorganic nutrients.

There is evidence that some blooms can be maintained within the midshelf zone and continually inoculate the near shore waters or recur in a “high occurrence zone” from Clearwater to Sanibel Island. *G. breve* thrives between 16 and 27°C with only a few cells surviving between 7 and 9.9°C.

G. breve blooms are shallow coastal water phenomena. The bloom model that is most consistent with observations made during the last 80-100 years starts with an offshore bloom initiation in late summer or fall in combination with a Gulf Loop intrusion on the outer continental shelf. Following cross-shelf transport, largely influenced by winds and wind-induced upwelling or downwelling, cells concentrate and grow at a region approximating the midshelf front. If cross-shelf transport mechanisms continue to operate on the bloom, cells concentrate in nearshore waters where movement is governed by winds and alongshore currents.

Valiela, I. *et al.* 1997. Macroalgal blooms in shallow estuaries: Controls and ecophysiological ecosystem consequences. *Limnol. Oceanogr.* 42(5.part 2): 1105-1118.

Macroalgal blooms are unlike microalgal blooms in that they lack direct chemical toxicity; however they have a broader range of ecological effects and last longer. The term “harmful algal blooms” generally refers to episodic increases in microalgal organisms that have a direct chemically-based toxic effect on animal or human health. However, the effects of macroalgal blooms are indirect and extensive – bloom seaweeds may remain in an environment for years to decades.

The proliferation of macroalgae may be another instance of bottom-up control by increased nutrient supply; nutrient enrichment seems involved in the initiation of virtually every macroalgal bloom. Nitrogen supply seems to control the peak seasonal rates of growth by macroalgae in most coastal systems. However, the identity of the limiting nutrient may also depend on the macroalgal taxon.

In general, macroalgae growing in estuaries with increased nutrient supply show elevated nutrient uptake rates, tissue nutrient contents, maximum photosynthetic rates, and macroalgal growth rates.

In studying two estuaries in Waquoit Bay, macroalgal biomass was consistently greater in the estuary that received the largest nitrogen load.

Studies have shown that in waters where nutrient supply increases, seagrasses are replaced by macroalgae, which in turn can be replaced by phytoplankton as the dominant producers. This relationship is illustrated in **Figure B2**. Even at modest increases in nitrogen loadings from watersheds, the macroalgae bloom and replace seagrasses as the dominant producers.

It is possible that as nitrogen loads increase and nutrient concentrations rise, N uptake by phytoplankton increase and cells divide faster. Further, in such N-enriched situations, phytoplankton biomass may increase sufficiently to shade and eventually replace bottom-dwelling macroalgae. In estuaries with longer residence times, phytoplankton may become the dominant producers at much lower rates of N loading.

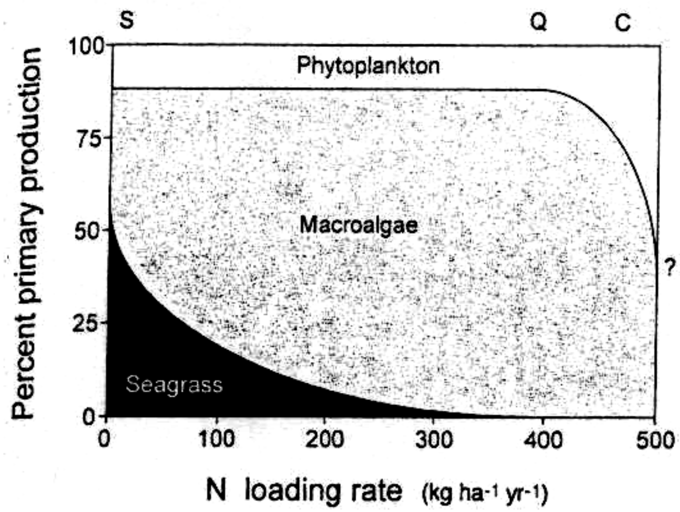


FIGURE B2
Proportion of total net production that is carried out by phytoplankton, macroalgae, and eelgrass in the three estuaries of Waquoit Bay that are subject to different nitrogen loading rates. The initials indicate the position of the three estuaries along the nitrogen loading axis

Macroalgal blooms uncouple biogeochemical cycles in sediments from those in water columns to a significant degree. Macroalgae that take nutrients up from water replace plants that "mine" nutrients from sediments using roots. The presence of macroalgal canopies seems likely to sequester nutrients that otherwise may have entered the water column and may enhance recycling of nutrients near the sediment surface.

Macroalgal dominated canopies are likely to increase the delivery of carbon compounds to estuarine waters. The released carbon may be sufficient to enter the microbial food web and increase BOD. The released DOC is perhaps involved in the increased frequency of anoxic events found in enriched waters.

Smith, V.H., Tilman, G.D., and J.C. Nekola. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environmental Pollution* 100 (1999): 179-196

Deliberate nutrient loading reductions have led to dramatic water quality improvements in Hillsborough Bay, a subdivision of Tampa Bay, Florida. Restrictions of N and P loading were accomplished by implementing advanced wastewater treatment in the watershed, and by reducing the nutrient inputs from fertilizer industries. This paper briefly reviews the process, impacts, and potential management of cultural eutrophication in freshwater, marine, and terrestrial ecosystems. Two case studies are presented, demonstrating that nutrient loading restriction is the essential cornerstone of aquatic eutrophication control.

Humans have approximately doubled the rate of N input into the terrestrial N cycle, and these rates are still increasing. Overall, anthropogenic inputs currently add at least as much fixed N to terrestrial ecosystems as do all natural sources combined.

A modeling framework based on a European eutrophication study was recommended at a US national nutrient assessment workshop. The critical load concept includes: (1) defining (if possible) site-specific relationships between spring or summer levels of chlorophyll and late winter maximum concentrations of dissolved N; (2) defining the critical load of N yielding a critical level of chlorophyll; and (3) defining the degree to which current loadings exceed the critical loading values; this latter calculation would provide an estimate of the minimum required load reduction needed to restore acceptable marine water quality.

Deliberate nutrient loading reductions have led to dramatic improvements in Hillsborough Bay, a subdivision of Tampa Bay, Florida. Restrictions of N and P loading were accomplished by implementing advanced wastewater treatment in the watershed, and by reducing the nutrient inputs from fertilizer industries. These loading reductions were almost immediately followed by significant reductions in phytoplankton biomass, and increases in water transparency and dissolved oxygen concentrations in the bay. Seagrasses and macroalgae have revegetated the shallow areas around the bay.

Appendix C – Detailed Land Use Data for the Caloosahatchee River/Estuary Watershed Basin

TABLE C1
Detailed 2000 Land Use by Sub-basin (acres)

Land Use Type	FLUCCS	Sub-basin						Watershed
		Caloosahatchee Estuary	East Caloosahatchee	S-4	Telegraph Swamp	Tidal Caloosahatchee	West Caloosahatchee	
Residential - Mobile Home Units	1009	6.71	195.88	334.91		4412.91	267.91	5218.33
Residential, Low Density	1100		14.19			228.03	137.92	380.14
Fixed Single Family Units	1110	9.46	1476.13	215.31	116.58	21230.56	11069.91	34117.96
Mixed Units, Fixed and Mobile Home Units	1130	0.32		99.58		381.53	143.89	625.32
Low Density, Under Construction	1190			7.53		116.93		124.46
Residential, Medium Density	1200					251.74	3.42	255.16
Fixed Single Family Units	1210	36.78	662.12	879.61		31094.31	1137.86	33810.68
Mixed Units, Fixed and Mobile Home Units	1230		594.28	680.79		609.39	601.64	2486.10
Medium Density, Under Construction	1290	0.45				352.19	3.41	356.05
Residential, High Density	1300					4.70		4.70
Fixed Single Family Units	1310	0.01				1477.44	14.22	1491.67
Multiple Dwelling Units, Low Rise	1330	2.59				2904.12	7.63	2914.33
Multiple Dwelling Units, High Rise	1340	0.43				494.78	143.93	639.14
Commercial and Services	1400			46.46		264.87		311.32
Retail Sales and Services	1410					514.21	35.12	549.33
Shopping Centers	1411					533.16		533.16

Land Use Type	FLUCCS	Sub-basin						Watershed
		Caloosahatchee Estuary	East Caloosahatchee	S-4	Telegraph Swamp	Tidal Caloosahatchee	West Caloosahatchee	
Wholesale Sales and Services	1420		19.26			3.73		22.98
Junk Yards	1423					95.49		95.49
Professional Services	1430		8.53	2.35		58.49		69.38
Cultural and Entertainment	1440					14.22		14.22
Tourist Services	1450	2.62	5.93			237.43		245.97
Oil and Gas Storage - not Industrial or Mfg	1460					19.64		19.64
Mixed Commercial Services	1470	15.27	45.44	98.34		3007.11	400.55	3566.71
Cemeteries	1480		37.67			121.21	2.95	161.83
Industrial	1500					33.09		33.09
Food Processing	1510		122.63	245.22			112.16	480.01
Mineral Processing	1530			28.69				28.69
Other Light Industrial	1550		14.33	5.13		2209.10		2228.55
Industrial Under Construction	1590					17.76		17.76
Strip Mines	1610					16.04		16.04
Sand and Gravel Pits	1620		442.65	2.67		1110.17		1555.50
Educational	1710		71.01	167.15		1028.56	117.56	1384.28
Religious	1720		3.47		4.83	141.22	9.11	158.62
Medical and Health Care	1740					123.62		123.62
Governmental	1750		6.22					6.22
Correctional	1760		123.92					123.92
Other Institutional	1770			7.28			8.81	16.10
Swimming Beach	1810	4.21		11.98		6.30		22.49
Golf Course	1820		188.49	149.04		2026.40	219.06	2582.99

Land Use Type	FLUCCS	Sub-basin						Watershed
		Caloosahatchee Estuary	East Caloosahatchee	S-4	Telegraph Swamp	Tidal Caloosahatchee	West Caloosahatchee	
Marinas and Fish Camps	1840	2.25	11.49	25.44		141.28	14.58	195.04
Parks and Zoos	1850		11.22	114.41		380.76	49.43	555.81
Community Recreational Facilities	1860					435.89		435.89
Historical Sites	1880		14.65					14.65
Other Recreational	1890			12.61		129.49	6.62	148.72
Undeveloped Land within Urban Areas	1910	0.46	38.85	28.30		1829.02	214.09	2110.72
Inactive Lands With Street Pattern	1920	2.09	1707.96	61.13	33.01	10765.55	16911.75	29481.49
Urban Land in Transition - Intended Activity Unknown	1930					432.51	28.56	461.06
Other Open Land	1940		144.71	26.95		229.20	598.15	999.01
Improved Pasture	2110	11.24	45024.75	1299.34	8540.32	14131.70	53336.79	122344.15
Unimproved Pasture	2120	0.13	9098.66		734.33	4252.27	17115.48	31200.89
Woodland Pasture	2130		1459.36		10.41		1600.31	3070.09
Row Crops	2140	0.08	1436.28	155.95	946.66	1339.18	5321.80	9199.95
Field Crops	2150		898.92	9.62	668.67	1256.74	1276.38	4110.32
Sugar Cane	2156		57789.45	30381.98			5159.30	93330.74
Citrus Groves	2210		26862.64	108.25	2.47	1056.14	70898.16	98927.65
Other Groves	2230		6.64	19.96	75.70	18.56	41.81	162.67
Cattle Feeding Operations	2310		8.35					8.35
Tree Nurseries	2410					22.47	52.17	74.64
Sod Farms	2420		9.01	241.87		503.55	195.32	949.75
Ornamentals	2430		2.43	35.40		182.40	49.87	270.10
Floriculture	2450					10.20	282.64	292.84

Land Use Type	FLUCCS	Sub-basin						Watershed
		Caloosahatchee Estuary	East Caloosahatchee	S-4	Telegraph Swamp	Tidal Caloosahatchee	West Caloosahatchee	
Horse Farms	2510		55.75			55.08	284.38	395.22
Dairies	2520		1081.30			351.83		1433.12
Aquaculture	2540					102.21	10.02	112.23
Other	2590		53.06	81.74			124.69	259.49
Fallow Crop Land	2610		1455.59	41.61	76.61	712.62	2080.84	4367.26
Herbaceous (Dry Prairie)	3100		22.49		187.45	229.32	245.96	685.22
Palmetto Prairies	3210		98.99		1034.21	394.74	4646.95	6174.88
Other Shrubs and Brush	3290		4708.47	26.65	161.66	2388.62	4202.43	11487.82
Mixed Rangeland	3300		2984.98		1199.59	7690.29	16611.80	28486.66
Pine Flatwoods	4110	0.41	11274.93		23124.25	25363.40	34403.66	94166.65
Pine Flatwoods - Melaleuca Infested	4119		817.47		311.20	3859.61	2287.10	7275.37
Sand Pine	4130		1397.91				251.10	1649.01
Pine - Mesic Oak4200Upland Hardwood Forests	4140		44.38			218.87	2.65	265.90
Other Pines	4190					8.98		8.98
Xeric Oak	4210		11.39			342.98	844.79	1199.16
Brazilian Pepper	4220		322.21	157.59		1100.97	1489.35	3070.11
Oak, Pine, Hickory	4230				53.26		188.89	242.15
Melaleuca	4240	0.70	254.56	283.89		251.48	176.19	966.82
Temperate/Tropical Hardwood	4250		3490.58			22.60	2390.83	5904.01
Tropical Hardwood	4260					5.55		5.55
Live Oak	4270		73.05			58.08	548.62	679.75
Cabbage Palm	4280		418.04					418.04
Wax Myrtle, Willow	4290		19.81			3.50		23.31

Land Use Type	FLUCCS	Sub-basin						Watershed
		Caloosahatchee Estuary	East Caloosahatchee	S-4	Telegraph Swamp	Tidal Caloosahatchee	West Caloosahatchee	
Sand Live Oak	4320						50.00	50.00
Western Everglades Hardwood	4330		4.05					4.05
Hardwood - Conifer Mixed	4340		1759.74	10.32	206.70	995.46	3986.17	6958.38
Dead Trees	4350						121.83	121.83
Australian Pine	4370					6.98		6.98
Mixed Hardwoods	4380		653.51			56.73	653.97	1364.20
Other Hardwoods	4390						50.95	50.95
Coniferous Plantations	4410		4036.95		797.79	24.26	17074.29	21933.29
Forest Regeneration Areas	4430		2598.27		3583.56	203.33	5735.31	12120.46
Streams and Waterways	5100	14387.36	797.52	465.90	3.08	1772.38	1103.80	18530.04
Lakes 10 to 100 acres	5230		143.58					143.58
Lakes less than 10 acres	5240		2.15			29.21		31.36
Reservoirs larger than 500 acres	5310			717.60				717.60
Reservoirs 100 - 500 acres	5320		632.98					632.98
Reservoirs 10 - 100 acres	5330		417.88	129.91		849.74	326.55	1724.08
Reservoirs less than 10 acres	5340	2.40	196.42	59.70	15.05	614.63	326.64	1214.84
Embayments opening directly to the Gulf or Ocean	5410	3.43				192.61		196.05
Slough Waters	5600	7.44				89.92	2.99	100.34
Bay Swamps	6110					62.87		62.87
Mangrove Swamp	6120	384.12				3202.89	84.62	3671.63
Gum Swamps	6130					9.69	4.26	13.95
Titi Swamps	6140		6.63			4.84		11.47
River/lake Swamps	6150	11.17			182.91	27.12	2466.56	2687.75

Land Use Type	FLUCCS	Sub-basin						Watershed
		Caloosahatchee Estuary	East Caloosahatchee	S-4	Telegraph Swamp	Tidal Caloosahatchee	West Caloosahatchee	
Inland Ponds and Sloughs	6160					139.16	730.03	869.18
Mixed Wetland Hardwoods	6170	5.64	616.01	37.28	289.62	2197.00	3884.67	7030.22
Mixed Wetland Hardwoods - Willows	6171		432.28		24.33	10.22	210.37	677.21
Mixed Wetland Hardwoods - Mixed Shrubs	6172	28.42	7470.36	647.30	799.40	6259.81	11066.64	26271.93
Cypress	6210		886.52		6815.04	442.40	5773.98	13917.95
Cypress - Melaleuca Infested	6218				6.14	326.95	535.41	868.50
Cypress - with Wet Prairies	6219		25.52		579.88	170.64	743.02	1519.07
Cypress - Pine - Cabbage Palm	6240		13.37		677.48	556.58	1887.29	3134.72
Wetland Forested Mixed	6300		2895.80		897.68	653.51	4078.18	8525.16
Freshwater Marshes / Graminoid Prairie - Marsh	6410		17313.65	292.84	1829.05	6480.16	25016.60	50932.29
Freshwater Marshes - Sawgrass	6411		151.08			10.50	142.06	303.64
Freshwater Marshes - Cattail	6412		155.75		17.64	261.02	678.88	1113.28
Saltwater Marshes / Halophytic Herbaceous Prairie	6420					351.08	6.90	357.97
Wet Prairies	6430		3494.49		1052.43	2674.00	4324.62	11545.54
Wet Prairies with Pine	6439		415.62		1015.79	1945.19	2204.80	5581.40
Emergent Aquatic Vegetation	6440		16.88				3.83	20.72
Disturbed Land	7400					4.08		4.08
Rural Land in Transition - Intended Activity Unknown	7410	0.01	331.44		288.23	1667.66	956.22	3243.57
Borrow Areas	7420		230.64	106.96		818.81	796.96	1953.37
Spoil Areas	7430	33.59	1557.01	510.05	42.76	953.54	1182.37	4279.33
Fill Areas	7440						149.10	149.10
Burned Areas	7450					4.83		4.83
Transportation	8100						42.59	42.59

Land Use Type	FLUCCS	Sub-basin						Watershed
		Caloosahatchee Estuary	East Caloosahatchee	S-4	Telegraph Swamp	Tidal Caloosahatchee	West Caloosahatchee	
Airports	8110		370.66	161.93	67.17	830.97	191.55	1622.27
Railroads and Railyards	8120		47.52	37.92				85.44
Roads and Highways	8140	33.61	500.37	145.75		1073.75	41.20	1794.68
Canals and Locks	8160	380.71	775.98	97.63	1.16	3246.10	1482.03	5983.61
Auto Parking Facilities	8180					5.19		5.19
Communication Facilities	8220					29.45		29.45
Electrical Power Facilities	8310		3.39	13.04		138.69		155.11
Electrical Power Transmission Lines	8320	1.84	506.44	122.14		1040.02	381.44	2051.88
Water Supply Plants - Including Pumping Stations	8330			22.25		145.12		167.37
Sewage Treatment	8340					142.90	48.26	191.16
Solid Waste Disposal	8350		28.90					28.90
Total by Sub-basin		15375.99	226631.83	39673.23	56474.08	196140.00	356927.39	891222.51

Appendix D – Detailed Summary of Water Quality Means and Extremes for the Caloosahatchee River/Estuary

TABLE D1

Summary of historic water quality data from the S-77 structure on the Caloosahatchee River (SFWMD DBHYDRO).

Parameter Group	Parameter	Units	Period-of-Record		Average	Minimum	Maximum	StdDev	Count
TEMPERATURE	TEMP	Deg C	6/18/73	6/13/05	25.3	11.6	36.3	4.49	623
DISSOLVED OXYGEN	DISSOLVED OXYGEN	mg/L	6/18/73	6/13/05	5.25	0.260	12.0	2.20	614
PHYSICAL	COLOR	PCU	8/23/76	6/13/05	95.1	9.00	564	89.9	529
	DEPTH, TOTAL	METERS	10/5/98	10/4/99	0.00	0.00	0.00	0.00	13
	PH, FIELD	UNITS	4/9/73	6/13/05	7.42	5.30	10.4	0.541	643
	PH, LAB	UNITS	10/1/73	3/27/84	7.69	7.17	8.40	0.330	25
	SECCHI DISK DEPTH	METERS	11/13/73	3/21/74	0.630	0.420	1.07	0.260	5
	SP CONDUCTIVITY, FIELD	uS/cm	7/22/74	6/13/05	525	120	2,700	195	609
	SP CONDUCTIVITY, LAB	uS/cm	5/13/74	6/21/88	542	280	920	184	23
	TURBIDITY	NTU	8/23/76	6/13/05	6.59	0.500	497	22.6	559
OXYGEN DEMAND	BOD	mg/L	5/29/79	9/17/80	2.69	2.00	4.40	0.702	11
SOLID	FIXED SUSPENDED SOLIDS	mg/L	5/3/76	5/3/76	21.1	21.1	21.1		1
	TOTAL DISSOLVED SOLIDS	mg/L	3/5/79	5/16/05	273	7.00	479	87.5	58
	TOTAL SUSPENDED SOLIDS	mg/L	11/13/73	6/13/05	8.67	0.200	158	12.4	534
	VOLATILE SUSPENDED SOLIDS	mg/L	5/3/76	5/3/76	29.8	29.8	29.8		1
BIOLOGICAL	CHLOROPHYLL-A	mg/M3	8/17/93	5/10/94	17.2	1.40	36.2	11.7	13
GENERAL INORGANIC	ALKALINITY, TOT, CACO3	mg/L	4/9/73	6/13/05	116	1.60	434	44.0	630
	CARBON, TOTAL	mg/L	12/23/74	9/6/77	41.2	18.0	83.0	18.8	19
	CARBON, TOTAL INORGANIC	mg/L	11/1/76	9/6/77	9.13	0.050	24.3	7.96	18
	CHLORIDE	mg/L	4/9/73	6/13/05	68.3	5.10	170	24.5	664
	HARDNESS AS CACO3	mg/L	4/9/73	5/16/05	169	36.4	362	54.6	248
	SILICA	mg/L	4/9/73	5/16/05	6.87	0.500	14.6	3.31	138
	SODIUM	mg/L	4/9/73	5/16/05	44.9	8.00	99.0	17.7	248
	SULFATE	mg/L	12/11/73	5/16/05	39.9	0.050	89.9	18.7	188
GENERAL ORGANIC	CARBON, DISSOLVED ORGANIC	mg/L	10/18/76	9/6/77	33.3	10.5	75.7	17.0	23
	CARBON, TOTAL ORGANIC	mg/L	9/19/77	4/5/82	22.1	13.2	36.5	4.98	99
NITROGEN	AMMONIA-N	mg/L	4/9/73	6/13/05	0.077	0.005	1.01	0.111	667
	KJELDAHL NITROGEN, DIS	mg/L	12/23/74	12/23/74	0.930	0.930	0.930		1
	KJELDAHL NITROGEN, TOTAL	mg/L	4/9/73	6/13/05	1.70	0.009	7.69	0.653	683
	NITRATE+NITRITE-N	mg/L	4/9/73	6/13/05	0.129	0.001	18.8	0.731	683
	NITRATE-N	mg/L	4/9/73	6/13/05	0.090	0.002	1.45	0.138	611
	NITRITE-N	mg/L	4/9/73	6/13/05	0.016	0.001	2.96	0.116	665
PHOSPHORUS	PHOSPHATE, DISSOLVED AS P	mg/L	8/27/73	3/13/02	0.052	0.012	0.143	0.062	4
	PHOSPHATE, ORTHO AS P	mg/L	4/9/73	6/13/05	0.040	0.001	0.470	0.053	648
	PHOSPHATE, TOTAL AS P	mg/L	4/9/73	6/13/05	0.094	0.008	0.838	0.074	692
METAL	ARSENIC, DISSOLVED	ug/L	5/14/79	7/28/81	8.14	3.00	14.0	4.19	7
	ARSENIC, TOTAL	ug/L	5/13/80	7/5/01	1.57	0.500	8.00	1.36	62
	CADMIUM, DISSOLVED	ug/L	10/17/77	7/28/81	1.25	0.500	3.00	0.920	10
	CADMIUM, TOTAL	ug/L	5/13/80	7/5/01	0.255	0.050	2.00	0.395	62
	CALCIUM	mg/L	4/9/73	5/16/05	45.3	9.80	99.4	15.0	249
	CHROMIUM, DISSOLVED	ug/L	10/17/77	7/28/81	0.672	0.401	1.29	0.412	4
	CHROMIUM, TOTAL	ug/L	2/28/84	8/13/84	0.522	0.419	0.625	0.146	2
	COBALT, DISSOLVED	ug/L	10/17/77	7/17/78	0.500	0.500	0.500	0.00	2
	COPPER, DISSOLVED	ug/L	12/11/73	7/28/81	16.7	0.500	106	33.9	9
	COPPER, TOTAL	ug/L	5/14/79	7/5/01	1.25	0.090	6.89	1.27	64
	IRON, DISSOLVED	ug/L	5/3/76	7/28/81	85.8	5.00	380	88.7	57
	IRON, TOTAL	ug/L	11/13/73	5/16/05	208	10.0	2,130	254	210
	LEAD, DISSOLVED	ug/L	12/11/73	7/28/81	8.64	0.500	64.0	18.6	11
	LEAD, TOTAL	ug/L	5/13/80	7/5/01	0.619	0.150	5.00	0.840	62
	MANGANESE, DISSOLVED	ug/L	12/11/73	2/10/81	9.60	2.00	21.0	7.02	5
	MAGNESIUM	mg/L	4/9/73	5/16/05	13.5	2.00	27.6	5.41	249
	MERCURY, DISSOLVED	ug/L	7/9/79	7/9/79	0.0005	0.0005	0.0005		1
	MERCURY, TOTAL	ug/L	5/14/79	10/16/00	0.089	0.0005	0.100	0.028	56
	MERCURY, TOT, ULTRATRACE	ng/L	2/14/01	6/29/05	2.62	0.800	6.70	1.63	18
	METH MERCURY, TOT ULTRATR	ng/L	11/28/00	6/29/05	0.282	0.040	1.60	0.402	17
	NICKEL, DISSOLVED	ug/L	10/17/77	7/28/81	4.35	0.500	12.1	6.67	3
	POTASSIUM	mg/L	4/9/73	5/16/05	4.88	1.20	9.67	1.64	192
	STRONTIUM, DISSOLVED	ug/L	7/17/78	8/13/84	1,041	677	1,640	316	7
	ZINC, DISSOLVED	ug/L	12/11/73	7/28/81	249	10.5	1,609	517	9
	ZINC, TOTAL	ug/L	5/14/79	7/5/01	37.8	2.00	1,378	174	63

Note: Half of the detection limit was used to calculate statistics when reported below the detection limit

TABLE D2

Summary of historic water quality data from the S-78 structure on the Caloosahatchee River (SFWMD DBHYDRO).

Parameter Group	Parameter	Units	Period-of-Record		Average	Minimum	Maximum	StdDev	Count
TEMPERATURE	TEMP	Deg C	1/13/81	5/18/05	25.5	14.0	32.9	4.60	141
DISSOLVED OXYGEN	DISSOLVED OXYGEN	mg/L	1/13/81	5/18/05	5.91	1.70	12.4	2.12	141
PHYSICAL	COLOR	PCU	3/5/79	5/18/05	101	22.0	644	67.8	146
	PH, FIELD	UNITS	1/13/81	5/18/05	7.43	6.56	8.69	0.416	142
	PH, LAB	UNITS	3/5/79	3/5/79	6.53	6.53	6.53		1
	SP CONDUCTIVITY, FIELD	uS/cm	1/13/81	5/18/05	537	274	852	113	142
	SP CONDUCTIVITY, LAB	uS/cm	3/5/79	12/15/99	365	171	556	193	3
	TURBIDITY	NTU	3/5/79	5/18/05	3.49	1.03	23.4	2.71	145
SOLID	TOTAL SUSPENDED SOLIDS	mg/L	3/10/81	5/18/05	4.40	0.500	27.0	4.55	143
BIOLOGICAL	CHLOROPHYLL-A	mg/M3	8/18/93	5/10/94	13.1	0.150	41.8	11.2	14
GENERAL INORGANIC	ALKALINITY, TOT, CACO3	mg/L	1/13/81	5/18/05	140	70.5	217	33.9	145
	CARBON, DISSOLVED INORGANIC	mg/L	9/18/96	9/18/96	40.0	40.0	40.0		1
	CHLORIDE	mg/L	1/13/81	5/18/05	61.3	24.7	191	21.2	144
	HARDNESS AS CACO3	mg/L	2/10/81	5/18/05	180	80.8	258	39.2	121
	SILICA	mg/L	6/30/82	5/18/05	8.07	3.32	12.6	2.07	110
	SODIUM	mg/L	2/10/81	5/18/05	35.4	13.0	80.3	11.3	124
	SULFATE	mg/L	2/10/81	5/18/05	31.4	10.3	64.9	11.2	120
GENERAL ORGANIC	CARBON, TOTAL ORGANIC	mg/L	1/13/81	12/5/94	23.3	17.9	31.5	4.41	16
NITROGEN	AMMONIA-N	mg/L	3/5/79	5/18/05	0.058	0.005	0.390	0.063	146
	KJELDAHL NITROGEN, TOTAL	mg/L	1/13/81	5/18/05	1.51	0.003	3.37	0.490	158
	NITRATE+NITRITE-N	mg/L	3/5/79	5/18/05	0.273	0.001	18.5	1.47	159
	NITRATE-N	mg/L	3/5/79	5/18/05	0.139	0.002	1.03	0.168	138
	NITRITE-N	mg/L	3/5/79	5/18/05	0.017	0.002	0.135	0.023	146
PHOSPHORUS	PHOSPHATE, DISSOLVED AS P	mg/L	3/13/02	3/13/02	0.045	0.045	0.045		1
	PHOSPHATE, ORTHO AS P	mg/L	3/5/79	5/18/05	0.083	0.007	0.468	0.063	143
	PHOSPHATE, TOTAL AS P	mg/L	3/5/79	5/18/05	0.131	0.002	0.561	0.069	159
METAL	ARSENIC, TOTAL	ug/L	2/28/84	12/14/00	1.51	0.500	4.14	0.837	35
	BERYLLIUM, TOTAL	ug/L	1/5/98	1/5/98	0.050	0.050	0.050		1
	CADMIUM, TOTAL	ug/L	2/28/84	12/14/00	0.152	0.050	0.400	0.103	37
	CADMIUM, DISSOLVED	ug/L	2/10/81	2/10/81	0.464	0.464	0.464		1
	CALCIUM	mg/L	2/10/81	5/18/05	54.5	26.9	86.4	15.0	123
	CHROMIUM, DISSOLVED	ug/L	2/10/81	2/10/81	0.404	0.404	0.404		1
	CHROMIUM, TOTAL	ug/L	2/28/84	8/13/84	0.433	0.123	0.743	0.438	2
	COPPER, DISSOLVED	ug/L	2/10/81	2/10/81	5.00	5.00	5.00		1
	COPPER, TOTAL	ug/L	2/28/84	12/14/00	1.44	0.250	6.28	1.17	36
	IRON, DISSOLVED	ug/L	2/10/81	2/10/81	100	100	100		1
	IRON, TOTAL	ug/L	3/10/81	4/9/01	266	25.0	770	178	101
	LEAD, DISSOLVED	ug/L	2/10/81	2/10/81	0.982	0.982	0.982		1
	LEAD, TOTAL	ug/L	2/28/84	12/14/00	0.426	0.100	1.23	0.271	37
	MANGANESE, DISSOLVED	ug/L	2/10/81	2/10/81	2.00	2.00	2.00		1
	MAGNESIUM	mg/L	2/10/81	5/18/05	10.7	3.30	18.2	2.89	123
	MERCURY, TOTAL	ug/L	2/12/85	12/14/00	0.096	0.050	0.100	0.014	27
	POTASSIUM	mg/L	2/10/81	5/18/05	5.45	1.72	10.6	1.32	123
	STRONTIUM, DISSOLVED	ug/L	2/10/81	2/12/85	982	630	1,520	350	5
	ZINC, DISSOLVED	ug/L	2/10/81	2/10/81	13.0	13.0	13.0		1
	ZINC, TOTAL	ug/L	8/13/84	12/14/00	15.7	0.500	135	28.1	36

Note: Half of the detection limit was used to calculate statistics when reported below the detection limit

TABLE D3

Summary of historic water quality data from the S-79 structure on the Caloosahatchee River (SFWMD DBHYDRO)

Parameter Group	Parameter	Units	Period-of-Record		Average	Minimum	Maximum	StdDev	Count
TEMPERATURE	TEMP	Deg C	1/13/81	5/18/05	26.0	14.6	33.2	4.58	138
DISSOLVED OXYGEN	DISSOLVED OXYGEN	mg/L	1/13/81	5/18/05	6.45	2.30	18.1	2.22	137
PHYSICAL	COLOR	PCU	1/13/81	5/18/05	89.3	23.0	258	48.6	141
	PH, FIELD	UNITS	1/13/81	5/18/05	7.52	6.10	8.59	0.420	138
	SP CONDUCTIVITY, FIELD	uS/cm	1/13/81	5/18/05	640	306	1,890	269	139
	SP CONDUCTIVITY, LAB	uS/cm	12/17/91	12/15/99	5,824	397	11,250	7,674	2
	TURBIDITY	NTU	1/13/81	5/18/05	2.72	0.700	17.7	2.17	141
SOLID	TOTAL SUSPENDED SOLIDS	mg/L	3/10/81	5/18/05	3.44	0.500	22.0	3.66	140
BIOLOGICAL	CHLOROPHYLL-A	mg/M3	8/19/93	5/10/94	3.48	0.100	15.3	3.93	14
GENERAL INORGANIC	ALKALINITY, TOT, CACO3	mg/L	1/13/81	5/18/05	148	38.9	931	73.7	142
	CARBON, DISS INORG	mg/L	9/18/96	9/18/96	39.6	39.6	39.6		1
	CHLORIDE	mg/L	1/13/81	5/18/05	162	22.9	6,445	644	141
	HARDNESS AS CACO3	mg/L	2/10/81	5/18/05	228	95.5	2,331	239	116
	SILICA	mg/L	6/30/82	5/18/05	7.47	0.500	11.8	2.31	106
	SODIUM	mg/L	2/10/81	5/18/05	83.2	14.6	3,985	371	119
	SULFATE	mg/L	2/10/81	5/18/05	48.1	12.4	873	94.0	115
GENERAL ORGANIC	CARBON, TOTAL ORGANIC	mg/L	1/13/81	12/5/94	19.2	15.7	29.1	3.32	15
NITROGEN	AMMONIA-N	mg/L	1/13/81	5/18/05	0.045	0.005	0.238	0.041	142
	KJELDAHL NITROGEN, TOTAL	mg/L	1/13/81	5/18/05	1.34	0.250	5.06	0.498	155
	NITRATE+NITRITE-N	mg/L	1/13/81	5/18/05	0.396	0.002	17.7	1.42	155
	NITRATE-N	mg/L	1/13/81	5/18/05	0.256	0.002	0.832	0.187	139
	NITRITE-N	mg/L	1/13/81	5/18/05	0.022	0.002	0.167	0.029	142
PHOSPHORUS	PHOSPHATE, ORTHO AS P	mg/L	1/13/81	5/18/05	0.094	0.011	0.262	0.046	140
	PHOSPHATE, TOTAL AS P	mg/L	1/13/81	5/18/05	0.138	0.051	0.460	0.063	155
METAL	ARSENIC, TOTAL	ug/L	2/28/84	12/14/00	1.46	0.500	2.40	0.645	36
	BERYLLIUM, TOTAL	ug/L	1/5/98	1/5/98	0.050	0.050	0.050		1
	CADMIUM, TOTAL	ug/L	2/28/84	12/14/00	0.193	0.050	1.28	0.215	37
	CADMIUM, DISSOLVED	ug/L	2/10/81	2/10/81	1.34	1.34	1.34		1
	CALCIUM	mg/L	2/10/81	5/18/05	60.4	31.5	210	20.8	118
	CHROMIUM, DISSOLVED	ug/L	2/10/81	2/10/81	0.385	0.385	0.385		1
	CHROMIUM, TOTAL	ug/L	2/28/84	8/13/84	0.876	0.345	1.41	0.750	2
	COPPER, DISSOLVED	ug/L	2/10/81	2/10/81	12.0	12.0	12.0		1
	COPPER, TOTAL	ug/L	2/28/84	12/14/00	3.75	0.250	63.0	10.2	36
	IRON, DISSOLVED	ug/L	2/10/81	2/10/81	90.0	90.0	90.0		1
	IRON, TOTAL	ug/L	3/10/81	2/12/01	222	20.0	680	155	98
	LEAD, DISSOLVED	ug/L	2/10/81	2/10/81	2.38	2.38	2.38		1
	LEAD, TOTAL	ug/L	2/28/84	12/14/00	0.448	0.100	2.36	0.407	37
	MANGANESE, DISSOLVED	ug/L	2/10/81	2/10/81	4.00	4.00	4.00		1
	MAGNESIUM	mg/L	2/10/81	5/18/05	18.4	4.10	439	47.1	119
	MERCURY, TOTAL	ug/L	2/12/85	12/14/00	0.096	0.050	0.100	0.013	28
	POTASSIUM	mg/L	2/10/81	5/18/05	7.66	2.22	148	15.5	119
	STRONTIUM, DISSOLVED	ug/L	2/10/81	2/12/85	887	650	1,220	243	5
	ZINC, DISSOLVED	ug/L	2/10/81	2/10/81	14.0	14.0	14.0		1
	ZINC, TOTAL	ug/L	2/28/84	12/14/00	9.90	0.024	35.3	9.44	37

Note: Half of the detection limit was used to calculate statistics when reported below the detection limit

TABLE D4

Summary of historic water quality data for the upper Caloosahatchee Estuary (SFWMD DBHYDRO)

Parameter Gourp	Parameter	Units	Period-of-Record		Average	Maximum	Minimum	StdDev	Count
TEMPERATURE	TEMP	Deg C	3/14/95	12/8/04	26.2	34.4	14.7	3.37	365
DISSOLVED OXYGEN	DISSOLVED OXYGEN	mg/L	3/14/95	12/8/04	5.45	10.6	0.200	2.07	363
PHYSICAL	COLOR	PCU	5/10/95	12/8/04	106	260	20.4	55.5	77
	DEPTH, TOTAL	METERS	5/10/95	3/21/02	9.40	79.0	0.500	18.0	17
	PAR, K VALUE	1/m	5/30/02	6/27/02	1.41	2.02	0.800	0.863	2
	PH, FIELD	UNITS	10/4/95	12/8/04	7.45	8.42	5.62	0.360	349
	PH, LAB	UNITS	3/14/95	2/14/96	7.80	7.85	7.75	0.071	2
	SECCHI DISK DEPTH	METERS	3/14/95	12/8/04	1.16	2.10	0.400	0.370	44
	SP CONDUCTIVITY, FIELD	uS/cm	3/14/95	12/8/04	1,896	20,383	291	3,708	363
	SP CONDUCTIVITY, LAB	uS/cm	5/10/95	9/6/95	440	495	385	77.8	2
	ORP	mv	11/27/01	12/13/01	145	146	144	0.957	4
	SALINITY	ppt	2/14/96	12/8/04	1.07	12.1	0.00	2.15	365
	TURBIDITY	NTU	3/14/95	12/8/04	2.56	14.3	0.270	2.26	79
SOLIDS	TOTAL DISSOLVED SOLIDS	mg/L	10/4/95	10/4/95	273	273	273		1
	TOTAL SUSPENDED SOLIDS	mg/L	3/14/95	12/8/04	6.09	48.3	0.500	7.65	78
	VOLATILE SUSPENDED SOLIDS	mg/L	3/14/95	2/14/96	2.71	10.0	1.00	3.30	7
BACTERIOLOGICAL	FECAL COLIFORM, MF	CFU/100m	11/27/01	12/13/01	45.0	60.0	30.0	21.2	2
BIOLOGICAL	CHLOROPHYLL-A	mg/M3	3/14/95	3/29/04	14.0	133	0.400	22.6	37
	CHLOROPHYLL-A, CORRECTED	mg/M3	3/14/95	12/8/04	7.27	50.0	0.250	7.99	66
	CHLOROPHYLL-B	mg/M3	3/14/95	4/13/99	0.650	1.70	0.500	0.424	8
	CHLOROPHYLL-C	mg/M3	3/14/95	4/13/99	0.688	2.00	0.500	0.530	8
	CAROTENOIDS	mg/M3	3/14/95	4/13/99	3.00	8.10	0.500	3.10	8
	PHEOPHYTIN	mg/M3	3/14/95	12/8/04	2.49	28.7	0.250	4.48	67
GENERAL INORGANIC	HARDNESS AS CACO3	mg/L							
	SULFATE	mg/L							
	SILICA	mg/L	11/27/01	12/8/04	6.69	10.4	2.20	2.19	73
GENERAL ORGANIC	CARBON, DISSOLVED ORGANIC	mg/L	3/14/95	2/14/96	18.5	23.4	15.5	2.82	7
	CARBON, TOTAL ORGANIC	mg/L	3/14/95	12/8/04	17.2	28.0	4.90	4.97	81
NITROGEN	AMMONIA, TOTAL AS N	mg/L	10/13/04	11/16/04	0.059	0.063	0.056	0.004	4
	AMMONIA-N	mg/L	3/14/95	11/16/04	0.086	0.470	0.004	0.075	73
	KJELDAHL NITROGEN, DIS	mg/L	3/14/95	2/14/96	1.08	1.43	0.827	0.196	6
	KJELDAHL NITROGEN, TOTAL	mg/L	3/14/95	12/8/04	1.08	1.70	0.390	0.248	81
	NITRATE+NITRITE-N	mg/L	3/14/95	12/8/04	0.174	0.460	0.010	0.125	79
	NITRATE-N	mg/L	3/14/95	12/8/04	0.145	0.440	0.005	0.108	79
	NITRITE-N	mg/L	3/14/95	12/8/04	0.031	0.198	0.0005	0.038	79
	TOTAL NITROGEN	MG N/L	5/30/02	12/8/04	1.26	1.88	0.480	0.295	64
PHOSPHORUS	PHOSPHATE, DISSOLVED AS P	mg/L	3/14/95	2/14/96	0.064	0.119	0.028	0.032	7
	PHOSPHATE, ORTHO AS P	mg/L	3/14/95	12/8/04	0.075	0.301	0.022	0.047	72
	PHOSPHATE, TOTAL AS P	mg/L	3/14/95	12/8/04	0.104	0.383	0.015	0.055	78

Note: Half of the detection limit was used to calculate statistics when reported below the detection limit

TABLE D5
Summary of historic water quality data for the middle Caloosahatchee Estuary (SFWMD DBHYDRO)

Parameter Group	Parameter	Units	Period-of-Record		Average	Maximum	Minimum	StdDev	Count
TEMPERATURE	TEMP	Deg C	11/5/87	12/8/04	26.4	31.7	17.3	3.67	260
DISSOLVED OXYGEN	DISSOLVED OXYGEN	mg/L	11/5/87	12/8/04	5.80	10.5	0.360	1.96	252
PHYSICAL	COLOR	PCU	11/5/87	12/8/04	98.0	240	19.5	52.8	94
	DEPTH, TOTAL	METERS	10/6/94	3/21/02	1.63	3.30	0.500	0.608	35
	PAR, K VALUE	1/m	5/30/02	6/27/02	1.35	1.99	0.715	0.898	2
	PH, FIELD	UNITS	11/5/87	12/8/04	7.58	8.70	5.96	0.372	244
	PH, LAB	UNITS	11/5/87	2/14/96	7.95	8.07	7.70	0.172	6
	SECCHI DISK DEPTH	METERS	11/5/87	12/8/04	0.955	1.80	0.500	0.278	58
	SP CONDUCTIVITY, FIELD	uS/cm	11/5/87	12/8/04	4,435	34,490	339	6,723	260
	SP CONDUCTIVITY, LAB	uS/cm	9/6/95	9/6/95	376	376	376		1
	ORP	mv	11/27/01	12/13/01	129	139	118	11.0	4
	SALINITY	ppt	2/14/96	12/8/04	2.47	15.2	0.00	3.83	260
	TURBIDITY	NTU	11/5/87	12/8/04	3.56	11.5	0.310	2.09	98
SOLIDS	TOTAL DISSOLVED SOLIDS	mg/L	1/10/95	10/4/95	361	423	298	88.4	2
	TOTAL SUSPENDED SOLIDS	mg/L	11/5/87	12/8/04	11.1	101	0.500	13.0	98
	VOLATILE SUSPENDED SOLIDS	mg/L	11/5/87	7/10/96	1.83	4.00	1.00	1.15	18
BACTERIOLOGICAL	FECAL COLIFORM, MF	CFU/100m	11/27/01	12/13/01	5.00	5.00	5.00	0.00	2
BIOLOGICAL	CHLOROPHYLL-A	mg/M3	1/10/95	3/29/04	8.75	46.0	0.500	8.82	47
	CHLOROPHYLL-A, CORRECTED	mg/M3	1/10/95	12/8/04	7.67	47.0	0.250	7.65	86
	CHLOROPHYLL-B	mg/M3	1/10/95	4/13/99	0.789	6.00	0.500	1.26	19
	CHLOROPHYLL-C	mg/M3	1/10/95	4/13/99	0.963	2.30	0.500	0.652	19
	CAROTENOIDS	mg/M3	1/10/95	4/13/99	3.12	7.40	0.500	1.87	19
	PHEOPHYTIN	mg/M3	1/10/95	12/8/04	2.08	9.49	0.250	1.91	86
GENERAL INORGANIC	HARDNESS AS CACO3	mg/L	11/5/87	12/6/88	1,156	2,171	145	1,168	4
	SULFATE	mg/L	11/5/87	12/6/88	429	844	20.9	470	4
	SILICA	mg/L	11/5/87	12/8/04	6.18	11.0	0.700	2.44	78
GENERAL ORGANIC	CARBON, DISSOLVED ORGANIC	mg/L	1/10/95	1/28/97	17.2	24.2	11.5	4.30	18
	CARBON, TOTAL ORGANIC	mg/L	1/10/95	12/8/04	16.2	28.0	4.20	5.68	87
NITROGEN	AMMONIA, TOTAL AS N	mg/L	10/13/04	12/8/04	0.052	0.060	0.033	0.010	6
	AMMONIA-N	mg/L	11/5/87	12/8/04	0.059	0.195	0.004	0.047	93
	KJELDAHL NITROGEN, DIS	mg/L	11/5/87	7/10/96	1.04	1.50	0.680	0.242	17
	KJELDAHL NITROGEN, TOTAL	mg/L	11/5/87	12/8/04	1.03	1.96	0.569	0.257	97
	NITRATE+NITRITE-N	mg/L	11/5/87	12/8/04	0.146	0.507	0.003	0.125	96
	NITRATE-N	mg/L	11/5/87	12/8/04	0.128	0.479	0.002	0.108	92
	NITRITE-N	mg/L	11/5/87	12/8/04	0.023	0.126	0.0005	0.028	97
	TOTAL NITROGEN	MG N/L	5/30/02	12/8/04	1.19	1.96	0.596	0.312	64
PHOSPHORUS	PHOSPHATE, DISSOLVED AS P	mg/L	11/5/87	7/10/96	0.090	0.145	0.031	0.041	18
	PHOSPHATE, ORTHO AS P	mg/L	11/5/87	12/8/04	0.070	0.198	0.008	0.037	91
	PHOSPHATE, TOTAL AS P	mg/L	11/5/87	12/8/04	0.107	0.290	0.030	0.051	97
METAL	CALCIUM	mg/L	11/5/87	12/6/88	112	177	47.6	74.6	4
	IRON, DISSOLVED	ug/L	11/5/87	12/6/88	160	260	60.0	110	4
	MAGNESIUM	mg/L	11/5/87	12/6/88	213	420	6.03	239	4
	POTASSIUM	mg/L	11/5/87	12/6/88	70.4	139	3.55	77.1	4

Note: Half of the detection limit was used to calculate statistics when reported below the detection limit

TABLE D6

Summary of historic water quality data for the lower Caloosahatchee Estuary (SFWMD DBHYDRO)

Parameter Group	Parameter	Units	Period-of-Record		Average	Maximum	Minimum	StdDev	Count
TEMPERATURE	TEMP	Deg C	11/5/87	12/8/04	26.3	32.6	14.2	3.51	832
DISSOLVED OXYGEN	DISSOLVED OXYGEN	mg/L	11/5/87	12/8/04	6.73	13.4	1.17	1.59	824
PHYSICAL	COLOR	PCU	11/5/87	12/8/04	67.8	257	3.50	52.2	123
	DEPTH, TOTAL	METERS	10/6/94	3/21/02	1.93	4.25	0.250	1.11	64
	PAR, K VALUE	1/m	5/30/02	6/27/02	1.50	2.65	0.353	1.62	2
	PH, FIELD	UNITS	11/5/87	12/8/04	7.84	9.18	5.91	0.294	818
	PH, LAB	UNITS	11/5/87	12/6/88	7.98	8.11	7.84	0.137	4
	SECCHI DISK DEPTH	METERS	11/5/87	12/8/04	1.26	2.30	0.400	0.482	68
	SP CONDUCTIVITY, FIELD	uS/cm	11/5/87	12/8/04	15,465	52,389	283	15,222	769
	ORP	mv	11/27/01	12/13/01	124	132	115	5.06	16
	SALINITY	ppt	5/8/96	12/8/04	9.56	34.6	0.00	9.86	771
	TURBIDITY	NTU	11/5/87	12/8/04	2.78	13.7	0.160	2.20	126
SOLID	TOTAL DISSOLVED SOLIDS	mg/L	5/8/96	5/8/96	25,000	25,000	25,000		1
	TOTAL SUSPENDED SOLIDS	mg/L	11/5/87	12/8/04	18.8	121	1.20	17.4	126
	VOLATILE SUSPENDED SOLIDS	mg/L	11/5/87	7/10/96	2.70	5.00	0.500	1.44	15
BACTERIOLOGICAL	FECAL COLIFORM, MF	CFU/100m	11/27/01	12/13/01	6.88	20.0	5.00	5.30	8
BIOLOGICAL	CHLOROPHYLL-A	mg/M3	5/8/96	3/29/04	10.5	95.5	0.230	16.1	132
	CHLOROPHYLL-A, CORRECTED	mg/M3	5/8/96	12/8/04	13.1	88.0	1.12	16.5	98
	CHLOROPHYLL-B	mg/M3	5/8/96	4/13/99	0.638	1.40	0.500	0.305	16
	CHLOROPHYLL-C	mg/M3	5/8/96	4/13/99	2.07	6.50	0.500	2.06	16
	CAROTENOIDS	mg/M3	5/8/96	4/13/99	7.59	24.1	0.500	7.99	16
	PHEOPHYTIN	mg/M3	5/8/96	12/8/04	1.84	10.3	0.250	2.24	98
GENERAL INORGANIC	HARDNESS AS CACO3	mg/L	11/5/87	12/6/88	1,519	2,871	174	1,533	4
	SULFATE	mg/L	11/5/87	12/6/88	573	1,110	31.9	616	4
	SILICA	mg/L	11/5/87	12/8/04	4.29	11.5	0.300	2.87	108
GENERAL ORGANIC	CARBON, DISSOLVED ORGANIC	mg/L	5/8/96	1/28/97	12.7	20.3	5.74	5.62	16
	CARBON, TOTAL ORGANIC	mg/L	5/8/96	12/8/04	10.9	23.0	3.00	6.21	114
NITROGEN	AMMONIA, TOTAL AS N	mg/L	10/13/04	11/16/04	0.028	0.053	0.013	0.022	3
	AMMONIA-N	mg/L	11/5/87	11/16/04	0.035	0.226	0.004	0.043	115
	KJELDAHL NITROGEN, DIS	mg/L	11/5/87	7/10/96	0.958	1.25	0.250	0.276	15
	KJELDAHL NITROGEN, TOTAL	mg/L	11/5/87	12/8/04	0.805	2.15	0.110	0.354	125
	NITRATE+NITRITE-N	mg/L	11/5/87	12/8/04	0.084	0.457	0.002	0.114	123
	NITRATE-N	mg/L	11/5/87	12/8/04	0.077	0.441	0.002	0.100	119
	NITRITE-N	mg/L	11/5/87	12/8/04	0.011	0.090	0.0005	0.018	125
	TOTAL NITROGEN	MG N/L	5/30/02	12/8/04	1.01	2.15	0.517	0.354	64
PHOSPHORUS	PHOSPHATE, DISSOLVED AS P	mg/L	11/5/87	7/10/96	0.096	0.131	0.061	0.021	15
	PHOSPHATE, ORTHO AS P	mg/L	11/5/87	12/8/04	0.054	0.232	0.002	0.035	114
	PHOSPHATE, TOTAL AS P	mg/L	11/5/87	12/8/04	0.097	0.270	0.015	0.048	125
METAL	CALCIUM	mg/L	11/5/87	12/6/88	134	219	50.0	95.3	4
	IRON, DISSOLVED	ug/L	11/5/87	12/6/88	118	210	25.0	107	4
	MAGNESIUM	mg/L	11/5/87	12/6/88	288	565	12.0	315	4
	POTASSIUM	mg/L	11/5/87	12/6/88	94.3	183	5.12	102	4

Note: Half of the detection limit was used to calculate statistics when reported below the detection limit