Wetland Solutions, Inc.

2809 NW 161 Court
Gainesville, FL 32609
(386) 462-1003
(386) 462-3196 fax

MEMORANDUM

Existing Treatment Facilities Evaluation

TO: Mike Taylor/Parsons

COPIES: Lynette Cardoch/Parsons

FROM: Chris Keller/WSI
Robert L. Knight/WSI

DATE: August 9, 2004

Contents

Contents 1
Introduction....1
Wetland Nitrogen Cycle 2
Lake Hancock Historical Water Quality and Flow Data 3
Review of Wetland and Aquatic Plant-Based Treatment System Performance....5
Everglades Agricultural Area Stormwater Treatment Areas....5
City of Lakeland Wetland Treatment System 16
Orlando Easterly Wetland....17
City of Titusville, Blue Heron Wetland Treatment System....22
Lake Apopka Marsh Flow Way Projects....23
Lake Griffin Flow Way 26
S-154 Algal Turf Scrubber/Water Hyacinth....31
Summary of Existing Treatment System Performance 31
Modeling Approach for Lake Hancock Conceptual Design 35
Sequential N Model....39
Calibration of Model Parameters for Florida Treatment Wetlands 40
Preliminary Lake Hancock Wetland Sizing....41
Summary....45
References....47

Introduction

Lake Hancock is a large, hypereutrophic lake located southeast of Lakeland and north of Bartow in Polk County, Florida. The surface area of the lake is approximately 4,550 acres, and the drainage basin contributing to the lake covers 135 square miles, including drainage from Lakeland and Auburndale. Three main tributaries located at the north half of the lake discharge into Lake Hancock. These include: Banana Creek from the northwest, North Saddle Creek from the north, and Lake Lena Run from the northeast. Discharge from the lake at its southern end is to South Saddle Creek at a gated control structure, Structure P-11, which is operated by the Southwest Florida Water Management District (District). The confluence of South Saddle Creek and Peace Creek Canal form the headwaters of the Peace River, which is the primary contributing watershed to Charlotte Harbor, a Surface Water Improvement and Management (SWIM) priority water body.

Contributing to Lake Hancock's hypereutrophic character and general poor water quality are high nutrient concentrations (i.e., nitrogen and phosphorus), which result in persistent blue-green algal blooms and widely fluctuating levels of dissolved oxygen (DO) and pH. The Trophic State Index (TSI) values for Lake Hancock have been in the hypereutrophic range since a least 1970. The lake contains approximately 18 million cubic yards of nutrient-rich flocculent bottom sediments that frequently re-suspend into the overlying water column as a result of wind action and varying DO levels. The lake is dominated by fish, vegetation, and wildlife populations that are also indicative of hypereutrophic conditions.

The District has initiated the Lake Hancock Outfall Treatment Project to improve water quality in flows discharged from Lake Hancock to the Peace River. Discharge from the lake has been documented as a major source of poor water quality in the upper Peace River. This poor water quality from the lake affects the entire river all the way to Charlotte Harbor, an "estuary of national significance," and a State SWIM priority water body. Wetland Solutions, Inc., has been contracted to prepare a review of wetland and aquatic plant-based treatment technologies in Florida and to estimate the benefits that can be achieved by these technologies to treat water from Lake Hancock. This memorandum focuses on nitrogen (N) performance, as N is the key parameter of concern in the watershed, but also provides information regarding the performance of wetlands for reducing other water quality parameters such as total phosphorus (TP) and total suspended solids (TSS).

Wetland Nitrogen Cycle

Nitrogen takes several dominant forms in wetland and aquatic environments. The most common nitrogen species are organic nitrogen (Org-N), ammonia nitrogen (NH_4-N), and nitrate nitrogen (NO_3-N). Nitrite nitrogen (NO_2-N) is rarely detectable because it is rapidly transformed to NO_3-N. Organic nitrogen and NH_4-N are commonly measured together and reported as total kjeldahl nitrogen (TKN). The sum of all nitrogen species is commonly reported as total nitrogen (TN).

A variety of nitrogen transformation processes occur in wetlands. **Exhibit 1** shows the simplified wetland nitrogen cycle. The dominant transformations that occur in treatment wetlands are ammonification of Org-N to NH_4-N, nitrification of NH_4-N to NO_2-N, and NO_3-N, and denitrification of NO_3-N to nitrogen gas (N_2). Other important transformations include fixation of atmospheric nitrogen and volatilization of dissolved NH_4-N.

Nitrogen is a pollutant when it exceeds the normal natural wetland background concentration. Depending upon the source of water, one or more species of N may be present in excess concentrations. Municipal wastewaters are commonly high in Org-N, but may also contain elevated levels of NH_4-N if the effluent is not nitrified, and NO_3-N if it is nitrified. Agricultural inputs, especially livestock runoff, are typically high in both Org-N and NH_4-N.

Kadlec and Knight (1996) reported that the global median Org-N background concentration in wetlands ranges from about 1 to 1.5 milligrams per liter (mg/L). If Org-N exceeds background levels, then a net TN reduction requires that Org-N is first mineralized, and then subsequent removal of NH_4-N and NO_3-N occurs. Typical unimpacted wetlands exhibit NH_4-N and NO_3-N concentrations that are below normal analytical detection levels (Kadlec and Knight, 1996).

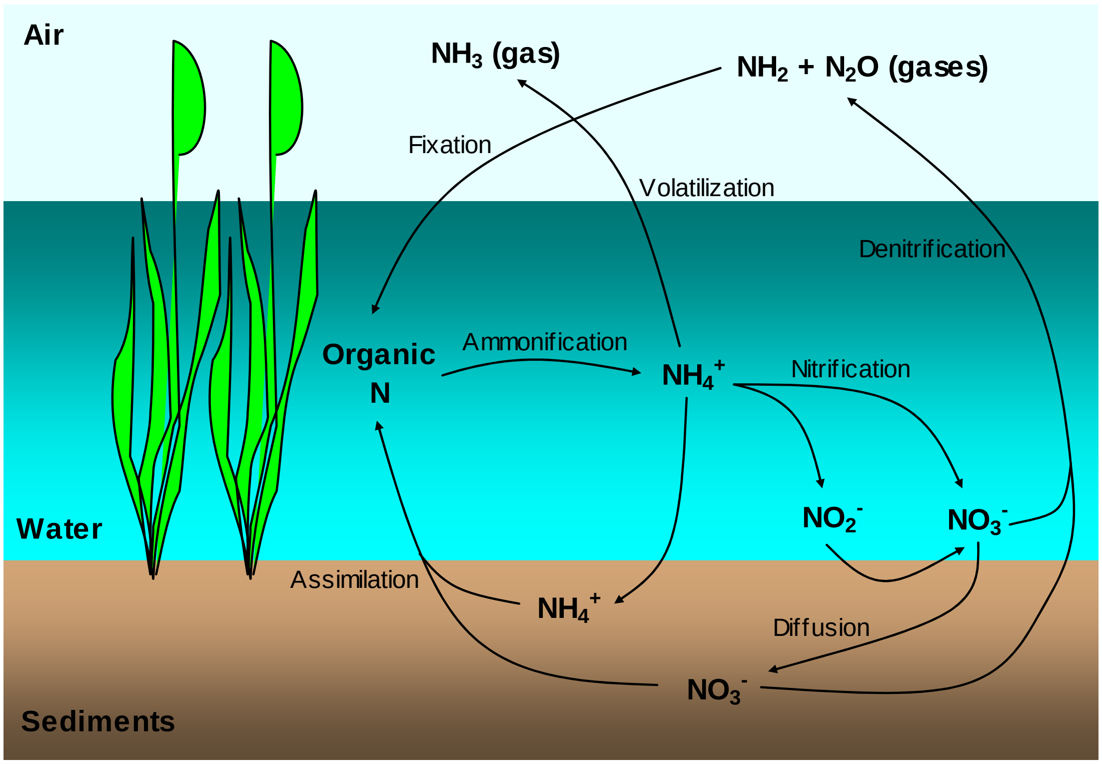


EXHIBIT 1
Simplified wetland nitrogen cycle (Source: Kadlec and Knight, 1996).

Lake Hancock Historical Water Quality and Flow Data

Water quality and flow data from Lake Hancock will be summarized under other project tasks, but background information is provided in this document to allow preliminary sizing of a wetland and aquatic plant-based treatment system.

Exhibit 2 summarizes historical water quality data from a variety of sources. ERD (1999) completed the most recent survey of water quality in Lake Hancock with samples collected between October 1998, and July 1999. For the recent data set, in-lake TN concentrations ranged from 2.73 to 11.9 mg/L, and averaged 5.96 mg/L. Almost all of the TN is comprised of organic nitrogen, as evidenced by the low values for NO_3-N and NH_4-N. ERD (1999) reported that 72 percent of the nitrogen was in the particulate form. Recent TP values ranged from 0.17 to 1.29 mg/L and averaged 0.50 mg/L.

The District regulates discharges from Lake Hancock through the P-11 structure located on Saddle Creek. **Exhibit 3** shows the period-of-record discharge data and **Exhibit 4** shows the frequency distribution of daily discharge rates. Daily discharge rates ranged from 0 to 936 cubic feet per second (cfs). The average daily discharge for the period-of-record was about 60 cfs.

EXHIBIT 2
Summary of historical water quality data from Lake Hancock

Parameter	STORET Legacy	STORET Modern	ERD (1999) Historical	ERD (1999) October 1998 – July 1999		
	Mean	Mean	Mean	Mean	Min	Max
NH_3-N	0.11	0.02	0.037	0.027	< 0.005	0.39
NO_x-N	0.06	0.03	0.01	0.027	< 0.005	0.30
Diss. Organic N	--	--	--	1.63	1.02	2.67
Particulate N	--	--	--	4.28	0.84	10.3
TKN	4.8	4.04	--	--	--	--
TN	4.4	4.1	5.99	5.96	2.73	11.9
Ortho-P	--	--	--	0.011	0.001	0.068
Particulate P	--	--	--	0.46	0.14	1.26
TP	0.67	0.54	0.63	0.50	0.17	1.29
TSS	36	70	--	115	27	313
BOD	13	7.2	--	17.9	5.1	34

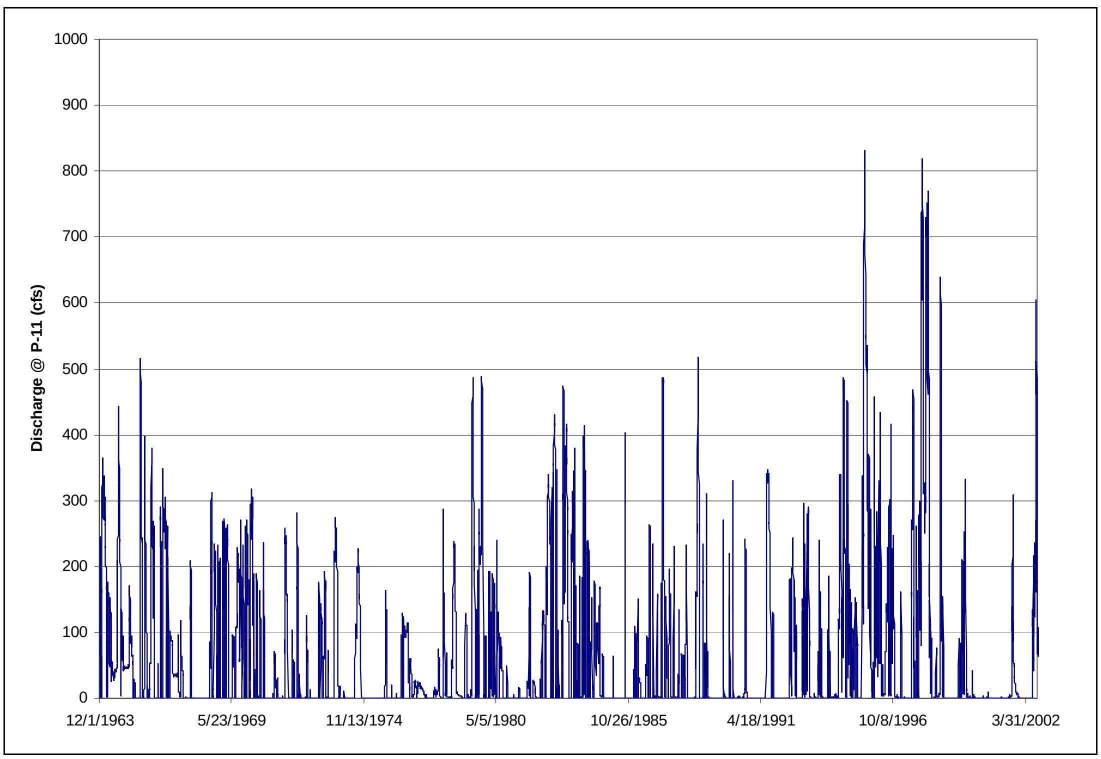


EXHIBIT 3
Period-of-record daily discharge from the P-11 structure (Source: USGS)

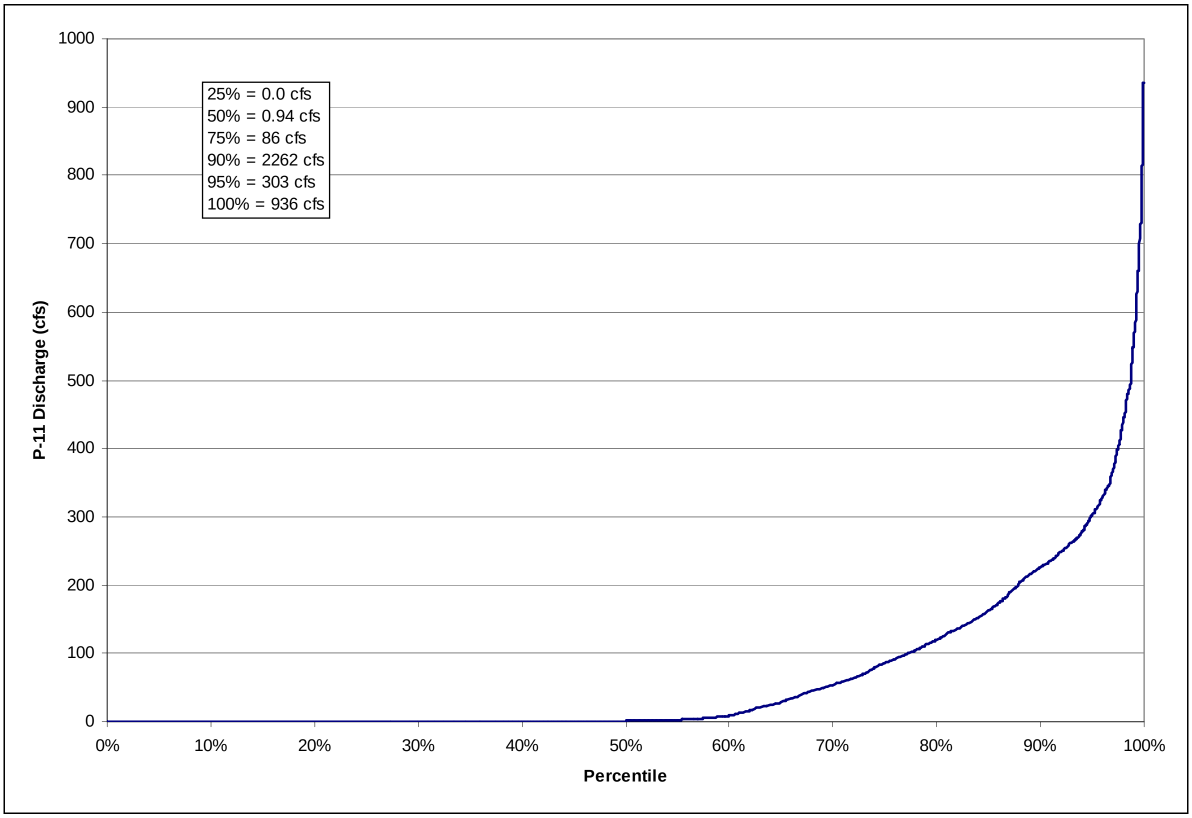


EXHIBIT 4
Frequency distribution of daily discharge rates from the P-11 structure (Source: USGS)

Review of Wetland and Aquatic Plant-Based Treatment System Performance

Performance data and operational information from several of Florida's largest (>200 ac) treatment wetlands and a demonstration-scale, combined water hyacinth/algal-based system were reviewed to determine appropriate design criteria (i.e. k values and mass loading rates) for a N treatment system adjacent to Lake Hancock. **Exhibit 5** shows the location of the sites reviewed for this memorandum. These sites are described in the following paragraphs and their major characteristics are summarized in **Exhibit 6**.

Everglades Agricultural Area Stormwater Treatment Areas

The South Florida Water Management District (SFWMD) has constructed massive treatment wetland projects to improve water quality in discharges to the Water Conservation Areas (WCAs) and Everglades National Park (ENP). To date, the SFWMD has constructed 5 stormwater treatment areas (STAs), each ranging in size from approximately 870 acres to over 16,500 acres.

The STAs were constructed on land that was formerly used for agricultural operations such as sugar-cane production and sod farming. Existing substrates ranged from sandy mineral soils to very thick organic peat soils to exposed limestone caprock. Some test plots were planted in one of the stormwater treatment areas (STA-1W), but most of the vegetation in these systems established through volunteer recruitment. Existing STA plant communities are diverse with a mixture of emergent wetland vegetation including cattails and bulrush, submerged aquatic vegetation such as southern naiad and coontail, and floating aquatic plant species such as water hyacinth and duckweed.

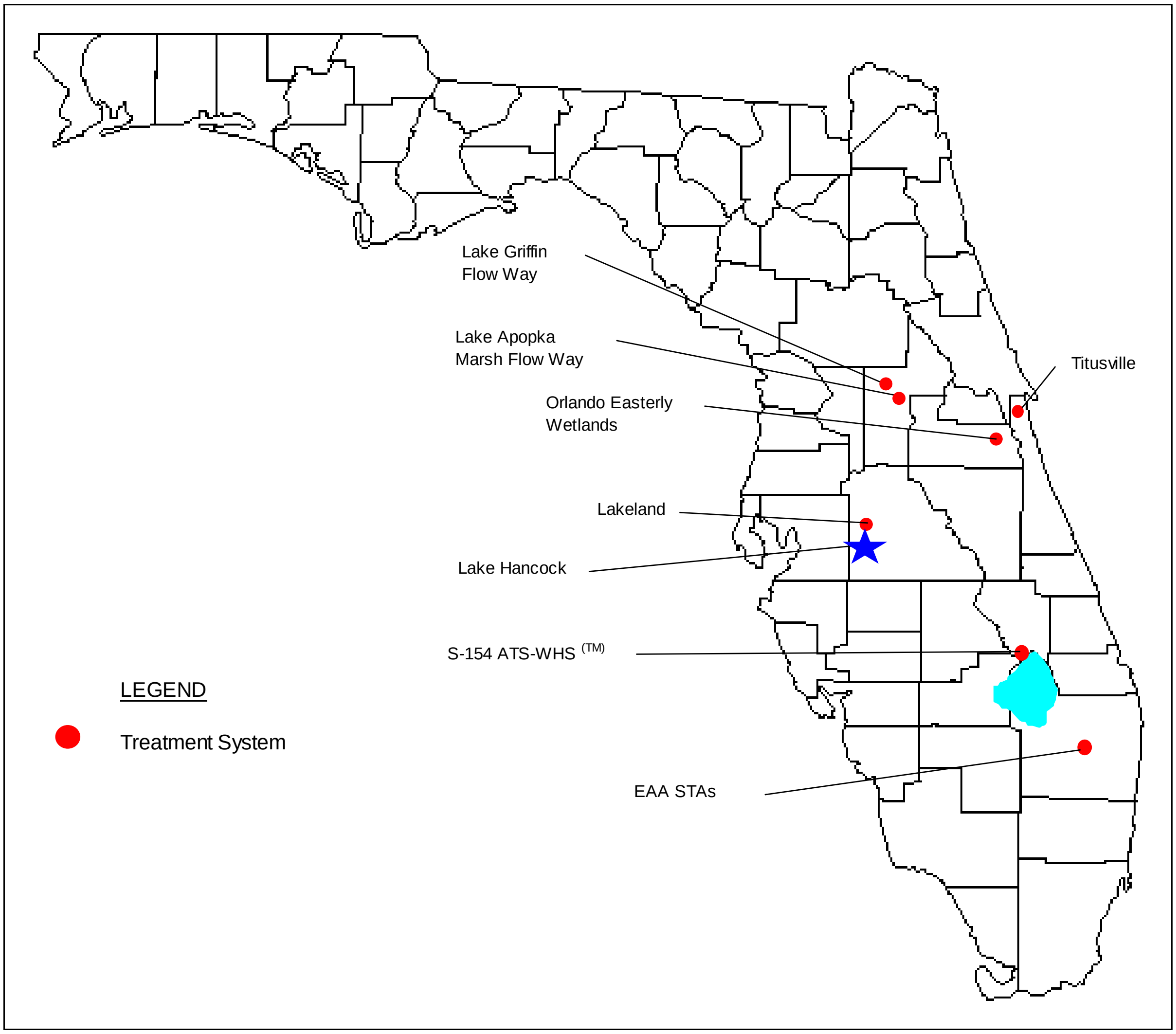


EXHIBIT 5
Location of large-scale treatment sites reviewed for the Lake Hancock Nutrient Removal Project

EXHIBIT 6
Summary of design criteria for existing treatment sites

Site	Area (ac)	Design Hydraulic Loading Rate (cm/d)	Period-of-Record
STA-1W	6,670	1.8	1/93 – 2/04
STA-2	6,430	2.1	3/00 – 12/03
STA-3/4	16,500	3.0	Not Available
STA-5	4,110	2.1	11/98 – 3/04
STA-6	870	1.8	12/97 – 12/03
Lakeland WTS	1,400	0.8	1/87 – 9/99
Orlando Easterly Wetlands	1,200	1.0	1/88 – 4/04
Blue Heron WTS	264	1.7	1/97 – 3/04
Lake Apopka Marsh Flow-Way	660	--	11/03 – 4-04
Lake Griffin Flow-Way	3,320	--	6/94 – 12/03
S-154 ATS™ - WHS™	5	9.4	2/03 – 10/03

The Everglades STA Design Model (Walker, 1995) was developed based upon a review of phosphorus gradient data from one of the WCAs (WCA-2A). The model consists of steady-state water and mass balance equations with a first-order kinetic term for phosphorus removal. This tool was used to estimate the area required to reduce phosphorus concentrations to about 50 parts per billion (ppb). The STAs were not sized with specific nitrogen reduction goals in mind.

The individual STAs are described further in the following paragraphs.

STA-1W

STA-1 West contains approximately 6,670 acres of effective treatment area arranged in three flow-ways (Goforth, et.al., 2004). The eastern flow-way contains Cells 1 and 3, the western flow-way contains Cells 2 and 4, and the northern flow-way consists of Cells 5A and 5B. Flow-through operations in Cells 1 through 4 began in August 1994 when the system was operating as a full-scale prototype (the Everglades Nutrient Removal Project) for future STAs. The system has been referred to as STA-1W since Cell 5 began operations in July 2000. Flow from STA-1W is discharged to Water Conservation Area 1A. **Exhibit 7** shows a schematic of STA-1W.

The design flow rate to STA-1W exceeds 143,000 acre-feet per year (ac-ft/yr). During the most recent reporting period, water year 2003 (WY2003), the average hydraulic loading rate (HLR, inflow divided by wetland area) was 7.4 centimeters per day (cm/d). The system-wide, period-of-record (POR) average HLR was 3.95 cm/d. **Exhibits 8** and **9** show the POR monthly average inflow and outflow TN and TP concentration data for each cell. TN was reduced by about 28 percent with passage through the system, but TN removal was limited because inflow concentrations are near regional background levels. TP performance was better with an overall system removal efficiency of approximately 70 percent.

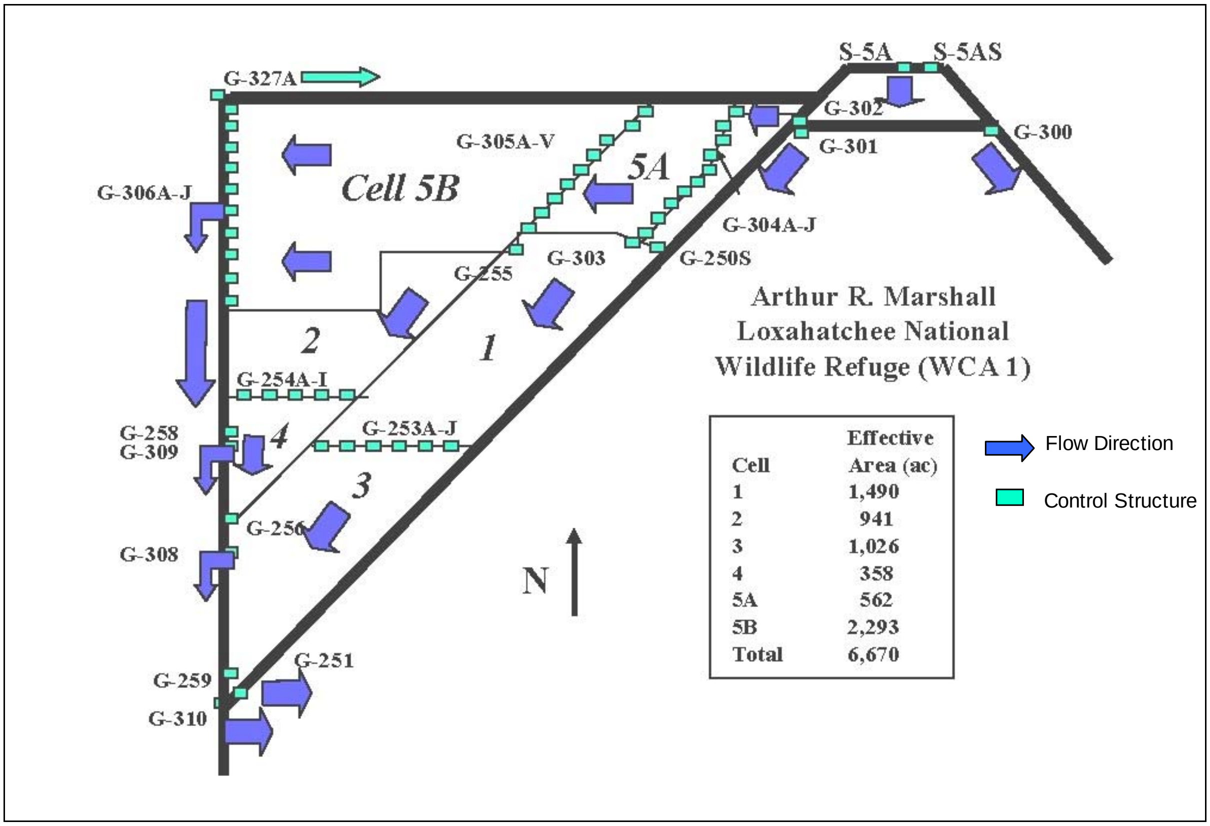


EXHIBIT 7
STA-1W Site Plan (Goforth, et.al., 2004)

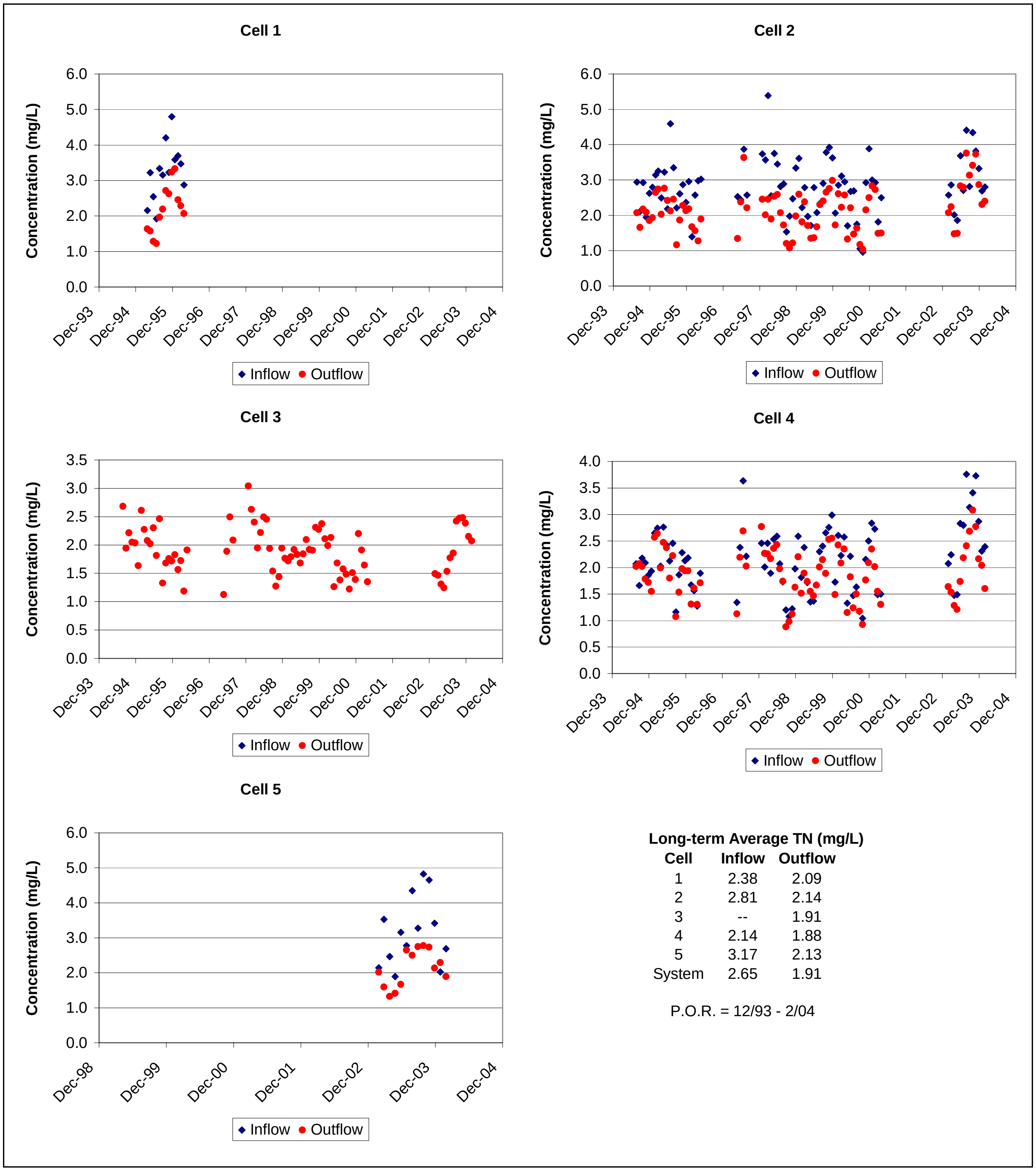
STA-2

STA-2 contains approximately 6,430 acres of treatment area arranged in three parallel cells (Goforth, et.al., 2004) and began operation in early 2001. A schematic of STA-2 is presented in **Exhibit 10**. Inflows are delivered through the S-6 pump station and structure G-328. Treated water is collected and discharged to WCA-2A via the G-335 outflow pump station. Discharges are directed to areas within WCA-2A that are already impacted by elevated nutrient levels.

The design flow for STA-2 is approximately 163,000 ac-ft/yr, but in WY2003, the actual flow was over 280,000 ac-ft, which equates to a HLR of 3.67 cm/d. **Exhibits 11** and **12** show POR monthly average inflow and outflow concentration data for TN and TP. TN concentrations were reduced by about 23 percent with passage through the system. The system-wide TP concentration reduction was about 59 percent.

STA-3/4

STA-3/4 is the largest of the existing STAs, with approximately 16,500 acres of treatment area. During an average year, STA-3/4 should receive approximately 600,000 ac-ft/yr of runoff from upstream basins and Lake Okeechobee releases. Flow and performance data were not available for STA-3/4 at the time this report was prepared. Like the other STAs, STA-3/4 was designed to reduce influent TP levels to 50 ppb. **Exhibit 13** shows a schematic of STA-3/4.

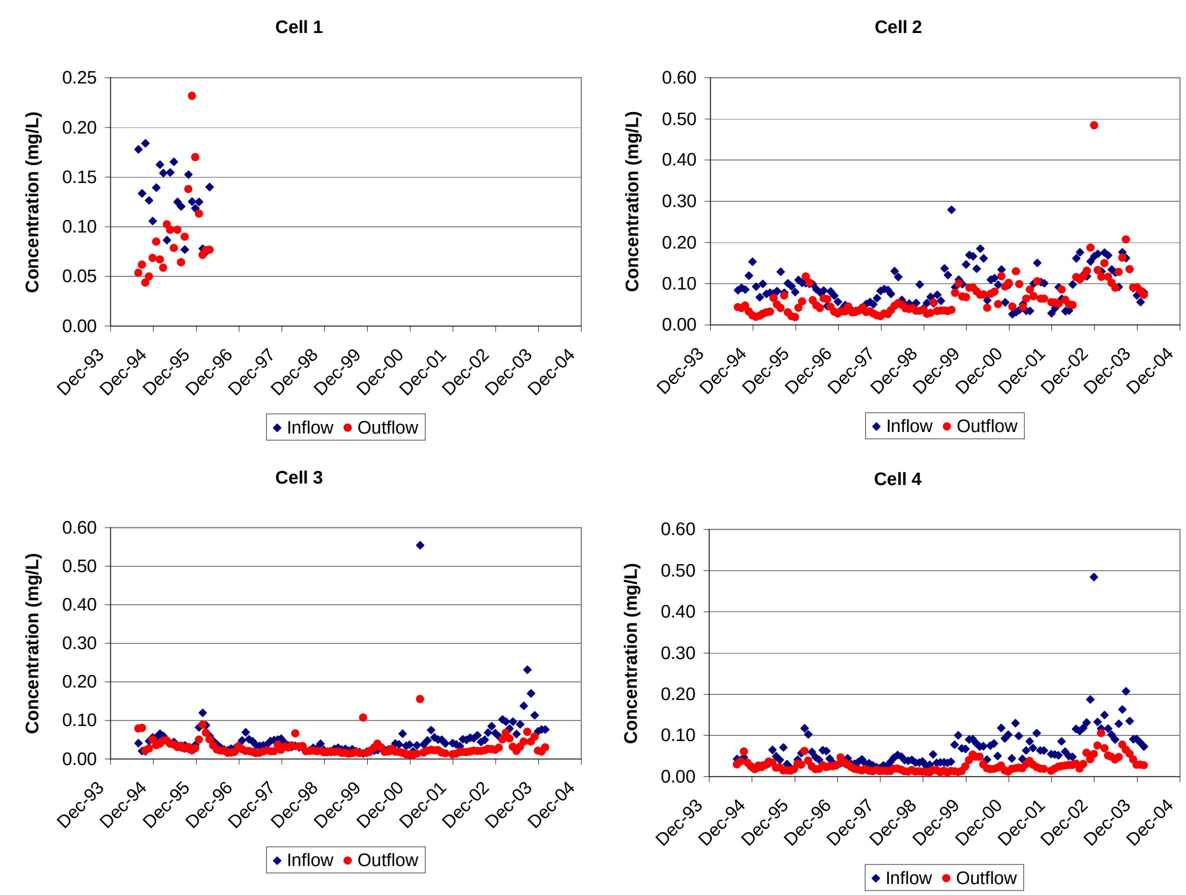


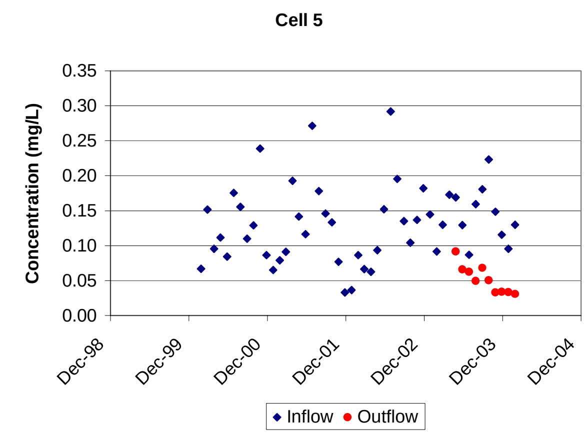
Long-term Average TN (mg/L)

Cell	Inflow	Outflow
1	2.38	2.09
2	2.81	2.14
3	--	1.91
4	2.14	1.88
5	3.17	2.13
System	2.65	1.91

P.O.R. = 12/93 - 2/04

EXHIBIT 8
Summary of monthly average TN data from STA-1W (Source: DBHYDRO)





Long-term Average TP (mg/L)

Cell	Inflow	Outflow
1	0.095	0.052
2	0.093	0.068
3	0.052	0.030
4	0.068	0.028
5	0.132	0.052
System	0.101	0.030

P.O.R. = 12/93 - 2/04

EXHIBIT 9
Summary of monthly average TP data from STA-1W (Source: DBHYDRO)

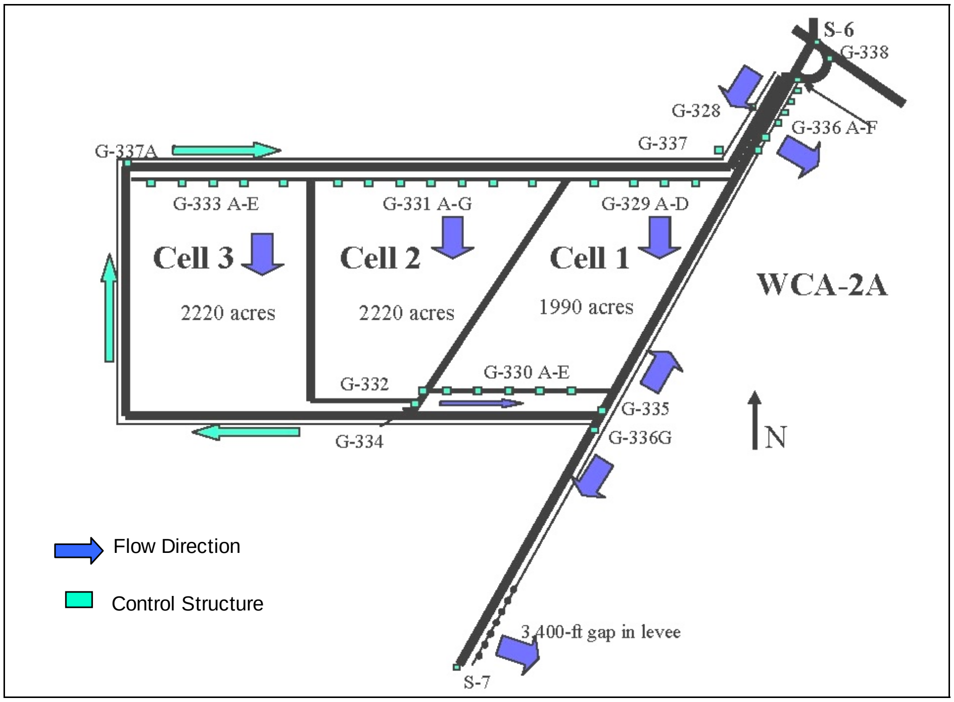
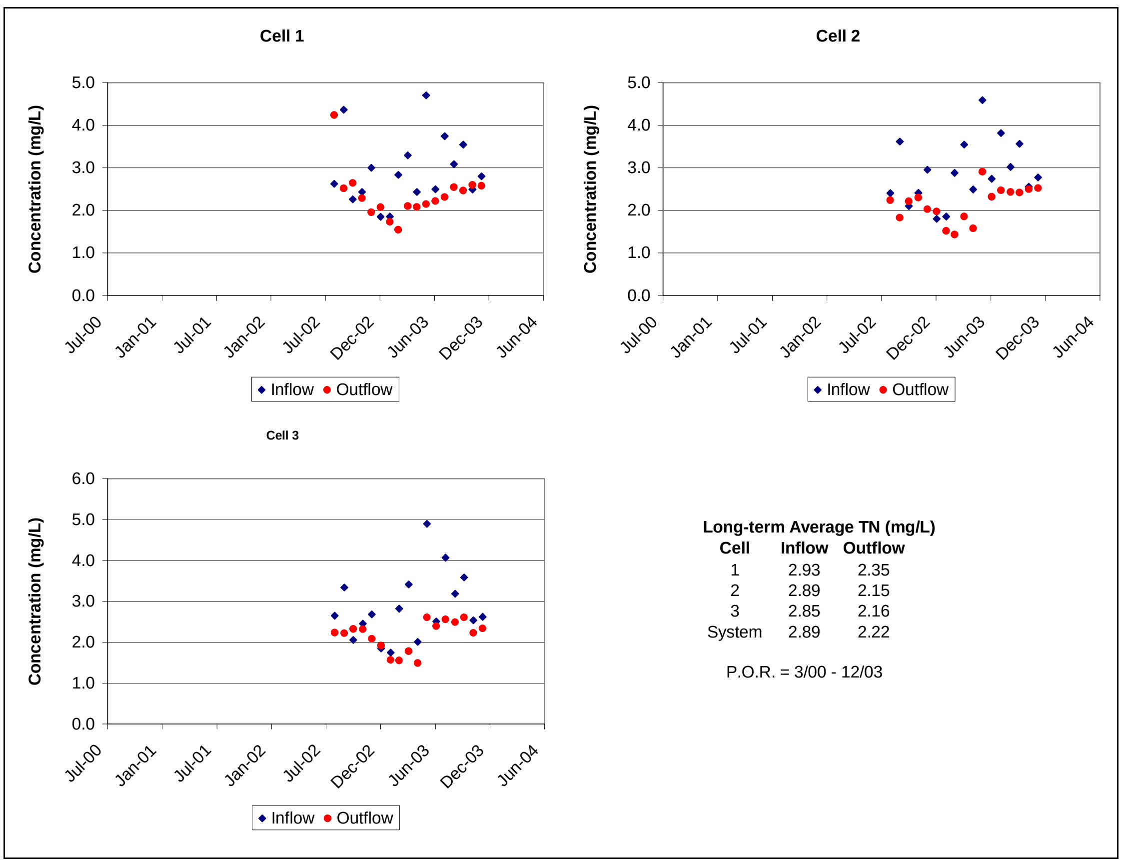


EXHIBIT 10
STA-2 Site Plan (Goforth, et.al., 2004)

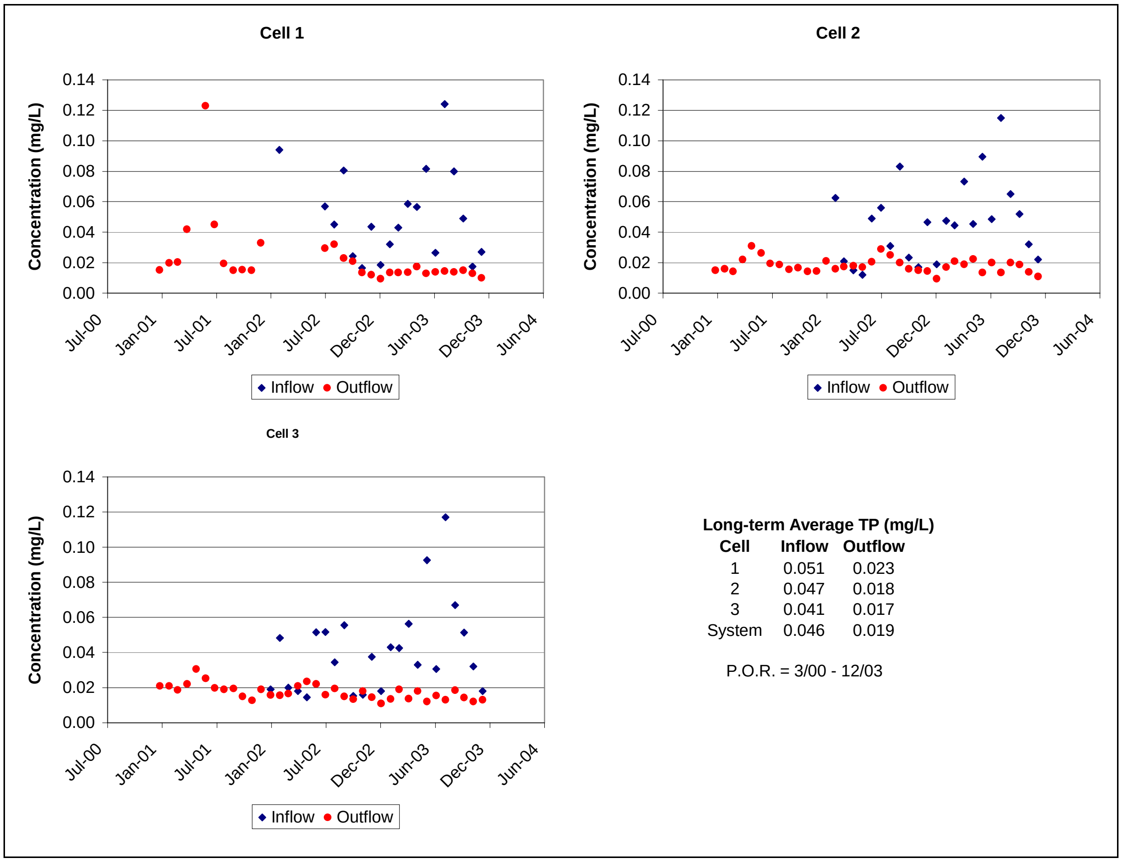


Long-term Average TN (mg/L)

Cell	Inflow	Outflow
1	2.93	2.35
2	2.89	2.15
3	2.85	2.16
System	2.89	2.22

P.O.R. = 3/00 - 12/03

EXHIBIT 11
Summary of monthly average TN data from STA-2 (Source: DBHYDRO)

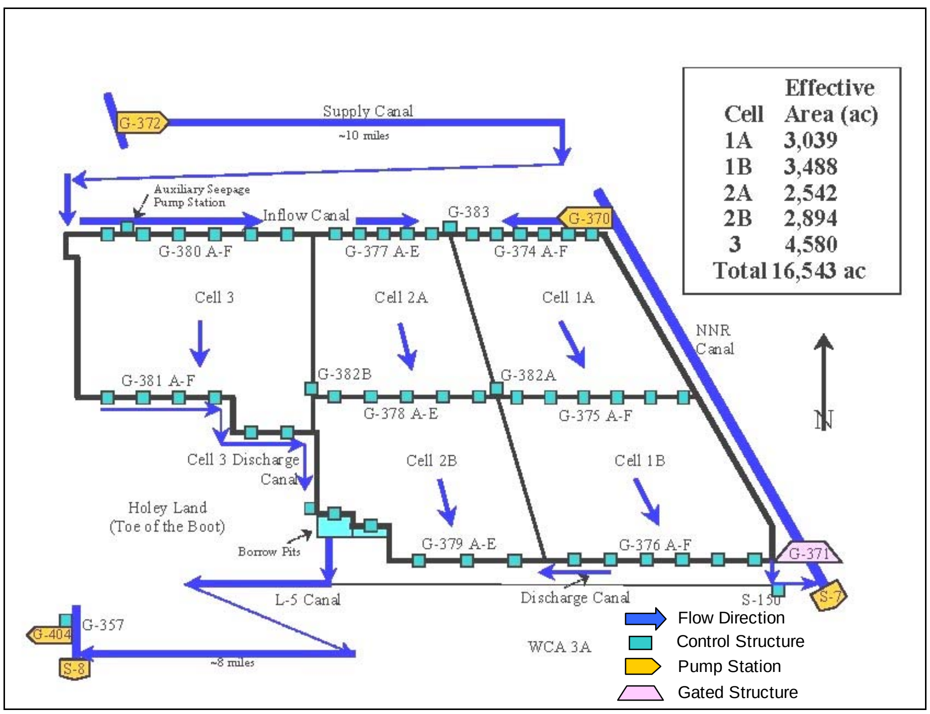


Long-term Average TP (mg/L)

Cell	Inflow	Outflow
1	0.051	0.023
2	0.047	0.018
3	0.041	0.017
System	0.046	0.019

P.O.R. = 3/00 - 12/03

EXHIBIT 12
Summary of monthly average TP data from STA-2 (Source: DBHYDRO)



Cell	Effective Area (ac)
1A	3,039
1B	3,488
2A	2,542
2B	2,894
3	4,580
Total	16,543 ac

EXHIBIT 13
STA-3/4 Site Plan (Goforth, et.al., 2004)

Though the STA recently began operating in October 2003, ongoing enhancements are planned to improve overall phosphorus removal performance. Parts of the system will be converted from emergent vegetation to a submerged aquatic vegetation community that is expected to further reduce TP levels.

Lessons learned from earlier STA designs were incorporated into the design for STA-3/4. These included compartmentalization of the system into a greater number of cells, back-filling farm ditches that channelize flow, and growing plants during the construction phase rather than following the completion of construction.

STA-5

STA-5 contains approximately 4,110 acres of effective treatment area arranged in two parallel flow-ways and began flow-through operation in January 1999. The average hydraulic loading rate during WY2003 was 3.45 cm/d. Dry out conditions were experienced in Cell 2B in May 2002.

Treated water is collected and discharged either to the Rotenberger Wildlife Management Area or the Miami Canal, where the majority of the water moves south to the northwest corner of WCA-3A. **Exhibit 14** shows a schematic of STA-5.

Exhibit 15 shows POR monthly average inflow and outflow TN and TP concentrations for STA-5. These concentration data do not indicate the removal of either nutrient in STA-5. TN and TP concentrations increased by 38 percent and 1 percent, respectively. The export of nutrients from STA-5 was caused by the release of soil TN and TP following initial flooding and again following the dry out events.

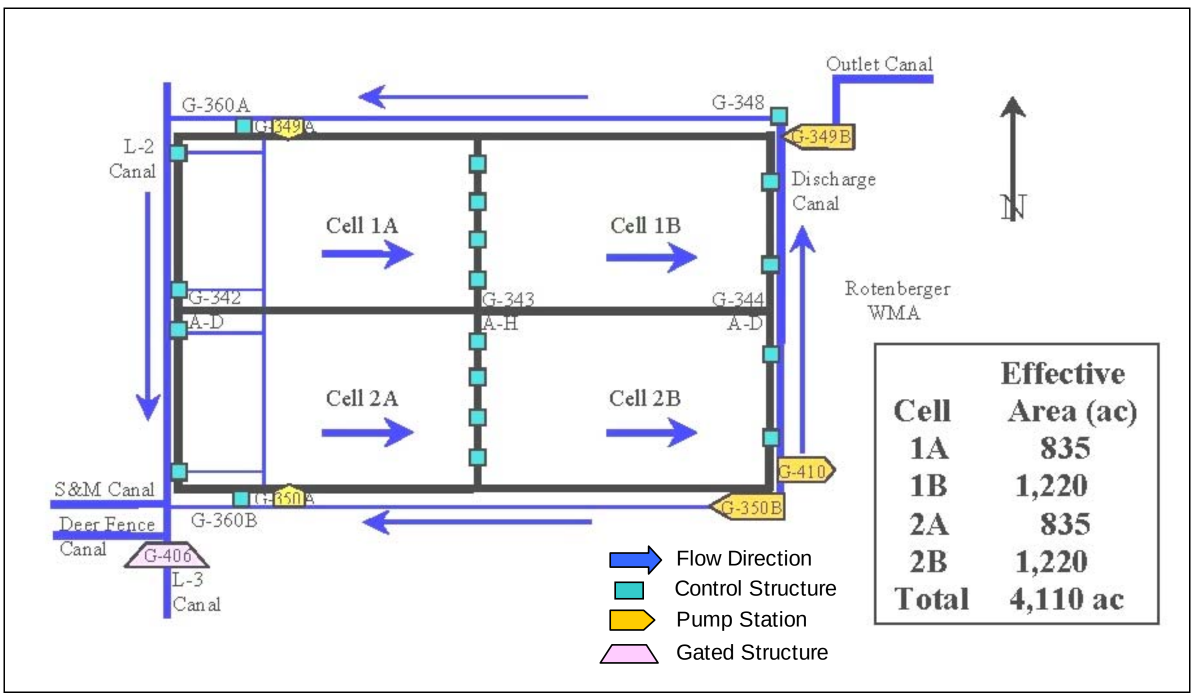
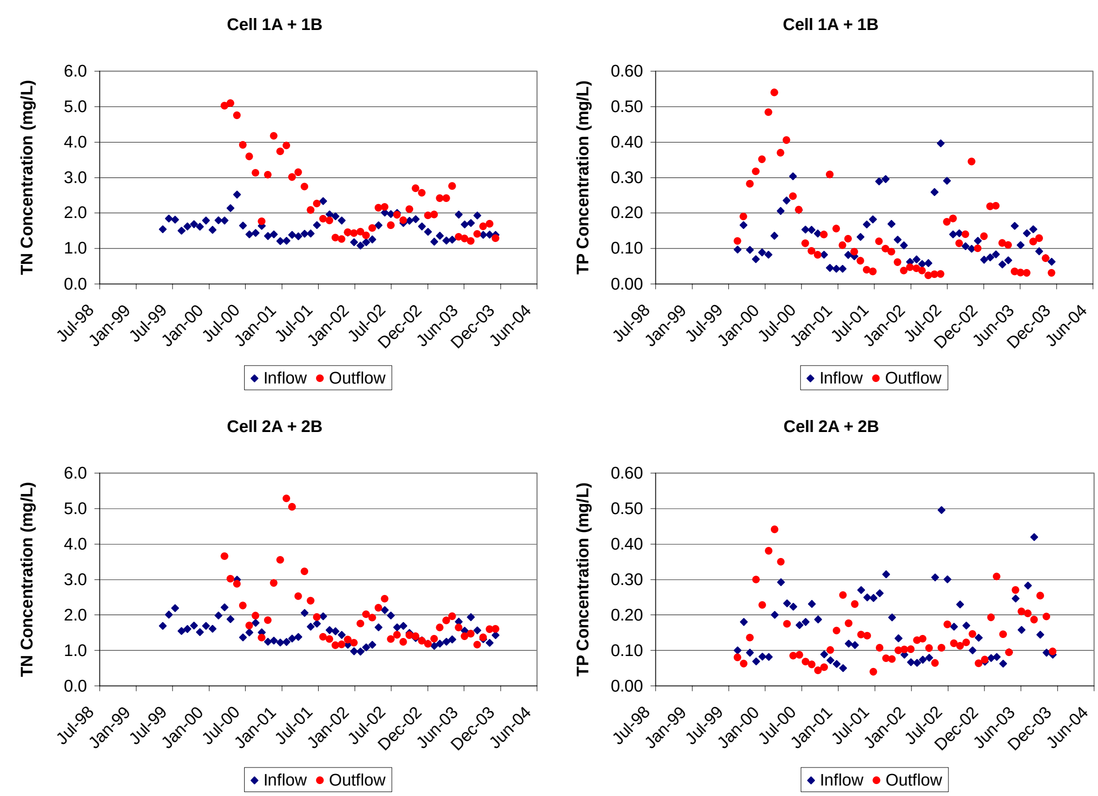


EXHIBIT 14
STA-5 Site Plan (Goforth, et.al., 2004)



Long-term Average TN (mg/L)

Cell	Inflow	Outflow
1A + 1B	1.61	2.38
2A + 2B	1.57	2.00
System	1.59	2.19

Long-term Average TP (mg/L)

Cell	Inflow	Outflow
1A + 1B	0.133	0.150
2A + 2B	0.165	0.151
System	0.149	0.151

EXHIBIT 15
Summary of monthly average TN and TP data from STA-5 (Source: DBHYDRO)

STA-6

STA-6 Section 1 is currently the smallest of the STAs at approximately 870 acres (**Exhibit 16**). STA-6 consists of two parallel cells and has a design flow of 18,300 ac-ft/yr. Section 1 (Cells 3 and 5) went into operation in late 1997. STA-6 Section 2 will add approximately 1,400 acres to the treatment system and is scheduled to be completed by December 31, 2006.

During WY2003, the average hydraulic loading rate to STA-6 was about 5.4 cm/d. Flow-weighted mean phosphorus concentrations were reduced from 0.077 mg/L to 0.026 mg/L. TKN was reduced from 1.8 mg/L to 1.5 mg/L. TSS concentrations were reduced from 6.5 mg/L to 1.4 mg/L. Dry out conditions have occurred in both cells as a result of limited water supply.

Exhibit 17 shows POR monthly average inflow and outflow TN and TP concentrations for STA-6. The TN concentration removal efficiency was about 25 percent, TP removal was about 63 percent, and TSS removal was about 78 percent.

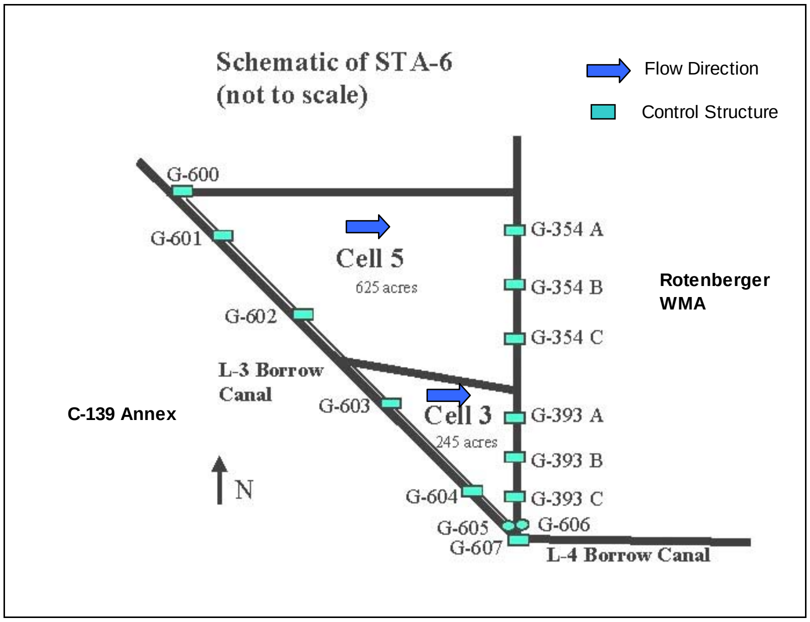
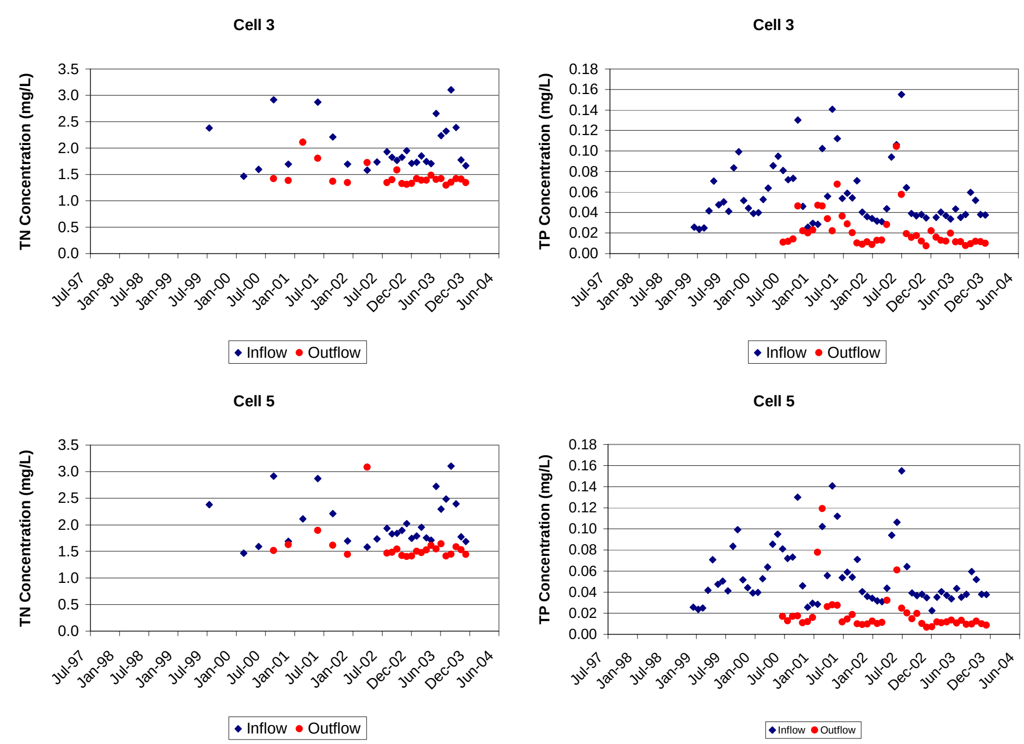


EXHIBIT 16
STA-6 Site Plan (Goforth, et.al., 2004)



Long-term Average TN (mg/L)

Cell	Inflow	Outflow
3	2.02	1.45
5	2.04	1.59
System	2.03	1.52

Long-term Average TP (mg/L)

Cell	Inflow	Outflow
3	0.056	0.023
5	0.056	0.020
System	0.056	0.021

EXHIBIT 17
Summary of monthly average TN and TP data from STA-6 (Source: DBHYDRO)

City of Lakeland Wetland Treatment System

The City of Lakeland Wetland Treatment System is a 1,400-acre site consisting of 7 cells. The wetland was created from former phosphate mine clay settling ponds. Cells 1 through 4 are shrub and emergent marsh wetlands. Cell 5 includes emergent marsh, but is primarily a shallow lake. Cells 6 and 7 are deep lakes and have experienced temporal changes in water hyacinth coverage. The Lakeland site receives up to 12 million gallons per day (mgd) of treated municipal effluent from the Glendale Wastewater Treatment Plant. **Exhibit 18** shows the layout of the Lakeland Wetland Treatment System.

EXHIBIT 18
Site plan of the Lakeland Wetland Treatment System

The site began operation in 1987, but underwent a series of modifications in the early and mid 1990's to control elevated TSS concentrations caused by algal blooms in the deeper lake cells. Modifications included the use of Aquashade® to limit algal production in Cells 6 and 7, lowering of control elevations in several cells to promote the growth of emergent vegetation, and construction of a bypass to provide the option to discharge directly from Cell 4. Typically, all permit limits are now met at the discharge from Cell 4.

The operating permit for the Lakeland system requires effluent BOD and TSS concentrations of 5 mg/L or less and TN of 3 mg/L or less. There is no TP standard in the current permit, in recognition of the high background levels exhibited at the site.

Exhibits 19 and **20** show POR monthly average TN and TP concentration data for each of the wetland cells. TN was reduced from about 11 mg/L to less than 2 mg/L (82 %), with most of the treatment occurring in the first three cells. TP was reduced from 6.4 mg/L to 3.9 mg/L (39 %), but remained high compared to other systems because of the site's geologic setting in the phosphate region and the site's former use as clay settling ponds. TSS was reduced from about 5.7 mg/L to 2.9 mg/L (49%).

Orlando Easterly Wetland

The 1,200-acre Orlando Easterly Wetlands (OEW) began operation in 1987, and polishes advanced treated municipal effluent from the City of Orlando's Iron Bridge Water Reclamation Facility. The OEW is sub-divided into 17 cells ranging in size from 14 to 186 acres. **Exhibit 21** shows the layout of the OEW system.

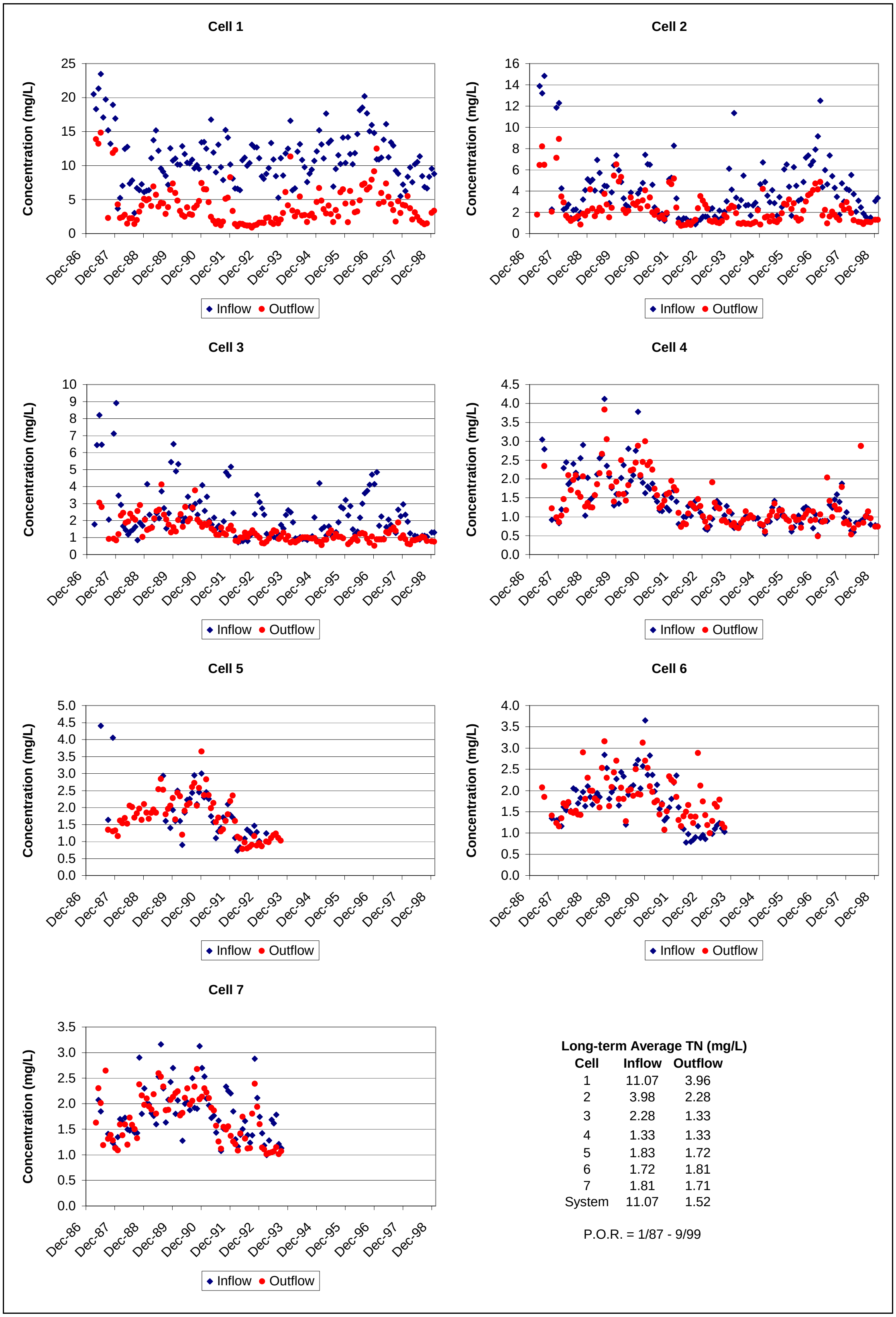
The OEW site was historically used as improved cattle pasture and consists of sandy soils underlain by clay. The wetland was created by constructing earthen berms and planting over 2 million aquatic plants (USEPA, 1993).

Water is pumped 17 miles from the Iron Bridge Water Pollution Control Facility to a splitter box that routes flow into three parallel treatment trains. Each train consists of deep marsh cells (approximately 3 feet in depth) initially planted with cattail and bulrush, followed by mixed emergent marsh cells, and finally a hardwood swamp. Bird rookeries in the hardwood swamp areas and antecedent soil TP concentrations contributed to a net release of TP from the system during the first several years following startup.

The current operational permit limits the flow rate to 35 mgd, and requires effluent concentrations of 2.31 mg/L for TN and 0.2 mg/L for TP.

Operators have used a variety of techniques to control vegetation and sediment accumulation, including prescribed burning, periodic drawdowns, and herbicide application.

Exhibit 22 shows POR (January 1988 – April 2004) monthly average inflow and outflow concentrations for TN and TP. The long-term average inflow and outflow TN concentrations were 2.37 mg/L and 0.80 mg/L, a 66 percent reduction. The long-term average inflow and outflow TP concentrations were 0.28 mg/L and 0.06 mg/L, a 79 percent reduction. Inflow and outflow TSS concentrations were 2.6 mg/L and 2.5 mg/L, reflecting the high quality of the applied wastewater. The POR average flow and hydraulic loading rate were 14.7 mgd and 1.15 cm/d.



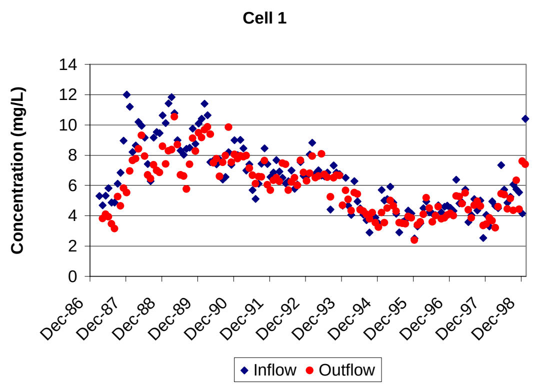
Long-term Average TN (mg/L)

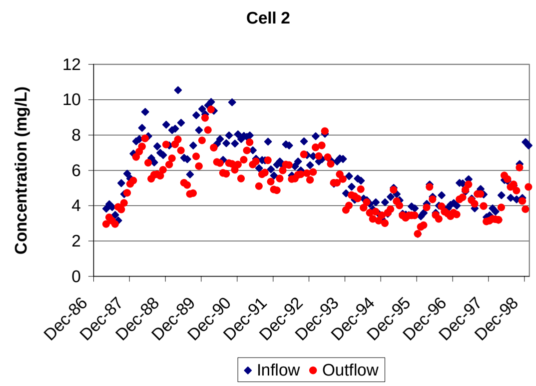
Cell	Inflow	Outflow
1	11.07	3.96
2	3.98	2.28
3	2.28	1.33
4	1.33	1.33
5	1.83	1.72
6	1.72	1.81
7	1.81	1.71
System	11.07	1.52

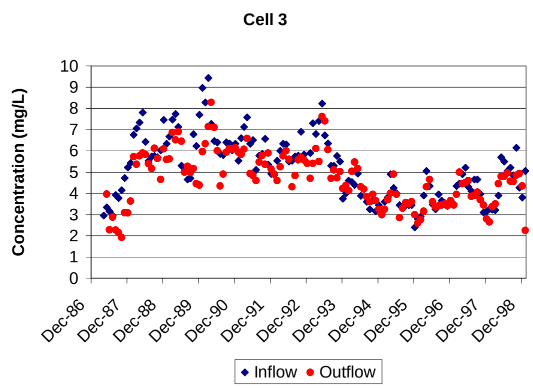
P.O.R. = 1/87 - 9/99

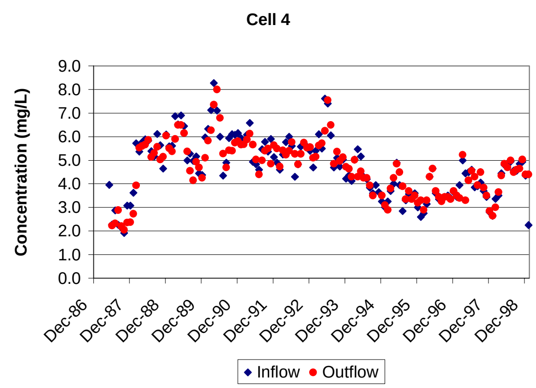
EXHIBIT 19

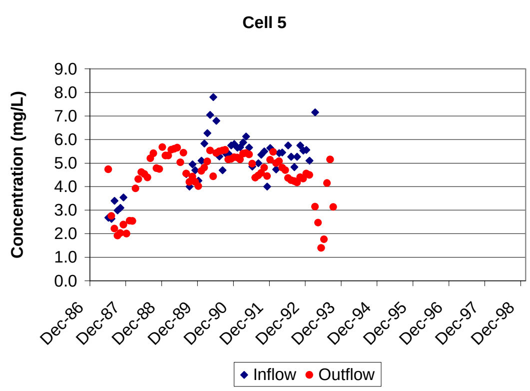
Summary of monthly average TN data from the Lakeland Wetland Treatment System (Source: NADB)

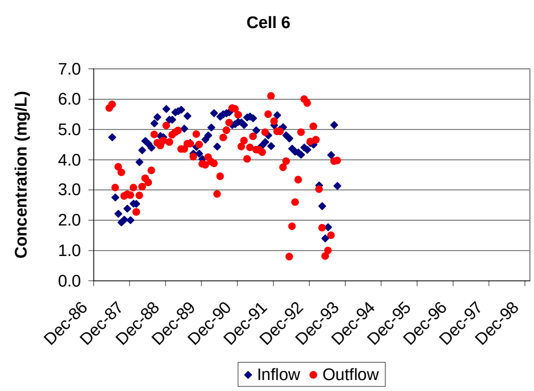


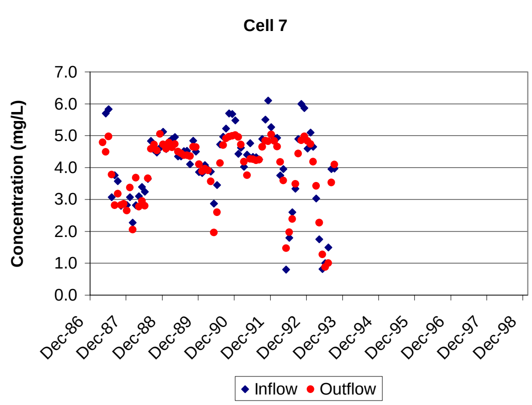












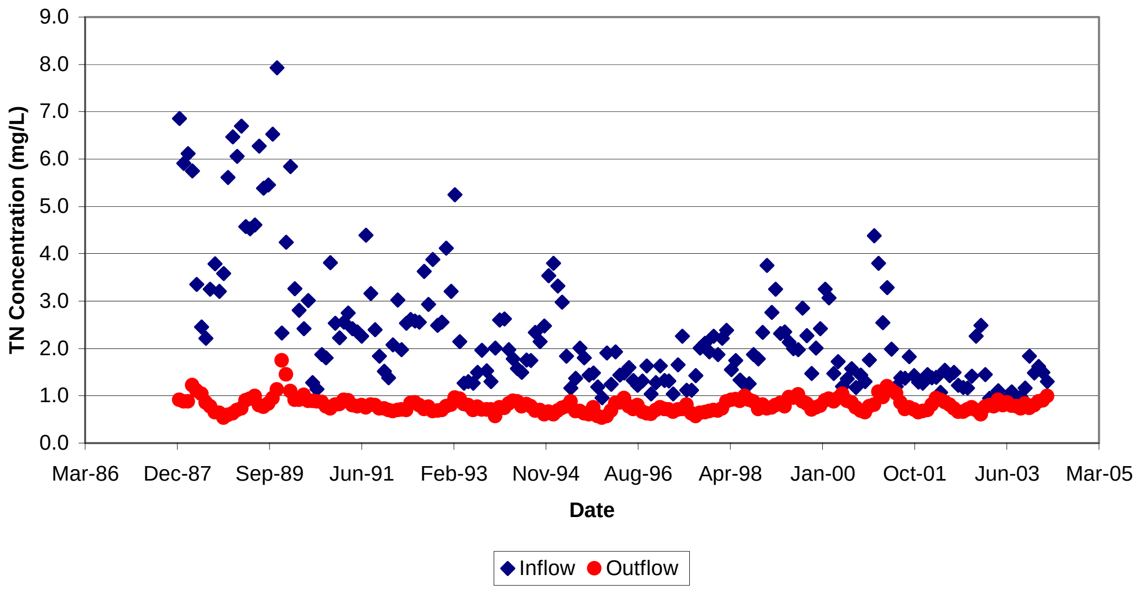
Long-term Average TP (mg/L)

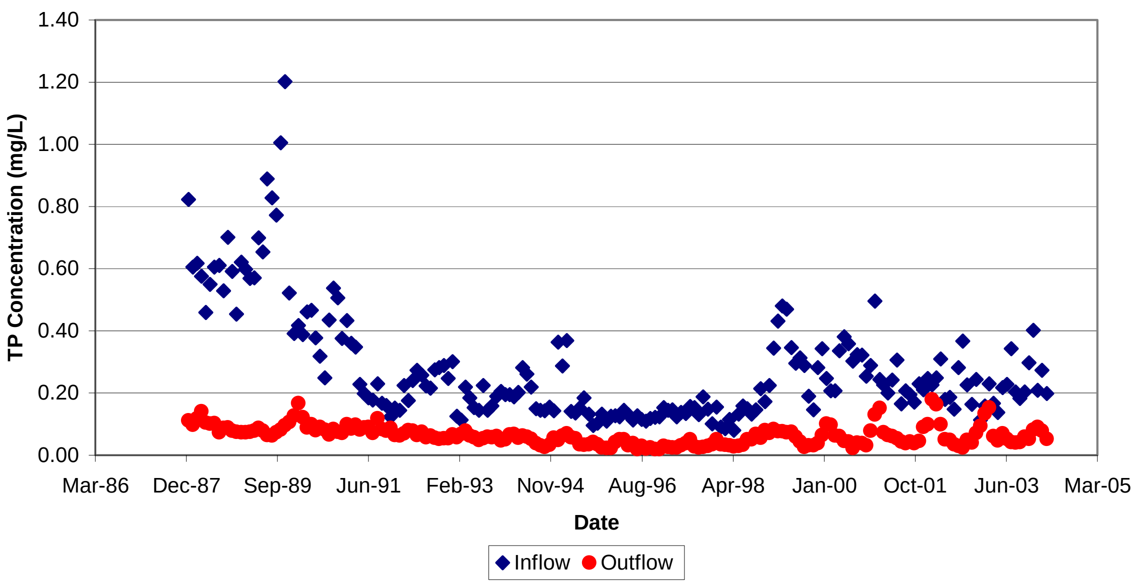
Cell	Inflow	Outflow
1	6.42	5.90
2	5.90	5.13
3	5.13	4.67
4	4.67	4.65
5	5.15	4.43
6	4.43	4.08
7	4.08	3.91
System	6.42	4.28

P.O.R. = 1/87 - 9/99

EXHIBIT 20
Summary of monthly average TP data from the Lakeland Wetland Treatment System (Sources: NADB)

EXHIBIT 21
Site plan of the Orlando Easterly Wetlands





Long-term Average (mg/L)

	Inflow	**Outflow**
TN	2.37	0.80
TP	0.279	0.063

P.O.R. = 1/88 - 4/04

EXHIBIT 22
Summary of monthly average TN and TP data from the Orlando Easterly Wetlands (Source: City of Orlando)

City of Titusville, Blue Heron Wetland Treatment System

The Blue Heron Wetland Treatment System (BHWTS) is located in Brevard County and receives treated municipal effluent from the City of Titusville's Blue Heron Water Reclamation Plant. The BHWTS consists of about 264 acres divided into seven cells (three deep marsh cells [Cells 1-3], one pond cell [Cell 4], and three shallow marsh cells [Cells 5-7]). **Exhibit 23** shows the layout of the BHWTS.

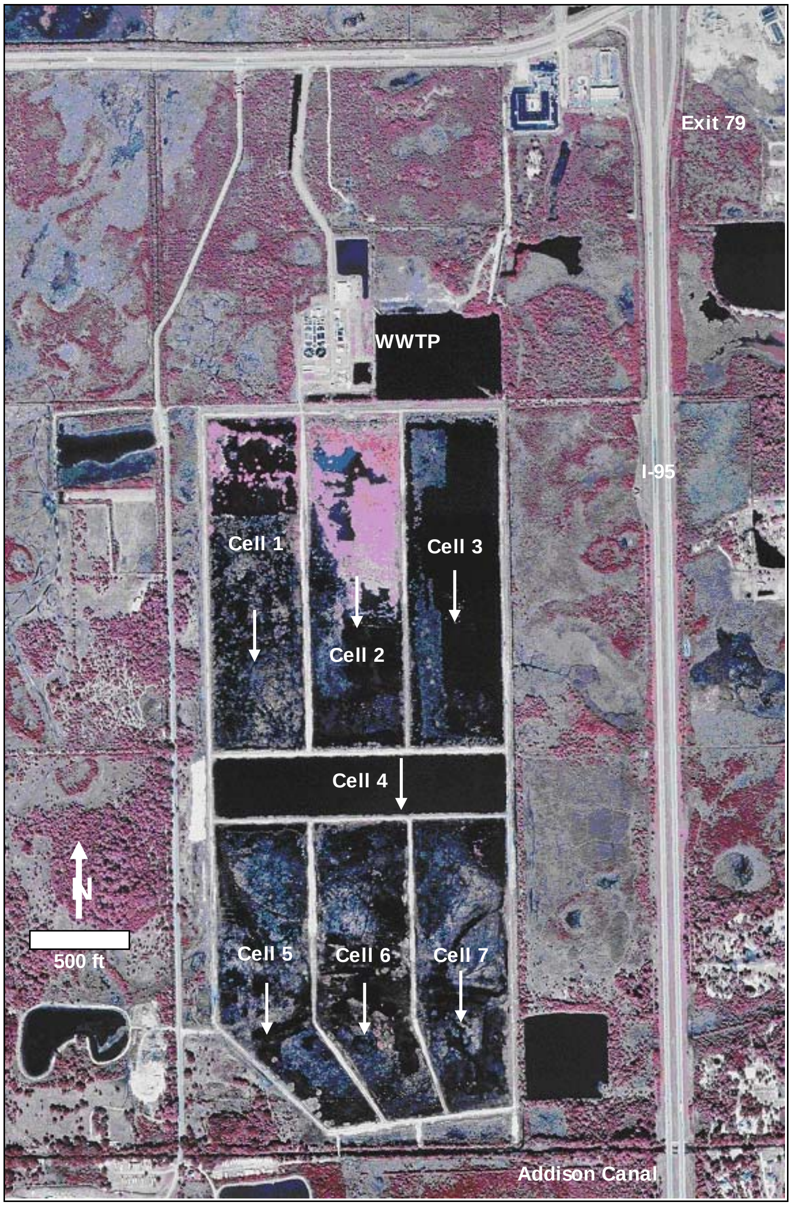


EXHIBIT 23
Site plan of the Blue Heron Wetland Treatment System

The BHWTS was constructed on land that historically formed part of the floodplain wetlands adjacent to the St. Johns River. Development and agricultural drainage activities over the past 50 years significantly altered the site, and the construction of the WTS reestablished portions of the historic ecological communities that were found on the site. The potential habitat value of the WTS site was enhanced by not grading the soil surface to uniform elevations throughout each of the cells. The uneven nature of the cell bottom allows different plant communities to develop and be maintained throughout the deep and shallow marsh cells.

Water flows by gravity through the seven cells to a collection system along the south side of the site, and then is discharged to the Addison Canal, which is a primary tributary to the St. Johns River.

The WTS was designed as a flow through, man-made wetland system (as defined by Chapter 62-611 F.A.C.) and is currently permitted to discharge an average daily flow of 4.68 mgd (6.75 mgd maximum monthly flow). Discharges from the BHWTS to Addison Canal must meet annual averages of 3.0 mg/L for BOD and TSS, 1.6 mg/L for TN, and 0.16 mg/L for TP. There are no specific numeric permit requirements for TKN, NH_4-N, and NO_3-N.

Cell 6 was taken off line in 2000 due to effluent TN concentrations exceeding the permit limit of 1.6 mg/L. Cells 2 and 3 have also been taken off line to increase the amount of flow through Cell 1 and to reduce the density of undesirable plant species such as water lettuce (*Pistia stratoites*) and pennywort (*Hydrocotyl spp.*) (Ecotech Consultants, Inc., 2002).

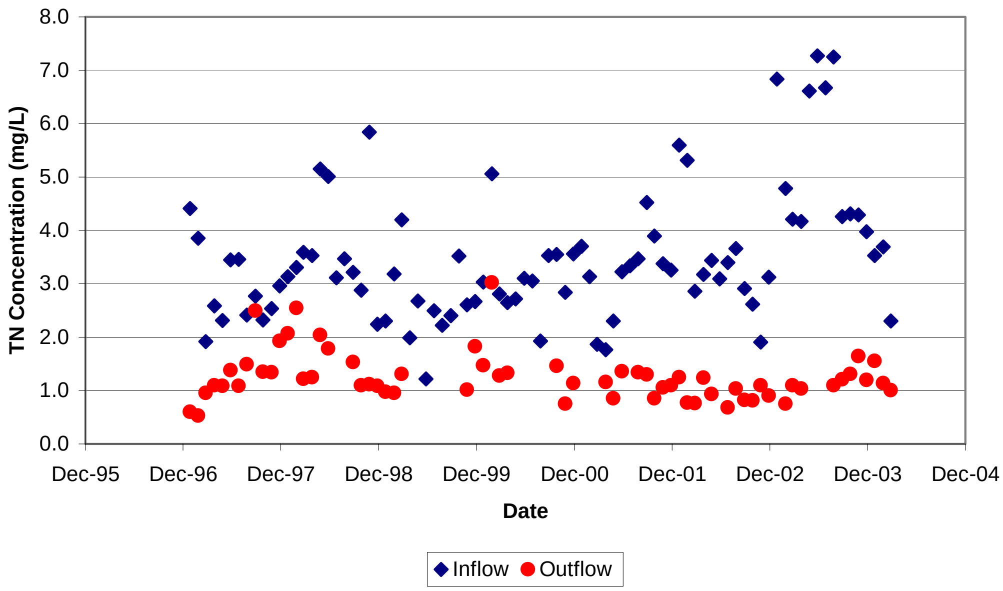
Exhibit 24 shows POR (January 1997 – March 2004) monthly average inflow and outflow concentrations for TN and TP. The long-term average inflow and outflow TN concentrations were 3.47 mg/L and 1.25 mg/L, a 64 percent reduction. The long-term average inflow and outflow TP concentrations were 0.30 mg/L and 0.07 mg/L, a 77 percent reduction. Inflow and outflow TSS concentrations were 0.6 mg/L and 1.1 mg/L. The average flow and HLR were 1.5 mgd and 0.57 cm/d.

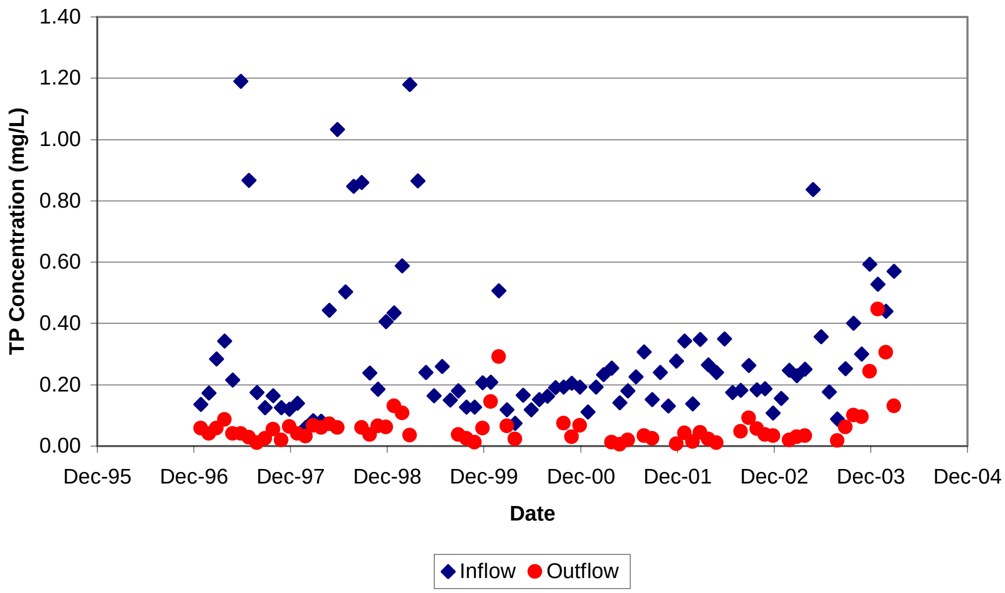
Lake Apopka Marsh Flow Way Projects

The St. John's River Water Management District's (SJRWMD) Lake Apopka Marsh Flow Way project began in 1990, with the construction of a 525-acre demonstration-scale facility that was designed to remove suspended sediments and particulate nutrients from lake water. Phase I of the full-scale Marsh Flow-Way (660 acres) began flow-through operations in November 2003. Ultimately, the Marsh Flow-Way will be expanded to approximately 3,400 acres. The Lake Apopka Flow-Ways were constructed on floodplain farmland on the northwest shore of Lake Apopka. **Exhibit 25** shows a schematic of the Lake Apopka demonstration and full-scale projects.

Marsh Flow-Way Demonstration Project

The demonstration project consisted of two cells that operated in series. Water was delivered to the southern cell via gravity flow or through pumps from Lake Apopka. Flow from the southern cell traveled through a canal to the northern cell where it received additional polishing prior to discharging back into the lake. Hydraulic modifications were made in 1992 in an attempt to improve flow distribution through the southern cell. These changes instead resulted in increased channelization of flow and reduced nutrient removal performance (Coveney, et.al., 1997).





Long-term Average (mg/L)

	Inflow	Outflow
TN	3.47	1.25
TP	0.302	0.066

P.O.R. = 1.97 - 3/04

EXHIBIT 24
Summary of monthly average TN and TP data from the Blue Heron Wetland Treatment System (Source: City of Titusville)

EXHIBIT 25
Site plan for the Lake Apopka Marsh Flow-Way Projects

SJRWMD project staff considered the southern cell as a good model for future expansions. Inflow TN concentrations ranged from 3 to 9 mg/L and were reduced by 30 to 50 percent with passage through the system at HLRs ranging from 4 to 18 cm/d (Coveney, et.al., 1997). Particulate organic nitrogen removal exceeded 75 percent. TP inflow concentrations ranged from 0.08 to 0.38 mg/L. Particulate phosphorus removal exceeded 90 percent, but the overall TP removal efficiency was affected by releases of soluble reactive P (SRP) from the soils. As soil SRP leaching decreased with time, TP removal ranged from 30 to 50 percent (Coveney, et.al., 1997).

Lessons learned from the demonstration project included (Coveney, et.al., 1997):

- Recognition that hydraulic efficiency is directly related to nutrient removal efficiency. Multiple cells are preferred to a single, larger cell. Inlet and outlet distribution and the incorporation of transverse deep zones improve hydraulic efficiency.

- Leaching of soil nutrients following initial inundation and dry-outs can be significant. Solutions include applying soil amendments, recycling flow, and minimizing the frequency and duration of drawdowns.
- Drawdown was determined to be an effective technique to consolidate accreted flocculent sediments. Sediment accretion was measured at 33 centimeters after 29 months of operation.

Detailed data for the demonstration project were not available for analysis at the time this draft document was prepared.

It should be noted that the Apopka system was not constructed with sufficient levee freeboard to accommodate observed sediment loads.

Phase I Marsh Flow-Way Project

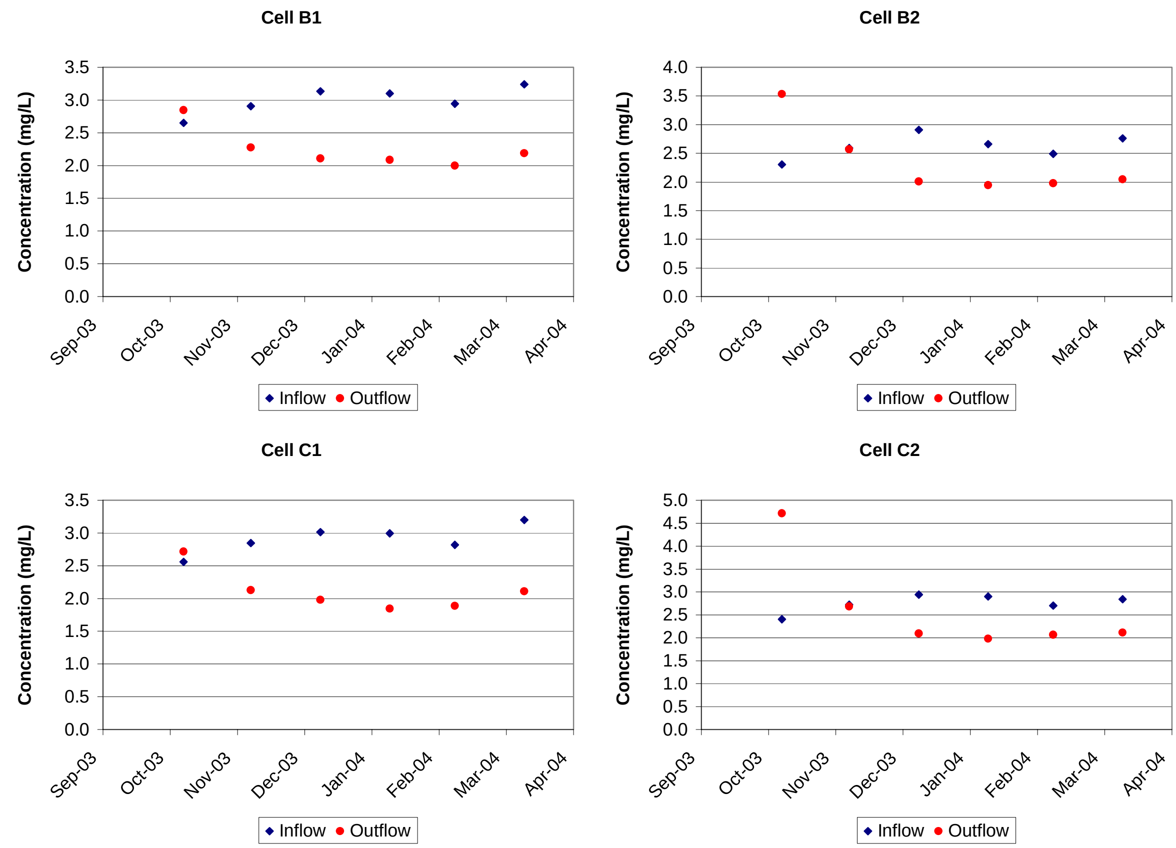
As indicated above, Phase I of the full-scale Marsh Flow-Way project began operation in November 2003. The design capacity is 150 to 180 cubic feet per second (cfs). Upon initial flooding, outflow nutrient concentrations exceeded inflow concentrations due to the release of soluble soil nutrients, however the system data indicate a trend towards positive removal efficiencies.

Exhibits 26 and **27** show monthly average inflow and outflow concentration data from the four Phase I cells (B1, B2, C1, and C2 shown on Exhibit 21). Average TN concentrations have declined from 2.6 to 3.0 mg/L at the inlets to 2.1 to 2.6 mg/L at the cell outlets. The cells are still exhibiting a net release of TP with inlet concentrations of 0.06 to 0.08 mg/L and outlet concentrations of 0.12 to 0.20 mg/L. Performance is expected to improve as vegetation biomass cycles stabilize, pools of labile P are depleted, and new sediments are deposited that bury the existing substrate. Inflow and outflow TSS concentrations were 29.5 mg/L and 1.4 mg/L, respectively, for an average concentration removal efficiency of about 95 percent

Lake Griffin Flow Way

The SJRWMD operates another treatment wetland known as the Lake Griffin Flow Way or Emeralda Marsh Conservation Area. This system consists of approximately 3,320 acres of restored floodplain wetlands that recirculate water from Lake Griffin. The system became operational in 1994. **Exhibit 28** shows the layout of the Lake Griffin Flow Way. Inflows are through gravity culverts at the northwest corner of the site and through a pump station at the northeast corner. Flow is generally from north to south within the marsh cells and is pumped back to Lake Griffin at the downstream end of Haines Creek.

Exhibit 29 shows the long-term monthly average inflow and outflow TN and TP concentrations from the Lake Griffin Flow Way. These data show that the system exports nutrients. This is most likely attributable to the previous use of the site for muck farming operations. The SJRWMD has completed studies to determine whether soil amendments could be applied to minimize the apparent release of nutrients from the existing substrates (ERD, 2001). The average flow to the systems was about 0.2 mgd, and the average HLR was less than 0.01 cm/d.

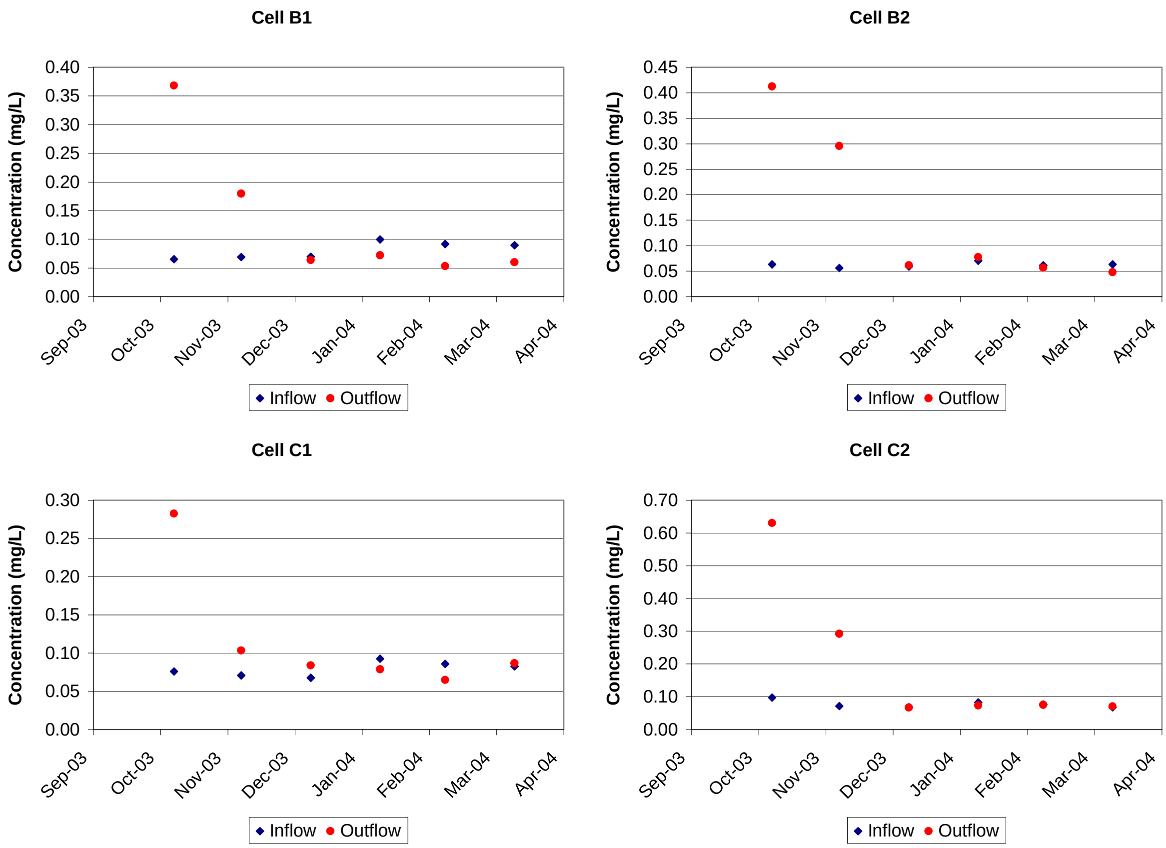


Long-term Average TN (mg/L)

Cell	Inflow	Outflow
B1	3.00	2.25
B2	2.62	2.35
C1	2.91	2.11
C2	2.75	2.61
System	2.95	2.18

P.O.R. = 11/03 - 4/04

EXHIBIT 26
Summary of monthly average TN data from the Phase I Apopka Marsh Flow-Way (Source: SJRWMD)



Long-term Average TP (mg/L)

Cell	Inflow	Outflow
B1	0.081	0.133
B2	0.062	0.159
C1	0.079	0.117
C2	0.077	0.201
System	0.080	0.125

P.O.R. = 11/03 - 4/04

EXHIBIT 27
Summary of monthly average TP data from the Phase I Apopka Marsh Flow-Way (Source: SJRWMD)

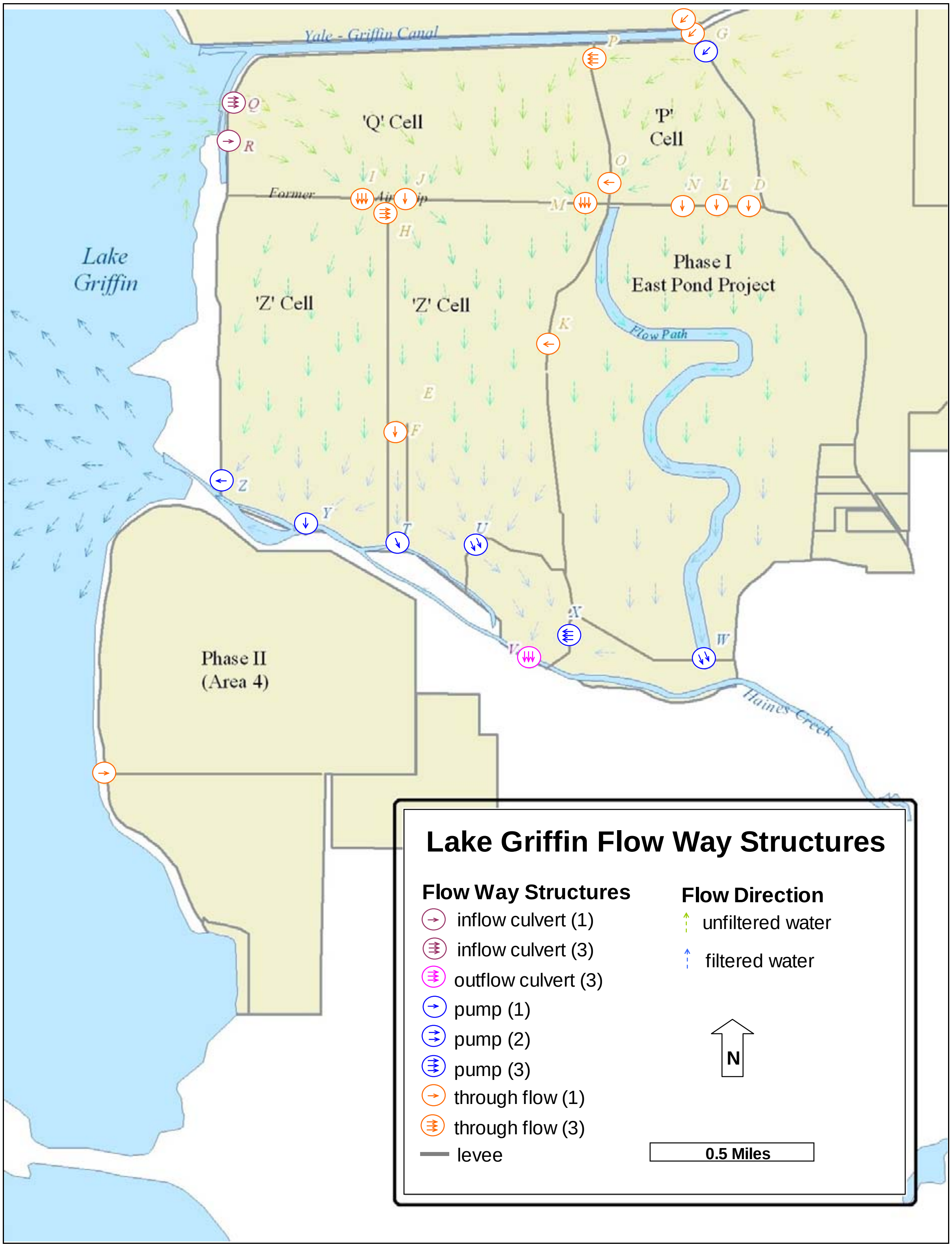
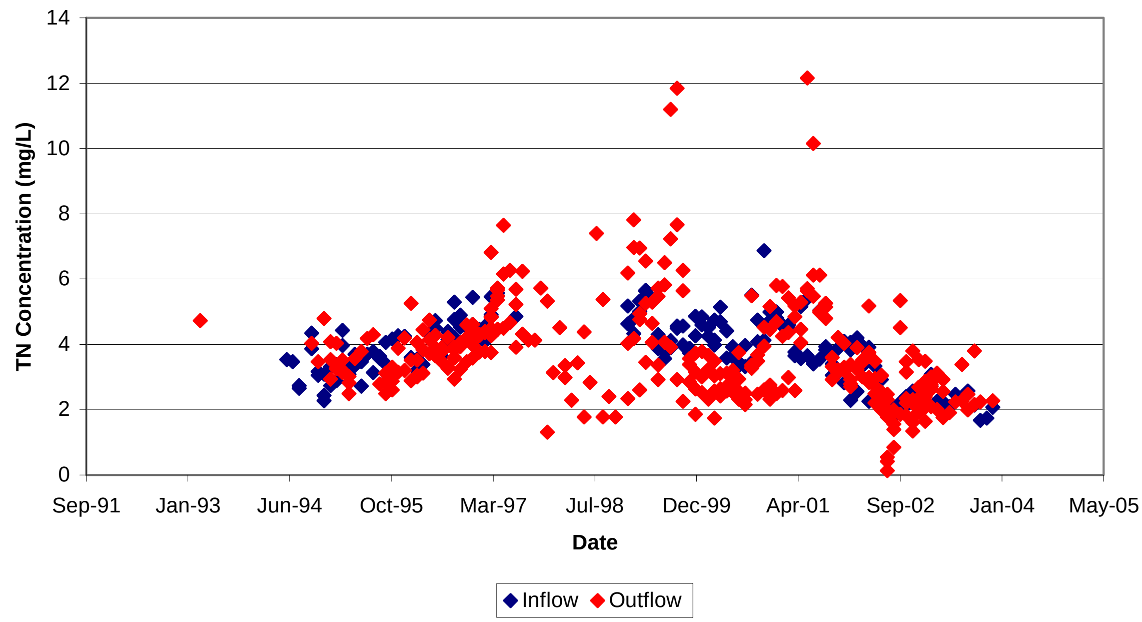
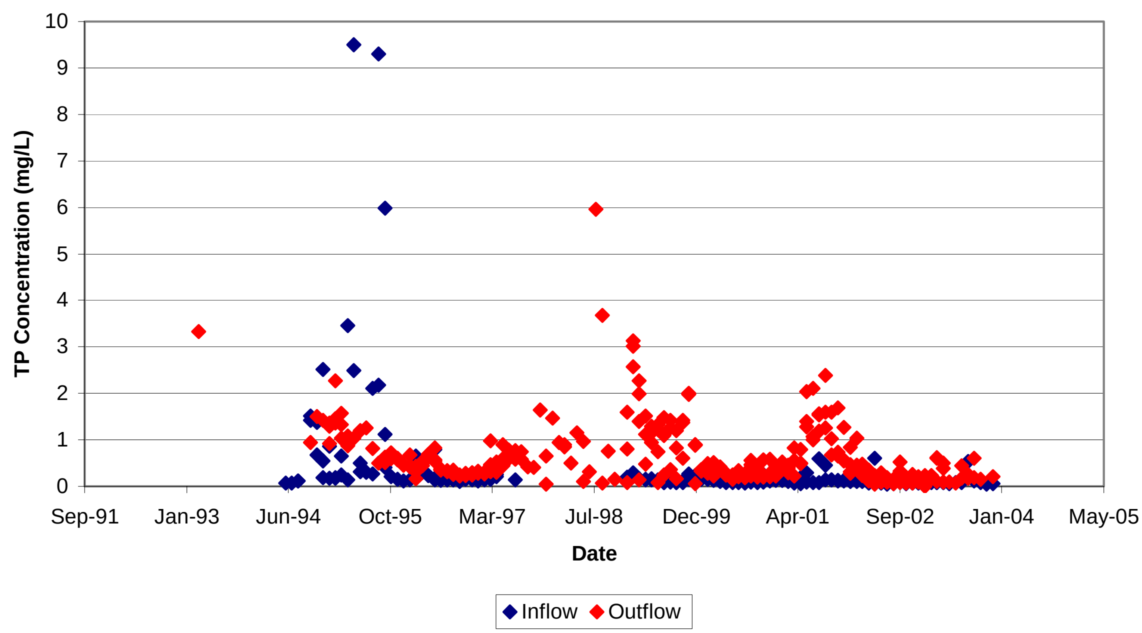


EXHIBIT 28
Site plan of the Lake Griffin Flow Way (Source: SJRWMD)





Long-term Average (mg/L)

	Inflow	Outflow
TN	3.79	3.69
TP	0.394	0.611

P.O.R. = 6/94 - 12/03

EXHIBIT 29
Summary of monthly average TN and TP data from the Lake Griffin Flow-Way (Source: USEPA STORET)

S-154 Algal Turf Scrubber/Water Hyacinth

The SFWMD contracted with Hydromentia, Inc., to develop a prototype aquatic vegetation treatment system located in the S-154 basin that contributes inflows to Lake Okeechobee. The system is patented as the Algal Turf Scrubber™ - Water Hyacinth Scrubber™ (ATS™-WHS™) and began operation in late January 2003. The primary removal mechanism for nutrients is through the harvesting of plant and algal biomass and the system is purported to have higher removal rates than emergent vegetation treatment wetlands (Hydromentia, 2004).

The major components of the system include two 1.25-acre water hyacinth ponds that are about 4 feet in depth, followed by two 1.25-acre inclined planes designed to facilitate the growth of attached filamentous algae (Hydromentia, 2004). Other components include harvesting equipment for both hyacinths and algae, a microscreen filtering unit, and an automatic feeder for the addition of chemical supplements. **Exhibit 30** shows the layout of the S-154 pilot-scale ATS™-WHS™.

The ATS™-WHS™ system could offer the advantage of greatly decreasing the land area required for treatment and yielding a marketable product (composted biomass) if sustainable removal rates are proven to be much higher than those for treatment wetlands. However, there is not a proven market for composted hyacinth biosolids. Other possible disadvantages include much greater operational and maintenance requirements and the potential need for chemical additions to maximize biomass growth rates. Additions of urea, potassium nitrate, boron, dolomite, ferrous sulfate, copper sulfate, zinc sulfate, and hydrochloric acid have been used in the pilot-scale system (Hydromentia, 2004).

Exhibit 31 shows the POR (February 2003 – October 2003) monthly average inflow and outflow concentrations for TN and TP. The average inflow and outflow TN concentrations were 2.53 mg/L and 1.85 mg/L, a 27 percent reduction. The average inflow and outflow TP concentrations were 0.48 mg/L and 0.08 mg/L, an 83 percent reduction. The average inflow and outflow TSS concentrations were 9.8 mg/L and 3.5 mg/L, a 64 percent reduction. The average flow and HLR were 0.43 mgd and 8.0 cm/d.

Summary of Existing Treatment System Performance

Exhibit 32 compares the inflow and outflow TN, TP, and TSS concentration data for the systems described in this memorandum. Lakeland had the highest inflow TN and TP concentrations. All systems exhibited a positive TN removal efficiency except for STA-5. Both the Lake Apopka Marsh Flow-Way and Lake Griffin Flow-Way sites exported TP and exhibited the highest inflow TSS concentrations (>20 mg/L). The high solids concentrations reflect the suspended algal material common in hypereutrophic systems. When these solids are deposited in the wetland, they contribute to the overall loading of dissolved Org-N and TP. For this reason, TN or TP removal efficiency is largely independent of the particulate or dissolved nature of the incoming pollutants.

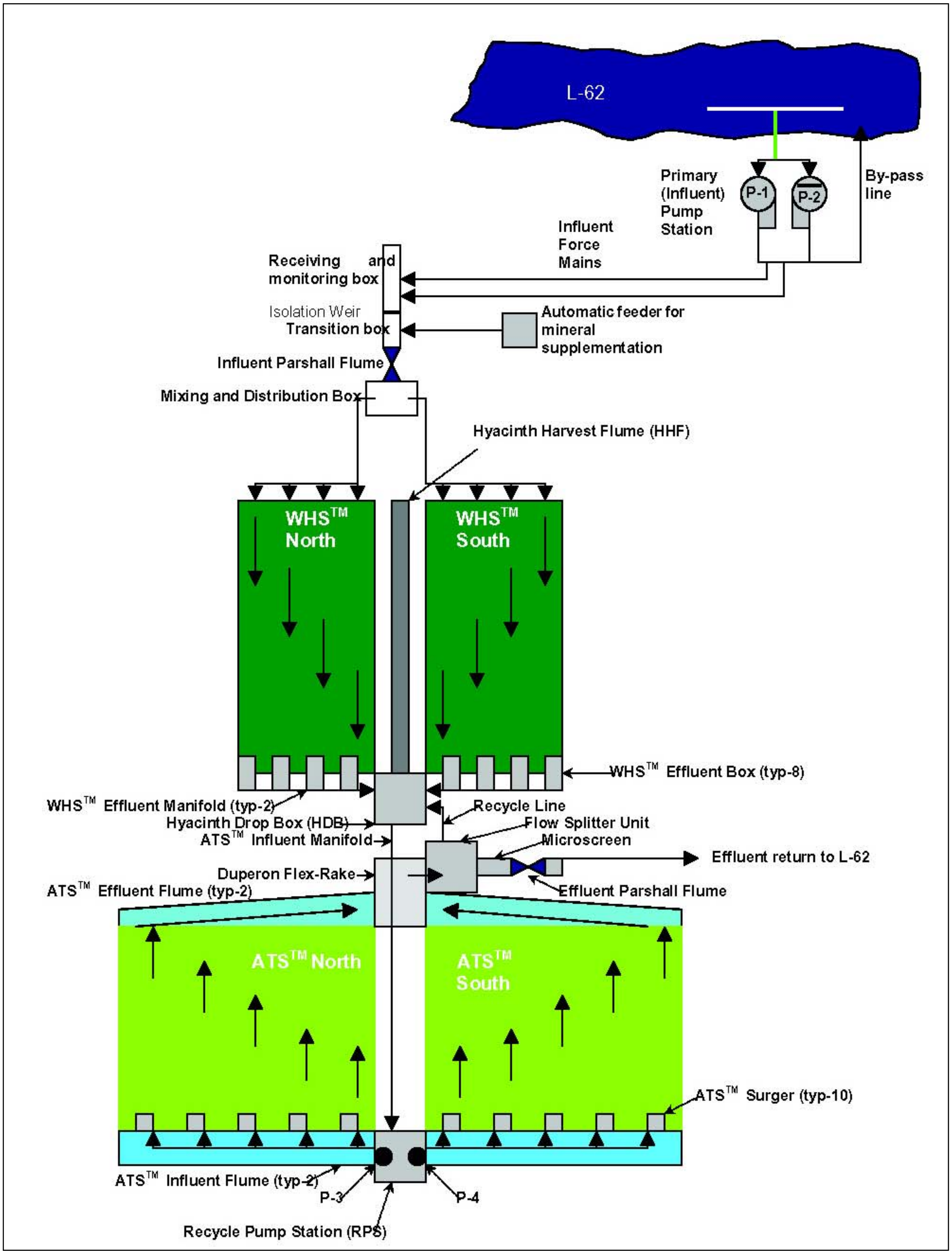
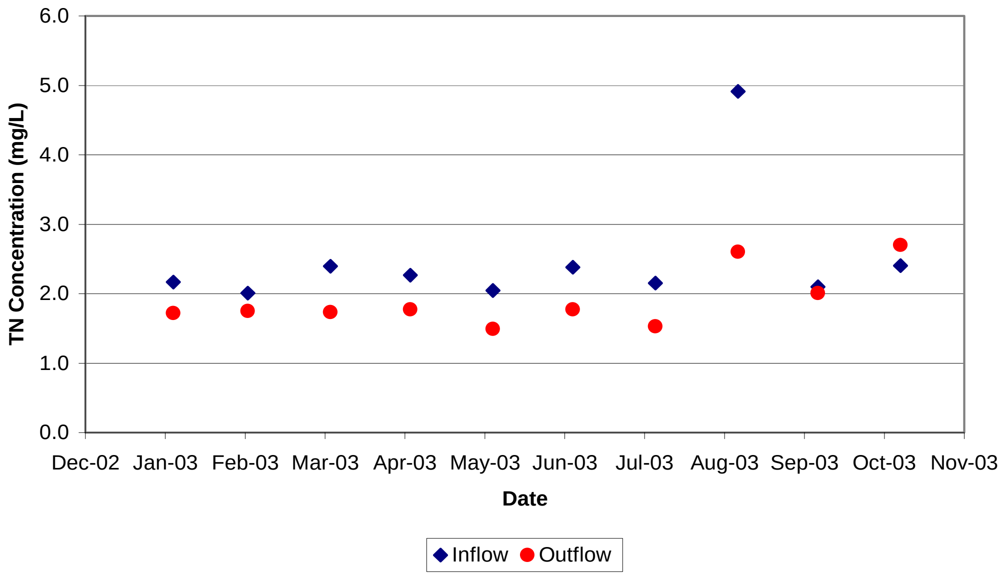
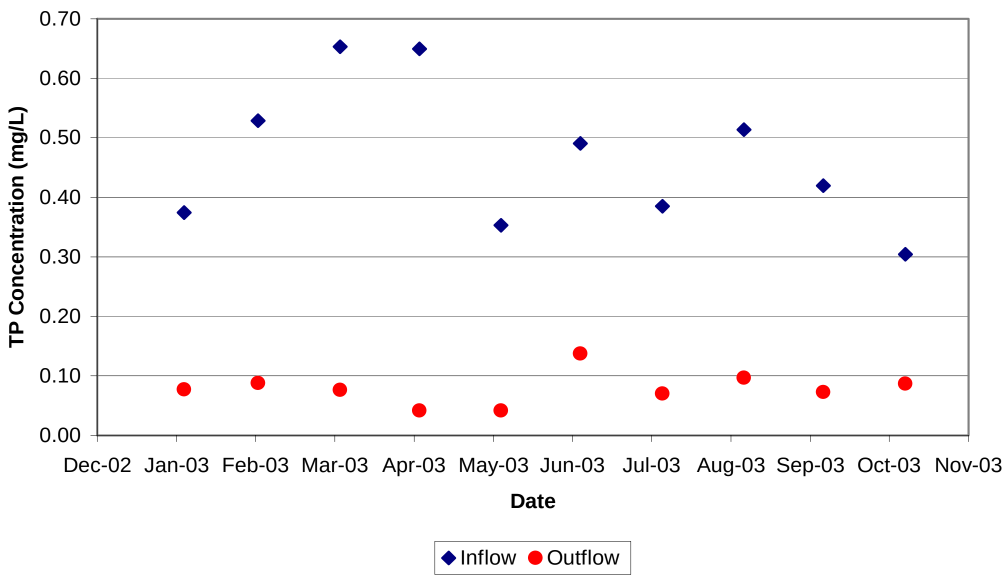


EXHIBIT 30
Site plan of the S-154 Basin ATS™-WHS™ (Source: Hydromentia, 2004)





Long-term Average (mg/L)

	Inflow	**Outflow**
TN	2.53	1.85
TP	0.479	0.078

P.O.R. = 2/03 - 10/03

EXHIBIT 31
Summary of monthly average TN and TP data from the S-154 ATS™-WHS™ (Source: Hydromentia, 2004)

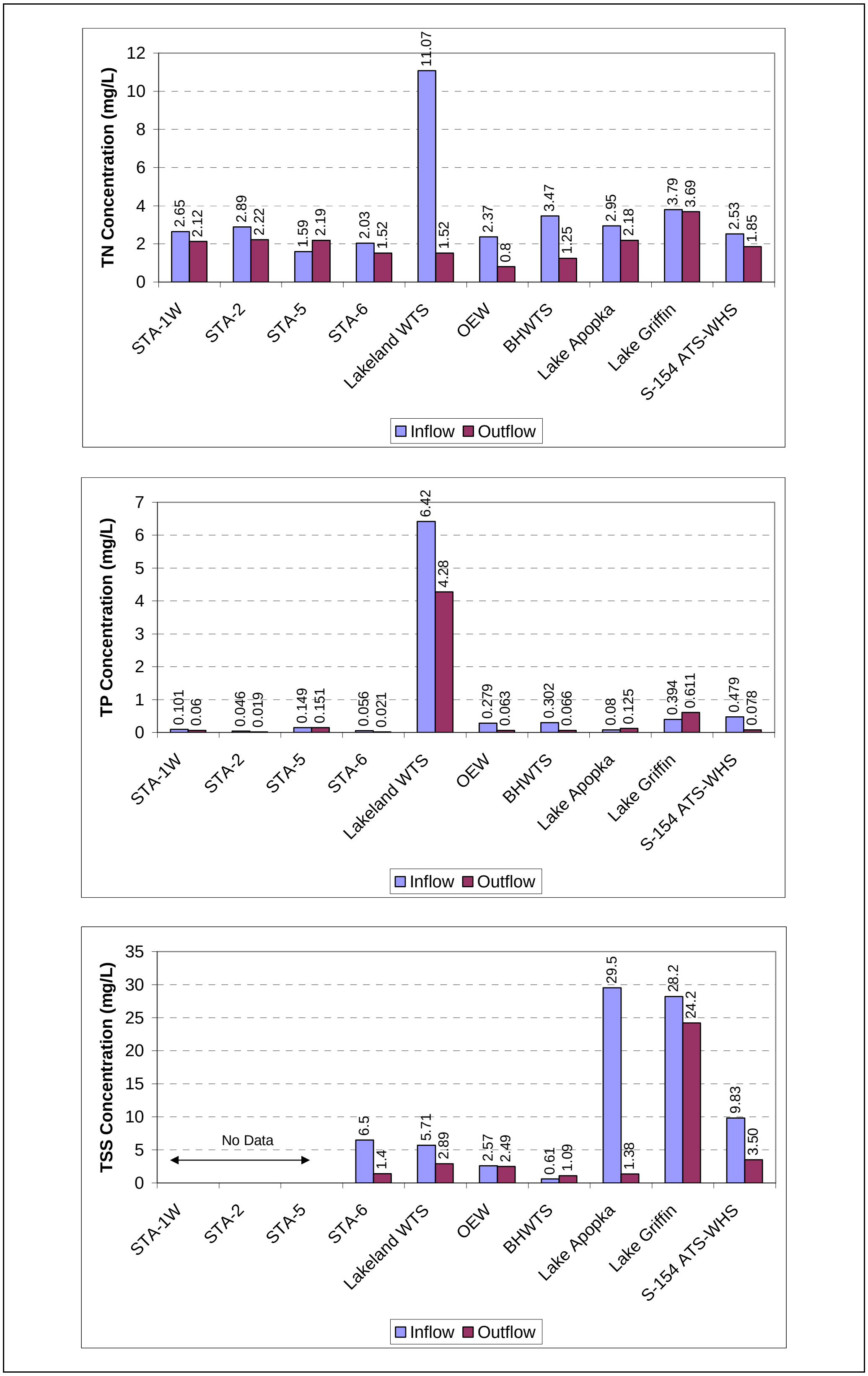


EXHIBIT 32
Summary of large-scale treatment wetland performance for TN and TP

Modeling Approach for Lake Hancock Conceptual Design

A variety of methods can be used for estimating pollutant removal performance of treatment wetlands. One commonly used approach is the application of average empirical removal efficiencies measured in existing wetlands (WPCF, 1990; Kadlec and Knight, 1996). A limitation of this methodology is the dependence of mass removal efficiency on inlet pollutant concentration (Kadlec and Knight, 1996). Typical data sets indicate that removal efficiency is somewhat dependent upon inflow pollutant concentration, declining to zero at natural pollutant background concentrations and becoming negative when input concentrations are lower than the inherent wetland background concentration.

Exhibit 33 presents an example of the mass removal efficiency versus concentration relationship, based upon monthly average data, for the Florida systems described in this memorandum. This graphic suggests that a wetland receiving inflows from Lake Hancock (TN ~ 6 mg/L) should operate in a mass removal efficiency range of about 20 to 90 percent, with an estimated median removal rate of about 75 percent. Application of a single removal efficiency value across the range of actual inflow concentrations experienced in a treatment wetland may over- or under-estimate performance, because removal efficiency is a stronger function of inlet load than just inlet concentration. This type of relationship is appropriate for generalizing wetland performance, but can not be directly translated to yield usable design criteria.

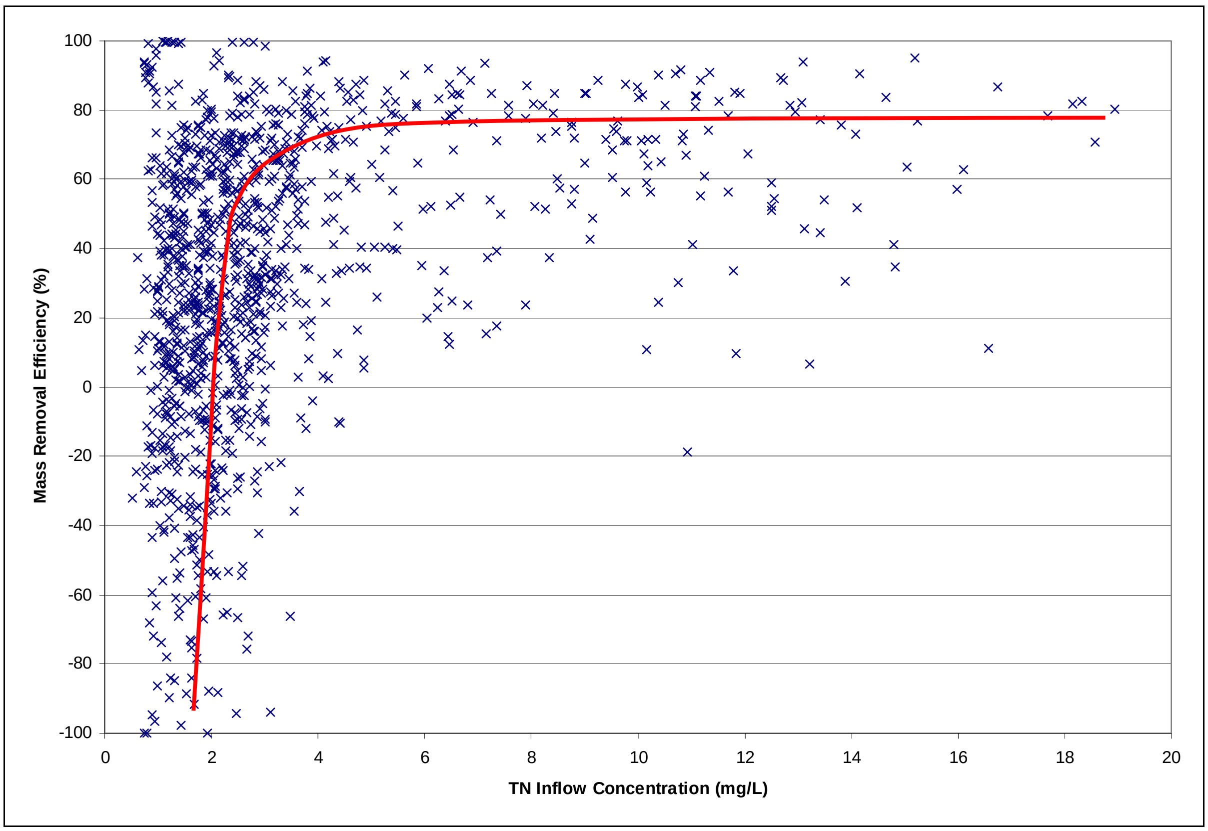


EXHIBIT 33
Relationship between inflow TN concentration and mass removal efficiency for large-scale Florida treatment wetlands

Alternative performance estimation methods include more complex regression equations, mass loading versus outflow concentration analyses, and models that incorporate first-order removals with a background, such as the k-C* model of Kadlec and Knight (1996). Regression models and mass loading analyses are limited to the range of the data used to generate the original regression. First-order removal models are less limited but their performance estimates should be compared to and validated against actual operational data whenever possible. The mass loading versus outflow concentration analyses and k-C* model are further described below.

Mass Loading Analyses

The North American Database (NADB) houses design criteria and operational performance data from over 250 treatment wetlands that receive municipal wastewater, industrial wastewater, agricultural wastewater, and/or stormwater (NADB: CH2M HILL, 1998; Kadlec and Knight, 1996; http://www.wetlandsolutionsinc.com). Inflow mass loads can be calculated from inflow rates and influent concentration values and plotted against observed effluent concentrations. Performance estimates generated from the k-C* model can be superimposed on the plots of the NADB data as a check of the wetland sizing approach.

Exhibits 34, **35**, and **36** compare the TN, TP, and TSS mass loading rates for the Florida systems described above with all the systems cataloged in the NADB. The Florida systems fall within a TN data cloud centered about a mass loading rate of 0.4 kg/ha/d, a TP cloud centered around a mass loading rate of 0.02 kg/ha/d, and a TSS cloud centered around a mass loading rate of 0.8 kg/ha/d. The data points at loading rates exceeding 10 kg/ha/d of TN represent wetlands that treat livestock runoff.

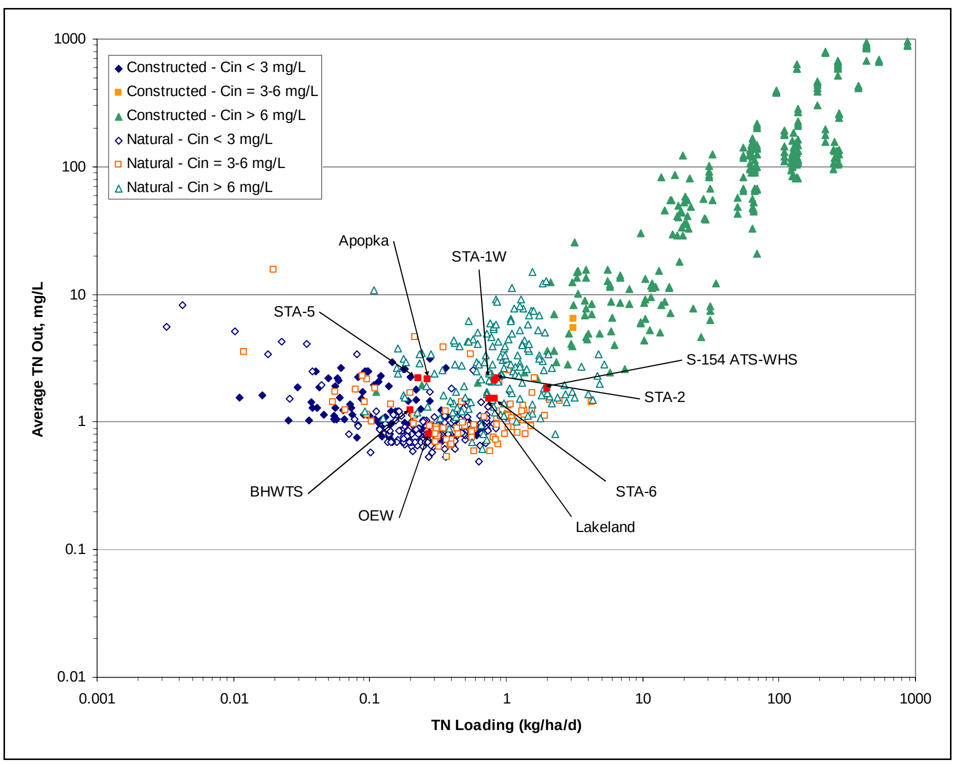


EXHIBIT 34
Comparison of selected Florida wetlands with NADB wetlands for TN mass loading rate versus TN outflow concentration

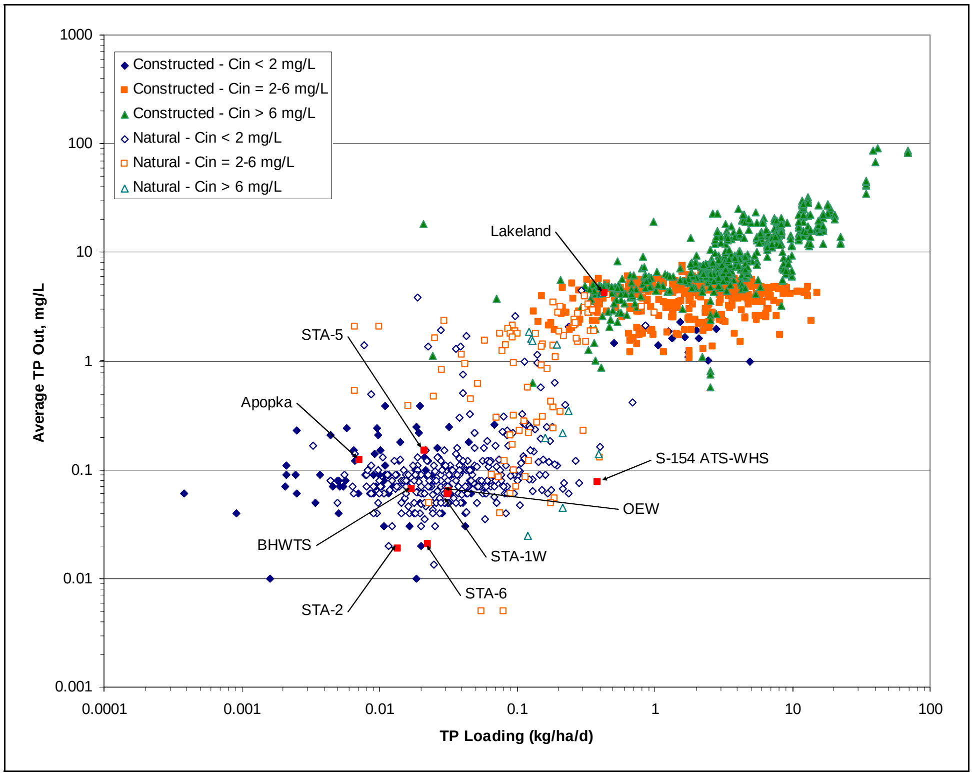


EXHIBIT 35
Comparison of selected Florida wetlands with NADB wetlands for TP mass loading rate versus TP outflow concentration

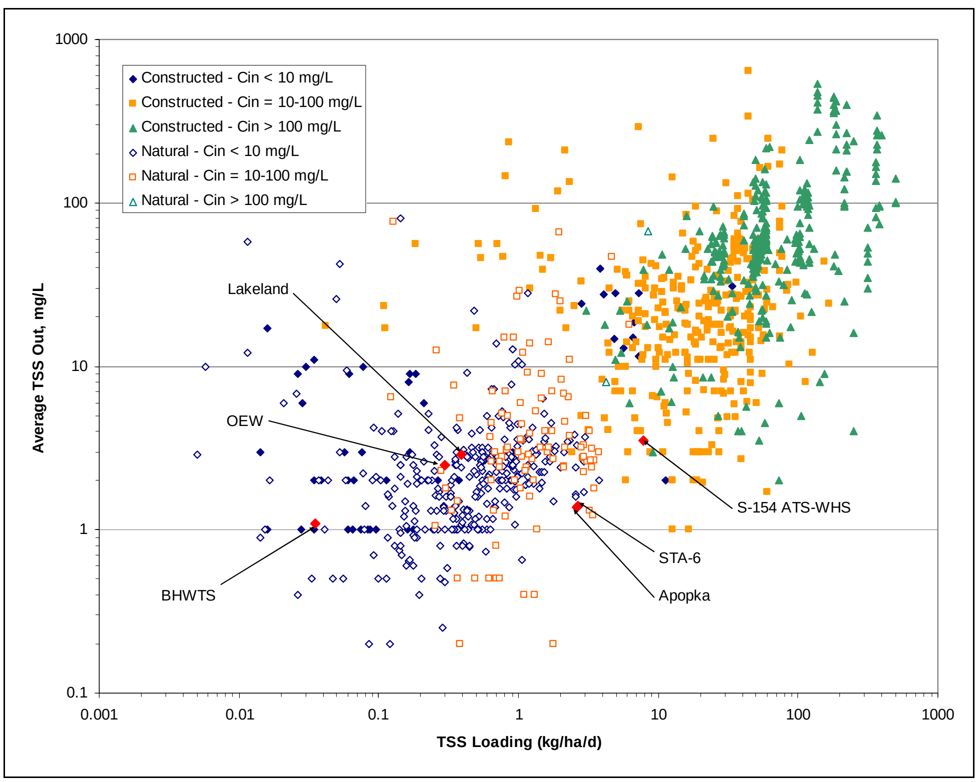


EXHIBIT 36
Comparison of selected Florida wetlands with NADB wetlands for TSS mass loading rate versus TSS outflow concentration

k-C* Tanks-in-Series Model

The simplest expression of the first-order, area-based plug flow wetland performance model, assuming no net rainfall or seepage, is:

$$\ln\left(\frac{C_1}{C_2}\right) = \frac{k}{q} \qquad [1]$$

where:

C_1 = average inlet concentration, mg/L

C_2 = average outlet concentration, mg/L

k = first-order, area-based rate constant, m/y

q = average hydraulic loading rate, m/y

Data from many treatment wetlands indicate that internal and external loading of pollutants such as some nitrogen species and phosphorus may result in non-zero, irreducible wetland water column constituent concentrations (Kadlec and Knight, 1996). In this situation, the plug flow model can be corrected by introducing a second parameter that represents the lowest achievable or irreducible concentration that will occur in a treatment wetland, C*. The two-parameter first-order, area-based plug flow model, or k-C* model, is:

$$-\ln\left(\frac{C_2 - C^*}{C_1 - C^*}\right) = \frac{k}{q} \qquad [2]$$

Treatment wetlands, however, do not perform as perfect plug-flow systems (Kadlec, 2003). Tracer study data from a variety of treatment wetlands indicate that their hydraulic mixing behavior is intermediate between two ideal hydraulic models, plug flow and complete mix or continuously stirred tank reactor (CSTR):

$$\left(\frac{C_2 - C^*}{C_1 - C^*}\right) = \frac{1}{1 + k/q} \qquad [3]$$

There are a range of physical factors that influence the degree of mixing in wetlands, including topography, wetland geometry, vegetation density and spatial distribution, and wind fetch. This behavior of treatment wetlands can typically be modeled as several CSTRs in series using the Tanks-in-Series (TIS) model:

$$\left(\frac{C_2 - C^*}{C_1 - C^*}\right) = \left(1 + \frac{k}{Nq}\right)^{-N} \qquad [4]$$

where: N = number of tanks in series

The TIS model is valid for all parameters of interest. The model can be used to fit a curve to existing wetland performance data by simultaneously solving for k, C*, and N. These parameters control the shape of the curve. In these cases, C* may represent an actual irreducible background concentration, or may represent a feedback of the constituent of interest from the wetland ecosystem. K values change in response to hydraulic loading rate, inflow concentration, and distance along the length of the flow path. The k value resulting from a curve-fitting exercise represents the net k for the system.

Care must be taken not to extrapolate outside the range of values (C_1, C_2, q, and N) used to "calibrate" the model parameters, or to transfer values between systems with vastly different designs.

Sequential N Model

Because nitrogen occurs in a number of different oxidation states in treatment wetlands, and numerous biological and physical-chemical processes can transform nitrogen between these different forms, a more complex version of the TIS model is required to predict nitrogen removal performance (Kadlec and Knight, 1996).

Organic nitrogen, NH_4-N, NO_3-N, and nitrogen gasses are the primary nitrogen forms in surface waters. A fraction of Org-N is mineralized to NH_4-N in aquatic and wetland systems. The reduction in Org-N, using the TIS model, is given by the following equation:

$$C_{ON} = C^*_{ON} + \left(C_{ONi} - C^*_{ON}\right)\left[1 + \frac{k_{ON}}{Nq}\right]^{-N} \qquad [5]$$

where C_{ONi} = inlet concentration of organic nitrogen, mg/L

C^*_{ON} = background concentration of organic nitrogen, mg/L

C_{ON} = outlet concentration of organic nitrogen, mg/L

k_{ON} = first-order area-based organic nitrogen rate constant, m/yr

q = hydraulic loading rate, m/yr

N = number of tanks-in-series

Water temperature and pH determine the extent to which NH_4-N is distributed between ammonium (ionized form) and its volatile form (un-ionized ammonia). NH_4-N can in turn be oxidized to NO_3-N through aerobic microbial processes (nitrification). Depending on the amount of Org-N found in the source water, NH_4-N can be both produced and consumed in wetlands. The following two-step reaction model from Kadlec and Knight (1996) can be used to estimate the concentration of NH_4-N (C_{AN}):

$$C_{AN} = C^*_{AN} + \left(C_{ANi} - C^*_{AN}\right)\left[1 + \frac{k_{AN}}{Nq}\right]^{-N} + \left(\frac{k_{ON}}{k_{AN} - k_{ON}}\right)\left(C_{ONi} - C^*_{ON}\right)\left(\left[1 + \frac{k_{ON}}{Nq}\right]^{-N} - \left[1 + \frac{k_{AN}}{Nq}\right]^{-N}\right) \qquad [6]$$

where C_{ANi} = inlet concentration of ammonium nitrogen, mg/L

C^*_{AN} = background concentration of ammonium nitrogen, mg/L

k_{AN} = first-order area-based ammonium nitrogen rate constant, m/yr

Oxidized nitrogen presents the same difficulty as ammonium: it is produced (nitrification) as well as consumed (nitrate reduction). Oxidized nitrogen may also be utilized in plant growth in the absence of significant ammonium nitrogen. The three-step equation from

Kadlec and Knight (1996) was used to estimate the combined effects of all processes on NO_3-N concentrations (C_{NN}):

$$C_{NN} = (C_{NNi})\left[1+\frac{k_{NN}}{Nq}\right]^{-N} + \psi\left\{\begin{aligned} &\left(\frac{k_{AN}}{k_{NN}-k_{AN}}\right)(C_{ANi})\left(\left[1+\frac{k_{AN}}{Nq}\right]^{-N} - \left[1+\frac{k_{NN}}{Nq}\right]^{-N}\right) \\ &+\left(\frac{k_{ON}}{k_{AN}-k_{ON}}\right)\left(\frac{k_{AN}}{k_{NN}-k_{ON}}\right)(C_{ONi}-C^*_{ON})\left(\left[1+\frac{k_{ON}}{Nq}\right]^{-N} - \left[1+\frac{k_{NN}}{Nq}\right]^{-N}\right) \\ &-\left(\frac{k_{ON}}{k_{AN}-k_{ON}}\right)\left(\frac{k_{AN}}{k_{NN}-k_{AN}}\right)(C_{ONi}-C^*_{ON})\left(\left[1+\frac{k_{AN}}{Nq}\right]^{-N} - \left[1+\frac{k_{NN}}{Nq}\right]^{-N}\right) \end{aligned}\right\} \quad [7]$$

where C_{NNi} = inlet concentration of nitrate nitrogen, mg/L

C^*_{NN} = background concentration of nitrate nitrogen, mg/L

k_{NN} = first-order area-based nitrate nitrogen rate constant, m/yr

ψ = fraction of ammonium nitrified (1 – fraction volatilized)

Calibration of Model Parameters for Florida Treatment Wetlands

Operational data from the systems described above were analyzed using a spreadsheet curve-fitting approach to provide estimates of the first order rate constant (k) and background concentration (C*). The curve-fitting approach is summarized in the following steps and was completed independently for each of the treatment wetlands:

- Raw data (q, C_1, and C_2) were rolled up to monthly averages.
- For each monthly record, an estimated value for C_2 was calculated using Equation 2 with assumed starting values for k and C*. The TIS version of the k-C* model was not used for this effort because system-wide N values have not been measured for the operational wetlands described above.
- The square of the difference between the observed and estimated C_2 values was calculated for each monthly record, and the sum of the squared differences was tracked.
- The initial values for k and C* were optimized using the SOLVER routine that is an add-in to the EXCEL™ spreadsheet program. Values for k and C* were simultaneously adjusted so that the sum of the squared differences in observed and estimated C_2 values was minimized.
- In some cases, the estimated optimum values for k were well outside the range of k values reported in the NADB. In these instances, the SOLVER-estimated k values were "tuned" by manually varying k and then plotting k versus the sum of squares. For decreasing values of k (starting at the SOLVER estimate), changes in k resulted in relatively small changes in the sum of squares until a "knee-point" was observed, at which small changes in k led to large changes in the sum of squares. Revised estimates of k were approximated as the values occurring at the "knee-point."

These data provide an indication of the range of nutrient removal performance that might be expected at the proposed Lake Hancock treatment wetland. **Exhibit 37** summarizes estimated k and C* values for the systems described in this document. There was considerable variability in parameter values. For all systems, the median TN removal rate was 17 m/yr and the background concentration was 1.8 mg/L. These values compare well with the median values from all the systems in the NADB. Model parameters were not estimated for the Lake Apopka Marsh Flow-Way (short period-of-record and still in start-up mode) or the Lake Griffin Flow-Way (limited flow data to construct mass balance).

Preliminary Lake Hancock Wetland Sizing

The District's primary objective for the Lake Hancock Outfall Treatment Project is to construct a cost-effective, regional surface water treatment system to reduce TN loads discharged from the lake to the Peace River by 45 percent or greater. ERD (1999) reported that the annual TN load from Lake Hancock to the Peace River is approximately 272,000 kg/yr (42,916 acre-ft/yr @ 5.13 mg/L of TN). A treatment system meeting the stated goal would have to remove at least 123,000 kg/yr of TN.

The District has purchased approximately 3,400 acres of land adjacent to the eastern and southern shores of Lake Hancock. Part of this land could be used to construct a treatment wetland to improve the water quality of discharges from the lake to the Peace River. **Exhibit 38** shows the District's property boundary.

The Lake Hancock water quality data (Org-N = 5.9 mg/L; NH_4-N = 0.03 mg/L; NO_3-N = 0.03 mg/L; TN = 6.0 mg/L) and the average treatment wetland performance parameters (k and C*) developed in this report (see **Exhibit 37**) were used as inputs for the TIS wetland sizing model (Equation 7) to determine the level of TN treatment that could be realized by converting the existing land uses to flow-through wetlands. An N value of 3 was selected as a conservative estimate for a wetland constructed with at least 3 cells that are operated in series. By default, each proposed cell must have an N value of 1, so the minimum cumulative effect is N=3.

Exhibit 39 presents a family of curves showing the relationship between flow rate and wetland area on TN mass load reduction and TN removal efficiency. The efficiency is expressed in terms of the percent reduction of the average annual P-11 TN load discharged to the Peace River (272,000 kg/yr), and is not the actual operating efficiency of the treatment wetland.

The smallest treatment wetland that meets the minimum load reduction goal is estimated to be about 1,150 acres (dashed green line in **Exhibit 39**). A 1,150-acre wetland is estimated to provide the required load reduction (~45 percent of 272,000 kg TN/yr) over a range of inflow rates from 60 to 100 cfs (60 cfs is the long-term average daily discharge rate at P-11). In many instances however, 60 cfs may not be available for discharge, so annual load reduction goals may not be achieved.

EXHIBIT 37

Summary of k and C* values for large-scale Florida treatment wetlands

	Area	HLR	TKN				NH_4-N				NO_3-N				TN				TP			
Site	**(acre)**	**(cm/d)**	**C_1 (mg/L)**	**C_2 (mg/L)**	**k**	**C***	**C_1 (mg/L)**	**C_2 (mg/L)**	**k**	**C***	**C_1 (mg/L)**	**C_2 (mg/L)**	**k**	**C***	**C_1 (mg/L)**	**C_2 (mg/L)**	**k**	**C***	**C_1 (mg/L)**	**C_2 (mg/L)**	**k**	**C***
STA-1W Cell 1		4.99	2.19	2.08	5	1.93	0.22	0.12	75	0.12	0.24	0.07	80	0.05	2.38	2.09	9	1.98	0.095	0.052	35	0.02
STA-1W Cell 2	941	6.09	2.50	2.09	9	1.80	0.44	0.13	46	0.10	0.41	0.08	49	0.02	2.81	2.14	17	1.83	0.093	0.068	16	0.05
STA-1W Cell 3	1,026	5.52	<--Data unavailable-->				0.12	0.05	150	0.00	0.07	0.03	200	0.03	<--Data unavailable-->				0.052	0.030	39	0.02
STA-1W Cell 4	358	13.9	2.09	1.89	9	1.52	0.13	0.06	75	0.06	0.08	0.05	200	0.05	2.14	1.88	11	1.61	0.068	0.028	100	0.01
STA-1W Cell 5	2,855	3.47	2.54	2.13	11	2.36	0.33	0.08	50	0.07	0.55	0.09	29	0.06	3.17	2.13	12	2.41	0.132	0.052	10	0.04
STA-2 Cell 1	1,990	2.97	2.36	2.34	15	2.38	0.35	0.03	100	0.03	0.56	0.01	150	0.01	2.93	2.35	125	2.35	0.051	0.023	50	0.01
STA-2 Cell 2	2,220	2.97	2.28	2.06	44	2.03	0.26	0.05	140	0.05	0.61	0.08	31	0.01	2.89	2.15	48	2.08	0.047	0.018	67	0.01
STA-2 Cell 3	2,220	2.97	2.23	2.08	43	2.05	0.22	0.03	144	0.02	0.62	0.08	41	0.02	2.85	2.16	58	2.10	0.041	0.017	89	0.01
STA-5 Cells 1A+1B	2,055	2.21	1.46	2.27	1	3.27	0.07	0.09	50	0.09	0.07	0.03	63	0.02	1.61	2.38	1	3.40	0.133	0.150	33	0.12
STA-5 Cells 2A+2B	2,055	2.07	1.43	1.91	2	2.51	0.06	0.06	22	0.06	0.07	0.03	32	0.03	1.57	2.00	2	2.63	0.165	0.151	50	0.14
STA-6 Cell 3	245	4.07	1.74	1.45	58	1.45	0.19	0.02	160	0.02	0.26	0.01	175	0.01	2.02	1.45	130	1.45	0.056	0.023	49	0.02
STA-6 Cell 5	625	4.07	1.75	1.64	1	2.60	0.19	0.06	67	0.05	0.27	0.01	260	0.01	2.04	1.59	92	1.59	0.056	0.020	88	0.02
OEW	1,200	1.15	1.57	0.79	13	0.76	0.74	0.07	16	0.05	0.80	0.05	74	0.05	2.37	0.80	13	0.74	0.279	0.063	10	0.04
BHWTS	264	0.57	1.39	1.21	68	1.21	0.35	0.33	8	0.32	2.07	0.05	61	0.05	3.47	1.25	24	1.24	0.302	0.066	15	0.07
Lakeland Cell 1	200	3.97	3.65	1.86	5	1.00	1.28	0.55	3	0.00	7.43	2.16	17	0.00	11.07	3.96	22	2.27	6.42	5.90	5	4.81
Lakeland Cell 2	190	3.66	1.87	1.26	2	1.00	0.56	0.29	2	0.00	2.16	1.09	15	0.68	3.98	2.28	15	1.84	5.90	5.13	4	3.26
Lakeland Cell 3	410	2.04	1.26	1.08	2	0.93	0.29	0.22	4	0.28	1.09	0.30	20	0.22	2.28	1.33	24	1.23	5.13	4.67	2	3.27
Lakeland Cell 4	75	10.4	1.08	1.09	3	1.34	0.22	0.14	75	0.13	0.30	0.26	6	0.28	1.33	1.33	4	1.54	4.67	4.65	1	3.63
Lakeland Cell 5	230	1.82	1.41	1.37	1	1.34	0.28	0.21	12	0.22	0.58	0.43	4	0.46	1.83	1.72	2	1.72	5.15	4.43	4	3.93
Lakeland Cell 6	49	8.11	1.37	1.41	15	1.52	0.21	0.28	33	0.33	0.43	0.41	2	0.52	1.72	1.81	18	1.96	4.43	4.08	6	3.77
Lakeland Cell 7	35	12.9	1.41	1.37	10	1.39	0.28	0.23	26	0.20	0.41	0.33	7	0.19	1.81	1.71	12	1.65	4.08	3.91	4	3.33
S-154 ATS-WHS	5	7.99	2.45	1.94	30	1.68	0.41	0.16	72	0.13	<--Data below detection limit-->				2.48	1.91	28	1.57	0.467	0.079	100	0.08
Average					17	1.72			60	0.11			72	0.13			32	1.87			35	1.21
Median					9	1.52			50	0.06			41	0.05			17	1.83			24	0.06
Maximum					68	3.27			160	0.33			260	0.68			130	3.40			100	4.81
Minimum					1	0.76			2	0.00			2	0.00			1	0.74			1	0.01

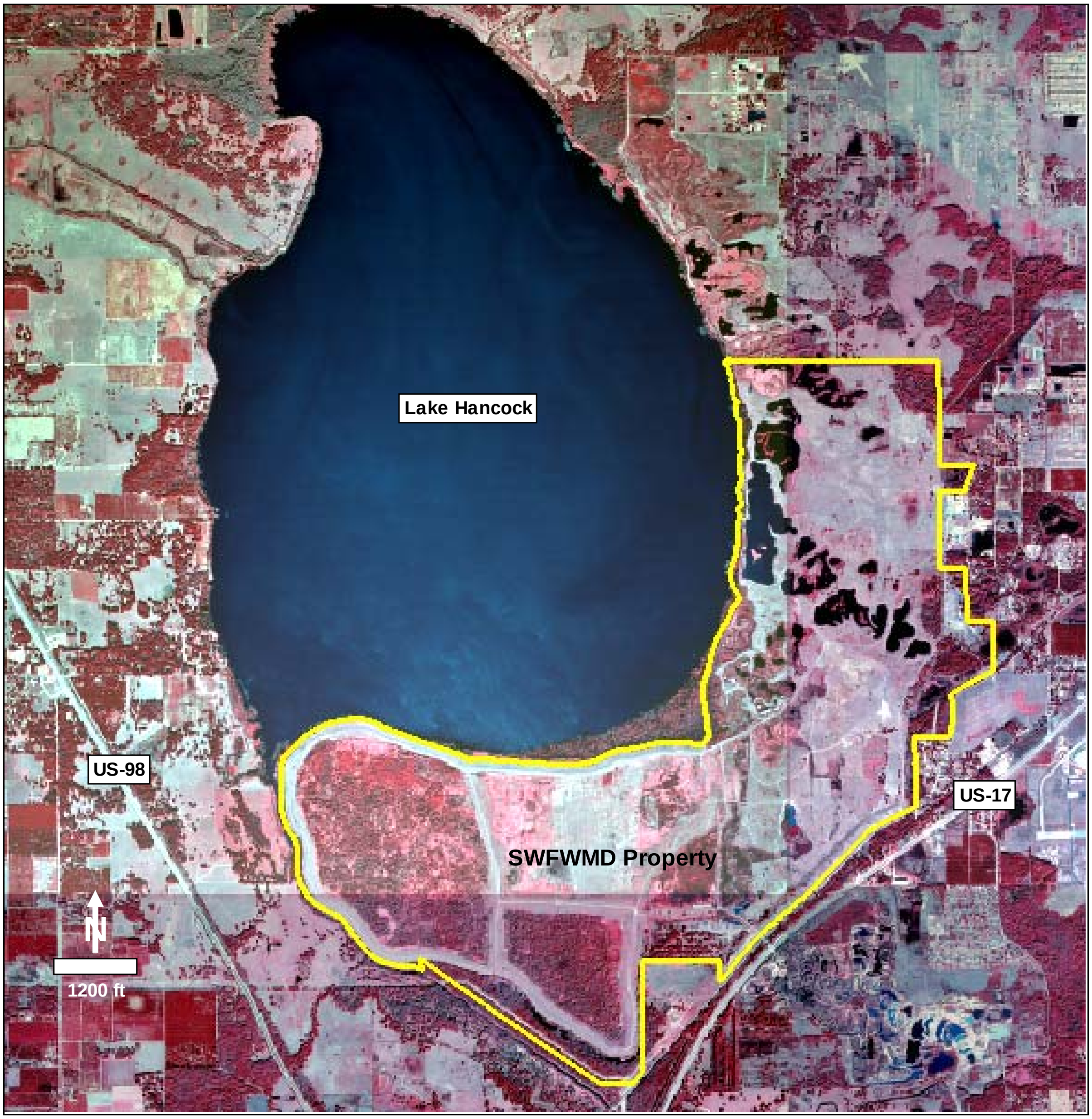


EXHIBIT 38
Lake Hancock project area and SWFWMD-owned land

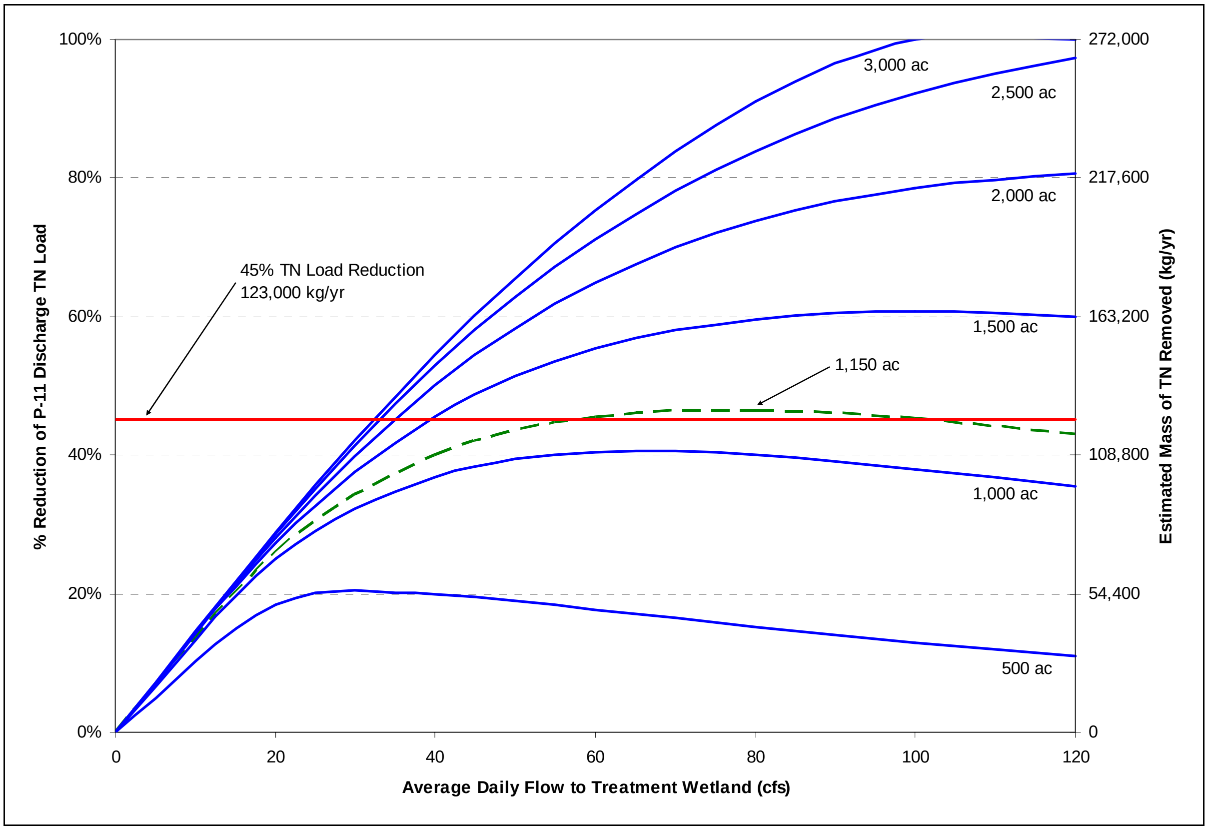


EXHIBIT 39
Treatment wetland TN performance for varying flow rates and area

The estimated performance curve for a 1,500-acre wetland (**Exhibit 39**) is steeper than that for smaller wetlands and meets the load reduction goal for flows exceeding about 40 cfs. A reasonable assumption can be made that the largest treatment wetland that can be constructed within District's property boundary is about 3,000 acres. For the 3,000-acre case, the load reduction goal is estimated to be achieved for average daily flows exceeding 30 cfs. This analysis indicates the following constraints:

- there is a minimum flow(~ 30 cfs) below which the project goals may not be met
- there is a narrow range of estimated minimum flows (30 to 40 cfs) that meet load reduction goals, but these threshold values occur for a wide range of wetland areas (1,500 to 3,000 acres)
- while load reduction goals are met for a range of wetland sizes, wetlands larger than 1,500 acres have the capacity to significantly add to total load reduction (i.e., the performance curves are relatively steep between 30 cfs and 80 to 100 cfs) when flows are available that exceed the minimum rates described above

Based upon these points, and for planning purposes, a 1,500-acre wetland is recommended as the minimum size that is estimated to meet the indicated load reduction goal. **Exhibit 40** compares a proposed operating scenario for a 1,500-acre wetland receiving a constant flow of 40 cfs, with an inflow TN concentration of 6.0 mg/L, to data from the Florida systems described in this study and natural and constructed wetlands from the NADB. At the proposed conceptual design TN loading rate of approximately 0.97 kg/ha/d, the loading scatter plot indicates a median outflow TN concentration of 1.5 mg/L, with a 95 percent confidence interval ranging from 0.7 to 4.3 mg/L.

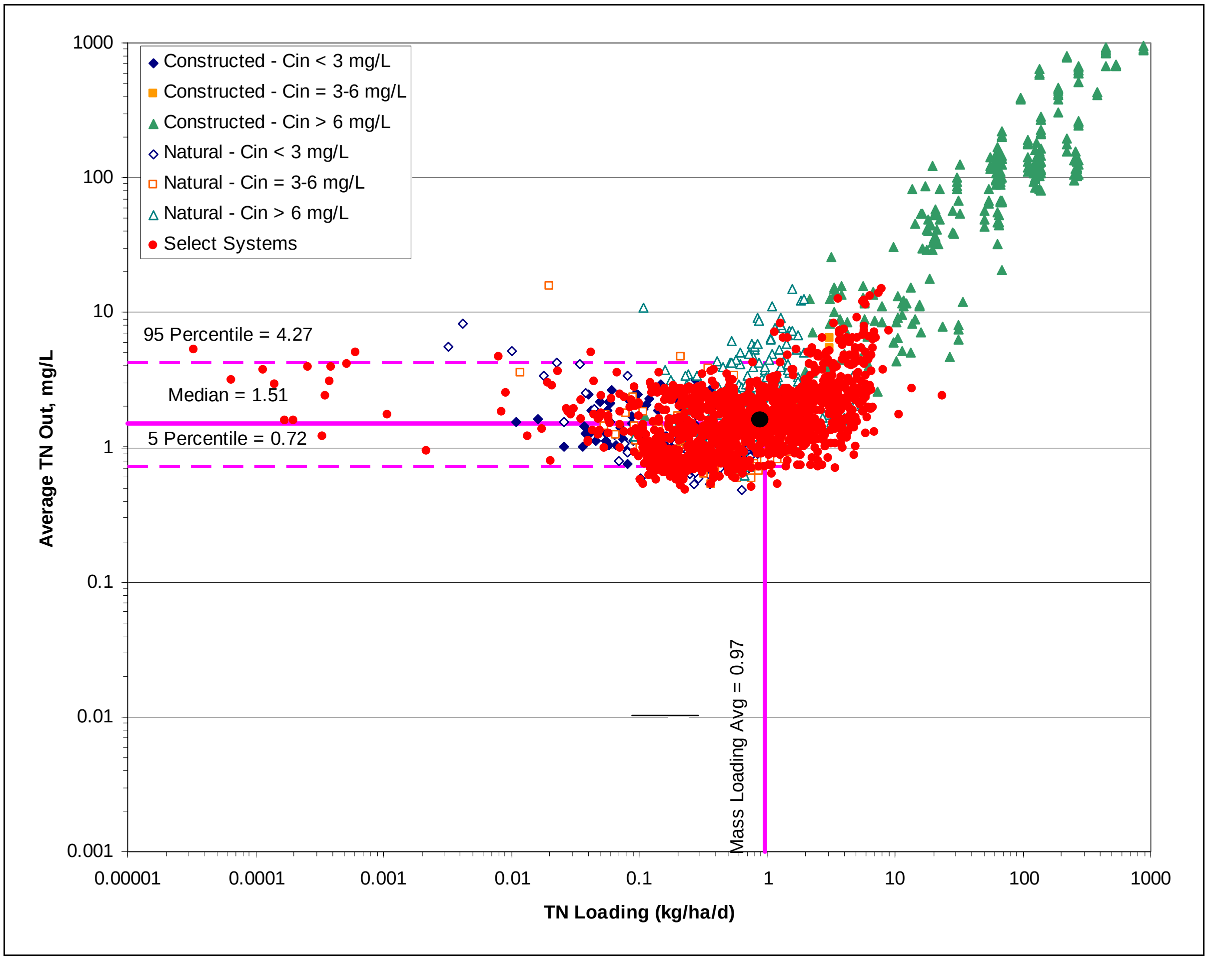


EXHIBIT 40
Estimated treatment wetland TN performance for Lake Hancock discharges

Wetland performance has been demonstrated to benefit from steady-state conditions (Kadlec and Knight, 1996). Lake Hancock could be used as a flow-equalization basin for the proposed treatment wetland. At times when discharge from Lake Hancock is necessary, flow could be routed through the wetland for polishing and discharged either upstream or downstream from the P-11 structure. During periods when no discharge is required, the wetland could still operate at 40 cfs or greater, but the wetland effluent could be recycled back to Lake Hancock. This operating strategy would tend to lower the long-term in-lake nutrient concentrations, while also reducing loads discharged to the Peace River.

Summary

Florida wetland and aquatic plant-based treatment system performance data were reviewed to estimate the efficacy for a natural system to provide the desired level of TN reduction at Lake Hancock. Most of the systems considered had influent TN concentrations below the mean value for Lake Hancock (approximately 6.0 mg/L). The Lakeland Wetland Treatment System had the highest inflow TN concentration at 11.0 mg/L, but still produces a final outlet TN concentration less than 2 mg/L. These data suggest that the District's TN reduction goals are achievable with a wetland or aquatic plant-based treatment system. This conclusion is also supported by data from the NADB.

The two systems that most closely parallel conditions at Lake Hancock are the Lake Apopka Marsh Flow-way and Lake Griffin Flow-way. Both of these emergent wetland plant-based systems treat hypereutrophic lake water with high particulate concentrations. The Apopka system experienced significant sediment deposition rates that prompted operators to draw the system down and induce consolidation of the sediments. Lake Hancock also contains high suspended solids concentrations (average > 100 mg/L) and can be expected to contribute a significant sediment load to the proposed treatment system. The expected sediment loads should be factored into the design of the system so that operational and maintenance impacts are minimized. WSI (2004) recently prepared a draft memorandum discussing sediment accretion in treatment wetlands. Preliminary conclusions from that effort are presented below:

- Sediment accretion is a normal and important process in treatment wetlands that provides a long-term, stable repository for nutrients and other pollutants of concern.
- Long-term net sediment accretion rates in treatment wetlands are reasonably predictable based upon observations from existing systems.
- Sediment accretion should be considered during the design of levees and deep zones for treatment wetlands to insure extended project life (>50 years) without the necessity for sediment removal or berm enhancement.
- Treatment wetland life can be extended cost-effectively beyond the normal design life by increasing existing berm dimensions.
- The potential impacts of dry-outs, dredging, and burning, such as water quality degradation following rehydration and economic impacts from necessary increases in treatment wetland area, mandate careful consideration before these approaches are used in treatment wetlands, should sediment management become necessary during the operational life.

Hydromentia's ATS™-WHS™ technology offers an alternative, highly-managed aquatic plant-based nutrient treatment technology. This system has not been evaluated under conditions similar to those in Lake Hancock (i.e., TN ~ 6 mg/L; TSS > 100 mg/L). Additional research may indicate that the Hydromentia system is capable of meeting the TN reduction goals, but the cost-effectiveness of a full-scale system at Lake Hancock is subject to a significant uncertainty regarding the need for and costs of chemical supplements, sediment management, and biomass recovery and marketability.

Existing information from full-scale constructed emergent wetland treatment systems in Florida indicates that this relatively passive but land-intensive technology provides a proven and cost effective alternative to meet the District's Lake Hancock nitrogen reduction goals. Preliminary sizing calculations indicate that a 1,500-acre treatment wetland that operates at a constant flow rate of 40 cfs can remove approximately 123,000 kg of TN per year. This level of removal meets the District's project objective of reducing the TN load from Lake Hancock to the Peace River by at least 45 percent. The District may wish to construct a demonstration treatment wetland project in one or more of the existing clay settling areas to develop site-specific performance data that can be used to refine performance expectations and guide the design of a full-scale treatment wetland.

References

CH2M HILL. 1998. Treatment Wetland Habitat and Wildlife Use Assessment Project. Prepared for U.S. Environmental Protection Agency Office of Wastewater Management, U.S. Bureau of Reclamation, and City of Phoenix, Arizona.

Coveney, M.F., D.L. Stites, E.F. Lowe, L.E. Battoe, and R. Conrow. 1997. Nutrient Removal and Lessons Learned in the Marsh Flow-Way Demonstration Project at Lake Apopka. In New Perspectives and Tools for Lake and Watershed Management, Proceedings of the Florida Lake Management Society, May 7-9, 1997.

Ecotech Consultants, Inc. 2002. Compliance and Performance Review for the City of Titusville Blue Heron Wetland Treatment System, 2002 Monitoring Report. Prepared for the Titusville City Council.

Environmental Research & Design, Inc. 2001. Lake Griffin Flow-Way Nutrient Control Feasibility and Design, Draft Final Report. Prepared for the St. John's River Water Management District.

Environmental Research & Design, Inc. 1999. Lake Hancock Water and Nutrient Budget and Water Quality Improvement Project. Prepared for the Southwest Florida Water Management District.

Goforth, G., et.al. 2004. Chapter 4A: STA Performance and Compliance, in 2004 Everglades Consolidated Report. South Florida Water Management District.

Hydromentia, Inc. 2004. S-154 Pilot ATS™-WHS™ Aquatic Plant Treatment System Q3 Report. Prepared for the South Florida Water Management District.

Kadlec, R.H. 2003. Effects of Pollutant Speciation in Treatment Wetlands Design. Ecol. Eng., 20(2003), pp. 1-16.

Kadlec, R.H., and R.L. Knight. 1996. Treatment Wetlands. CRC Lewis, Boca Raton, FL. 893 p.

Stites, D.L., and V. Phlegm. 1997. Design of the Lake Apopka Marsh Flow-Way. In New Perspectives and Tools for Lake and Watershed Management, Proceedings of the Florida Lake Management Society, May 7-9, 1997.

Walker, W.W. 1995. Design Basis for Everglades Stormwater Treatment Areas. Water Resources Bulletin, 31(4), pp. 671–685.

WSI. 2004. Sediment Accretion and Ageing in Treatment Wetlands. Draft memorandum prepared for HDR.

USEPA. 1993. Constructed Wetlands for Wastewater Treatment and Wildlife Habitat: 17 Case Studies. EPA832-R-93-005.