Final Task 2 Report

Evaluation of Total Nitrogen Reduction Options for the C-43 Water Quality Treatment Area Test Facility

Prepared for

South Florida Water Management District

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Prepared by

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Exhibits

Acronyms

AN	Ammonia N
ANAMMOX	Anaerobic ammonium oxidation
BHWTS	Blue Heron Wetland Treatment System
BOD	Biochemical Oxygen Demand
C*	Irreducible background concentration
$CaCO_3$	Calcium Carbonate
COD	Chemical Oxygen Demand
CRE	Caloosahatchee River and Estuary
DIN	Dissolved Inorganic Nitrogen
DMSTA2	Dynamic Model for Stormwater Treatment Areas Version 2
DO	Dissolved Oxygen
DON	Dissolved Organic Nitrogen
EAA	Everglades Agricultural Area
EMV	Emergent Macrophyte Vegetation
ENP	Everglades National Park
ENRP	Everglades Nutrient Removal Project
USEPA	US Environmental Protection Agency
FAC	Facultative
FAV	Floating Aquatic Vegetation
FDEP	Florida Department of Environmental Protection
HLR	Hydraulic Loading Rate
MDL	Minimum Detection Limit
N_2O	Nitrous Oxide
NH_3-N	Unionized form of AN
NH_4-N	Ammonium Nitrogen
NOx-N	Nitrate+Nitrite Nitrogen
OBL	Obligate
OEW	Orlando Easterly Wetlands
OW	Open Water
POR	Period of Record
Porta-PSTAs	Portable Experimental PSTA Mesocosms
PSTA	Periphyton Stormwater Treatment Area
SAV	Submerged Aquatic Vegetation
SFWMD	South Florida Water Management District
SJRWMD	St. John's River Water Management District
SRP	Soluble Reactive Phosphorus
STAs	Stormwater Treatment Areas
SWFWMD	Southwest Florida Water Management District
TCSTA	Taylor Creek STA
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Loads

TN	Total Nitrogen
TON	Total Organic Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
UPL	Upland
WCA	Water Conservation Areas
WQTA	Water Quality Treatment Area
WSI	Wetland Solutions, Inc.

Section 1.0 Introduction

1.1 Background

Elevated concentrations of nitrogen and phosphorus in the Caloosahatchee River and Estuary (CRE) are contributing to water quality impairments in this system as evidenced by excessive algae blooms and decreased water clarity and dissolved oxygen content (Knight and Steele 2005). The reduction of nutrient concentrations and loads to these water bodies was required by the Northern Everglades and Estuaries Protection Program passed by the Florida Legislature and signed into law in 2007, and by CRE Total Maximum Daily Loads (TMDL) published by the Florida Department of Environmental Protection (FDEP) (Bailey *et al.* 2009) [Rule 62-304.800, Florida Administrative Code (F.A.C.)]. FDEP is currently in the planning stages of the Caloosahatchee Estuary Basin Management Action Plan (BMAP) which is the roadmap to implement the TMDL. Concurrent with the BMAP planning, FDEP is revising the estuary TMDL and developing several tributary and freshwater Caloosahatchee River TMDLs.

The development of numeric nutrient criteria (NNC) is another water quality process with the potential to influence future nutrient targets in the Caloosahatchee River and Estuary. The United States Environmental Protection Agency (USEPA) and FDEP both have their own rulemaking processes that may or may not be reconciled during design or construction of the test facility. The future of both federal and state criteria implementation is therefore uncertain at this time and the details of this dynamic process are beyond the scope of this report.

In order to increase nutrient reductions to the downstream estuary, the South Florida Water Management District (District or SFWMD) and Lee County have been partnering on the C-43 Water Quality Treatment Area Testing Facility Project (the "C-43 WQTA Project"). The purpose of the C-43 WQTA Project is to investigate and demonstrate cost effective strategies for reducing loadings of total nitrogen (TN) and other constituents including total phosphorus (TP) and total suspended solids (TSS) to the C-43 Canal (Caloosahatchee River) to improve water quality in the downstream estuarine ecosystems. The District also anticipated that the C-43 WQTA Project will generate strategies that can be applied to estuaries throughout south Florida.

Through a decade of successful operation of Stormwater Treatment Areas (STAs), the District has built an extensive expertise in TP removal from storm water runoff using wetland treatment systems. However, the mechanisms for TN removal via wetland treatment systems have not been studied to the same extent. The existing data from STAs mostly indicate that currently designed wetland treatment systems are not optimized to reduce TN (especially dissolved organic nitrogen, DON) although they can remove dissolved inorganic nitrogen (DIN) with high efficiency, which accounts for, at most, 20% of the TN present in the CRE system. Thus, the District contracted with CH2M HILL to identify the best option(s) for achieving the C-43 WQTA Project's goals of nutrient reduction in CRE and to design a test facility prior to construction of the full-scale C-43 WQTA Project. CH2M HILL completed three tasks from 2007-2009, including:

- Initial Data Collection and TN Reduction Technologies Assessment;

- Water Quality Evaluation and Characterization of DON; and
- C-43 WQTA Project Test Facility Conceptual Plan Development.

CH2M HILL's efforts resulted in several deliverables and recommendations, such as developing constructed wetland treatment systems as the most cost-effective means for nutrient removal. The recommended plan included design, construction, and operation of a multi-scale test/demonstration facility on a 1,750-acre parcel (see Exhibit 1) purchased by the District and Lee County for the proposed WQTA. This test/demonstration facility is intended to provide the basis for design of constructed wetlands to assist with ultimate compliance of the CRE TMDL.

Wetland Solutions, Inc. (WSI) has been selected to provide additional expert technical support to develop the detailed C-43 WQTA Project Testing Plan, including a conceptual design of the proposed test facilities and an operational testing plan. This project plan is intended to provide the flexibility to test multiple nitrogen removal approaches to determine which approaches are most effective.

Exhibit 1 - Location of the C-43 Water Quality Treatment and Demonstration Project (top panel) and layout of the test and demonstration cells (bottom panel). ***(CH2M HILL 2009)*.**

1.2 Project Goals and Objectives

The goal of this project is to develop a conceptual design of a test facility comprised of mesocosms and test cells that: 1) will test and demonstrate wetland technologies that have the potential to effectively remove and/or reduce background TN loading from the facility's C-43 inflows; 2) identifies the range of hydrological loading rates per unit area to achieve optimal removal/reduction rates; 3) is based on a review of available information and sound science; and 4) is implementable and cost effective on larger scales and/or applicable to other south

Florida estuarine systems. Phase 2 will be focused on the design of a full-scale test facility, and construction and operation and maintenance (O&M) for this facility.

The objective of this work is for WSI, with expertise in the field of nitrogen and nutrient removal using constructed wetlands, to develop a conceptual design for a testing facility including testing plans. WSI will conduct an evaluation of relevant treatment options to remove TN using constructed wetlands, propose a conceptual design, which is based on sound science, provide a conceptual design of the testing systems and provide estimated probable construction, operating, and testing costs of the proposed design.

The C-43 WQTA Test Facility Conceptual Design Project has three tasks:

1. Project Management and Communication
2. Evaluation of Total Nitrogen Reduction Options
3. Conceptual Design

This report provides the results of Task 2, namely an updated evaluation of the constructed wetland alternatives for total nitrogen load reduction in the C-43 Basin.

1.3 Evaluation of Total Nitrogen Reduction Options

The objective of this task is to provide a summary of information related to the use of constructed wetland technologies for TN removal with an emphasis on the removal of various TN fractions, including inorganic and organic forms. This evaluation will primarily draw information from the WSI Expert Panel report (WSI 2010) as well as the *Total Nitrogen Reduction Technologies Review* previously conducted by CH2M HILL for the District (CH2M HILL 2008). More recent literature and operational data on TN removal in Florida constructed treatment wetlands has been reviewed and is also summarized. The potential to degrade and remove organic nitrogen fractions in constructed wetland environments is of particular interest for this evaluation since these are the most recalcitrant forms of nitrogen and constitute the principal nitrogen fraction in the CRE system. The CH2M HILL and Expert Panel reports provide a relatively detailed description of the various passive environmental processes that can result in the breakdown of organic nitrogen. The reader is advised to review those documents to learn more about individual nitrogen-removal processes.

This report evaluates relevant treatment options for reduction of TN using constructed wetland systems by comparing and summarizing scientific merits and limitations and associated costs of each treatment system. Based on guidance from District staff, this report focuses attention on the treatment options discussed in the *C-43 Water Quality Treatment Area - Technical Expert Review Panel Consolidated Report* prepared by WSI (2010). The results of this evaluation were discussed by WSI and the District Project Team on April 2, 2012 by teleconference. Approval of the Final Task 2 report by the District Project Team is required for initiation of *Task 3 - Conceptual Design of Nitrogen Removal Technologies for the C-43 Test Facility*. This Task 2 report does not provide detailed design guidance for a full-scale C-43 WQTA. It is intended that design guidance for the proposed full-scale C-43 WQTA will be the outcome of monitoring and analysis of data from the C-43 Test Facility.

Task 3 of this project will include the conceptual plan for the C-43 WQTA test facility. The proposed test facility conceptual plan will include a discussion and rationale for the use of mesocosms as compared to larger test cells, recommended test cell treatments, a preliminary operations and monitoring plan, and estimated costs for design, construction, and operation of the proposed test facility. Experimentation of alternative wetland/aquatic plant communities arranged in different sequences will be conducted in the testing facility at the mesocosm level, larger scale test cells, or both. First consideration will be given to treatment trains comprised of conventional wetland and/or aquatic plant community cells that are optimized for the treatment of total nitrogen through natural microbial and photodegradation processes. Should the operation and sampling of the testing facility reveal that these different treatment trains are not as effective as needed to achieve the TN TMDL, other less-conventional TN removal technologies might be considered at that time.

Section 2.0 General Description of Treatment Wetland Technologies

2.1 Background

Constructed treatment wetlands include a broad variety of technologies that rely on the use of aquatic and wetland plants and associated microbial communities to provide water quality benefits. All constructed treatment wetlands have the following basic characteristics in common:

- One or more shallow (water depths typically average less than three feet) basins that receive, hold, and release water to be treated;
- Treatment process that primarily relies on the growth of hydrophytes (aquatic and wetland plants) and associated microbial biogeochemical processes; and
- Relatively large land area requirement necessary to utilize solar input as the primary energy source for the treatment process.

There are two basic hydrologic variants of constructed treatment wetlands:

- Surface flow wetlands that route water aboveground; and
- Subsurface flow wetlands where water is primarily below ground.

Subsurface flow constructed wetlands have significant hydrologic and cost constraints and are not discussed further in this technology evaluation.

The different types of surface flow constructed treatment wetlands are generally similar in design with the exception of water regime (depth and duration of flooding) and the selection of the appropriate plant community that is adapted to the selected water regime. A considerable variety of hydrophytic plant species are available for use in constructed surface flow treatment wetlands in south Florida. Plant selection for constructed treatment wetlands is based on a number of considerations, including:

- Growth form/habit (floating, submerged, rooted, emergent, etc.);
- Flooding tolerance (saturated soil only, periodic flooding, continuous flooding, etc.);
- Salinity tolerance (strictly freshwater, mildly tolerant, halophyte, etc.);
- Pollution tolerance (oligotrophic, mesotrophic, eutrophic, etc.);
- Resistance to frost (intolerant or tolerant);
- Seasonality (annual, perennial, seasonal, etc.);
- Resistance to pests; and
- Value for wildlife habitat (cover, food, nesting, etc.).

By definition, treatment wetlands are constructed to provide water quality treatment. This implies the presence of pollution or wastes above ambient levels in the water source requiring treatment. Water sources that are commonly treated using wetland technologies include:

- Municipal wastewater;
- Domestic wastewater;
- Urban stormwater;
- Non-point source stormwater;
- Commercial and industrial wastewaters;
- River and lake waters; and
- Polluted groundwaters.

Treatment wetlands have been proven effective for the removal of a wide range of inorganic and organic pollutants. The following pollutants are being attenuated by constructed treatment wetlands, roughly in order of the number of applications worldwide:

- Biochemical oxygen demand (BOD);
- Total suspended solids (TSS);
- Nitrogen (N) forms – total nitrogen (TN), total organic N (TON), ammonia N (AN), and nitrate+nitrite N (NO_x-N);
- Chemical oxygen demand (COD);
- Phosphorus (P) forms – total phosphorus (TP), inorganic or soluble reactive phosphorus (SRP), particulate P, and organic P;
- Trace metals (e.g., arsenic, cadmium, chromium, copper, lead, nickel, silver, and zinc); and
- Trace organics (e.g., pesticides, petroleum, aromatic hydrocarbons, alcohols, aliphatic hydrocarbons, volatile organics, etc.).

The focus of this report is the use of constructed treatment wetlands for reduction of TN concentrations and loads. Pollutants of secondary interest for the C-43 WQTA Project are TSS and TP, and are briefly discussed in this report. While wetlands constructed for TN reduction will provide benefits for removal of many of the other pollutants listed above, they are not explicitly considered further in this document.

2.2 Summary of Nitrogen Chemistry Relevant to Treatment Wetlands

The focus of this report is the use of constructed treatment wetlands for removal of TN, with particular reference to the removal of various forms of TON. This section provides a brief summary of nitrogen chemistry. The reader who needs more information about this subject is referred to the detailed discussion of wetland nitrogen chemistry provided by Kadlec and Wallace (2009) and Reddy and DeLaune (2008).

Nitrogen has five different oxidation states that commonly occur in nature. These range from the most oxidized form - nitrate N (oxidation state +5), to nitrite N (+3), to nitrous oxide (+1), to di-nitrogen gas (0), to ammonium N (-3) and organic N (-3). Di-nitrogen gas (N_2) is the ultimate sink for much of the TN transformed by treatment wetlands. Nitrogen gas makes up about 78% of the atmosphere and due to its triple bond it is relatively stable with the exception of N-fixation processes such as lightning and a small number of plant species that have developed enzyme and energy systems necessary to convert this gas back to dissolved ammonia. Industrial fixation of N_2 has been greatly accelerated by the use of fossil fuel energies and is at least partially responsible for worldwide increases in agricultural production and the resulting global imbalance of nitrogen in the environment and eutrophication of surface waters.

Nitrogen pollution in water frequently occurs as one or more of the four non-gaseous forms of nitrogen and is often assessed as the total combined aqueous form - TN. However the actual mix of individual nitrogen forms in polluted waters is very important for assessing impacts in the receiving water and treatment options for reducing the concentration and load of TN.

For example, TON is derived from organic pollution, often resulting from the discharge of domestic and some industrial wastewaters and from runoff from agricultural areas. Organic N in wastewater and runoff can degrade by physical and microbial mineralization to AN. Other important sources of TON in runoff result from the oxidation and decomposition of organic (peat or mucky) soils and dead plant and animal materials.

Ammonia N may also be high in human and animal wastewaters and in agricultural and urban runoff when liquid ammonia fertilizer is used. Ammonia N is in turn chemically reactive in surface waters where its bacterial transformation exerts a high demand for dissolved oxygen. The unionized form of AN (NH_3-N) is acutely and chronically toxic to sensitive aquatic organisms. In most aquatic environments most of the AN is in the ionized form known as ammonium (NH_4-N). Ammonia N is a plant growth nutrient and can stimulate algal blooms. In aerobic aquatic systems, AN can be microbially converted by the process termed "nitrification" to nitrite N which is subsequently converted to nitrate N.

Nitrate and nitrite N are often contained in wastewater and stormwater. Municipal and industrial wastewaters that have received advanced secondary treatment in activated sludge systems commonly discharge TN predominately as NO_x-N. Nitrate and nitrite N are also commonly found in runoff from agricultural and urban areas that use inorganic fertilizers. Nitrite is unstable in aquatic systems and readily converts to nitrate N. For this reason, the two oxidized nitrogen forms are often considered together. Nitrate N is also a plant growth nutrient and can stimulate algal blooms. Nitrate N is readily converted by the microbial denitrification process in constructed treatment wetlands to di-nitrogen gas.

All of these forms of nitrogen are continuously transformed from one compound to another and back again in biological systems, including constructed treatment wetlands. Organic and AN forms release energy when utilized and serve as food for adapted microbes and higher organisms. Oxidized forms of nitrogen (NO_x-N) provide oxygen for microbial metabolism in anaerobic environments and organic energy sources (primarily reduced carbon from wetland plants) are necessary to fuel these transformations. Most of the microbial nitrogen conversions are dependent upon enzymes and catalysts that are relatively specific to the individual conversion processes. Because of the inter-conversion of nitrogen forms in wetlands, it is necessary to consider a reaction sequence when examining the rate and ultimate fate of various incoming water sources.

To-date there have been limited efforts to design treatment wetlands to optimize nitrogen removal at TN concentrations less than about 3 mg/L (Kadlec and Wallace 2009). A few Florida municipal treatment wetlands do have TN permit limits in the range from 1.6 to 2.3 mg/L (Titusville Blue Heron and Orlando Easterly Wetland, respectively). TN mass reduction goals for the CRE TMDL are 23% of current loads. Based on ambient TN concentrations measured between S-77 and S-79 (1.61 to 1.79 mg/L), this may result in the need to achieve TN concentration targets as low as 1.24 mg/L, less than one half of the 3 mg/L limit for most advanced wastewater treatment projects in Florida. Because of this focus on very low TN concentrations this report summarizes a selection of data from full-scale treatment wetlands that operate at relatively low TN levels, and especially those that have demonstrated the capability to achieve TN concentrations less than 1 mg/L.

2.3 Pollutant Sources and Forms in the C-43 Study Area

A number of authors have estimated the inputs of nitrogen to the Caloosahatchee River/Estuary (CRE) system (Bailey et al. 2009; WSI 2007a; Knight and Steele 2005; JEI 2003; and Doering and Chamberlain 2004). An actual nutrient budget for the Caloosahatchee Watershed has not been done to the same level of detail as that for phosphorus inputs to the Lake Okeechobee Watershed (Hiscock *et al.* 2003). Collectively, the authors identify the following as the principal sources of TN inputs to the study area:

- Atmospheric inputs as rainfall and dryfall, including nitrogen fixation;
- Inputs as fertilizer N;
- Inputs from Lake Okeechobee;
- Inputs in animal and human food;
- Wastewater discharges;
- Mixing with the Gulf of Mexico waters;
- Release of nitrogen from soil oxidation and subsidence.

The following discussion takes a closer look at these TN inputs and their potential contributions of TN loading to the freshwater portion of the river. Before proceeding with that discussion however it is worth pointing out that the water quality data at S-79 was collected every other month while the water quality data for the ambient Caloosahatchee River Estuary sampling was collected every month. The loads and concentrations calculated for S-79 therefore may not be as accurate as those upstream (i.e. S-77 and S-78). Additionally, flow estimates may not reflect all the source data for a structure but are acceptable for comparing the estimated volumes of water that travels through the structures from Lake Okeechobee and the surrounding watershed.

Atmospheric TN inputs include all N forms (particulate, dissolved, inorganic, and organic) and typically average about 10 to 20 kilograms per hectare per year (kg/ha/yr) in the U.S. (Kadlec and Wallace 2009). No known atmospheric TN input estimates specific to south Florida were found. For the C-43 watershed area above the S-79 (2,413 km^2) this is equivalent to an estimated average loading rate ranging from about 2,413 to 4,826 metric tons per year (MT/yr). There is uncertainty on what portion of the TN atmospheric inputs actually reach the C-43 canal. It is likely that a large percentage of atmospheric TN inputs to the C-43 watershed are assimilated or denitrified and never reach the surface waters in the C-43 Canal.

Average annual fertilizer nitrogen inputs to Glades and Hendry Counties were reported by the Florida Department of Agriculture and Consumer Services as 12,625 MT/yr for the 2009-2010 period. Only a portion of these counties' surface area is tributary to the C-43 canal. Much of the N present in fertilizer nitrogen is taken up in crops, assimilated or denitrified and never reaches the river While estimating the amount of fertilizer nitrogen reaching the river has not been done, there have been estimates of nutrient loading from different land use types in the Caloosahatchee Watershed. In work done for a recent SFWMD document (CRWPP 2012), nutrient loading from watershed contributions upstream of S-79 were estimated at 1,624 Mt/yr based on a 1996-2010 POR. The land use in this area is primarily agricultural (67 percent) followed by natural areas (27 percent).

The estimated average TN input from Lake Okeechobee at S-77 for the period of record between 1965 and 2011 was 1,235 MT/yr. Inputs of total nitrogen associated with Lake Okeechobee discharges are highly variable from year-to-year and have ranged from 190 to 16,842 MT/yr. Animal and human feed related nitrogen loads to the CRE have not been estimated. With the exception of benthic flux analysis in the estuary, internal TN loads to the freshwater portion of the river from soil oxidation and subsidence and the decomposition of plant and animal wastes have not been estimated as well. Neither have TN loads been estimated from the mixing with Gulf of Mexico waters and waste water discharges which inherently are not easily quantifiable.

During extreme conditions of high rainfall and resulting high water releases from Lake Okeechobee, that source likely dominates the TN mass budget for this watershed. The dominant sources of N loads to the CRE are likely to affect the relative proportions of chemical forms of N that will need to be removed by a wetland treatment system.

Of particular interest to the C-43 WQTA Project are the total nitrogen loads and concentrations recorded at the three principal monitoring points in the C-43 Canal, namely S-77, S-78, and S-79 (Exhibit 2). Exhibit 3 provides a summary of these loads and concentrations of the various fractions of TN, as well as TP and TSS, observed at these stations over the period-of-record (POR January 1981-October 2011). Historically, water quality samples at S77 have been collected on at least a monthly basis, depending on flowing conditions. Sampling at this station is scheduled to occur two times during a month. During the first sampling event of the month, samples are only collected if the structure is flowing. Water quality samples are collected regardless if the structure is flowing during the second sampling event of the month. In contrast, water quality samples have been collected on more irregular frequencies at S78 and S79. Typically, water quality samples have been collected approximately once every other month at these two structures. Starting with 2010, samples at these three structures are collected on a weekly basis. Water quality means and extremes for monthly averages are included in Exhibit 3 and reflect the full range of seasonal and annual variation.

The TN entering the C-43 system from Lake Okeechobee has an average concentration of 1.76 mg/L (range 0.29 to 8.12 mg/L) and is predominantly in the organic form (average 1.57 mg/L [89%], range 0.24 to 4.38 mg/L). Nitrate+nitrite N makes up the next most abundant fraction (average 0.114 mg/L [6.5%], range 0.002 to 6.65 mg/L). Ammonia N averages 0.075 mg/L (4.3% of TN) with an observed range from 0.005 to 1.13 mg/L.

Average TN in C-43 decreases slightly with travel distance downstream. The mean TN concentration at S-78 is 1.64 mg/L and 1.61 mg/L at S-79. The fraction of the TN in the TON form also declines from 89% at S-77 to 85% at S-78 and 78% at S-79. These data indicate that as the distance downstream increases from S-77 to S-79 on average the proportion of the more easily removed inorganic forms increases. On an average concentration basis, the concentration of TON in the C-43 at S-77 is reduced by about 20% by the time it reaches S-79. However, the total TON load increases on average by about 917 MT/yr (83%) with distance downstream between S-77 and S-79.

Total suspended solids concentrations decline along the C-43 from an average of 8.5 mg/L at S-77 to 3.4 mg/L at S-79. TSS loads also decline between S-77 and S-79 on average from 9,593 MT/yr to 6,751 MT/yr respectively.

In contrast to TN and TSS, TP concentrations increase with travel distance downstream, from an average of 0.094 mg/L at S-77 to 0.14 mg/L at S-79 (49% increase). The average TP load also increases between these stations from 61 to 235 MT/yr.

These data illustrate the observation that the concentrations of TN and TSS generally decrease as water travels along the C-43 Canal and that the fraction of organic nitrogen also declines along this waterway. The estimated average TSS load also declines downstream while the TN mass load increases significantly. TP concentrations and loads increase with distance downstream.

2.4 Discussion of Nitrogen Removal Processes in Treatment Wetlands

Total nitrogen concentrations are reduced in treatment wetlands through a sequence of chemical and microbial processes (Kadlec and Wallace 2009). Organic N must be mineralized to inorganic N forms before it can be further oxidized and ultimately removed via denitrification. This section briefly summarizes each of the basic unit processes that occur in treatment wetlands designed for N removal.

2.4.1 Organic Nitrogen Removal

Organic N in the environment may be in simple forms (e.g., urea and uric acid) or moderately to highly complex organic molecules that include amines, amides, purines, and pyrimidines. Organic N primarily in the form of amino acids comprises from 1-7% of the dry weight of plants and animals (Kadlec and Wallace 2009). Urea and uric acid are readily converted in treatment wetlands to AN by chemical or microbial hydrolyzation. More complex organic N forms are often associated with aromatic organic molecules and have varying resistance to mineralization. Some of the more recalcitrant forms of TON, which have half-lives of months to years, require conditioning (i.e. cleaving of amine groups from complex organic molecules) and development of specific microbial communities (i.e. adaptation) that are capable of metabolizing complex TON molecules.

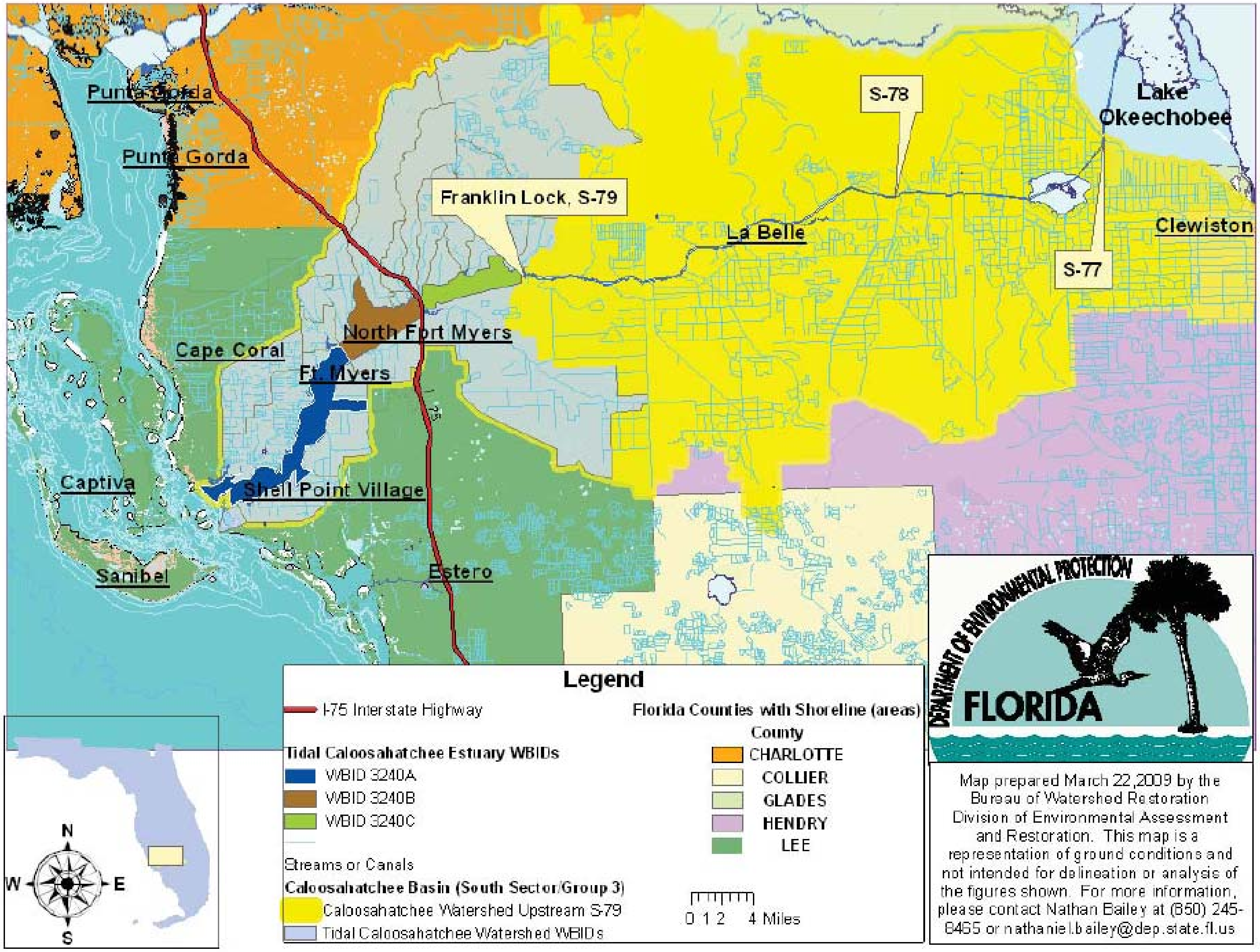


Exhibit 2 - Location of the C-43 Water Discharge and Quality Sampling Stations Referenced in Exhibit 3. (Bailey et al. 2009).

Exhibit 3 - Caloosahatchee River Flows and Nutrient Concentrations and Cumulative Loads at Structures S-77, S-78, S-79 (SFWMD DBHYDRO, January 1981 - October 2011). Values are Averages of Monthly Data (n refers to the number of months in each average)

		Flow	TP		TN		ON		TKN		NOx-N		NH_4-N		TSS	
Structure	Stats	cfs	mg/L	MT/yr	mg/L	MT/yr	mg/L	MT/yr	mg/L	MT/yr	mg/L	MT/yr	mg/L	MT/yr	mg/L	MT/yr
S-77	Avg	755	0.094	60.8	1.76	1,235	1.57	1,105	1.65	1,149	0.114	84.5	0.075	42.9	8.46	9,593
	Median	164	0.075	13.3	1.65	331	1.50	309	1.56	316	0.056	7.26	0.048	6.90	6.00	1,204
	Min	-879	0.020	0.010	0.294	0.190	0.245	0.178	0.250	0.182	0.002	0.008	0.005	0.004	0.500	0.685
	Max	8,330	0.392	0,846	8.12	16,842	4.38	16,607	4.75	16,743	6.65	1,780	1.13	1,001	103	299,635
	StdDev	1,415	0.060	117	0.633	2,274	0.482	2,047	0.519	2,117	0.344	227	0.097	103	9.76	25,546
	N	560	449	410	450	411	447	408	451	412	450	411	447	408	402	364
S-78	Avg	997	0.131	115	1.64	1,465	1.40	1,252	1.45	1,327	0.195	150	0.059	72.2	4.43	7,267
	Median	357	0.117	44.4	1.50	610	1.30	0,515	1.34	0,531	0.096	40	0.040	10.6	3.00	1,128
	Min	0.229	0.039	0.029	0.349	0.429	0.245	0.43	0.250	0.43	0.002	0.001	0.005	0.002	0.500	1.43
	Max	8,724	0.561	0,904	11.4	13,295	3.34	10,448	3.37	11,059	9.85	3,092	0.390	0,750	36.0	227,476
	StdDev	1,527	0.066	170	0.825	2,205	0.437	1,912	0.447	2,005	0.703	344	0.060	128	5.00	23,025
	N	466	203	185	199	181	195	177	202	184	201	183	197	179	183	174
S-79	Avg	1,730	0.140	235	1.61	2,532	1.26	2,021	1.31	2,146	0.308	409	0.045	92.4	3.44	6,751
	Median	798	0.128	114	1.46	1,425	1.15	1,018	1.19	1,057	0.256	170	0.033	22.9	1.50	1,944
	Min	0.00	0.051	0.52	0.330	5.44	0.210	3.91	0.250	4.01	0.002	0.197	0.003	0.039	0.500	2.54
	Max	10,928	0.460	1,973	10.8	13,276	5.05	10,549	5.06	11,124	9.63	7,351	0.279	811	22.0	72,006
	StdDev	2,169	0.062	298	0.802	2,902	0.468	2,407	0.464	2,530	0.692	699	0.042	146	3.41	11,998
	N	546	199	194	197	192	191	186	199	194	198	193	192	187	193	188

S-77 DBKEY: P1022 (01/1965-12/2005); 15635 (01/2006-08/2011)
S-78 DBKEY: 00857 (07/1971-09/2003); WN161 (10/2003-04/2010)
S-79 DBKEY: 00865 (05/1966-10/2011)

2.4.2 Ammonia Nitrogen Removal

Ammonia N is highly reactive in wetland environments. Ammonia N is the generally preferred form of N for plant uptake and assimilation into plant organic matter. Ammonia N is nitrified to NO_x-N in aerobic wetland environments that have high microbial populations. Aerated ponds and wetland deep zones are not particularly effective for this conversion because of the relative absence of suspended or attached nitrifying bacteria. Shallow wetlands with high water velocity generally provide enough dissolved oxygen by diffusion from the atmosphere to provide higher rates of nitrification. Alkalinity is consumed in the nitrification process and low alkalinity can result in diminished rates of AN conversion to NO_x-N. Additional AN removal processes that are known to occur in treatment wetlands include ammonia volatilization, anaerobic ammonium oxidation (anammox) and other related anaerobic pathways (Kadlec and Wallace 2009). Ammonia N must be in the unionized form to be susceptible to volatilization and this is somewhat limited to very high pH and temperature conditions that do not typically occur in treatment wetlands. Open-water pond areas dominated by phytoplanktonic algae are likely to have the highest rates of AN volatilization (Kadlec and Wallace 2009). Anammox and related AN transformation processes appear to rely on NO_x-N as an electron acceptor, thereby competing with denitrification in treatment wetlands (see below) and having lower kinetic rate constants than aerobic nitrification. For this reason, the anammox biogeochemical pathway is not currently considered responsible for a significant amount of AN removal in wetland treatment systems with light to moderate AN loading rates.

2.4.3 Nitrate+Nitrite Nitrogen Removal

Nitrate+nitrite N is highly reactive in anaerobic wetland environments, especially at the interface between the detritus/sediments with the water column. Assimilatory nitrate reduction consists of the conversion of nitrate to ammonia and subsequent cell synthesis. In dissimilatory nitrate reduction, anaerobic bacteria use these forms of nitrogen to provide electron acceptors (oxygen) for their decomposition of organic carbon to carbon dioxide. Organic carbon produced by the decaying plants and dead microbes in the wetland sediments and detritus layers provide the energy resource for this heterotrophic process. There is extensive evidence in the literature that most nitrate disappearance in full-scale treatment wetlands is primarily due to the denitrification reaction rather than due to undocumented internal storages of the compound (Kadlec and Wallace 2009). Denitrification is generally the ultimate nitrogen sink in treatment wetlands since the byproducts are gases – namely nitrous oxide (N_2O) and N_2. The denitrification process in treatment wetlands is generally considered to be complete, with little to no N_2O (a potential air pollutant) produced. Di-nitrogen gas is relatively inert and is the dominant gas in the earth's atmosphere.

2.5 Design Considerations

2.5.1 Optimizing the Total Nitrogen Treatment Process

The above discussion can be summarized as follows:

- In a treatment wetland or a series of wetland-based treatment steps, the removal of TN from a polluted water source will only occur through a sequential biological process;

- The rate of this overall TN removal process is limited by its slowest intermediate step;
- To achieve effective TN removal in a treatment wetland it is essential that no step in the N sequential transformation is omitted;
- It is also essential to maximize the efficiency of each N transformation step to the extent possible allowed by optimal biological process rates.

Based on this summary, it is concluded that the preliminary step or steps in the N transformation process should be focused on TON mineralization. TON in the source waters to the proposed C-43 WQTA Project are thought to be particularly recalcitrant (CH2M HILL 2009). When biologically-available TON is converted to AN early in the wetland process, this will allow greater time for nitrification and denitrification in the downstream portions of the wetland treatment system. However, since some forms of biologically-available TON are more recalcitrant than others, it is necessary to provide continuing favorable conditions for TON mineralization throughout the downstream wetland treatment train. The Expert Panel recommended that the District consider developing an analytical indicator to rapidly assess the biological availability of TON in the CRE system (WSI 2010). It was suggested that this test might be based on a modification of the commonly-used analytical procedure to measure TKN, e.g., a modified digestion sequence using something less reactive than the sulfuric acid that mineralizes TON to AN in the TKN test.

The Expert Panel also concluded that five unit processes that hold most promise included: a very shallow (<15 cm) emergent wetland marsh for nitrification, a classic emergent wetland (about 30 to 45 cm deep) for denitrification, a deeper water mixed wetland or slough dominated by a mix of FAV, SAV, and tolerant rooted plants for long hydraulic residence time and conversion of BDON to DIN, an innovative POP (Periphyton-enhanced Oxidative Photodegradation) mixed open water wetland system with pulsed operation for physical DON degradation, and a final polishing emergent marsh for removal of DIN and algal solids. With the exception of POP, these unit processes are considered conventional and likely candidates for evaluation in the testing facility. Since WSI was unable to locate any data or information about full-scale applications for the POP unit process, it is considered to be "unconventional" (experimental) and is not evaluated further in this report. However, the periphyton-dominated treatment process discussed below shares a similar algal-dominated plant community with POP and, if evaluated in the test facility, a periphyton-dominated process can be manipulated to simulate POP.

In most treatment wetlands receiving pretreated municipal wastewater, nitrification of AN is the rate-limiting step. While this is not expected for the C-43 WQTA Project source water, it indicates that for those forms of TON that can be readily decomposed in a wetland, the most limiting transformation is likely to be nitrification of AN. For this reason, it will be important to optimize the nitrification process beginning near the front end of the treatment wetland process train. Ammonia is the principal ingredient needed for nitrification. For AN removal in treatment wetlands there are two potential constraints of primary interest – adequate dissolved oxygen (DO) and alkalinity. From 4.3 to 4.6 grams of O_2 are required for each gram of AN oxidized in the nitrification process (Kadlec and Wallace 2009). This oxygen is typically supplied from the oxygen in the atmosphere by the physical process of oxygen diffusion. One empirical method used to reduce DO limitations is to increase oxygen diffusion by increasing water velocity. For a given hydraulic loading rate, shallow, narrow, and longer wetlands have the highest velocities.

Alkalinity is also consumed during the nitrification of AN, resulting in a loss of about 7.1 g of alkalinity (as calcium carbonate [$CaCO_3$]) per gram of AN nitrified (Kadlec and Wallace 2009). Alkalinity is critical to buffer the pH of a treatment wetland used for nitrification. This is because the nitrification process produces hydrogen ions, which must be neutralized by the wetland to maintain the optimum pH range for nitrification (reported to be from 7.2 to 9.0 in wastewater treatment systems by Metcalf and Eddy 1991). For this analysis, it is assumed that alkalinity is high enough in C-43 source waters (average values of 116 to 148 mg/L as calcium carbonate from S-77 to S-79) that it is not likely to limit the removal of the relatively low concentrations of AN expected.

Denitrification is typically the last microbial N transformation needed in treatment wetlands. In addition to the reactant (nitrate N), the availability of reduced organic carbon is essential for this biogeochemical process. Kadlec and Wallace (2009) estimate an average organic carbon requirement of about 3.0 grams of organic matter per gram of nitrate N. Denitrification is favored under anaerobic conditions. With these two considerations in mind, the optimal treatment wetland system for denitrification is generally thought to be a system with high organic carbon production in close proximity to anaerobic conditions suitable for the growth of denitrifying bacteria. These conditions are met in almost all well-vegetated treatment wetlands.

There are also other variables that will be important in design of a full-scale C-43 WQTA for lowering concentrations of TN. One factor of high importance will be the seasonal and annual variability of source water chemistry. Depending on the origin of flow, water in the C-43 shows considerable variability as evidenced by the data summarized in Exhibit 3. This variability and the ability of a full-scale WQTA system is an important consideration in preliminary design and is not discussed further in this report. Other design criteria of importance that will be developed based on results from the proposed C-43 WQTA Test Facility will include: hydraulic loading rate, water depth, plant community composition, and soil suitability.

Possible operational strategies for a full-scale C-43 WQTA will also need to be considered during final design. The occurrence of dry-outs or controlled burns on plant community composition and mobilization of nutrients are important operational issues. More information on a variety of possible management strategies will be provided in the Task 3 report that describes the recommended operations plan for the Test Facility.

2.5.2 Treatment Wetland Plant Communities

Plant communities in existing treatment wetlands have been described in a number of available publications (Kadlec and Wallace 2009, Kadlec and Knight 1996, Vymazal *et al.* 1998). The use of the term "treatment wetland" is inclusive in this report. All low energy "natural" aquatic treatment systems are included under the treatment wetland epithet. This includes wetlands and aquatic ecosystems dominated by a range of non-vascular to vascular vegetation, including open water systems dominated by planktonic algae, systems dominated by masses of filamentous algae, and wetlands dominated by vascular plant communities including rooted, submerged, and floating aquatic herbaceous (non-woody) plants. In this sense, the following ecosystem types are included in this definition: pond, slough, and marsh. Forested wetlands (swamps) are not included in this discussion since they have not shown as much promise for water quality performance as wetland systems dominated by herbaceous plant species (Kadlec and Knight 1996).

In general, similar or identical plant types and species are utilized in treatment wetlands worldwide. Specific plant species recommended for use in south Florida, and particularly in treatment wetlands to be developed in the vicinity of the C-43 basin are well known, both from experience with the Everglades Agricultural Area (EAA) STAs south of Lake Okeechobee and from a variety of full and pilot-scale constructed wetlands in south and central Florida north of the Lake (e.g., Taylor Creek STA, the Periphyton Stormwater Treatment Area (PSTA) test projects, Lakeland Constructed Wetland, Apopka Wetland, Titusville Blue Heron Wetland, and Orlando Easterly Wetland in Orange County).

Five general plant community types typically can be found in constructed treatment wetlands and STAs:

- Emergent macrophyte vegetation (EMV)
- Submerged aquatic vegetation (SAV)
- Floating aquatic vegetation (FAV)
- Attached and floating algal-dominated systems algae (PSTA or periphyton stormwater treatment area)
- Open water (OW)

The dominant plant community in most constructed treatment wetlands is EMV (Kadlec and Knight 1996). EMV wetlands typically have average water depths less than 1 meter (m) and the dominant plants are rooted in the wetland sediments. Since the majority of plant productivity in these wetlands takes place above the water level, EMV wetlands typically have low dissolved oxygen concentrations in the water column. This plant community type has been found to be highly reliable for nutrient removal in most applications and is likely to be the first choice for constructed water quality treatment wetlands in the C-43 basin southwest of Lake Okeechobee. All nitrogen reduction processes, including mineralization or TON, nitrification of AN, and denitrification of NOx-N have been demonstrated in EMV systems.

The use of SAV as a dominant plant community was first carefully evaluated for enhanced phosphorus concentration reduction south of Lake Okeechobee in the District’s EAA STAs. Now this plant community is being used extensively at those locations. One large constructed wetland in central Florida (Orlando Easterly Project) has converted EMV to SAV in some downstream cells in an effort to enhance TP removal rates. SAV may or may not be rooted and most plant biomass is within the water column and below the water surface. For this reason, the primary productivity of these systems generally results in high daily concentrations of dissolved oxygen. Water depths in SAV cells are typically greater than 1 m and may be up to 6 or more meters deep. SAV systems are expected to incorporate all of the nitrogen reduction processes listed above for EMV systems, but with higher or lower effective rate constants as evaluated below.

Floating Aquatic Vegetation plant communities have been used extensively in treatment ponds throughout the southern U.S. and data are available from California and Texas for nutrient removal in ponds dominated by either water hyacinth or duckweed. A few pilot-scale FAV systems have been monitored in south Florida. Historically, the Everglades Nutrient Removal Project's (ENRP) Buffer Cell included about 39% cover by a FAV plant community. FAV is generally not rooted and these systems typically have deeper water conditions than EMV and SAV systems (greater than 2 m) and this water depth is generally effective at excluding significant colonization of these systems by EMV plants. FAV systems typically shade out other plants and algae in the water column and have very low levels of dissolved oxygen. FAV systems are expected to incorporate all of the nitrogen reduction processes listed above for EMV systems, but with higher or lower effective rate constants as evaluated below.

Algal-dominated wetlands include relatively shallow systems with attached and/or floating filamentous algae. This algae community may be called *aufwuchs*, periphyton, epiphytic, benthic, or floating. PSTA is used as a convenient descriptor for this highly variable treatment wetland plant community. POP (periphyton-enhanced oxidative photodegradation) systems also fit into this category. Typical water depths in algal-dominated treatment systems are less than 0.6 m. Since algal productivity occurs in the water column, these PSTA systems have high daily concentrations of dissolved oxygen. This category does not include the Algal Turf Scrubber technology since those systems are highly managed through continuous harvesting and biomass disposal. PSTA systems are expected to incorporate all of the nitrogen reduction processes listed above for EMV systems, but with higher or lower effective rate constants as evaluated below.

Open water treatment wetlands include a variety of shallow ponds and lakes where floating aquatic plants are excluded by use of herbicides and/or wind fetch (large dimensions). These open water systems typically have average water depths greater than 2 m and are dominated by planktonic (free-floating) unicellular and colonial algae species. Treatment ponds and open water areas in treatment wetlands are typically aerobic near the surface of the water column due to high algal productivity, but also may be anaerobic at the level of the sediments due to high sediment oxygen demand. OW systems are expected to incorporate all of the nitrogen reduction processes listed above for EMV systems, but with higher or lower effective rate constants as evaluated below.

2.5.3 Wetland Plant Community Maintenance

In most treatment wetlands, a specific plant community is initially specified by the designer, planted following the completion of site grading, and watered during establishment with site water. While survival of planted species is not typically 100%, these species can be established with care in relatively predictable plant assemblages or monospecific stands. In the EAA STAs, plant community establishment has generally relied on little to no planting and natural recruitment of adapted wetland plant species following construction and site hydration. For SAV systems, emergent macrophytes are increasingly being planted to keep SAV species in place and to improve system hydraulics.

Following initial plant establishment and startup, plant community composition often deviates from plan and follows a course dictated by the multiple environmental influences of water depth and flooding duration, water quality, pre-existing seed bank in site soils, weather, herbivorous insects, and other fauna and plant diseases. Over time, all plant communities in treatment wetlands tend to deviate from the original planned assemblage unless they are rigorously maintained. These shifts are not necessarily detrimental to wetland water quality treatment performance. In light of minimizing unproductive costs, maintenance activities in constructed wetlands should be limited to only as much as necessary to maintain the desired wetland plant community type – not a preordained list of "desirable" plant species.

Emergent and submerged aquatic plant communities have been identified as being most desirable for STA performance south of Lake Okeechobee. The actual plant communities occurring in the existing STAs and in most other treatment wetlands are much more complex than indicated by general terms such as "emergent" or "submerged aquatic". A total of 121 plant species (not including algae) have been reported from the EAA STAs (Chimney 2012, in press). Exhibit 4 provides an edited list of the dominant plant species currently recorded from the existing south Florida STAs. When possible all plant species in this list are categorized into three groups based on their origin (native or exotic), their general tolerance to flooding as indicated by the classification scheme developed by the U.S. Fish and Wildlife Service (ranging from obligate [OBL] at the wet end of the hydrologic spectrum, through facultative [FAC, FACW, and FACU] in the middle, and to upland [UPL] at the driest end of the spectrum), and their growth habit (emergent, submerged, floating, shrub = woody, or vines). While most of these species are herbaceous (soft plant tissues) a few are woody (such as willow, primrose willow, wax myrtle, and elderberry). This list primarily includes obligate and facultative wetland plant species and does not include upland plant species that have been observed in the STAs along the levee side slopes and under highly unfavorable conditions of extended drought.

2.5.4 Emergent Wetland Plant Communities

The majority of wetlands constructed for water quality improvement worldwide and in the U.S. have targeted an emergent plant community (Kadlec and Knight 1996). Dominant species used in these EMV designs have included:

- *Typha* spp. (cattail)
- *Phragmites communis* (common reed)
- *Schoenoplectus* (*Scirpus*) spp. (bulrush)

These particular plant species have been favored worldwide in treatment wetlands for two primary reasons: they are highly tolerant of continuous inundation (at least in the root zone) and they are highly productive and produce a large amount of fixed carbon that is essential for most of the water quality purification microbial processes that occur in treatment wetlands. The published literature for treatment wetlands shows no consistent preference for any single emergent plant species for phosphorus removal but does indicate that wetlands with emergent plants are significantly more effective than systems without plants (open water). An EMV plant community was favored in early south Florida STA designs due to the proven track record of this plant community type in dozens of constructed wetlands designed for phosphorus removal and due to its occurrence in Water Conservation Area (WCA) 2A which was used as a data source for initial STA process design (Kadlec and Newman 1992).

The ENRP Project was the prototype for all later STA designs and principally relied on natural recruitment by cattail (primarily *Typha domingensis*). A variety of other emergent wetland plant species were purposely planted in the ENRP, but this practice was found to be cost-prohibitive and unnecessary for meeting Phase 1 Everglades Construction Project phosphorus removal goals. While cattail-dominated treatment wetlands are highly effective for water quality improvement, tolerant of a wide range of water levels and hydraulic loading rates, and require minimal maintenance, cattail monocultures are not typical in the STAs. In addition to dominance of the plant community by cattails, a mix of emergent and floating plant species is typical of all of the existing south Florida STA EMV cells. Bulrush species (*Schoenoplectus* [*Scirpus*] spp.) have been recorded in STA 1-W and STA 1-E where they were purposely planted and common reed has not been reported from any of the south Florida STAs. For these reasons, cattails are the primary species of choice in EMV STA cells south of Lake Okeechobee.

Cattails dominated three of the original four cells in the ENRP for more than five years following construction and initial vegetation recruitment. Experience gained in the ENRP and in its later incarnation as STA 1-W indicated that cattail would continue to dominate the wetland plant community as long as water depths were adequate but not too deep. Long-term periods with high hydraulic loading rates to STA 1-W resulted in prolonged water depths greater than 2 feet in STA 1-W cells 1-3 and the gradual attrition of the dominant cattail community until water levels were subsequently lowered. There is good evidence from STA 1-W that an emergent wetland plant community will shift to an ecosystem dominated by floating and/or submerged aquatic species when water depths consistently exceed about 2 feet.

Colonization and disturbance history are also important in establishing an emergent wetland plant community. Natural recruitment of cattail and other desirable wetland emergent species is retarded in the presence of an existing upland plant community such as exotic grasses or shrubs. With careful site preparation and water management during construction, cattail recruitment can be optimized (GGI 2005). Once an emergent plant community dominated by cattails is established it is resilient to invasion by upland plant species during droughts. However, an EMV plant community with poor cover and open un-vegetated areas is susceptible to invasion by competitive upland plant species following an extended drought.

In summary, the target EMV plant community is dominated by a high cover of cattail. Based on the list presented in Exhibit 4 and from experience from other Florida constructed treatment wetlands, other emergent plant species that could also contribute to high primary productivity and plant cover in STA emergent zones include the following:

- *Eleocharis* spp. (spikerush)
- *Schoenoplectus* spp. (bulrush)
- *Cladium jamaicense* (sawgrass)
- *Pontederia cordata* (pickerelweed)
- *Panicum hemitomum* (maidencane)
- *Sagittaria* spp. (duck potato/arrowhead)

However, due to the hydrological and water quality conditions in continuously-flooded EMV treatment wetlands, only the first three of these species, spikerush, bulrush, and sawgrass, are likely to be candidates as suitable alternative dominants in south Florida. The last three plant species in this list (pickerelweed, maidencane, and duck potato) are all intolerant of continuous deep flooding.

2.5.5 Submerged Aquatic Vegetation Wetland Plant Community

Following construction in 1994, Cell 4 of the ENRP/STA 1-W was intentionally treated with herbicides to encourage a non-emergent wetland plant community. The original intention was to create an open water/mixed marsh/periphyton dominated system that was similar to plant communities in WCA 2A and in the natural Everglades wetland mosaic that were known to predominate in areas of low phosphorus concentrations. The actual result of herbicide applications in Cell 4 was the creation of a deep-water wetland dominated by two submerged aquatic plant species, *Najas guadalupensis* (southern naiad) and *Ceratophyllum demersum* (coontail). After about five years of operation of Cell 4 with this SAV plant community, phosphorus removal results were remarkable in this cell, both in terms of the first-order area-based phosphorus removal rate constant and with respect to the lowest achievable P concentration.

Concurrent research in a variety of experimental mesocosms helped to verify and refine these full-scale results and subsequently led the District to an across-the-board program to replace downstream cattail emergent cells in all of the STAs with SAV cells. This re-engineering has had mixed success as various unexpected consequences of wetland plant ecology have been experienced by the District. *Hydrilla verticillata* (hydrilla), an exotic and invasive species, has been found to be highly competitive with the desired SAV species (southern naiad and coontail) and is now tolerated, although not preferred, in SAV cells. Herbicide control of hydrilla has not been effective in the STAs (Toth, pers. comm. 2008). All SAV plant communities were adversely affected by high water velocities induced by excessive hydraulic loading rates or by high winds during hurricanes. Use of transverse emergent plant zones at frequent intervals across SAV-dominated STA cells has been adopted as a reasonable method to counteract wind or velocity-induced wholesale movement of SAV. SAV plant species are also easily impacted by continuous shading due to highly colored inflow waters and by floating aquatic plants such as *Eichhornia crassipes* (water hyacinth) and *Hydrocotyle* spp. (pennywort). Perhaps the most significant challenge for maintenance of SAV-dominated plant communities in south Florida STAs is drought management. Most SAV species cannot withstand extensive periods of dryout and may be totally replaced by open-water conditions following a drought. Even after a short period of dry down, most SAV plant communities require an extended period of several months to re-establish pre-drought plant biomass levels. Wholesale loss of SAV plant species during a drought may require costly re-inoculation when adequate water inflows are re-established.

Exhibit 4 - Dominant Plants Occurring in the Everglades Agricultural Area STAs (Data assembled by Mike Chimney 2012)

SPECIES	COMMON NAME	STA-1E	STA-1W	STA-2	STA-3/4	STA-5	STA-6	ORIGIN	HABITAT	COMMUNITY TYPE
Acrostichum danaeifolium	giant leather fern		X	X				NAT	OBL	EMV
Alternanthera philoxeroides	alligatorweed	X	X		X	X	X	EXO	OBL	EMV
Amaranthus australis	southern amaranth; southern waterhemp	X	X			X		NAT	OBL	EMV
Azolla caroliniana	Carolina mosquitofern	X	X	X	X	X		NAT	OBL	FAV
Bacopa caroliniana	lemon bacopa; blue waterhyssop		X		X			NAT	OBL	EMV
Bacopa monnieri	herb-of-grace; smooth waterhyssop		X		X			NAT	OBL	EMV
Ceratophyllum demersum	coontail	X	X	X	X	X		NAT	OBL	SAV
Chara sp.	muskgrass	X	X	X	X	X	X	NAT	OBL	SAV
Cladium jamaicense	Jamaica swamp sawgrass		X	X	X		X	NAT	OBL	EMV
Commelina sp.	dayflower	X	X					-	FACW	EMV
Cyperus esculentus	yellow nutgrass; chufa flatsedge	X	X					EXO	FAC	EMV
Cyperus sp.	sedge		X		X	X		-	FACW	EMV
Eichhornia crassipes	common water hyacinth		X			X		EXO	OBL	FAV
Eleocharis interstincta	knotted spikerush	X	X		X		X	NAT	OBL	EMV

Exhibit 4 - Dominant Plants Occurring in the Everglades Agricultural Area STAs (Data assembled by Mike Chimney 2012)

SPECIES	COMMON NAME	STA-1E	STA-1W	STA-2	STA-3/4	STA-5	STA-6	ORIGIN	HABITAT	COMMUNITY TYPE
Eleocharis sp.	spikerush		X	X				NAT	OBL	EMV
Equisetum sp.	horsetail; scouring rush		X			X		-	FACW	EMV
Eupatorium capillifolium	dogfennel		X			X		NAT	FAC	EMV
Hydrilla verticillata	waterthyme; hydrilla	X	X	X	X	X		EXO	OBL	SAV
Hydrocotyle sp.	marshpennywort	X	X		X	X		-	FACW	EMV
Ipomoea cordatotriloba	tievine		X			X		NAT	FACU	EMV
Lemna sp.	duckweed	X	X	X	X	X	X	NAT	OBL	FAV
Limnobium spongia	American spongeplant; frog's-bit		X			X		NAT	OBL	FAV
Ludwigia peruviana	Peruvian primrosewillow	X	X		X	X		EXO	OBL	EMV
Ludwigia repens	creeping primrosewillow; red ludwigia	X	X	X	X	X		NAT	OBL	SAV
Mikania scandens	climbing hempvine		X		X	X	X	NAT	FACW	VINE
Myrica cerifera	southern bayberry; wax myrtle			X	X			NAT	FAC	EMV
Najas guadalupensis	southern waternymph; southern naiad	X	X	X	X	X		NAT	OBL	SAV
Nuphar advena	spatterdock; yellow pondlily				X	X		NAT	OBL	FAV

Exhibit 4 - Dominant Plants Occurring in the Everglades Agricultural Area STAs (Data assembled by Mike Chimney 2012)

SPECIES	COMMON NAME	STA-1E	STA-1W	STA-2	STA-3/4	STA-5	STA-6	ORIGIN	HABITAT	COMMUNITY TYPE
Nymphaea odorata	American white waterlily; fragrant waterlily		X	X	X	X	X	NAT	OBL	FAV
Nymphoides aquatica	big floatingheart; banana lily	X			X	X		NAT	OBL	FAV
Panicum hemitomon	maidencane	X	X	X	X	X	X	NAT	OBL	EMV
Panicum repens	torpedograss	X	X	X	X	X	X	EXO	FACW	EMV
Panicum sp.	-	X	X		X	X		-	FACW	-
Phyla nodiflora	turkey tangle fogfruit; capeweed	X	X					NAT	FAC	EMV
Pistia stratiotes	water lettuce	X	X	X	X	X		NAT	OBL	FLT
Pluchea odorata	sweetscent		X		X			NAT	FACW	EMV
Polygonum sp.	smartweed; knotweed	X	X	X	X	X	X	-	OBL	EMV
Pontederia cordata	pickerelweed		X	X	X	X	X	NAT	OBL	EMV
Potamogeton sp.	pondweed		X	X	X	X		-	OBL	SAV
Sagittaria kurziana	springtape; strap-leaf sagittaria		X		X			NAT	OBL	SAV
Sagittaria lancifolia	bulltongue arrowhead; duck potato	X	X	X	X	X	X	NAT	OBL	EMV
Sagittaria latifolia	broadleaf arrowhead; duck potato		X	X			X	NAT	OBL	EMV

Exhibit 4 - Dominant Plants Occurring in the Everglades Agricultural Area STAs (Data assembled by Mike Chimney 2012)

SPECIES	COMMON NAME	STA-1E	STA-1W	STA-2	STA-3/4	STA-5	STA-6	ORIGIN	HABITAT	COMMUNITY TYPE
Sagittaria sp.	arrowhead				X		X	-	OBL	-
Salix caroliniana	carolina willow; coastalplain willow	X	X	X	X	X	X	NAT	OBL	EMV
Salvinia minima	water spangles; water fern		X	X	X	X	X	EXO	OBL	FAV
Sambucus nigra	American elder; elderberry		X			X		NAT	FACW	EMV
Sarcostemma clausum	white twinevine		X	X	X	X	X	NAT	FACW	VINE
Spirodela polyrhiza	common duckweed; giant duckweed		X			X		NAT	OBL	FAV
Typha domingensis	southern cattail	X	X	X	X	X	X	NAT	OBL	EMV
Typha sp.	cattail	X	X	X	X	X	X	-	OBL	EMV
Urochloa mutica	paragrass					X	X	EXO	FACW	EMV
Utricularia floridana	Florida yellow bladderwort			X		X	X	NAT	OBL	SAV
Utricularia sp.	bladderwort	X	X		X	X	X	NAT	OBL	SAV
	Taxa Counts	26	47	26	37	39	22			

In summary, the most desirable SAV species in the STAs are southern naiad and coontail. Other SAV species such as *Potamogeton* spp. (pondweed) and *Sagittaria kurtziana* (strap-leaf sagittaria) that occur rarely and at low densities in the STAs are not considered viable substitutes for the two species listed above. Other subdominant SAV plant species such as *Utricularia* spp. (bladderwort) and the macroalga *Chara* spp. (muskgrass) are also found in the south Florida SAV plant communities and occasionally occur at high densities. However, these species do not prefer habitats with elevated phosphorus concentrations and these species are not expected to provide acceptable phosphorus removal rates.

2.5.6 Floating Aquatic Vegetation Wetland Plant Community

The two floating aquatic plant species that have been most widely used in nutrient removal treatment wetlands are water hyacinth (*Eicchornia crassipes*) and a variety of duckweed and related small-leaved species (*Lemna minor, Lemna spp, Spirodela*, etc.). Other floating leaved wetland plants that are often found in treatment wetlands include pennywort (*Hydrocotyle* spp.), frog's bit (*Limnobium spongia*), water lettuce (*Pistia stratiodes*), water lily (*Nymphaea* spp.), and spadderdock (*Nuphar luteum*). Pennywort, water lily, and spatterdock are all rooted plants capable of growing in deeper water locations (up to about 2 m). The other species can grow at greater water depths as long as they are not continually dispersed by wind and currents.

FAV species are particularly effective at shading the underlying water column, preventing the growth of planktonic or attached algae. The water column in FAV treatment systems is typically dark and low in dissolved oxygen. Aerobic treatment processes such as nitrification of AN are severely limited in FAV systems.

2.5.7 Periphyton-Dominated Wetlands

Periphyton-dominated stormwater treatment area (PSTA) systems have been extensively studied in south Florida (CH2M HILL 2003a; Kadlec and Walker 2003; Goforth 2011; WSI and Anamar 2011). Periphyton is a complex plant community composed of blue-green algae, green algae, diatoms, fungi, bacteria, micro- and macroinvertebrates, and detrital material that colonize submerged surfaces in aquatic systems. Everglades periphyton occurs as benthic mats growing underwater on the sediment surface (epipelon); benthic mats that have become unattached from the sediments and rise to the water surface forming floating mats (metaphyton); or attached to the surface of rocks (epilithic) or plant surfaces (epiphyton). The taxonomic composition of Everglades periphtyon varies as a function of water chemistry and hydroperiod. Calcareous periphtyon, which is recognized by a prevalence of filamentous blue-green algae and diatoms, dominate in areas of the Everglades with short hydroperiods (short periods of inundation followed by dessication), low TP concentrations (<20 ppb), high calcium concentrations (>50 milligrams per liter [mg/L]), and relatively high pH (6.9 to 7.5). At the other end of the environmental spectrum that includes longer hydroperiods, lower calcium concentrations (<5 mg/L), lower pH (5 to 7), and higher TP concentrations (>20 to 50 ppb), periphtyon assemblages are often dominated by a greater percentage of species of filamentous green algae and desmids.

Peat soils were found to encourage undesirable colonization by emergent vegetation and discouraged the colonization by periphyton. Shellrock, sand, and limerock soils were all found to be viable options for development of periphyton biomass. It was anticipated that some level of macrophyte management would be required in PSTAs built on any substrate.

Based on this review of existing published results and findings (WSI and Anamar 2011), the success of PSTA relies on the following principal design and operational considerations:

- Construction of a relatively shallow, level impoundment (less than about 60 cm in average water depth);
- Use of a substrate/sediment that has very low antecedent concentrations of available P;
- Moderate to low (< 20 ppb) inflow phosphorus concentrations;
- Adequate dissolved calcium available in the source water and/or in the substrate; and
- Maintenance of a relatively low density of emergent or floating vegetation.

2.5.8 Open Water Systems

Areas of perennially deep (greater than 1 m) open water in south Florida are typically dominated by floating aquatic plants, submerged aquatic plants, or planktonic algae (phytoplankton). These three plant community types are somewhat mutually exclusive due to their competition for nutrients and light. Floating aquatic plant dominance is optimized by smaller open water areas that have less wind fetch. Larger open water systems (with dimensions greater than a few hundred m) tend to be free of floating aquatic vegetation unless there are barriers that help to anchor the plants against windy conditions. These barriers may be islands, relic trees in impoundments, and even topped-out submerged aquatic vegetation. In relatively large open-water areas such as lakes and reservoirs, phytoplankton dominates the plant community. These unicellular and colonial algae are free floating and can form massive algal blooms under conditions of high nutrients. Water quality in these systems is characterized by highly variable concentrations of dissolved oxygen and pH and production of large amounts of total suspended solids.

2.5.9 Hydrologic Optima and Tolerance Ranges for Target Treatment Wetland Plant Communities

All wetland plants exhibit tolerance to a range of hydrologic conditions. The optimal portion of this range can be considered the zone where a given plant species is able to maximize its net primary production, resulting in the greatest amount of accumulated plant tissue in a given growing season. The range of tolerance to flooding may be considered as the portion of the water regime between low and high water conditions where the plant is actually found in natural field conditions (under competitive stress from other plants and due to grazing by wildlife). While many wetland plants in the absence of competing species actually have their highest growth rates in saturated but unflooded conditions, in the competitive environment that occurs in constructed wetlands, the optimal plant growth may occur in deeper water due to exclusion of upland plant species that would otherwise compete for sunlight and nutrients.

Plant tolerance to a range of hydrologic conditions can best be observed by looking for zonation of plant communities over a vertical gradient. Ideal data sets are most likely to be collected from bowl-shaped wetlands and lakes with long periods of hydrologic data collection. In such an ideal study site plant communities typically follow a progression of upland species at the highest elevations, through facultative and obligate wetland species with distance down gradient. Plant community zonation in response to water depth variation may be much more difficult to observe in relatively level wetlands where water depth does not vary along a gradient but is more stochastic.

Based on previous reviews (Kadlec and Knight 1996; WSI 2009) the following specific depth ranges and average are suggested for each of these plant communities:

- EMV – average 45 to 60 cm
- PSTA – 60 to 90 cm
- SAV – 90 to 120 cm
- FAV – 1 to 2 m
- OW - >2 m

Currently, there is no single publication that summarizes plant gradient studies and tolerance ranges in Florida or that synthesizes these data into a general model that can be used to predict plant survival under a range of water regimes. Until such a comprehensive synthesis is available, it is still advantageous to analyze relevant local data to develop general hydrologic tolerance ranges for the target EMV and SAV wetland plant communities.

2.5.10 Other Treatment Wetland Plant Community Design Considerations

Treatment wetland (i.e., STA) design is not one-dimensional and multiple constraints must be met in order to create a successful project (Kadlec and Wallace 2009; WSI 2009). Owners and operators of wetland systems frequently inquire as to the optimum value for any particular variable that is under the designer's control. The reality of wetland design and behavior is that all of the key design parameters are inter-related and any adjustment to one may cause a response in one or more of the others. In many cases, the reaction of one variable to the manipulation of another is counteractive to water quality improvement processes. For example, increasing aspect ratio presumably to improve hydraulic efficiency and pollutant removal effectiveness will, at some threshold inflow rate, increase frictional losses to the point that hydrologic impacts to the wetland vegetation occur and pollutant removal actually decreases. At the other end of the spectrum, lowering hydraulic loading rates to levels that minimize outflow pollutant concentrations could starve the wetland for water if evapotranspiration and seepage demands are not met.

Section 3.0 Performance Summary for Florida Treatment Wetlands

3.1 Background

Florida has long been a leader in the engineering, operation, and optimization of treatment wetlands. Starting with the Cypress Dome Natural Treatment Wetland project in the mid-1970s, a dozen other natural treatment wetlands, the first two large constructed treatment wetlands in 1987 (Lakeland and Orlando) and at least a half dozen other municipal systems, the south Florida Stormwater Treatment Areas (STAs), and dozens of large and small-scale urban and agricultural stormwater treatment wetlands, Florida systems include a broad range of treatment wetland alternatives. Treatment wetland data reviewed for this evaluation are limited to Florida systems because they have reported very complete and intensive water quality and operational data and because they are most similar to the proposed C-43 WQTA treatment wetland project in terms of climatic variables, incoming water quality, soil properties, and biological communities.

Exhibit 5 lists the treatment wetland systems evaluated for this summary. Exhibit 6 provides a map showing the locations of these pilot and full-scale treatment wetland projects in central and south Florida. These projects cover a very broad range of conditions, including inflow nitrogen and phosphorus concentrations and forms, soils diversity, loading rates, and effluent concentrations. This performance evaluation is empirical in that it compares actual operational data for these systems and does not rely on model estimates. Pollutant-specific kinetic rate constants based on the k-C* model of Kadlec and Knight (1996) and the p-k-C* model of Kadlec and Wallace (2009) do not include the level of detail needed for this evaluation since they do not separate systems by plant community dominants, water depth, presence of open water, and site soil conditions. Calibrated values for a variety of treatment wetland plant communities are available for removal of TP using the Dynamic Model for Stormwater Treatment Areas version 2 (DMSTA2) supported by Walker and Kadlec (2008).

The reader is cautioned that there is some operational and analytical uncertainty in the data used for these analyses. This uncertainty is variable between data sets and could not be quantified by WSI for this evaluation. For example, Minimum Detection Limits (MDLs) may vary in some labs from year-to-year and researchers may report levels less than the MDL using different protocols. In some cases flow-weighted means were reported and in others only arithmetic means were available. These uncertainties result in statistical errors of unknown magnitude at the lower pollutant concentrations. One half of the MDL was used by WSI in generating statistics when researchers identified values below the MDL. The various treatment wetlands described below also have a wide range of design and operational variation that is incompletely known. The purpose of this analysis is to look at a large body of empirical data from a wide variety of Florida full-scale treatment wetland systems. Using this approach it is assumed that important data trends can be observed and that, if data trends are not obvious, they are probably not important or reproducible. Also, it is not likely to be productive for this evaluation of wetland treatment options to dwell too much on the inter-annual behavior of treatment wetlands experiencing a wide range of environmental variables. For these reasons

WSI does not attempt to offer informed conclusions about why treatment systems had positive nutrient removal performance in some years and negative removals in other years.

Exhibit 5 - Summary of Design Criteria for Existing Treatment Sites Evaluated

System	Area (ha)	HLR (cm/d)	Period-of-Record		Substrate	Vegetation
Phase I Apopka Marsh Flow-Way						
Cell B1	67.99	11.31	Nov-03	Dec-09	PEAT	EMERGENT
Cell B2	45.73	13.82	Nov-03	Dec-09	PEAT	EMERGENT
Cell C1	74.06	11.75	Nov-03	Dec-09	PEAT	EMERGENT
Cell C2	73.25	10.51	Nov-03	Dec-09	PEAT	EMERGENT
C-43 West Storage Reservoir Test Cell						
Cell 1	1.82	5.15	Jun-06	May-07	SAND	OPEN
Cell 2	1.82	5.15	Jun-06	May-07	SAND	OPEN
C-44 Reservoir / Stormwater Treatment Area Test Cells						
STA Cell 1	1.74	3.35	Jul-06	Dec-06	SAND	EMERGENT
STA Cell 2	1.74	7.82	Jul-06	Dec-06	SAND	EMERGENT
Test Cell 1	1.50	3.59	Jul-06	Jun-07	SAND	OPEN
Test Cell 2	1.50	4.60	Jul-06	Jun-07	SAND	OPEN
City of Lakeland Wetland Treatment System Cell 1						
Cell 1	81.40	3.84	Jan-87	Sep-08	CLAY	EMERGENT
Cell 2	77.33	3.43	Jan-87	Sep-08	CLAY	EMERGENT
Cell 3	166.87	2.07	Jan-87	Sep-08	CLAY	EMERGENT
Cell 4	30.53	9.02	Jan-87	Sep-08	CLAY	EMERGENT
Cell 5	93.61	1.12	Jan-87	Sep-08	CLAY	SAV
Cell 6	19.94	6.89	Jan-87	Sep-08	CLAY	FAV
Cell 7	14.25	7.80	Jan-87	Sep-08	CLAY	FAV
Orlando Easterly Wetlands	485.64	1.15	Jan-88	Nov-11	SAND	EMERGENT
SFWMD Field-Scale PSTA Cells						
FS-1	2.08	8.37	Aug-01	Dec-02	LIME ROCK	PSTA
FS-2	2.08	12.07	Sep-01	Dec-02	LIME ROCK	PSTA
FS-3	2.08	9.27	Aug-01	Dec-02	LIME ROCK	PSTA
FS-4	2.08	11.03	Nov-01	Dec-02	PEAT	PSTA
SFWMD Porta-PSTA Mesocosms Treatments						
Treatment 1	0.0006	7.17	Apr-99	Jan-00	PEAT	PSTA
Treatment 2	0.0006	7.11	Apr-99	Jan-00	LIME ROCK	PSTA
Treatment 3	0.0006	7.18	Apr-99	Feb-01	PEAT	PSTA
Treatment 4	0.0006	7.49	Apr-99	Feb-01	LIME ROCK	PSTA
Treatment 5	0.0006	13.84	Apr-99	Mar-00	LIME ROCK	PSTA
Treatment 6	0.0006	5.54	Apr-99	Mar-00	LIME ROCK	PSTA
Treatment 7	0.0006	7.36	Apr-99	Feb-01	SAND	PSTA
Treatment 8	0.0006	7.32	Apr-99	Jan-00	SAND	PSTA
Treatment 9	0.0006	7.32	Apr-99	Mar-00	PEAT	OPEN
Treatment 10	0.0006	7.14	Apr-99	Mar-00	LIME ROCK	OPEN
Treatment 11	0.0018	7.78	Apr-99	Feb-01	LIME ROCK	PSTA
Treatment 12	0.0018	7.63	Apr-99	Feb-01	PEAT	PSTA
Treatment 13	0.0006	8.14	Apr-00	Feb-01	PEAT	PSTA
Treatment 14	0.0006	8.03	Apr-00	Feb-01	LIME ROCK	PSTA
Treatment 15	0.0006	7.40	Apr-00	Feb-01	LIME ROCK	PSTA
Treatment 16	0.0006	15.69	May-00	Feb-01	LIME ROCK	PSTA
Treatment 17	0.0006	7.49	Apr-00	Feb-01	SAND	PSTA
Treatment 18	0.0006	8.11	Apr-00	Feb-01	NONE	OPEN
Treatment 19	0.0006	7.84	Apr-00	Feb-01	NONE	PSTA
SFWMD PSTA Test Cells Treatments						
Treatment 1	0.26	4.57	Feb-99	Jan-00	PEAT	PSTA
Treatment 2	0.26	4.65	Feb-99	Mar-00	LIME ROCK	PSTA
Treatment 3	0.26	4.03	Feb-99	Mar-00	LIME ROCK	PSTA
Treatment 4	0.24	5.08	Apr-00	Mar-01	PEAT	PSTA
Treatment 5	0.24	5.14	Apr-00	Mar-01	LIME ROCK	PSTA
Treatment 6	0.25	5.35	May-00	Mar-01	LIME ROCK	PSTA
STA-1E						
Cell 3	214.48	7.28	May-06	Jan-12	SAND	EMERGENT
Cell 4N	257.35	6.38	May-06	Jan-12	SAND	SAV
Cell 4S	291.98	6.92	May-06	Jan-12	PEAT	SAV
Cell 5	209.19	3.25	May-06	Jan-12	SAND	EMERGENT
Cell 6	417.65	3.27	May-06	Jan-12	PEAT	SAV
Cell 7	166.33	3.55	May-06	Jan-12	PEAT	EMERGENT

Exhibit 5 Cont. - Summary of Design Criteria for Existing Treatment Sites Evaluated

System	Area (ha)	HLR (cm/d)	Period-of-Record		Substrate	Vegetation
STA-1W						
Cell 1	602.99	8.46	Jun-00	Jan-08	PEAT	EMERGENT
Cell 1A	301.51	10.21	May-08	Jan-12	PEAT	EMERGENT
Cell 1B+3	716.70	5.40	May-08	Jan-12	PEAT	SAV
Cell 2	380.82	6.44	Jun-00	Nov-04	PEAT	EMERGENT
Cell 3	415.22	9.31	Jun-00	Jan-08	PEAT	EMERGENT
Cell 4	144.88	18.39	Jun-00	Nov-04	PEAT	SAV
North Flow-way	1155.38	3.08	Jun-00	Feb-12	PEAT	SAV
West Flow-way	525.69	3.36	Feb-08	Feb-12	PEAT	SAV
STA-2						
Cell 1A	805.00	2.41	Mar-02	May-05	PEAT	EMERGENT
Cell 1B	805.00	2.39	Jun-05	Feb-12	PEAT	EMERGENT
Cell 2	898.00	3.97	Mar-02	Feb-12	PEAT	EMERGENT
Cell 3	898.00	3.86	Mar-02	Feb-12	PEAT	SAV
Cell 4	769.71	1.19	Feb-08	Feb-12	PEAT	SAV
STA-3/4						
Cell 1A	1229.84	4.61	May-05	Jan-12	PEAT	EMERGENT
Cell 1B	1411.55	5.40	May-05	Feb-12	PEAT	SAV
Cell 2A	1028.71	4.65	May-05	Jan-12	PEAT	EMERGENT
Cell 2B	1171.16	4.54	May-05	Feb-12	PEAT	SAV
Cell 3A	871.29	6.17	Apr-08	Feb-12	PEAT	EMERGENT
Cell 3B	982.17	10.04	Apr-08	Nov-11	PEAT	SAV
STA-5						
Cell 1A	337.91	3.09	Apr-08	Feb-12	PEAT	EMERGENT
Cell 1B	493.72	3.80	Apr-08	Jan-12	PEAT	SAV
Cell 2A	337.91	3.54	Apr-08	Feb-12	PEAT	EMERGENT
Cell 2B	493.72	2.66	Apr-08	Feb-12	PEAT	SAV
Cell 3A	405.50	0.68	Apr-08	Feb-12	PEAT	EMERGENT
Cell 3B	397.81	0.83	Apr-08	Feb-12	PEAT	SAV
Center Flow-way	831.63	2.58	May-00	Mar-08	PEAT	EMERGENT
North Flow-way	803.30	3.48	May-00	Mar-08	PEAT	EMERGENT
STA-6						
Cell 3	99.00	2.89	Oct-02	Feb-12	PEAT	EMERGENT
Cell 5	253.00	2.46	Oct-02	Feb-12	PEAT	EMERGENT
Section 2	561.30	3.13	May-08	Oct-11	PEAT	SAV
Taylor Creek Pilot STA	57.47	7.29	Jun-08	Jan-12	SAND	EMERGENT
City of Titusville, Blue Heron Wetland	101.56	0.65	Jan-97	Dec-11	SAND	EMERGENT
Wellington Aquatics Pilot Test Facility						
Cell E1	0.055	26.97	Nov-01	Feb-03	SAND	EMERGENT
Cell E2	0.044	19.08	Nov-01	Feb-03	SAND	SAV
Cell E3	0.049	19.82	Nov-01	Feb-03	LIME ROCK	PSTA
Cell W1	0.047	33.49	Nov-01	Feb-03	SAND	FAV
Cell W2	0.055	13.30	Nov-01	Feb-03	SAND	EMERGENT
Cell W3	0.049	11.77	Nov-01	Feb-03	LIME ROCK	PSTA

HLR = Hydraulic Loading Rate

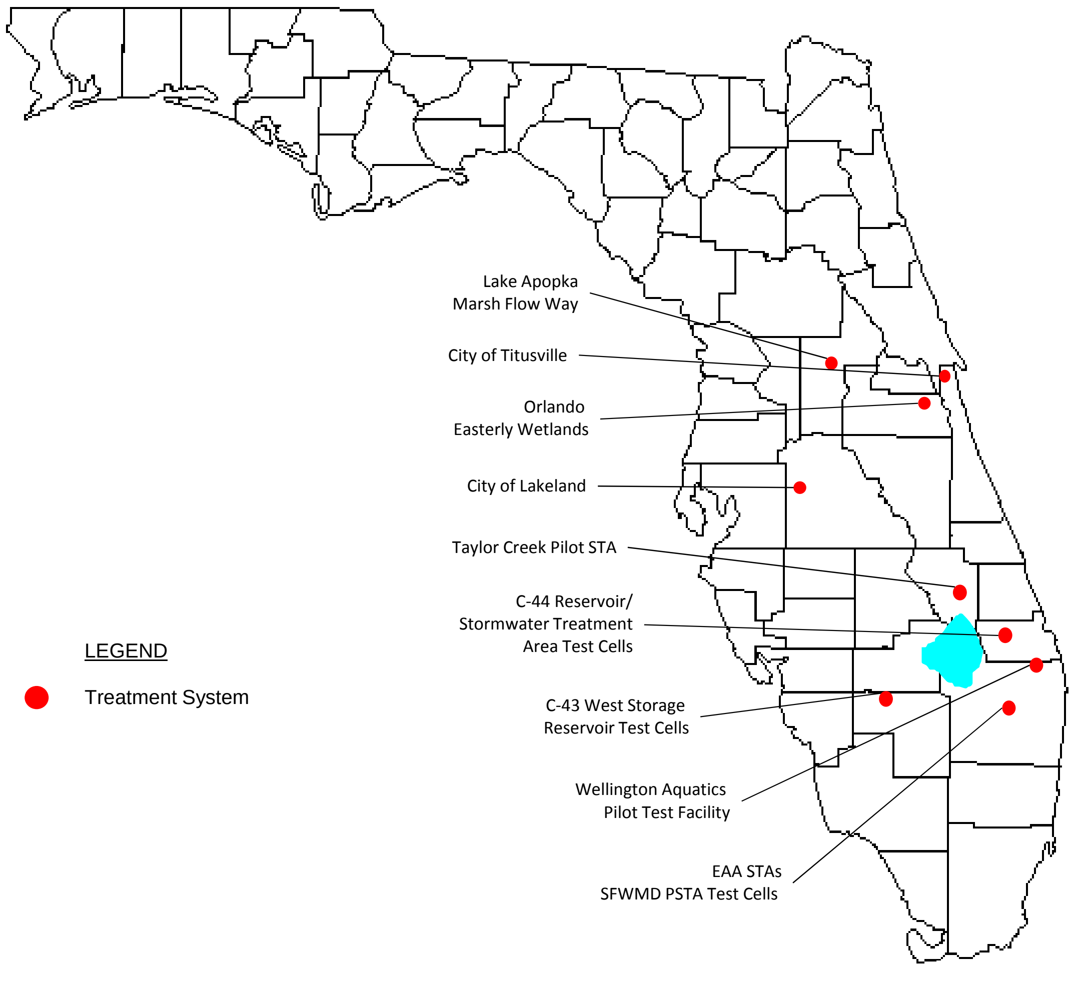


Exhibit 6 - Location of Reviewed Florida Treatment Wetland Sites

3.2 Description of Florida Treatment Wetlands Reviewed for Performance Evaluation

3.2.1 Everglades Agricultural Area Stormwater Treatment Areas

The SFWMD has constructed massive treatment wetland projects, the STAs, to improve water quality in discharges to the Water Conservation Areas (WCAs) and Everglades National Park (ENP). To date, the SFWMD has constructed six STAs south of Lake Okeechobee, each ranging in size from approximately 2,250 acres (910 ha) to over 16,500 acres (6,680 ha). Exhibit 7 provides a map of the Everglades Agricultural Area (EAA) and the locations of these six STAs. Exhibit 8 provides site plans, cell configurations, and structure locations for each of the EAA STAs.

The EAA STAs were largely constructed on land that was formerly used for agricultural operations such as sugar-cane production, sod production, and citrus groves. Existing substrates ranged from sandy mineral soils to very thick organic peat soils to exposed limestone caprock. The majority of the vegetation in the STAs was 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.

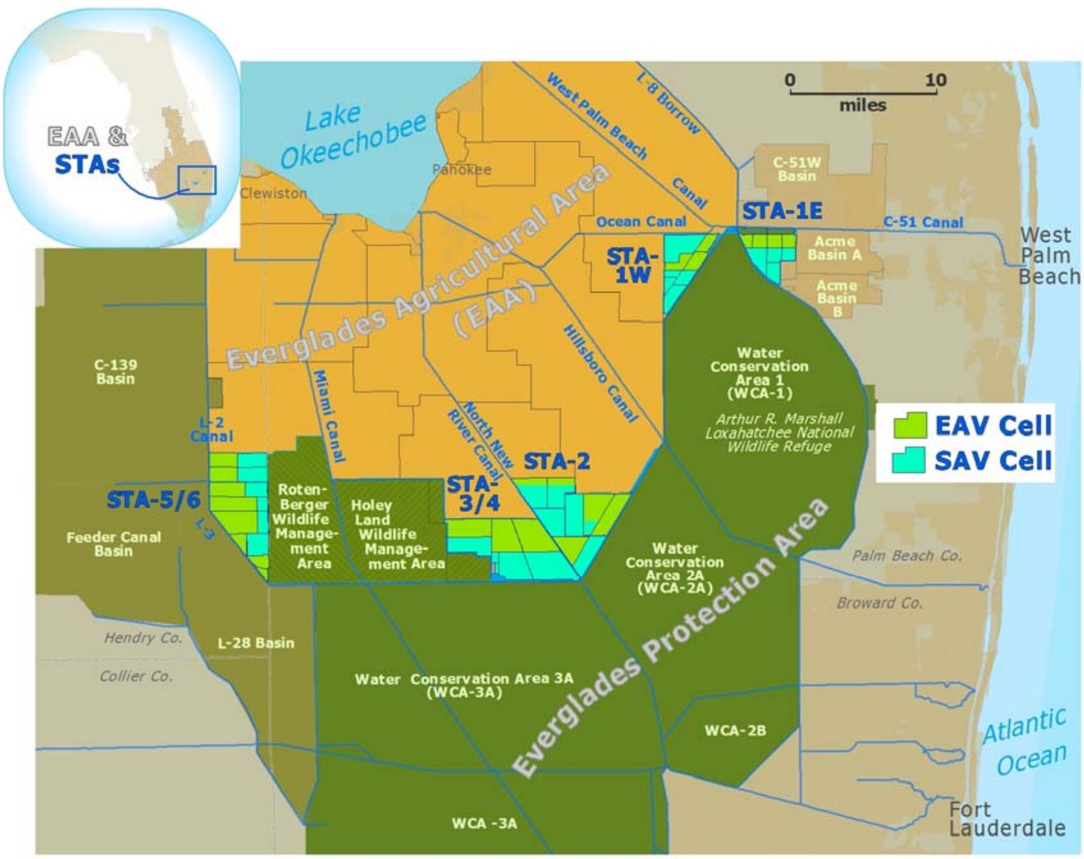


Exhibit 7 - Location of Stormwater Treatment Areas (SFWMD SFER 2011)

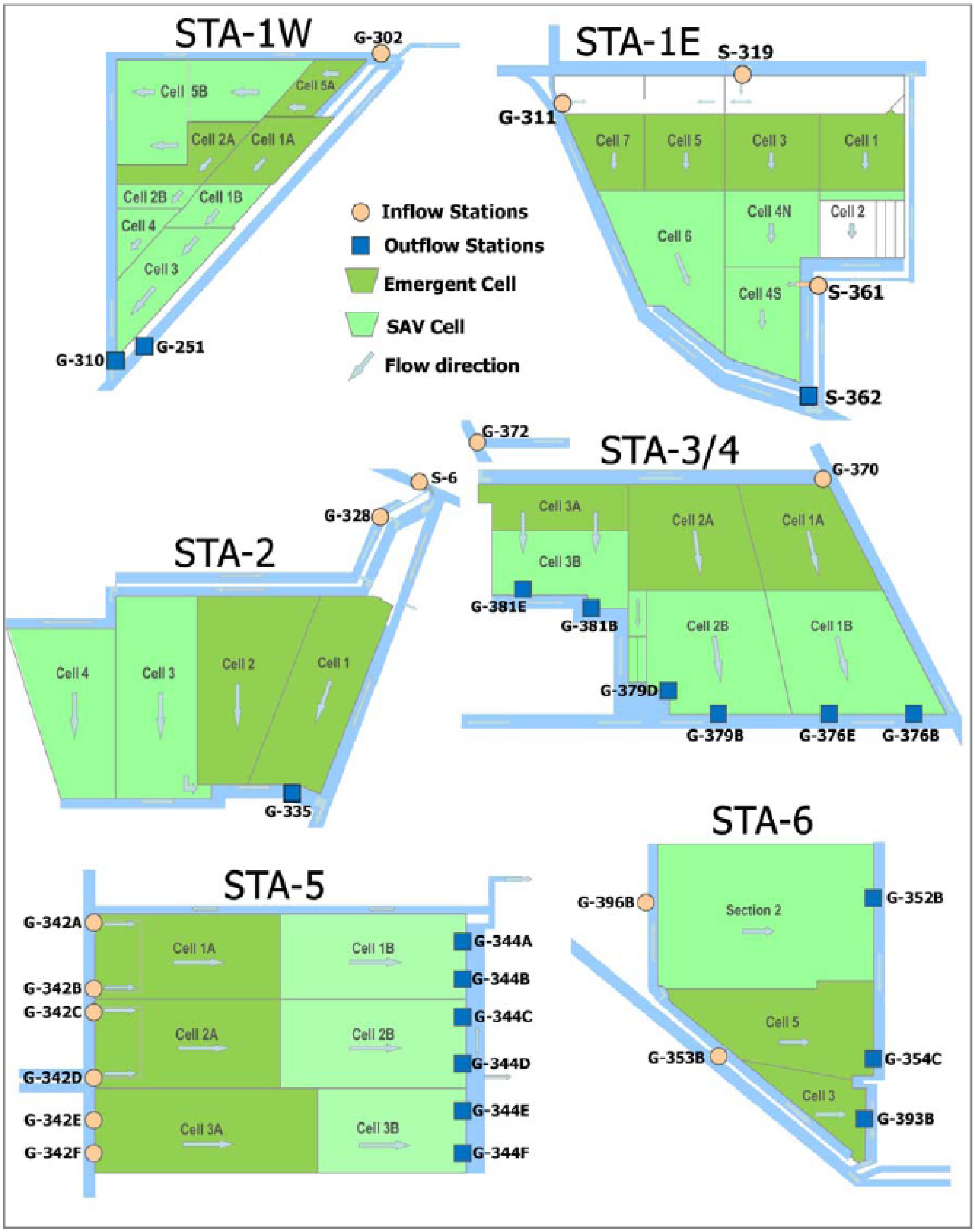


Exhibit 8 - Stormwater Treatment Areas Inlet and Outlet Structures and Cell Configuration (SFWMD SFER 2011)

3.2.1.1 STA-1E

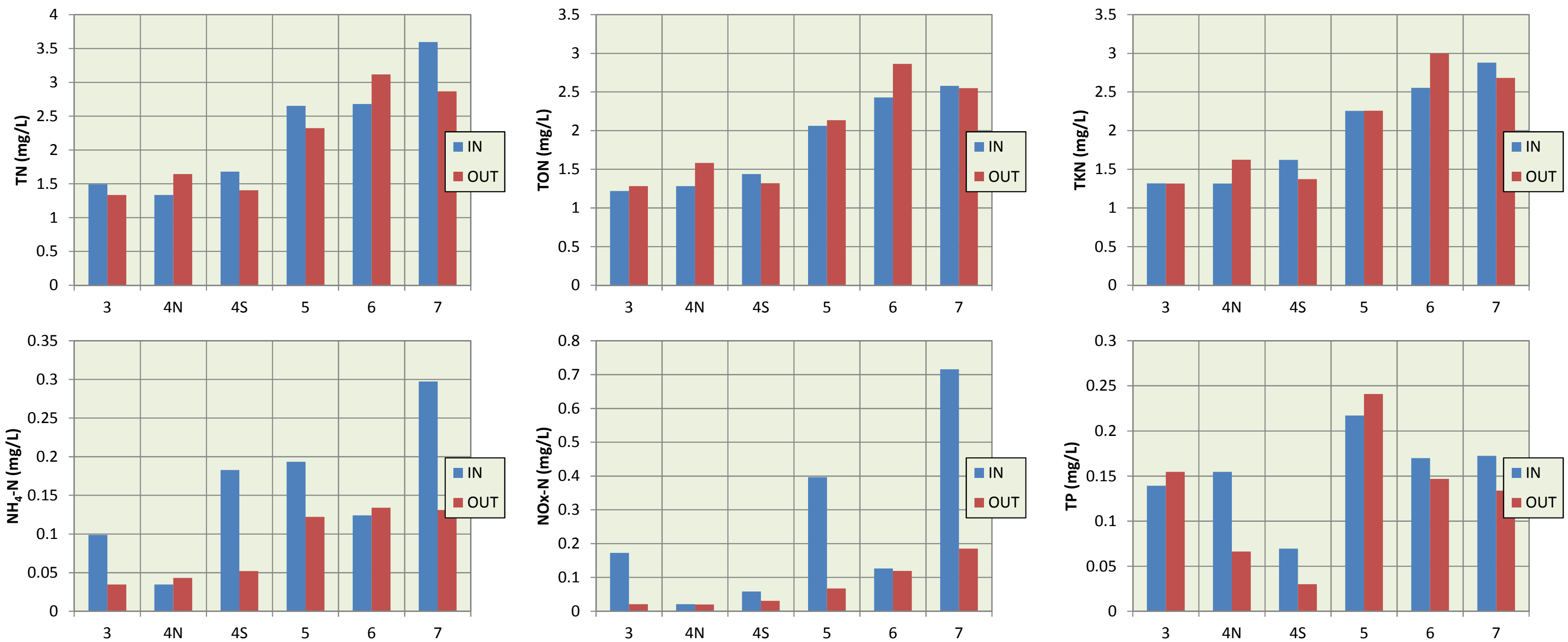
STA-1 East (STA-1E) was permitted for approximately 5,132 acres (2,077 ha) of effective treatment area arranged in three flow-ways (WSI and Anamar 2011). STA-1E has been operated for multiple purposes including water treatment and water treatment research. The eastern flow-way contains Cells 1 and 2; the central flow-way contains Cell 3 upstream, Cell 4N in the center, and Cell 4S downstream; and the western flow-way contains Cells 5 and 7 upstream and Cell 6 downstream. Cells 1 and 2 have been operated by the USACE for the purpose of testing PSTA; data from this flow-way are not discussed in this report. The current effective area of STA-1E including the PSTA test cells is 3,199 acres (SFWMD 2011). Flow-through operations in the center and western flow-way began in the summer of 2004. Flow from STA-1E is discharged to Loxahatchee National Wildlife Refuge.

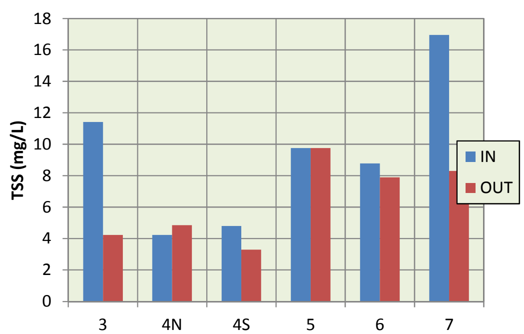
The design flow rate to STA-1E (including Cells 1 and 2) is about 111 mgd (420,000 m^3/d). The system-wide, period-of-record (POR) (May 2006-January 2012) average inflow was 78 mgd (301,000 m^3/d), excluding Cells 1 and 2. Within this STA, Cells 3, 4N, and 5 have sandy soils and Cells 4S, 6, and 7 have peat soils (Appendix A). Vegetation consists primarily of EMV in Cells 3, 5, and 7 and primarily SAV in Cells 4N, 4S, and 6. Exhibit 9 shows the long-term average nutrient and solids inflow and outflow concentration data for each cell with monthly time series data presented in Appendix B. It should be noted that some of the cells in many of these treatment wetlands are arranged in series and that the sum of the individual cell inflows is therefore greater than the overall site inflow.

3.2.1.2 STA-1W

STA-1 West (STA-1W) contains approximately 6,670 acres (2,700 ha) of effective treatment area arranged in three flow-ways (Goforth *et al*. 2004). The eastern flow-way (EFW) contains Cells 1A, 1B, and 3; the western flow-way (WFW) contains Cells 2A, 2B, and 4; and the northern flow-way (NFW) 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 ENRP, for future STAs. The system has been referred to as STA-1W since Cell 5 began operations in July 2000. In 2004, additional modifications were made to divide Cells 1 and 2 to create Cells 1A and 1B in the footprint of Cell 1 and Cells 2A and 2B in the footprint of Cell 2. Flow from STA-1W is discharged to Water Conservation Area 1A.

The design flow rate to STA-1W exceeds 128 mgd (483,000 m3/d). During the POR, the system-wide average flow was 87.2 mgd (330,000 m3/d). In this STA, all cells were constructed on peat (Appendix A) with Cells 1A, 2A, 3, and 5A dominated by EMV plant communities and Cells 1B, 2B, 4, and 5B predominantly containing SAV plant communities. Exhibit 10 shows the POR (June 2000 - February 2012) average inflow and outflow nutrient and solids concentrations by cell with monthly time series data presented in Appendix B.

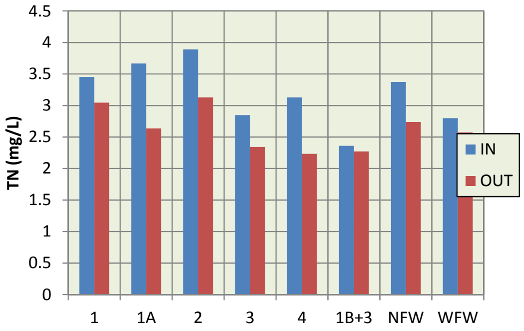


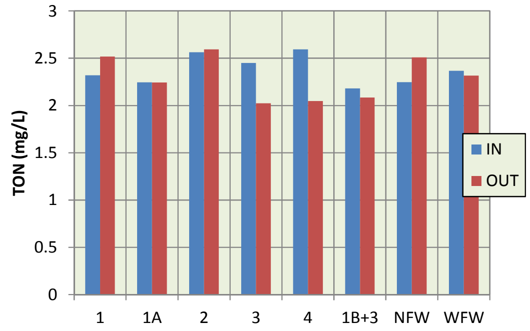


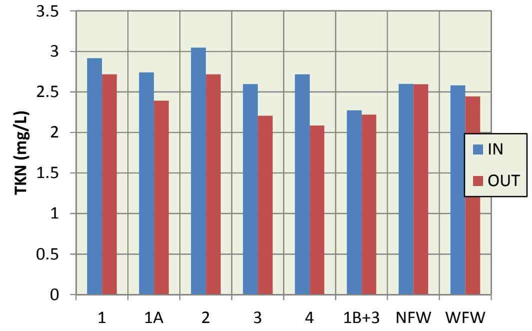
STA-1E

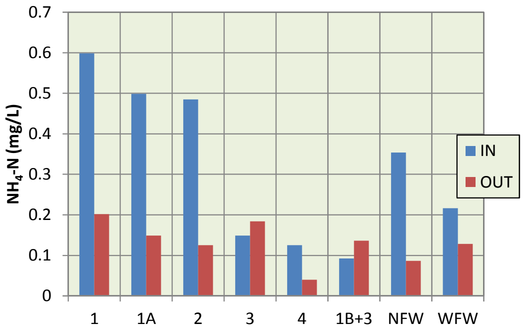
Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
3	214.48	156,044	164,292	7.28	SAND	EMERGENT
4N	257.35	164,292	170,220	6.38	SAND	SAV
4S	291.98	202,059	193,543	6.92	PEAT	SAV
5	209.19	68,033	70,813	3.25	SAND	EMERGENT
6	417.65	136,713	125,726	3.27	PEAT	SAV
7	166.33	59,049	65,900	3.55	PEAT	EMERGENT
Period of Record	May-06	Jan-12				

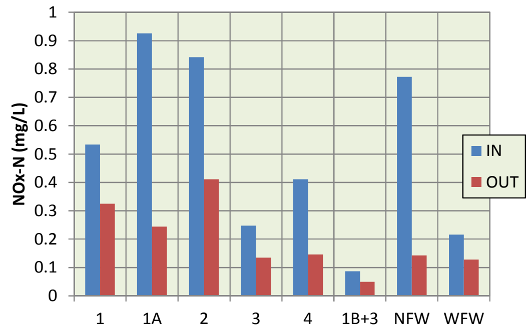
Exhibit 9 - STA-1E Long-term Average Water Quality Summary

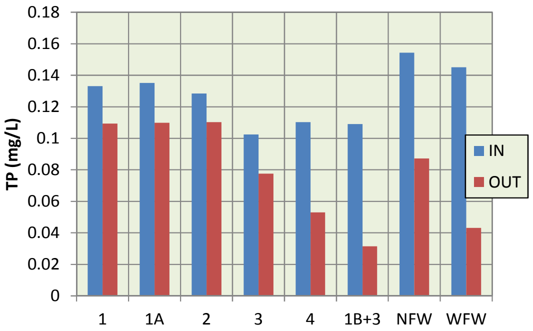


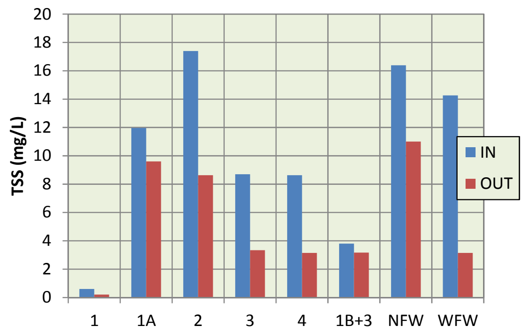












STA-1W

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
1	602.99	510,425	451,537	8.46	PEAT	EMERGENT
1A	301.51	307,926	557,194	10.21	PEAT	EMERGENT
2	380.82	245,317	266,479	6.44	PEAT	EMERGENT
3	415.22	386,760	328,464	9.31	PEAT	EMERGENT
4	144.88	266,479	307,405	18.39	PEAT	SAV
1B+3	716.70	386,821	165,056	5.40	PEAT	SAV
NFW	1155.38	356,403	370,844	3.08	PEAT	SAV
WFW	525.69	176,541	128,603	3.36	PEAT	SAV
Period of Record	Jun-00	Feb-12				

Exhibit 10 - STA-1W Long-term Average Water Quality Summary

3.2.1.3 STA-2

STA-2 contains approximately 8,240 acres (3,335 ha) of treatment area arranged in four parallel cells (SFWMD 2011) and began operation in mid-1999. All four cells were constructed on peat soils (Appendix A) with Cells 1 and 2 dominated by EMV plant communities and Cells 3 and 4 predominantly containing SAV plant communities. Cells 1A and 1B represent different time periods for Cell 1 (A = March 2002 – May 2005; B = June 2005 – February 2012).

The design flow for STA-2 is approximately 208 mgd (787,000 m^3/d). Exhibit 11 shows POR (March 2002 to February 2012) average inflow and outflow concentration data for nutrient and solids by cell with monthly time series data presented in Appendix B.

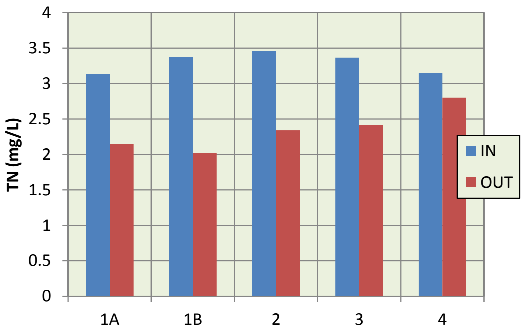
3.2.1.4 STA-3/4

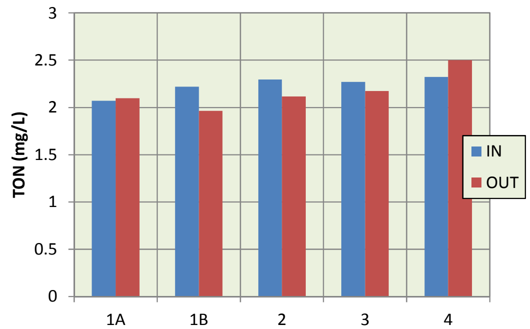
STA-3/4 is the largest of the existing STAs, with 16,543 acres of treatment area (SFWMD 2011). STA-3/4 has three flow-ways: the east flow-way is made up of Cells 1A and 1B, the central flow-way is made up of Cells 2A and 2B, and the west flow-way is Cells 3A and 3B. A 400-acre portion of Cell 2B has been converted to a PSTA demonstration project and is operated independently for water quality performance.

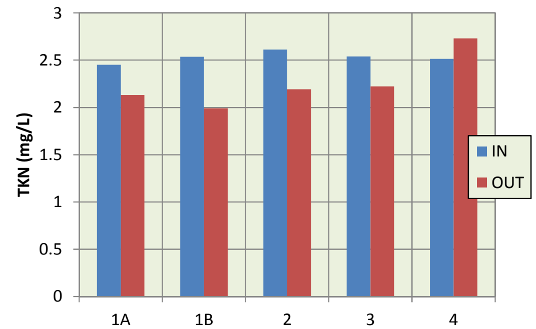
Lessons learned from earlier STA designs were incorporated into the design for STA-3/4 which was placed into operation in October 2003. These included compartmentalization of the system into a greater number of cells, back-filling farm ditches that channelize flow, and growing plants during the construction phase rather than following the completion of construction.

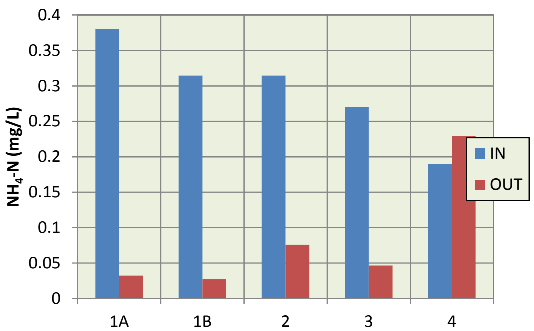
As with most of the STAs, the upstream cells (1A, 2A, and 3A) are dominated by EMV, and the downstream cells (1B, 2B, and 3B) are primarily SAV vegetation. Peat soils are the primary soil type for all of STA-3/4 (Appendix A).

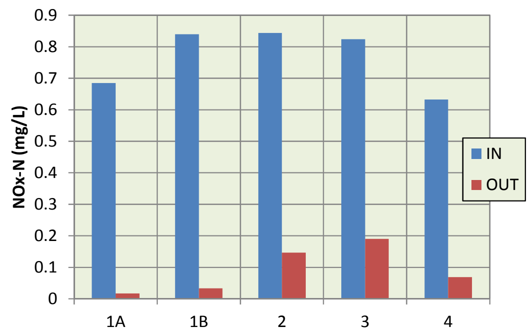
During the POR, inflows have averaged 418 mgd (1,583,000 m^3/d). Exhibit 12 shows the POR (May 2005 to February 2012) average inflow and outflow concentration data for nutrient and solids by cell with monthly time series data presented in Appendix B.

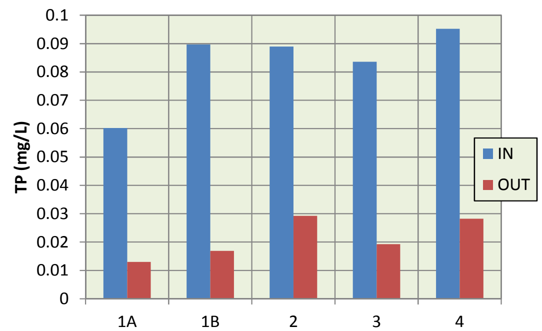


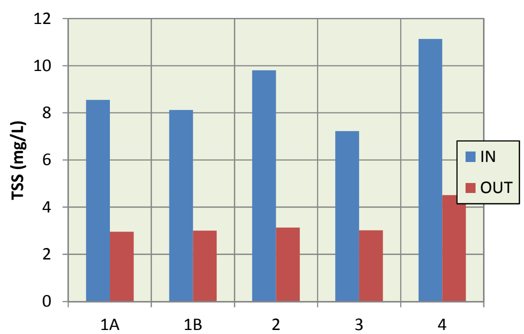










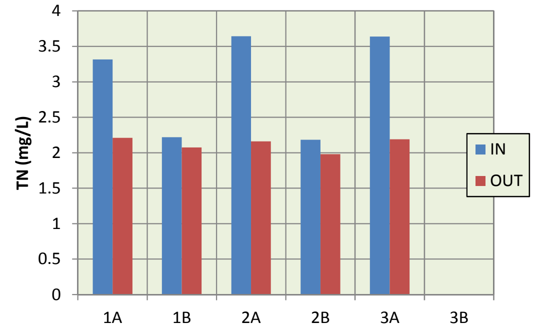


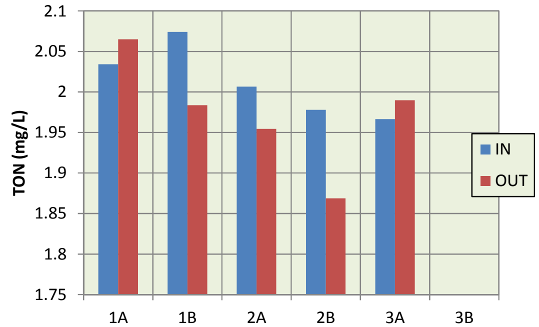
STA-2

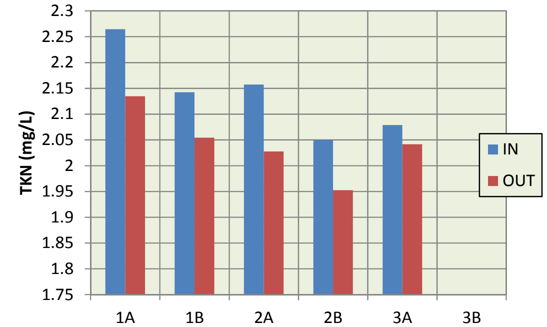
Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
1A	805.00	194,267	139,901	2.41	PEAT	EMERGENT
1B	805.00	192,542	172,734	2.39	PEAT	EMERGENT
2	898.00	356,453	340,917	3.97	PEAT	EMERGENT
3	898.00	346,738	332,035	3.86	PEAT	SAV
4	769.71	91,214	112,855	1.19	PEAT	SAV

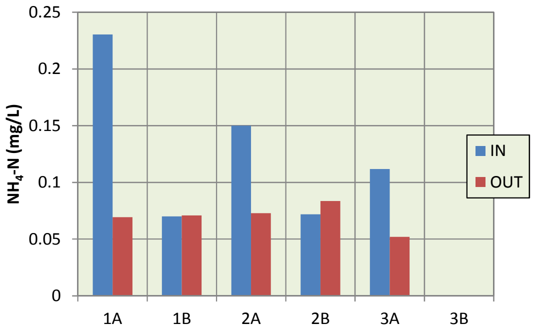
Period of Record Mar-02 Feb-12

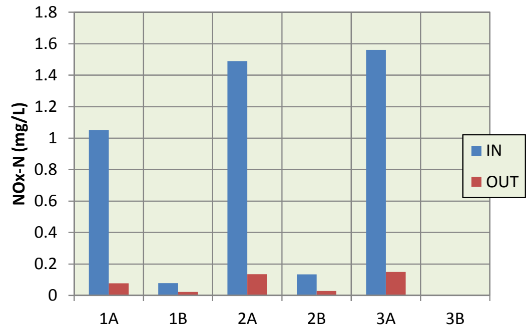
Exhibit 11 - STA-2 Long-term Average Water Quality Summary

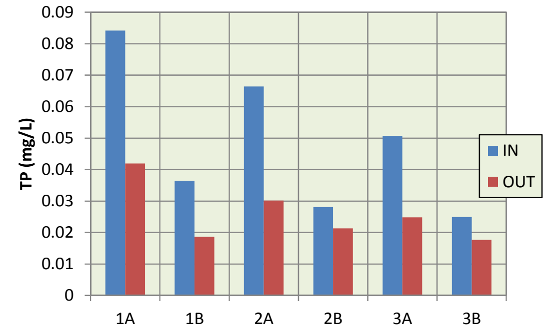


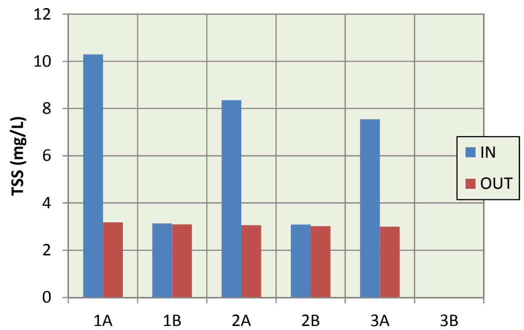












STA-3/4

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
1A	1,229.84	567,471	772,007	4.61	PEAT	EMERGENT
1B	1,411.55	762,447	650,478	5.40	PEAT	SAV
2A	1,028.71	477,921	536,763	4.65	PEAT	EMERGENT
2B	1,171.16	532,116	485,111	4.54	PEAT	SAV
3A	871.29	537,615	985,158	6.17	PEAT	EMERGENT
3B	982.17	986,219	550,439	10.04	PEAT	SAV

Period of Record May-05 Feb-12

Exhibit 12 - STA-3/4 Long-term Average Water Quality Summary

3.2.1.5 STA-5

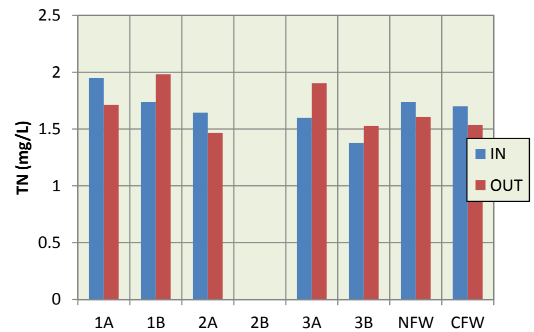
STA-5 contains 4,082 acres (1,652 ha) of effective treatment area arranged in three parallel flow-ways. The POR average inflow volume has been 67 mgd (252,000 m^3/d). This STA has a northern flow-way (NFW - Cells 1A and 1B), a central flow-way (CFW - Cells 2A and 2B), and a southern flow-way (SFW - Cells 3A and 3B). The upstream cells (1A, 2A, and 3A) are primarily dominated by EMV while the downstream cells (1B, 2B, and 3B) are SAV dominated. The majority of the soils beneath the STA-5 are organic peat soils (Appendix A). Treated water is discharged to either the Rotenberger Wildlife Management Area or the Miami Canal, where the majority of the water moves south to the northwest corner of WCA-3A.

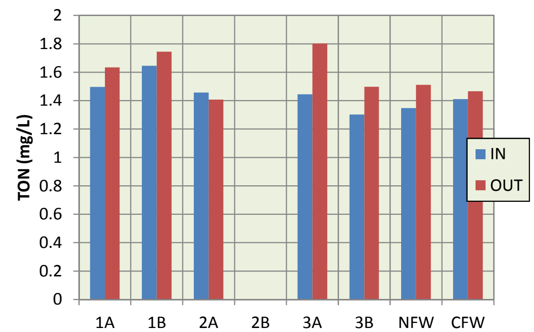
Exhibit 13 shows the POR (May 2000 to February 2012) average inflow and outflow concentration data for nutrient and solids by cell with monthly time series data presented in Appendix B. Water quality data from Cell 2B was not available at the time of this report.

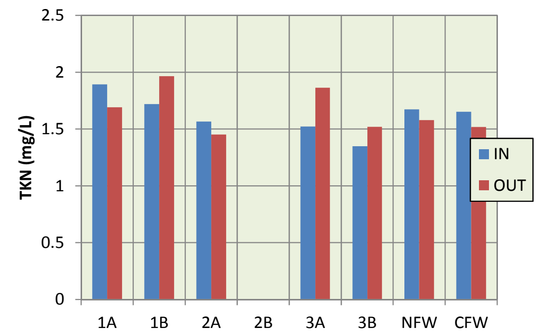
3.2.1.6 STA-6

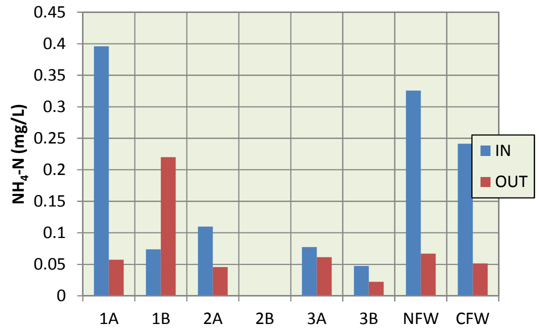
STA-6 is currently the smallest of the STAs at 2,257 acres (913 ha). STA-6 consists of three parallel cells and has a design flow of 4.8 mgd (18,300 m^3/d). Section 1 (Cells 3 and 5) went into operation in late 1997. STA-6 Section 2, constructed in 2007, added approximately 1,400 acres to the treatment system. STA-6 discharges to either Rotenberger Wildlife Management Area or the Miami Canal, where the majority of the water moves south to the northwest corner of WCA-3A. Cells 3 and 5 are operated as emergent wetland cells with Section 2 operated as an SAV dominated cell. All of STA-6 is dominated by organic peat soils (Appendix A).

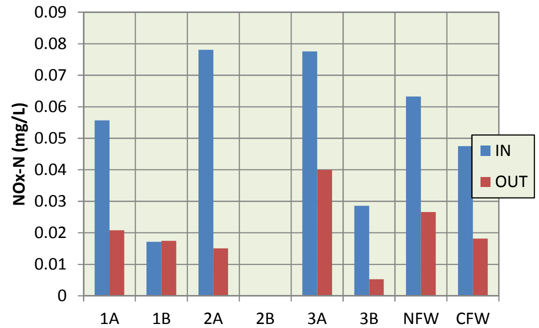
Exhibit 14 shows POR (October 2002 to October 2011) monthly average inflow and outflow concentration data for nutrient and solids by cell with monthly time series data presented in Appendix B.

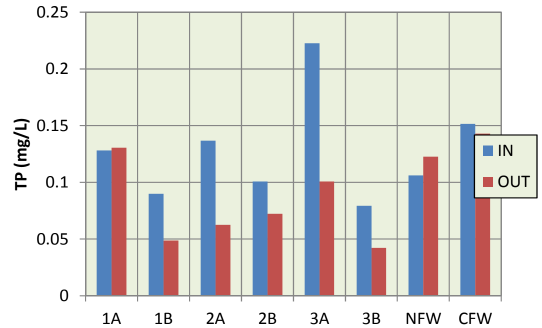


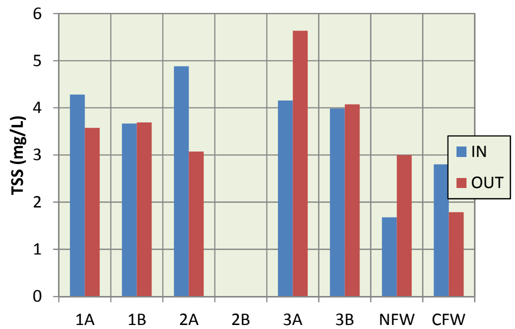








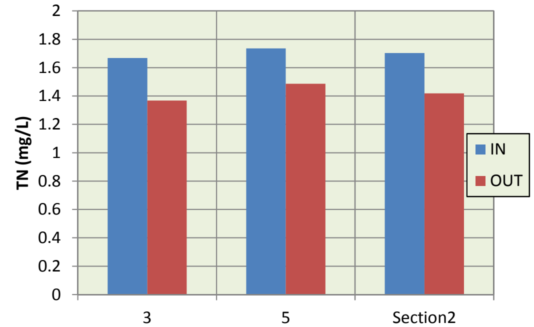


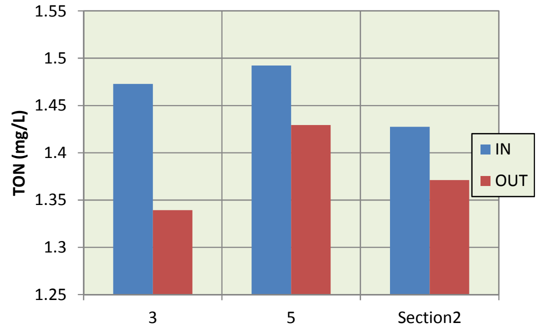


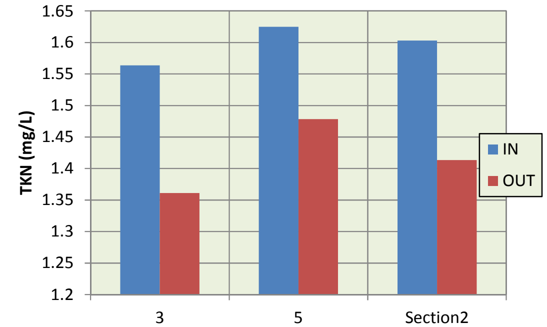
STA-5

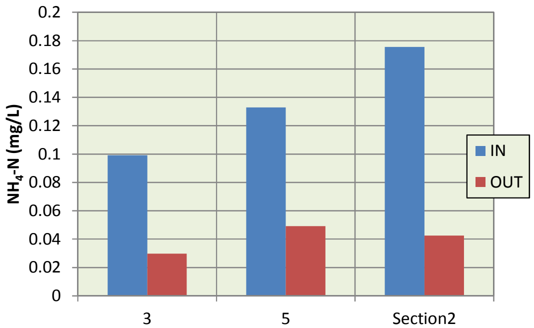
Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
1A	337.91	104,287	179,667	3.09	PEAT	EMERGENT
1B	493.72	187,411	121,147	3.80	PEAT	SAV
2A	337.91	119,656	124,114	3.54	PEAT	EMERGENT
2B	493.72	131,104	122,118	2.66	PEAT	SAV
3A	405.50	27,481	27,406	0.68	PEAT	EMERGENT
3B	397.81	33,208	8,301	0.83	PEAT	SAV
NFW	803.30	279,798	238,632	3.48	PEAT	EMERGENT
CFW	831.63	214,342	130,106	2.58	PEAT	EMERGENT
Period of Record	May-00	Feb-12				

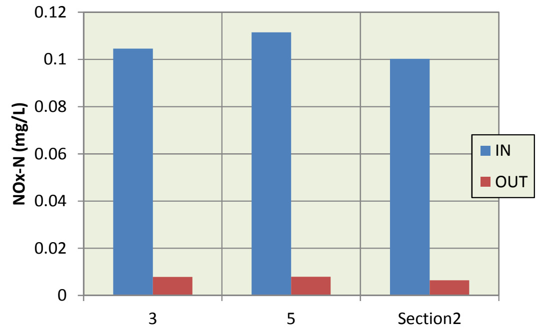
Exhibit 13 - STA-5 Long-term Average Water Quality Summary

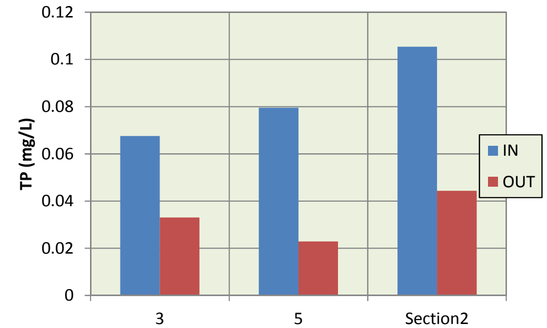


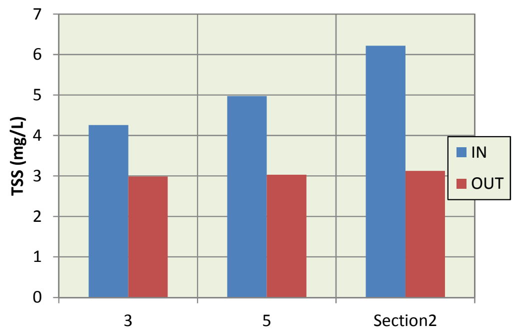












STA-6

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
3	99.00	28,600	20,286	2.89	PEAT	EMERGENT
5	253.00	62,164	32,589	2.46	PEAT	EMERGENT
Section2	561.30	175,643	152,911	3.13	PEAT	SAV
Period of Record	Oct-02	Feb-12				

Exhibit 14 - STA-6 Long-term Average Water Quality Summary

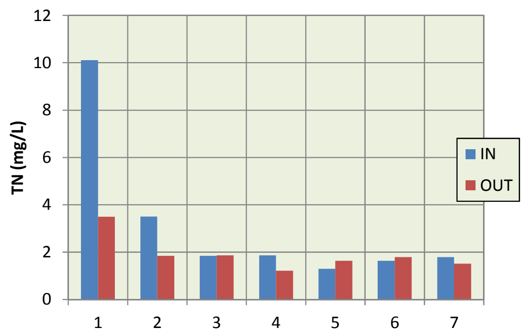
3.2.2 City of Lakeland Wetland Treatment System

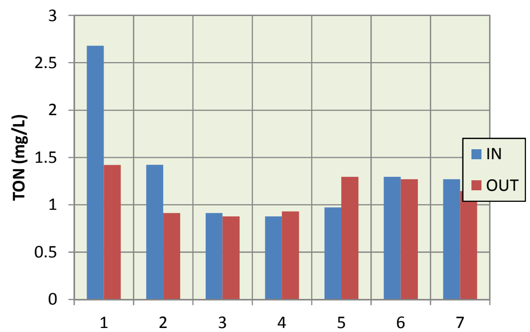
The City of Lakeland Wetland Treatment System is a 1,400-acre (565 ha) site consisting of 7 cells built on a former phosphate mine (Exhibit 15). Cells 1 through 4 are shrub and emergent marsh wetlands. Cell 5 includes emergent marsh, but is primarily a shallow lake. Deep-water systems such as Lakeland's Cell 5 typically grow phytoplanktonic algae that increase concentrations of TSS and atmospheric-fixed TON. Cells 6 and 7 are deep lakes and have experienced temporal changes in water hyacinth coverage. The Lakeland site receives up to 12 mgd (45,425 m^3/d) of treated municipal effluent from the Glendale Wastewater Treatment Plant.

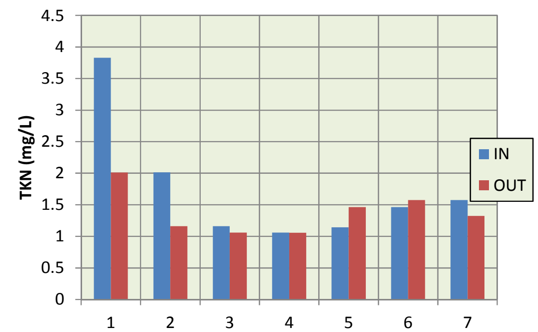
The site began operation in 1987, but underwent a series of modifications in the early- and mid-1990's to control elevated TSS concentrations caused by algal blooms in the deeper lake cells. Modifications included the use of Aquashade® to limit algal production in Cells 6 and 7, lowering of control elevations 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 (Exhibit 16 and Appendix B).

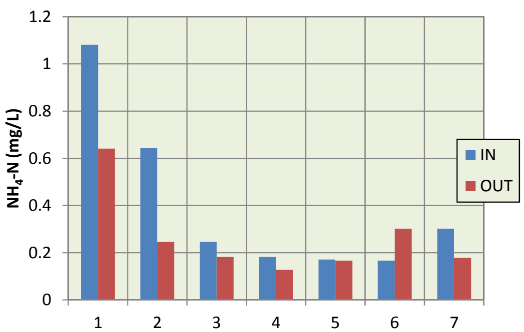
The operating permit for the Lakeland system requires effluent BOD and TSS concentrations of 5 mg/L or less and TN of 3 mg/L or less. There is no TP standard in the current permit, in recognition of the high background TP levels exhibited at the site.

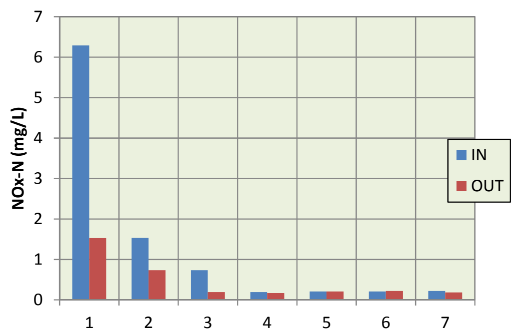
Exhibit 15 - Site plan of the Lakeland Wetland Treatment System

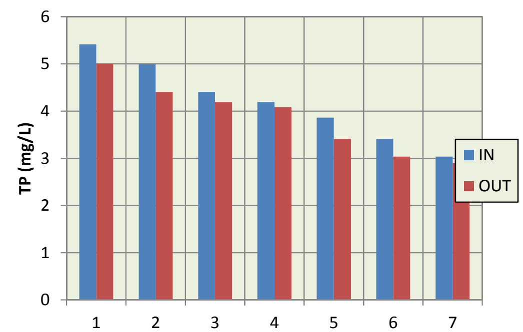


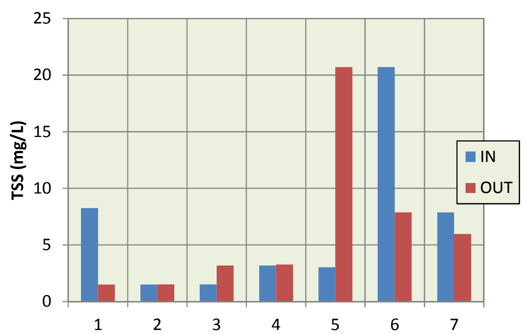












City of Lakeland Wetland Treatment System

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
1	81.40	31,283	26,526	3.84	CLAY	EMERGENT
2	77.33	26,536	34,838	3.43	CLAY	EMERGENT
3	166.87	34,609	27,548	2.07	CLAY	EMERGENT
4	30.53	27,548	18,324	9.02	CLAY	EMERGENT
5	93.61	10,505	13,748	1.12	CLAY	SAV
6	19.94	13,735	11,133	6.89	CLAY	FAV
7	14.25	11,122	17,758	7.80	CLAY	FAV
Period of Record	Jan-87	Sep-08				

Exhibit 16 - Lakeland Wetland Treatment System Long-term Average Water Quality Summary

3.2.3 Orlando Easterly Wetland

The 1,200-acre (485 ha) 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 divided into 17 cells ranging in size from 14 to 186 acres (5.6 to 75 ha). Exhibit 17 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 (Appendix A). The wetland was created by constructing earthen berms and planting over 2 million aquatic plants (USEPA, 1993).

Water is pumped 17 miles (27 km) 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.

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

Exhibit 18 shows POR (January 1988 to November 2011) monthly average inflow and outflow concentrations for nutrients and solids with monthly time series data presented in Appendix B. The long-term average inflow and outflow TN concentrations were 2.23 mg/L and 0.87 mg/L, respectively, a 61 percent reduction. The long-term average inflow and outflow TP concentrations were 0.27 mg/L and 0.06 mg/L, respectively, a 78 percent reduction. Inflow and outflow TSS concentrations were 2.0 mg/L and 2.7 mg/L, reflecting the high quality of the applied wastewater. This type of TSS increase is indicative of phytoplankton growth and is commonly seen in treatment wetlands with excessive open water areas near the outflow. The POR average flow and hydraulic loading rate were 14.7 mgd (55,700 m^3/d) and 1.15 cm/d.

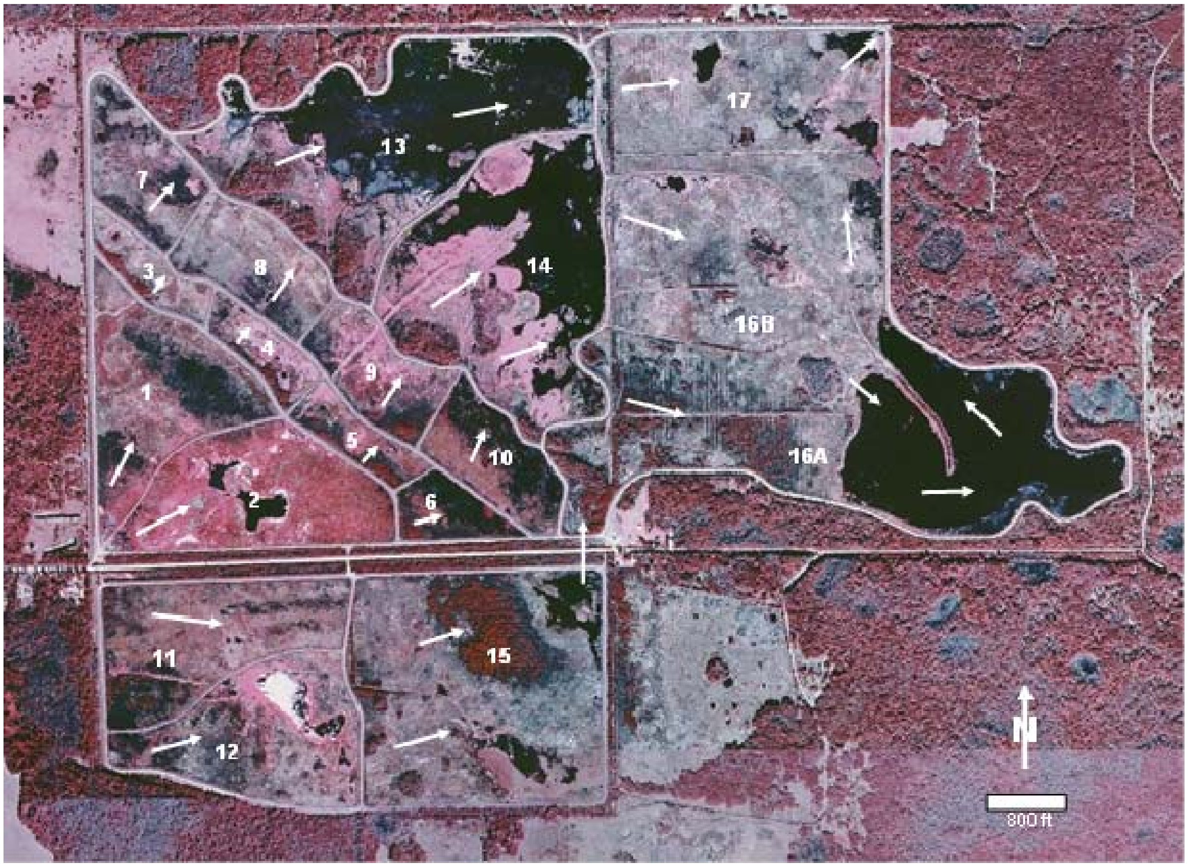
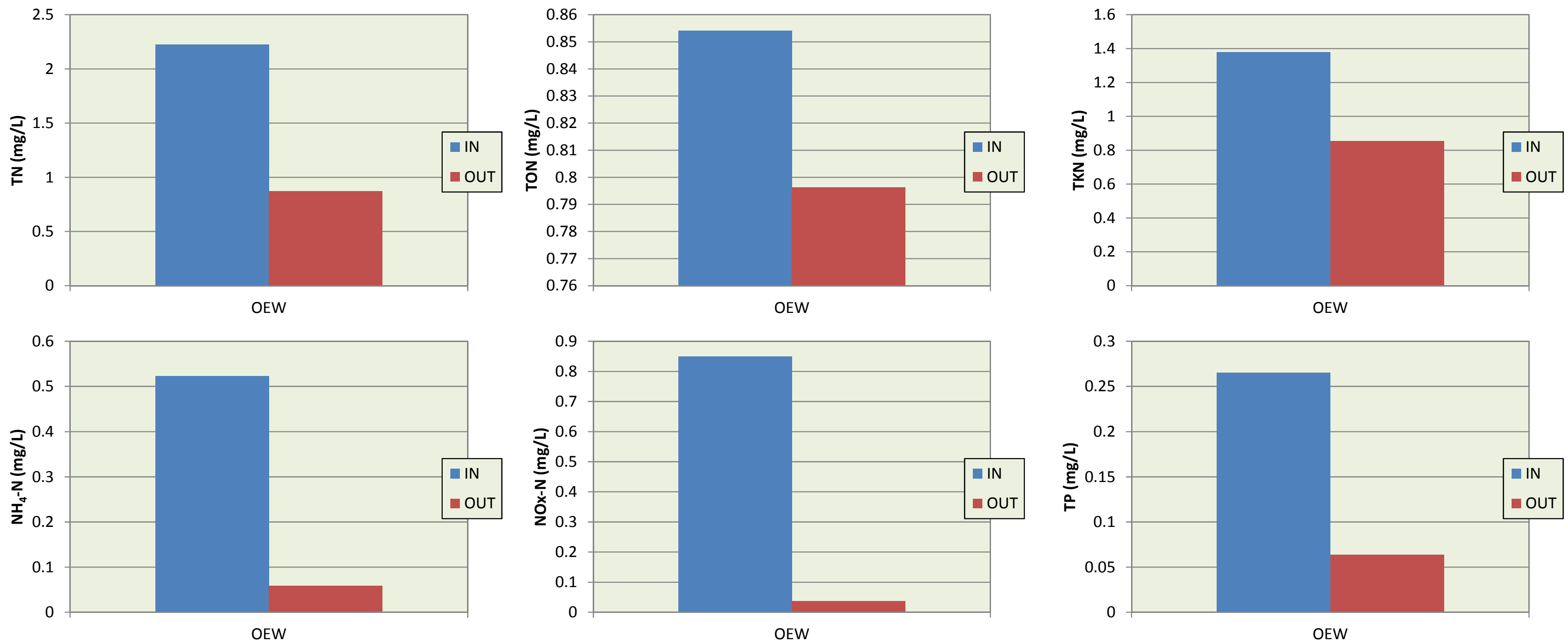


Exhibit 17 - Site Plan of the Orlando Easterly Wetlands



Orlando Easterly Wetlands

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
OEW	485.64	55,703	60,659	1.15	SAND	EMERGENT
Period of Record	Jan-88	Nov-11				

Exhibit 18 - Orlando Easterly Wetlands Long-term Average Water Quality Summary

3.2.4 City of Titusville, Blue Heron Wetland Treatment System

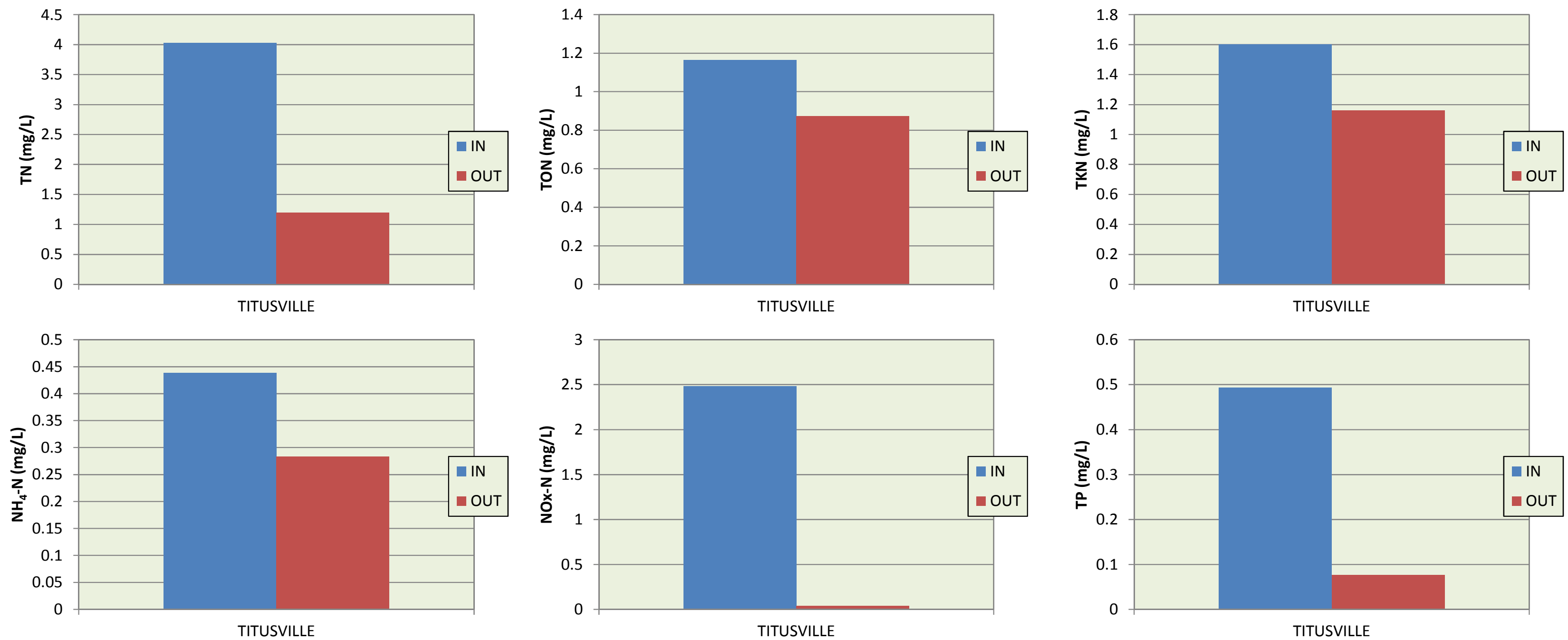
The Blue Heron Wetland Treatment System (BHWTS) is located in Brevard County and receives treated municipal effluent from the City of Titusville's Blue Heron Water Reclamation Plant. The BHWTS consists of about 264 acres (107 ha) divided into seven cells (three deep marsh cells [Cells 1-3], one pond cell [Cell 4], and three shallow marsh cells [Cells 5-7]). Exhibit 19 shows the layout of the BHWTS.

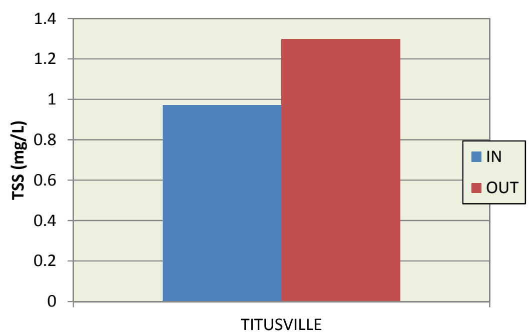
The BHWTS was constructed on land that historically formed part of the floodplain wetlands adjacent to the St. Johns River is dominated by sandy soils (Appendix A). Development and agricultural drainage activities over the past 50 years significantly altered the site, and the construction of the WTS re-established 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.

Exhibit 20 shows POR (January 1997 to December 2011) monthly average inflow and outflow concentrations for nutrients and solids with monthly time series data presented in Appendix B. The long-term average inflow and outflow TN concentrations were 4.02 mg/L and 1.19 mg/L, respectively, a 70 percent reduction. The long-term average inflow and outflow TP concentrations were 0.49 mg/L and 0.08 mg/L, respectively, a 84 percent reduction. Inflow and outflow TSS concentrations were 1.0 mg/L and 1.3 mg/L, respectively. This type of TSS increase is indicative of phytoplankton growth and is commonly seen in treatment wetlands with excessive open water areas near the outflow. The average flow and HLR were 1.8 mgd (6,611 m^3/d) and 0.65 cm/d, respectively.

Exhibit 19 - Site Plan of the Blue Heron Wetland Treatment System





City of Titusville, Blue Heron Wetland Treatment System

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
TITUSVILLE	101.56	6,611	4,430	0.65	SAND	EMERGENT

Period of Record Jan-97 Dec-11

Exhibit 20 - Blue Heron Wetland Treatment System Long-term Average Water Quality Summary

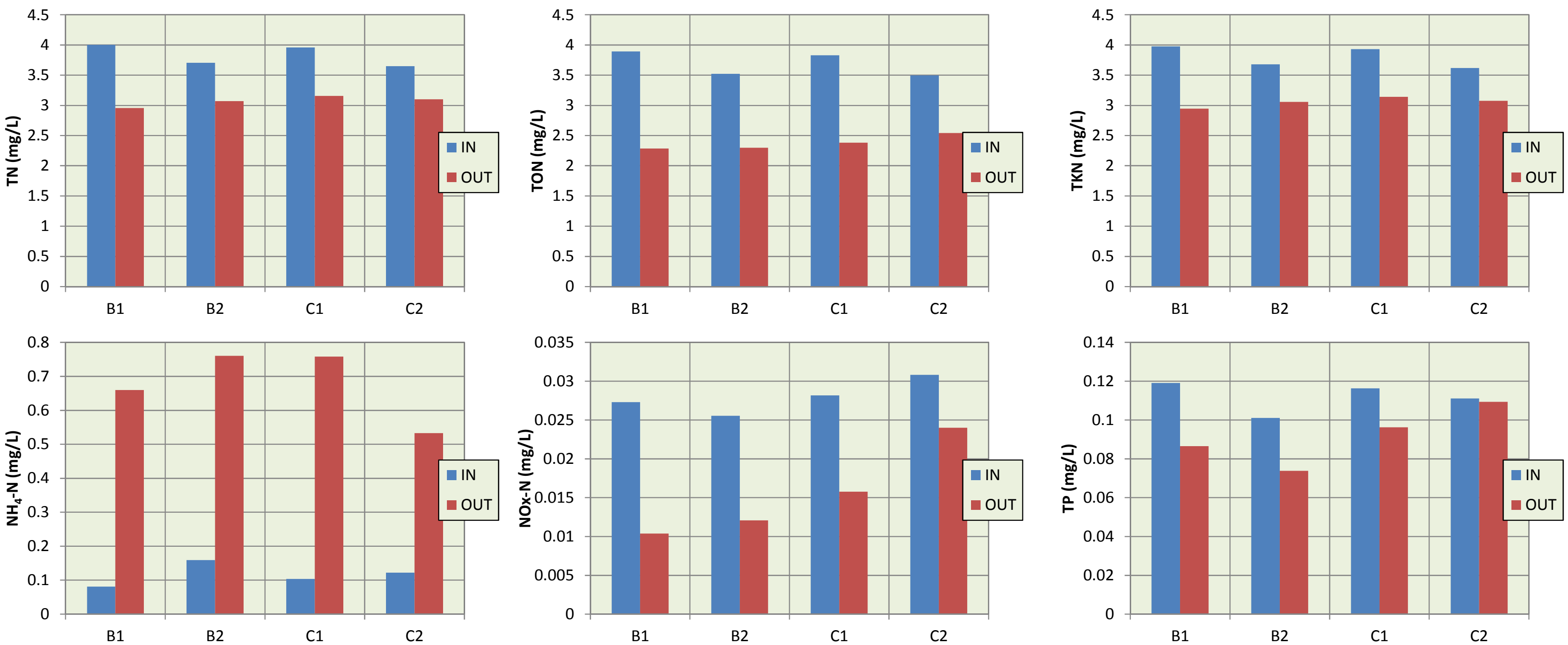
3.2.5 Lake Apopka Marsh Flow Way Project

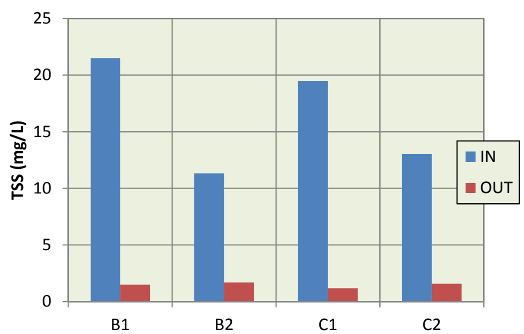
The St. John's River Water Management District's (SJRWMD) Phase I Lake Apopka Marsh Flow Way project began in November 2003, with the construction of a 660-acre (267 ha) full-scale facility that was designed to remove suspended sediments and particulate nutrients from lake water. The Lake Apopka Flow-Way was constructed on floodplain muck farmland soils on the northwest shore of Lake Apopka (Appendix A). Exhibit 21 shows a schematic of the Lake Apopka full-scale project.

Upon initial flooding, outflow nutrient concentrations exceeded inflow concentrations due to the release of soluble soil nutrients, however positive removal efficiencies were observed after vegetation biomass cycles stabilized, pools of labile P were depleted, and new sediments were deposited over the existing substrate.

Exhibit 22 shows POR (November 2003 – December 2009) monthly average inflow and outflow concentration data from the four Phase I Cells (B1, B2, C1, and C2). Average TN concentrations have declined from 4.0 mg/L at the inlets to 3.0 mg/L (25% concentration reduction) at the cell outlets. Long-term average TP concentrations have declined with inlet concentrations of 0.12 mg/L and outlet concentration of 0.09 mg/L (25% concentration reduction). Inflow and outflow TSS concentrations were 20.5 mg/L and 1.3 mg/L, respectively, for an average concentration removal efficiency of about 94 percent

Exhibit 21 - Site Plan for the Lake Apopka Marsh Flow-Way Project





Phase I Apopka Marsh Flow-Way

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
B1	67.99	76,892	76,897	11.31	PEAT	EMERGENT
B2	45.73	63,182	63,245	13.82	PEAT	EMERGENT
C1	74.06	87,045	87,126	11.75	PEAT	EMERGENT
C2	73.25	77,012	76,793	10.51	PEAT	EMERGENT

Period of Record Nov-03 Dec-09

Exhibit 22 - Lake Apopka Marsh Flow-Way Project Long-term Average Water Quality Summary

3.2.6 Taylor Creek STA

The construction and operation of the Taylor Creek STA (TCSTA) in the Lake Okeechobee Watershed is a major component of the Lake Okeechobee Protection Plan. The Plan seeks to restore and protect Lake Okeechobee by achieving and maintaining compliance with lake water quality standards. The Plan's innovative restoration program is designed to reduce total phosphorus loads and implement long-term solutions, in accordance to the lake's Total Maximum Daily Load.

The Taylor Creek STA is one of the two pilot-scale STAs to be implemented north of the lake with flow-through operations starting in June 2008. The STA was inactive from February 2009 through September 2010 while repairs were being made on a culvert at the outfall structure.

The Taylor Creek STA is located about 1.4 miles (2.2 km) north of the city of Okeechobee in central Okeechobee County. It is bordered on the east by U.S. 441 and by Taylor Creek on the west (Exhibit 23). The site is approximately 142 acres (57 ha) in total area and the STA has a treatment area of about 118 acres (48 ha). The STA is divided into two cells operated in series and dominated by emergent vegetation on sandy soils (Appendix A).

Exhibit 23 - Site Plan of the Taylor Creek Pilot STA

Exhibit 24 shows POR (June 2008 to January 2012) monthly average inflow and outflow concentrations for nutrients and solids with monthly time series data presented in Appendix B. The long-term average inflow and outflow TN concentrations were 1.74 mg/L and 1.56 mg/L respectively, a 10 percent reduction. The long-term average inflow and outflow TP concentrations were 0.32 mg/L and 0.23 mg/L, respectively, a 28 percent reduction. Inflow and outflow TSS concentrations were 5.19 mg/L and 3.27 mg/L, respectively, a 37 percent reduction. The average flow and HLR were 11.1 mgd (41,879 m^3/d) and 7.29 cm/d, respectively.

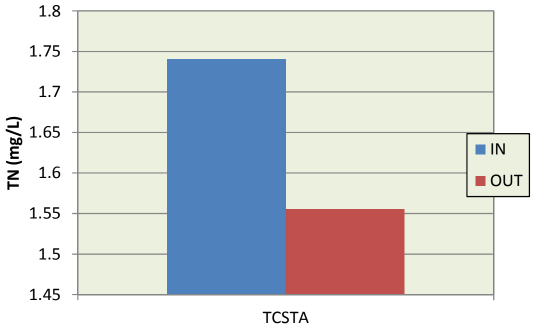
3.2.7 Periphyton-based Stormwater Treatment Areas

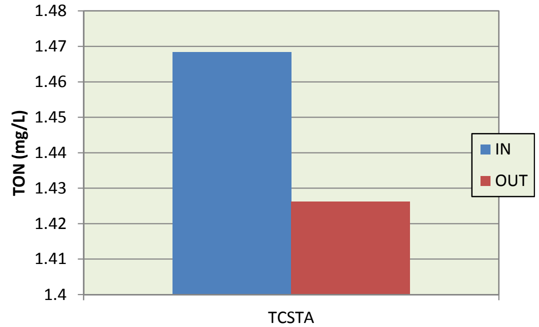
From 1999 to 2002 the District conducted research focused on determining the effectiveness and design criteria of Periphyton-based Stormwater Treatment Areas (PSTA) to support reduction of phosphorus loads in surface waters entering the EAA and ultimately meet the Everglades TP criterion of 10 ppb (CH2M Hill 2003a).

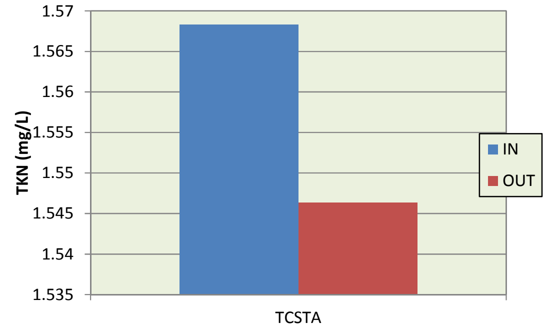
A multi-phase approach was developed to include an experimental phase of 24 portable experimental mesocosms (Porta-PSTAs), three experimental Test Cells (PSTA Test Cells), and a demonstration phase of four 5-acre (2 ha) Field Scale PSTA cells. A summary of the PSTA design criteria and experimental treatments are summarized in Exhibit 25.

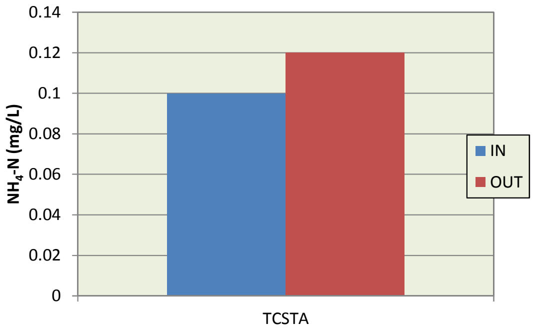
3.2.7.1 Porta-PSTA Mesocosms

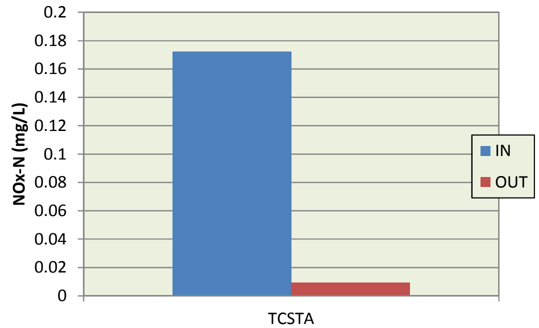
Twenty-four Porta-PSTA fiberglass mesocosms were installed at the STA-1W Supplemental Technology Research Compound and became operational in April 1999. The Porta-PSTA mesocosms included two sizes (22 at 6m x 1m and 2 at 6m x 3m) operated at various target water depths (30 and 60 cm) and loading rates (6 and 12 cm/d). The mesocosms were planted with a low density of macrophytes (*Eleocharis*) to provide periphyton mat stability within various substrates (organic soils, calcareous material, and sand). Exhibit 26 through Exhibit 28 summarize POR (April 1999 to February 2001) monthly average inflow and outflow concentrations for nutrients and solids with monthly time series data presented in Appendix B. Average outflow TP concentrations as low as 11 to 15 ppb were achieved in the calcareous and sand substrate treatments, while more internal P loading and higher outflow TP concentrations were observed in the peat substrate treatments (CH2M HILL 2003a). The Porta-PSTA mesocosms generally reduced concentrations of TN and TON in STA source water and achieved low NOx-N concentrations (generally less than 0.04 mg/L).

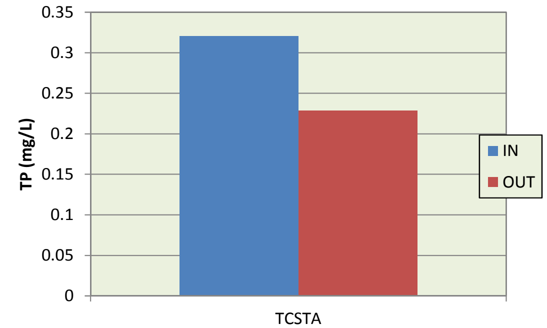


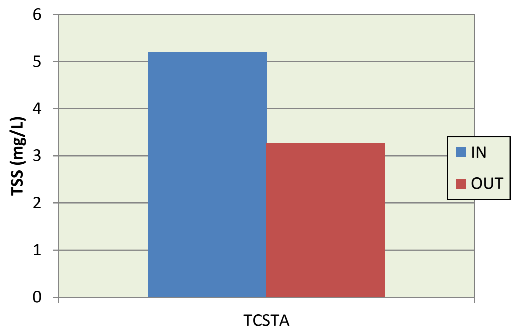












Taylor Creek Pilot STA

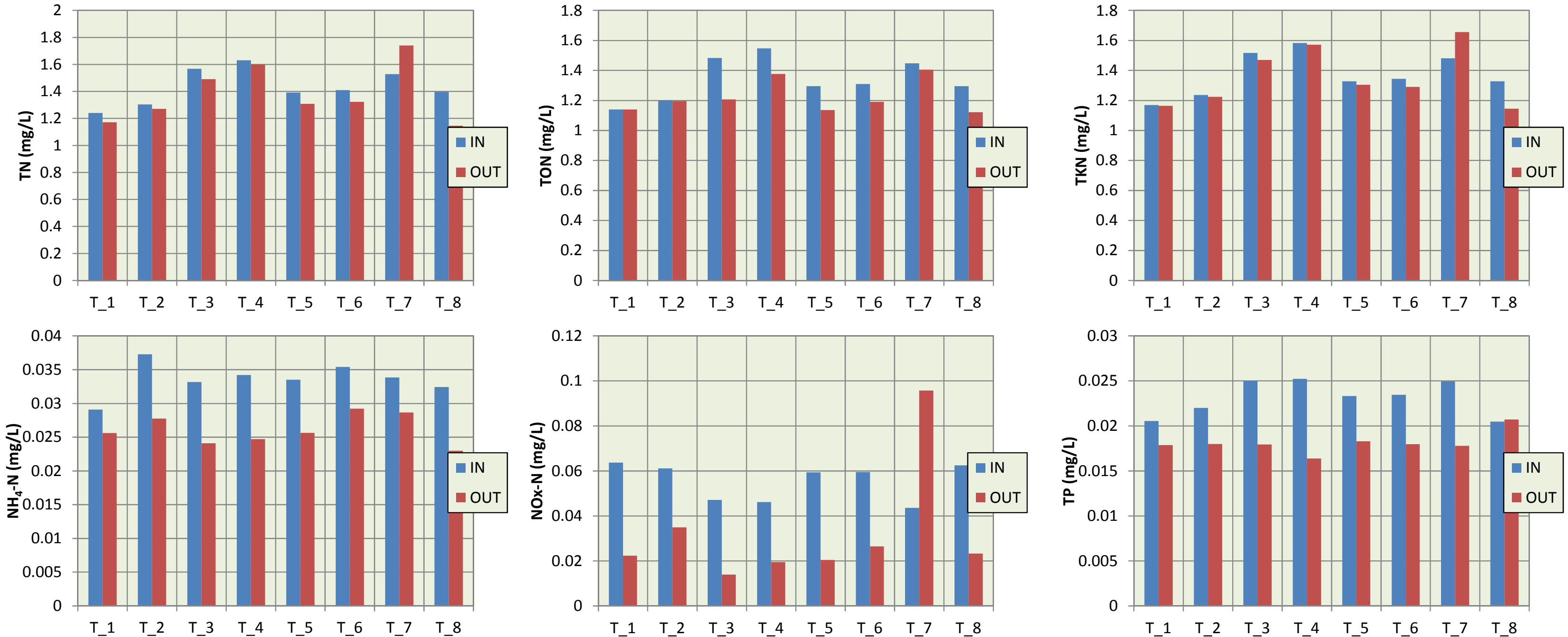
Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
TCSTA	57.47	41,879	38,843	7.29	SAND	EMERGENT
Period of Record	Jun-08	Jan-12				

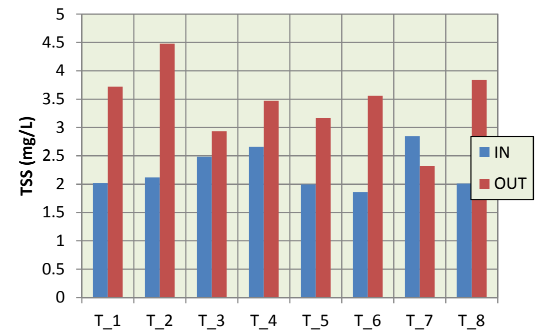
Exhibit 24 - Taylor Creek STA Long-term Average Water Quality Summary

Exhibit 25 - PSTA Treatment Summary Table

PSTA Treatment	Phase	Cells	Area (m^2)	Substrate Type	Target Wtr Depth (cm)	Target HLR (cm/d)	Target Depth:Width Ratio	Other Considerations
Porta-PSTA Mesocosms								
PP-1	1	9, 11, 18	6	Peat	60	6	0.6	macrophytes
PP-2	1	4, 7, 8	6	Shellrock	60	6	0.6	macrophytes
PP-3	1, 2	12, 14, 17	6	Peat	30	6	0.3	macrophytes
PP-4	1, 2	3, 5, 10	6	Shellrock	30	6	0.3	macrophytes
PP-5	1	2, 13, 16	6	Shellrock	60	12	0.6	macrophytes
PP-6	1	1, 6, 15	6	Shellrock	0-60	0-12	0-0.6	macrophytes
PP-7	1, 2	19	6	Sand	30	6	0.3	macrophytes
PP-8	1	20	6	Sand	60	6	0.6	macrophytes
PP-9	1	21	6	Peat	60	6	0.6	Aquashade; no macrophytes
PP-10	1	22	6	Shellrock	60	6	0.6	Aquashade; no Macrophytes
PP-11	1, 2	23	18	Shellrock	30	6	0.1	macrophytes
PP-12	1, 2	24	18	Peat	30	6	0.1	macrophytes
PP-13	2	9, 11, 18	6	peat (Ca)	30	6	0.3	macrophytes
PP-14	2	4, 7, 8	6	Limerock	30	6	0.3	macrophytes
PP-15	2	2, 13, 16	6	Shellrock	30	6	0.3	macrophytes; recirculation
PP-16	2	1, 6, 15	6	Shellrock	0-30	0-6	0-0.3	macrophytes
PP-17	2	20	6	sand (HCl)	30	6	0.3	macrophytes
PP-18	2	21	6	None	30	6	0.3	no macrophytes
PP-19	2	22	6	Aquamat	30	6	0.3	no macrophytes
Test Cell PSTAs								
STC-1	1	13	2,240	Peat	60	6	0.02	macrophytes
STC-2	1	8	2,240	Shellrock	60	6	0.02	macrophytes
STC-3	1	3	2,240	shellrock	0-60	0-12	0-0.02	macrophytes
STC-4	2	13	2,240	peat (Ca)	30	6	0.01	macrophytes
STC-5	2	8	2,240	shellrock	30	6	0.01	macrophytes
STC-6	2	13	2,240	shellrock	0-30	0-12	0-0.01	macrophytes
Field-Scale PSTAs								
FSC-1	3	1	20,790	Limerock/Peat	0-60	0-12	0.005	macrophytes
FSC-2	3	2	20,790	Limerock/Peat	0-60	0-12	0.014	macrophytes
FSC-3	3	3	20,790	Caprock	0-60	0-12	0.005	macrophytes
FSC-4	3	4	20,790	Peat	0-60	0-12	0.005	macrophytes

Notes:
PP = Porta-PSTA
STC = South Test Cell
FSC = Field-Scale Cell

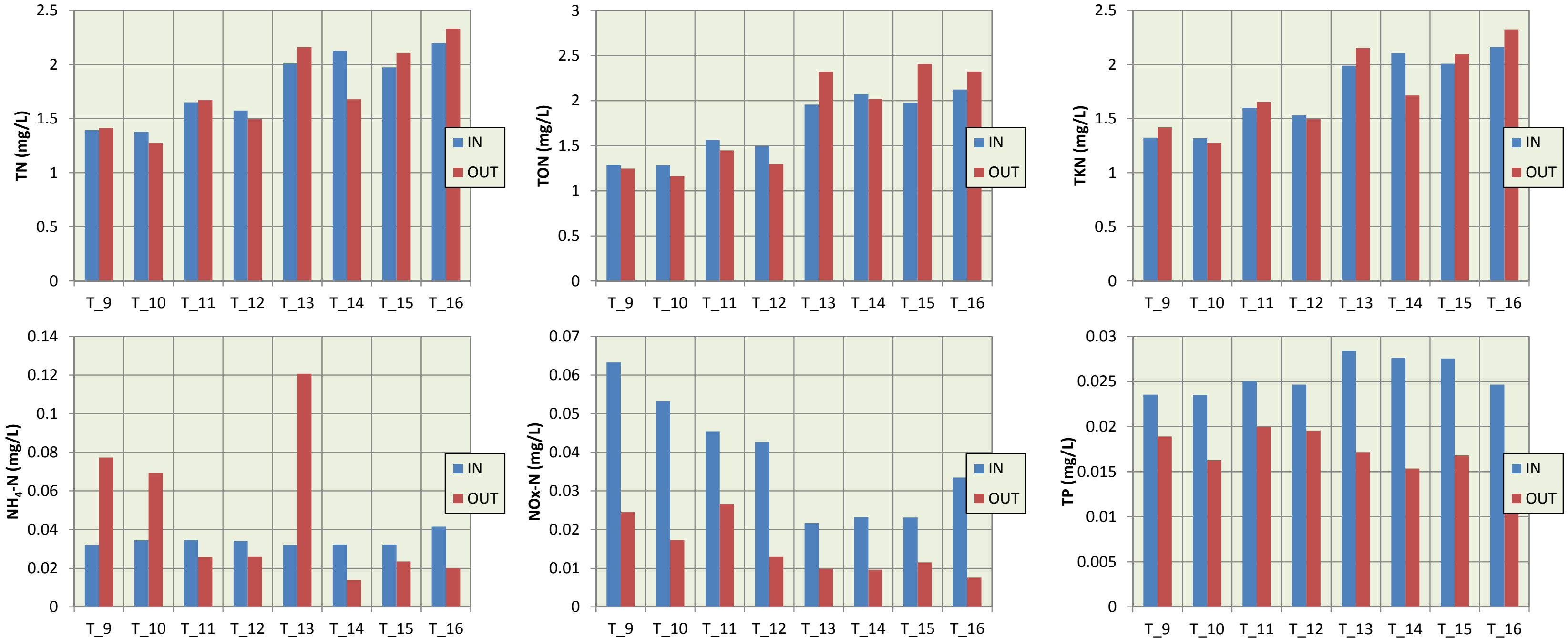


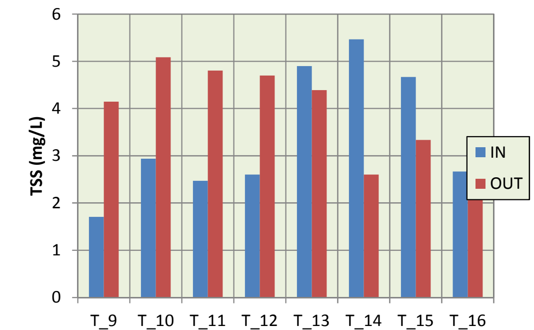


SFWMD Porta-PSTA Mesocosms

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
T_1	0.0006	0.43	0.39	7.17	PEAT	PSTA
T_2	0.0006	0.43	0.39	7.11	LIME ROCK	PSTA
T_3	0.0006	0.43	0.40	7.18	PEAT	PSTA
T_4	0.0006	0.45	0.45	7.49	LIME ROCK	PSTA
T_5	0.0006	0.83	0.77	13.84	LIME ROCK	PSTA
T_6	0.0006	0.33	0.32	5.54	LIME ROCK	PSTA
T_7	0.0006	0.44	0.41	7.36	SAND	PSTA
T_8	0.0006	0.44	0.36	7.32	SAND	PSTA
Period of Record	Apr-99	Feb-01				

Exhibit 26 - SFWMD Porta-PSTA Mesocosm (Treatments) Long-term Average Water Quality Summary

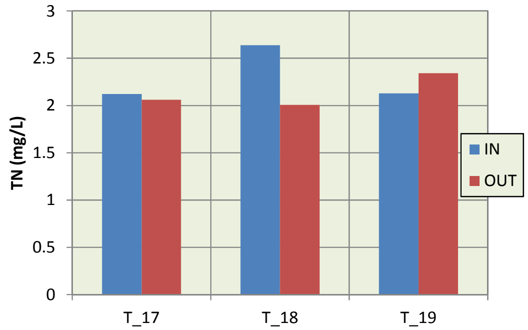


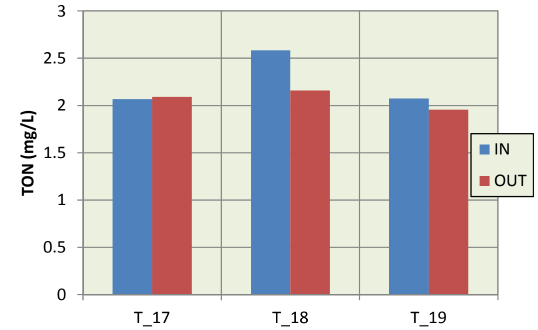


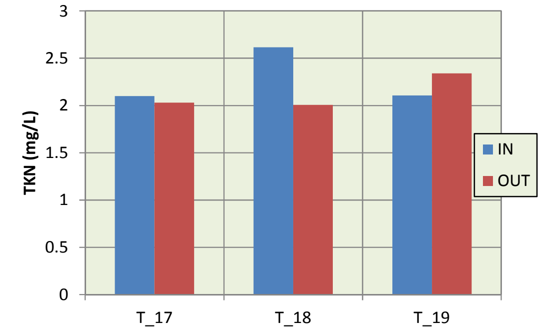
SFWMD Porta-PSTA Mesocosms

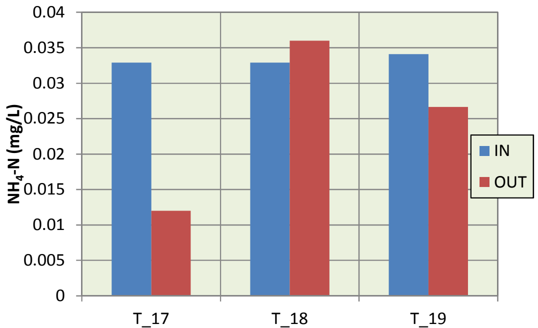
Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
T_9	0.0006	0.44	0.42	7.32	PEAT	OPEN
T_10	0.0006	0.43	0.37	7.14	LIME ROCK	OPEN
T_11	0.0018	1.40	1.39	7.78	LIME ROCK	PSTA
T_12	0.0018	1.37	1.36	7.63	PEAT	PSTA
T_13	0.0006	0.49	0.48	8.14	PEAT	PSTA
T_14	0.0006	0.48	0.52	8.03	LIME ROCK	PSTA
T_15	0.0006	0.44	0.41	7.40	LIME ROCK	PSTA
T_16	0.0006	0.94	0.96	15.69	LIME ROCK	PSTA
Period of Record	Apr-99	Feb-01				

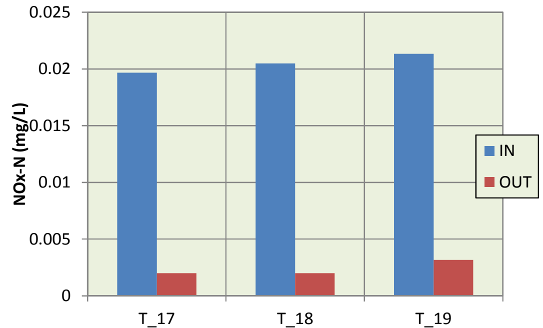
Exhibit 27 - SFWMD Porta-PSTA Mesocosm (Treatments) Long-term Average Water Quality Summary

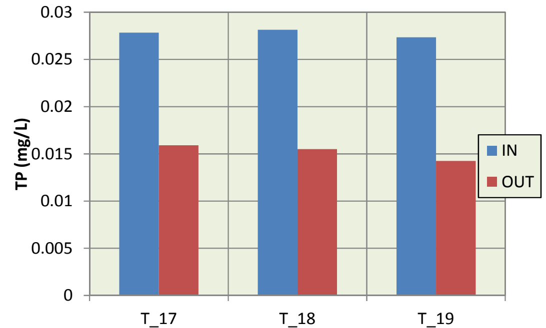


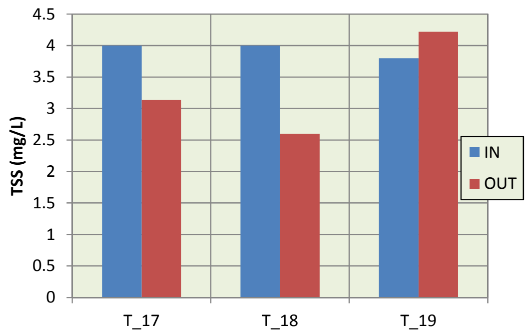












SFWMD Porta-PSTA Mesocosms

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
T_17	0.0006	0.45	0.46	7.49	SAND	PSTA
T_18	0.0006	0.49	0.53	8.11	NONE	OPEN
T_19	0.0006	0.47	0.52	7.84	NONE	PSTA
Period of Record	Apr-00	Feb-01				

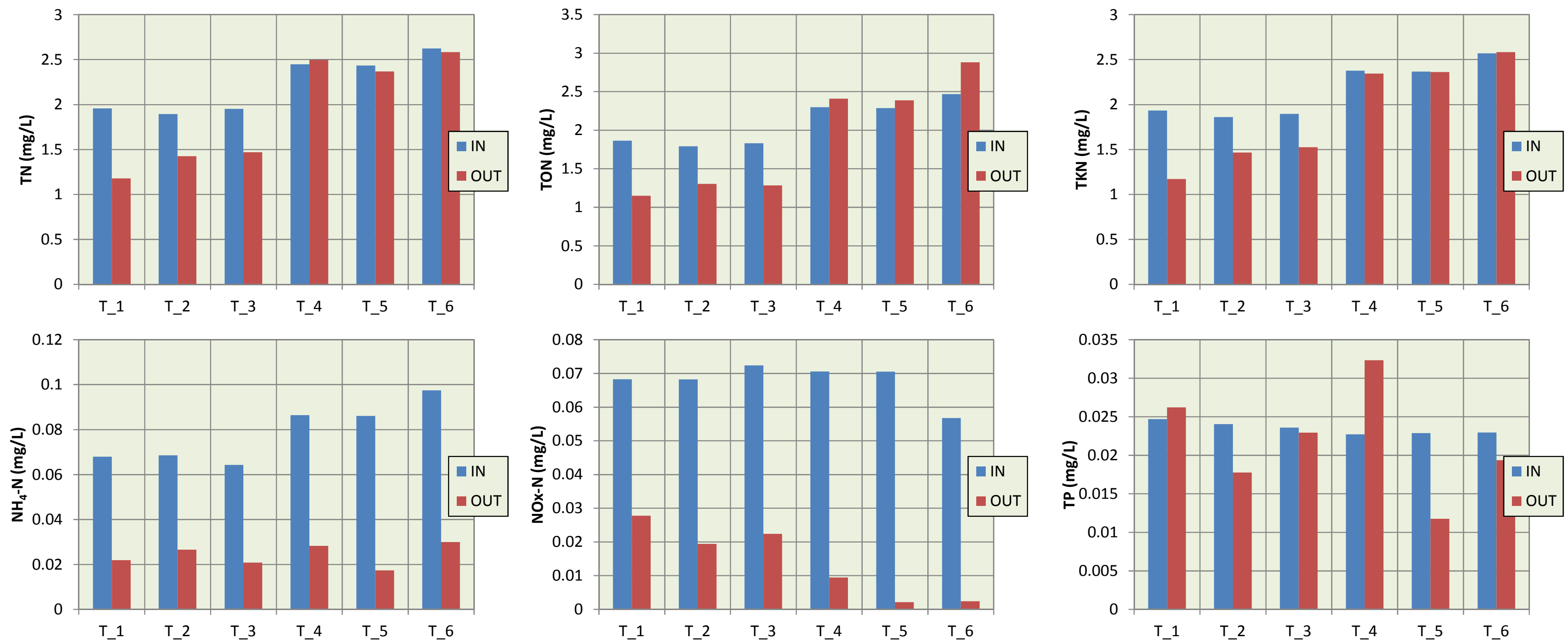
Exhibit 28 - SFWMD Porta-PSTA Mesocosm (Treatments) Long-term Average Water Quality Summary

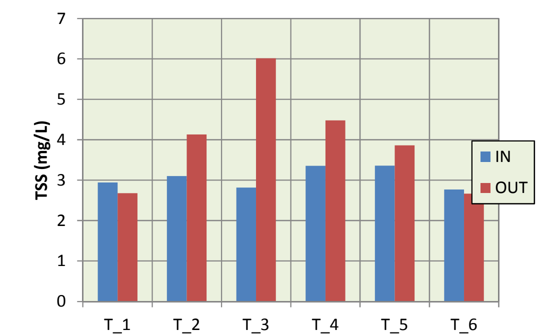
3.2.7.2 South STA-1W PSTA Test Cells

The South STA-1W Test Cells consist of fifteen 0.5-acre (2,020 m^2) full-lined parallel cells receiving flows from STA-1W Cell 3 by means of a single head cell. The District assigned three Test Cells for PSTA Research (cells 3, 8, and 13). Organic and calcareous material substrates were placed over the liners and the Test Cells were planted with a low density of macrophytes (*Eleocharis*) for periphyton mat stability. The Test Cells were operated at various target water depths (30 and 60 cm) and loading rates (6 and 12 cm/d). Exhibit 29 shows POR (February 1999 to March 2001) monthly average inflow and outflow concentrations for nutrients and solids with monthly time series data presented in Appendix B. As noted above, the calcareous substrate treatments achieved lower average TP concentrations in comparison to the peat substrate. The South STA PSTA Test Cells generally reduced concentrations of TN and TON in STA source water and achieved low NOx-N concentrations (generally less than 0.02 mg/L).

3.2.7.3 Field-Scale PSTA Cells

Four Field-Scale PSTA cells were constructed west of STA-2 Cell 3, each about 5 acres in surface area (3 – 61m x 317m, 1 – 21m x 951m). Two cells had compact limerock placed over the native peat soils, one cell had the peat removed to expose the underlying caprock, and the remaining cell had the unaltered native peat soils. The Field-Scale PSTA Cells were also planted with a low density of macrophytes (*Eleocharis*) for periphyton mat stability and operated at variable water depths (< 60 cm) and loading rates (< 12 cm/d). Exhibit 30 shows POR (August 2001 to December 2002) monthly average inflow and outflow concentrations for nutrients and solids with monthly time series data presented in Appendix B. As noted above for the other PSTA cells, the calcareous substrate cells achieved lower average TP concentrations in comparison to the peat substrate. The presence of underlying and adjacent peat soils resulted in a net increase of TON in all cells, even those covered by limerock and in the cell where the peat was removed to caprock. Inorganic nitrogen concentrations (AN and NOx-N) were generally reduced in the Field-Scale PSTA cells.

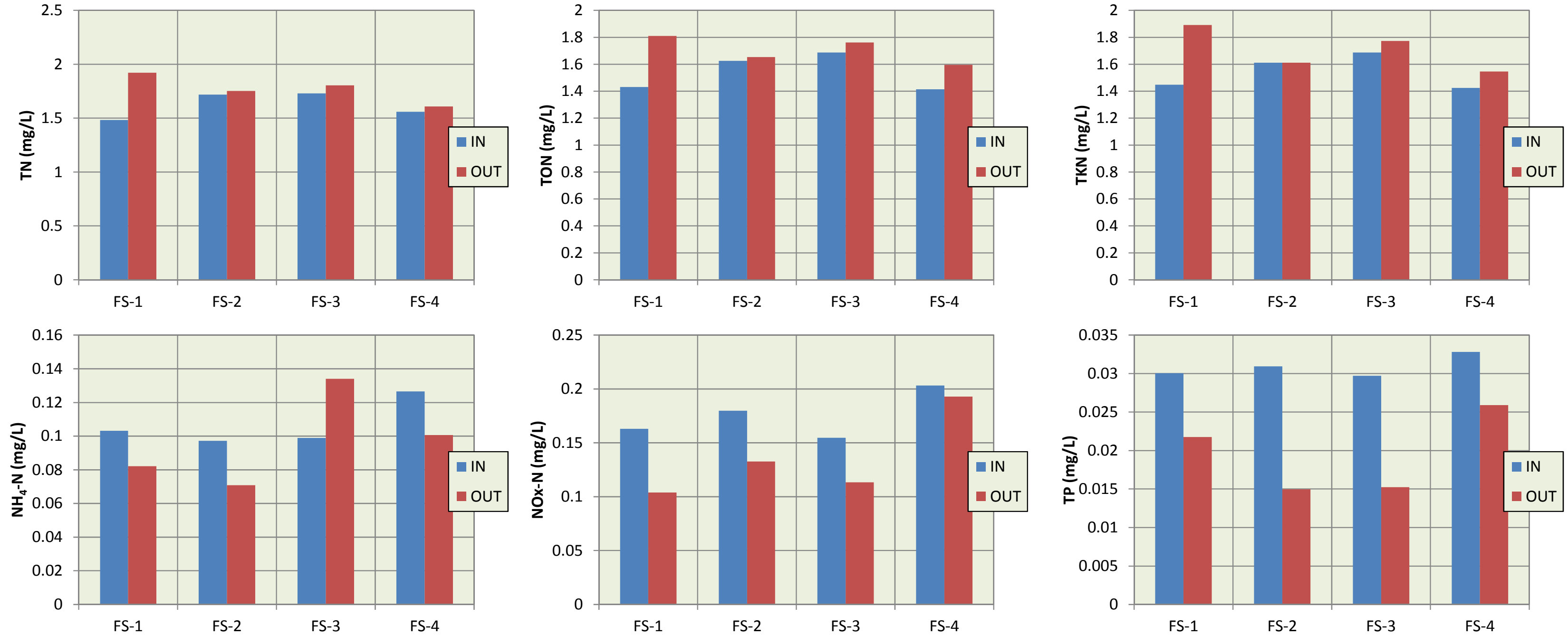


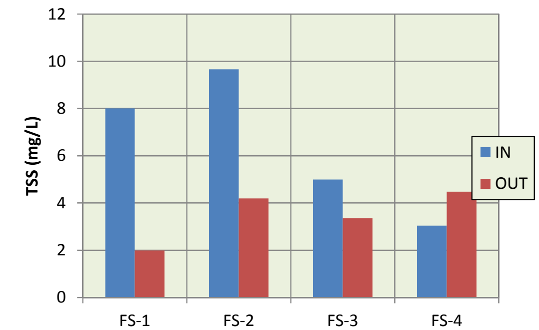


SFWMD PSTA Test Cells (Treatments)

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
T_1	0.26	120.84	120.85	4.57	PEAT	PSTA
T_2	0.26	120.36	103.99	4.65	LIME ROCK	PSTA
T_3	0.26	106.75	88.02	4.03	LIME ROCK	PSTA
T_4	0.24	121.86	116.72	5.08	PEAT	PSTA
T_5	0.24	123.12	118.87	5.14	LIME ROCK	PSTA
T_6	0.25	134.53	126.84	5.35	LIME ROCK	PSTA
Period of Record	Feb-99	Mar-01				

Exhibit 29 - SFWMD PSTA Test Cells (Treatments) Long-term Average Water Quality Summary





SFWMD Field-Scale PSTA Cells

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
FS-1	2.08	1,739.50	739.74	8.37	LIME ROCK	PSTA
FS-2	2.08	2,508.93	1,183.30	12.07	LIME ROCK	PSTA
FS-3	2.08	1,927.82	1,901.01	9.27	LIME ROCK	PSTA
FS-4	2.08	2,294.13	443.76	11.03	PEAT	PSTA

Period of Record Aug-01 Dec-02

Exhibit 30 - SFWMD Field-Scale PSTA Cells Long-term Average Water Quality Summary

3.2.8 Wellington Aquatics Pilot Test Facility

The Village of Wellington initiated the Aquatics Pilot Program to demonstrate how well natural treatment wetlands may work to meet the anticipated 10 ppb Everglades Forever Act phosphorus threshold requirement. The Village of Wellington is responsible for the surface water management of a 13.6-square mile (3,500 ha) area within the Village (CH2M HILL 2003b). The Wellington Aquatics Pilot Test Facility is a 2.0-acre (8,000 m^2) site consisting of six cells operated in two parallel treatment series (East and West) of three cells each (Exhibit 31). The West series included a FAV cell followed by an EMV cell and finally a PSTA cell. The East series included an EMV cell followed by a SAV cell and finally a PSTA cell.

Exhibit 32 shows POR (November 2001 to February 2003) monthly average inflow and outflow concentrations for nutrients and solids with monthly time series data presented in Appendix B. Inflow to the East and West series averaged 149 m^3/d and 156 m^3/d, respectively. Phosphorus concentrations were reduced by approximately 86 percent in the East series and 94 percent in the West series (CH2M HILL 2003b). Concentrations of TN and NOx-N were lowered slightly in the Wellington Test Facility treatments.

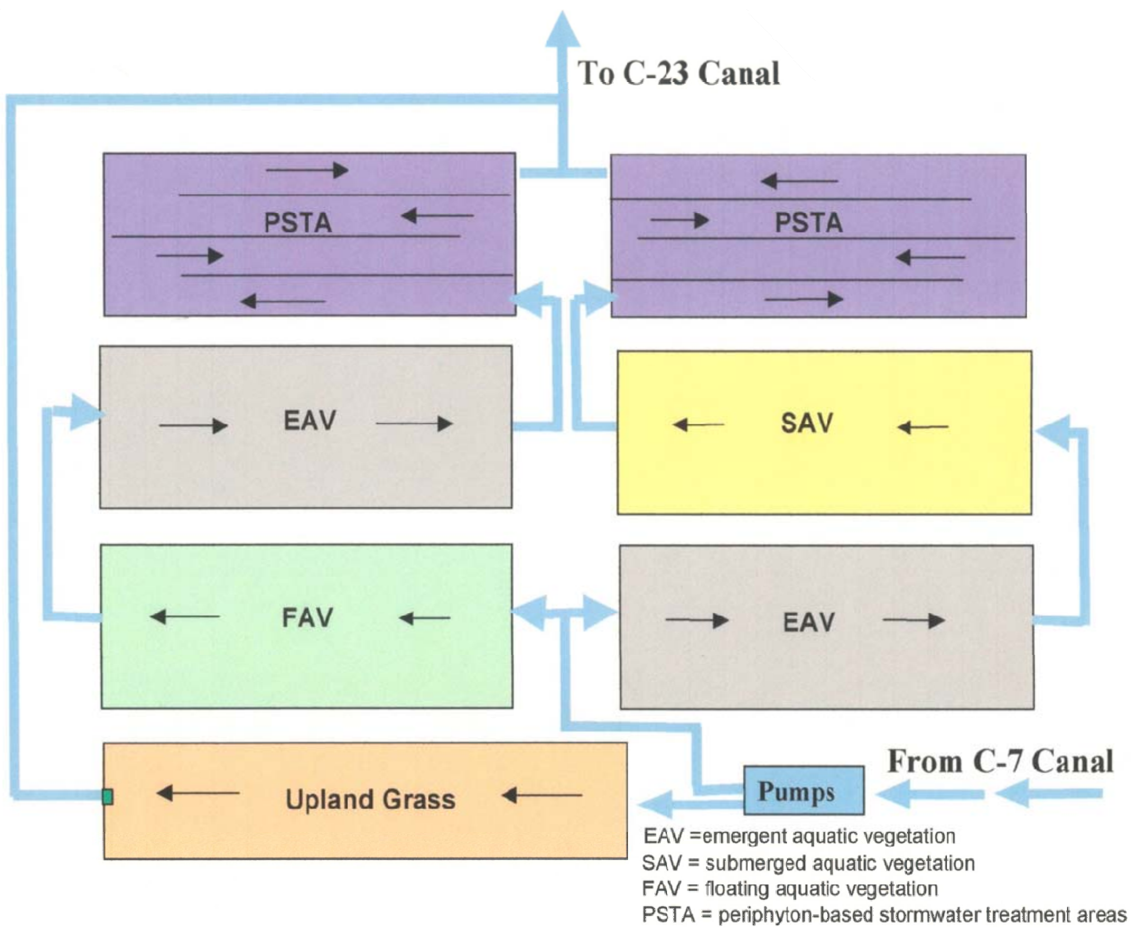
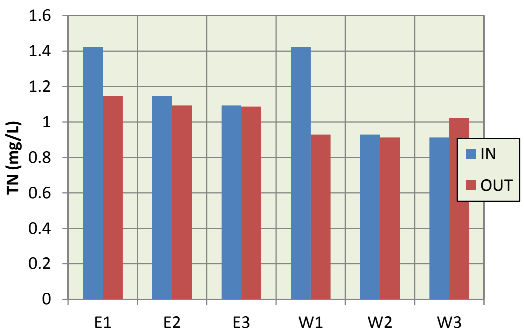
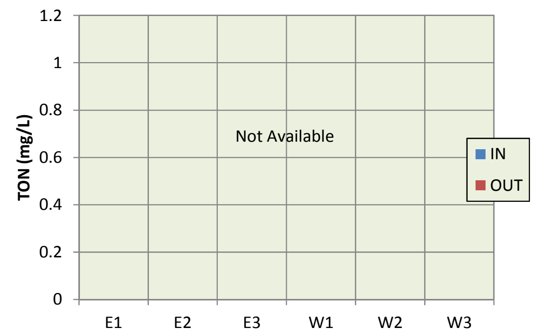
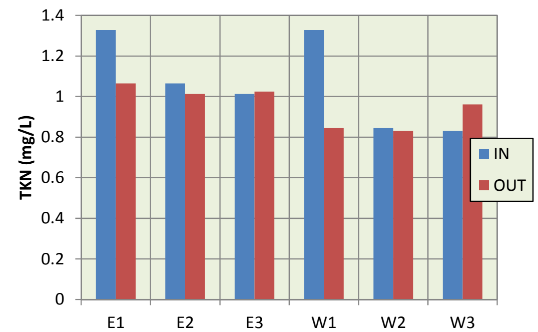
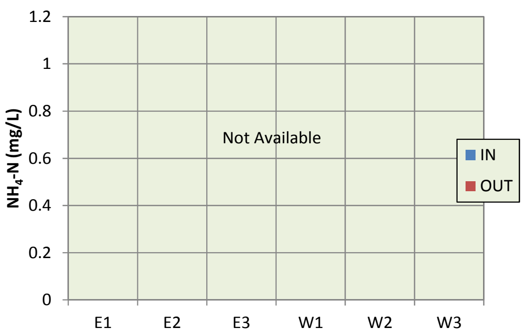


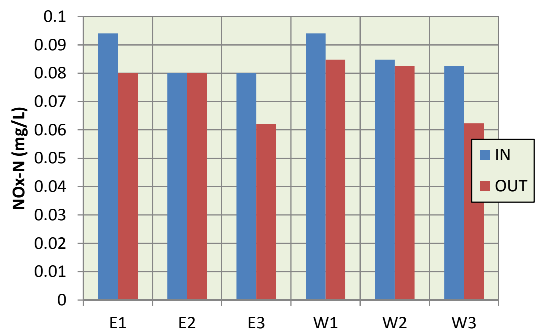
Exhibit 31 - Site Plan of the Wellington Aquatics Pilot Test Facility Showing the East (right side of drawing) and West Flow-Paths.

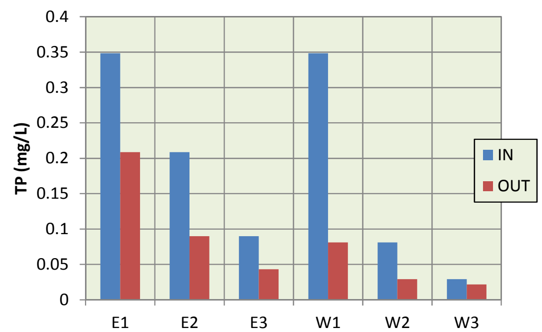


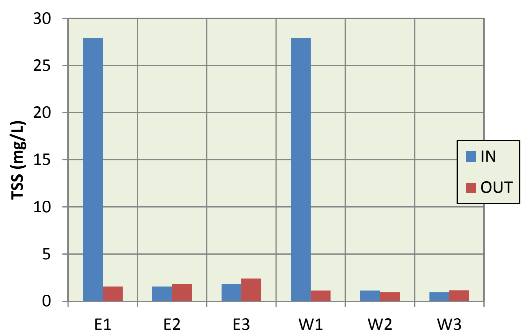












Wellington Aquatics Pilot Test Facility

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
E1	0.055	148.89	83.36	26.97	SAND	EMERGENT
E2	0.044	83.36	97.73	19.08	SAND	SAV
E3	0.049	97.73	52.80	19.82	LIME ROCK	PSTA
W1	0.047	155.74	73.39	33.49	SAND	FAV
W2	0.055	73.39	58.01	13.30	SAND	EMERGENT
W3	0.049	58.01	25.11	11.77	LIME ROCK	PSTA
Period of Record	Nov-01	Feb-03				

Exhibit 32 - Wellington Aquatics Pilot Test Facility Long-term Average Water Quality Summary for the East (E1 through E3) and West (W1 through W3) Flow Paths

3.2.9 C-43 West Storage Reservoir Test Cells

The C-43 West Storage Reservoir Project is an important component of the Comprehensive Everglades Restoration Program and is expected to capture and store approximately 170,000 acre-feet (210 million m^3) of water during Florida's rainy season. Initially, in response to a concern raised to the District about the accuracy of seepage estimates for the full-scale Project, the District implemented a C-43 Storage Reservoir Test Cell Program. This Test Cell Program consisted of two test cells constructed within the footprint of the Project reservoir (Exhibit 33). Although the primary purpose of this Test Cell Program is to evaluate two different methods of reducing seepage, the test cells were utilized to provide a limited evaluation of water quality benefits and liabilities associated with reservoir start-up and operation (WSI 2007a).

The C-43 West Storage Reservoir Test Cells are located in Hendry County about 30 miles east of Fort Myers. Two Test Cells were constructed between March and June 2006, with initial pumping to fill the cells beginning on June 2006. The Test Cells were constructed with a wetted area of approximately 2.5 acres (1 ha) at the inside toe of slope and 4.5 acres (1.8 ha) at the target maximum water depth of 19 feet (5.8 m). These test cells were operated with no surface outflows (pumping was controlled within a target range of stages and all outflows were by evapotranspiration and leakage).

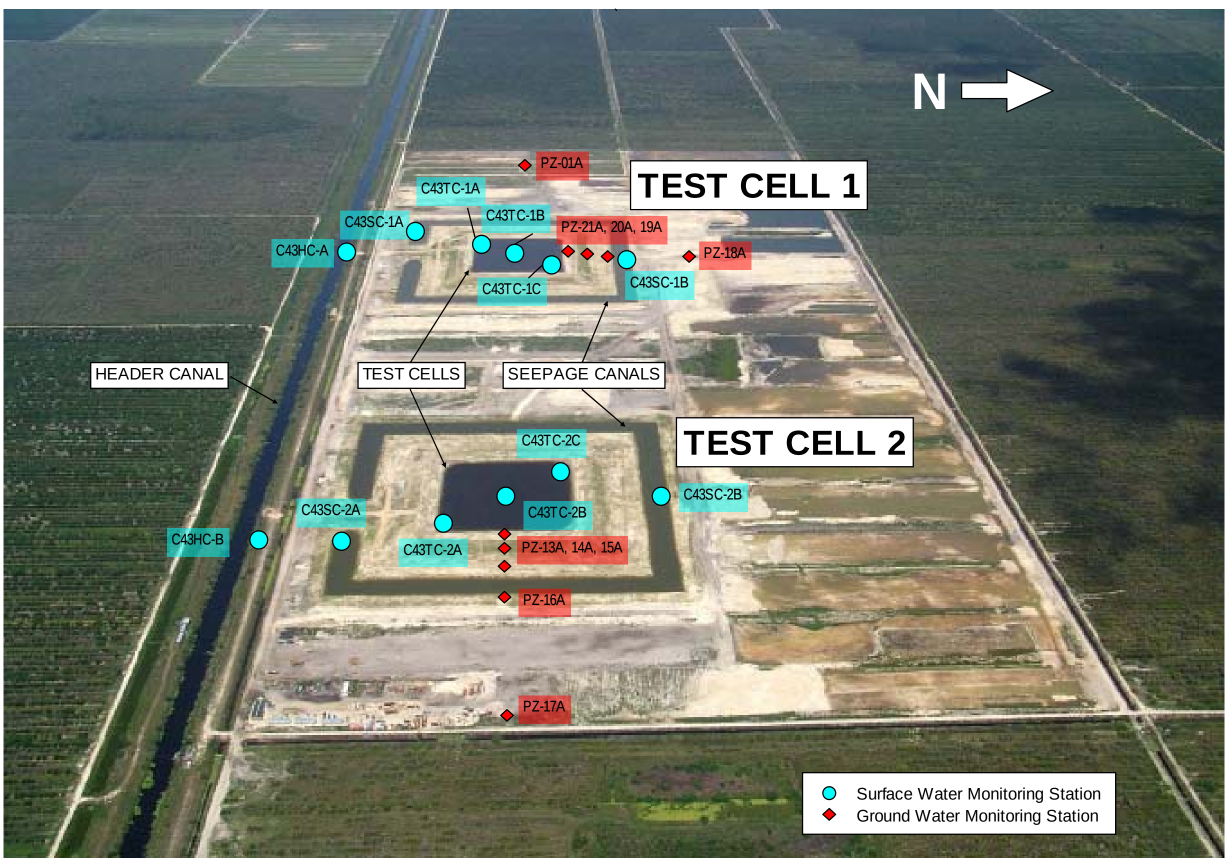


Exhibit 33 - Site Plan of the C-43 West Storage Reservoir Test Cells

Exhibit 34 shows POR (June 2006 to May 2007) monthly average inflow and outflow concentrations for nutrients and solids with monthly time series data presented in Appendix B. Nutrient concentrations were generally reduced through the Test Cells with an 14 percent long-term average reduction of TN (1.22 to 1.05 mg/L) and an average 74 percent reduction for TP (0.141 to 0.037 mg/L). The long-term average TSS was relatively unchanged with a concentration of 5.17 mg/L at the inflow and within the Test Cells. TSS was being produced in these OW cells due to growth of phytoplankton.

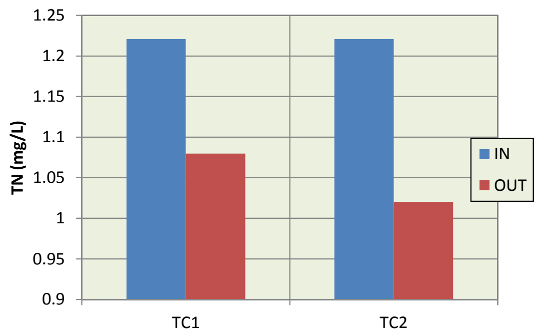
3.2.10 C-44 Reservoir/Stormwater Treatment Area Test Cells

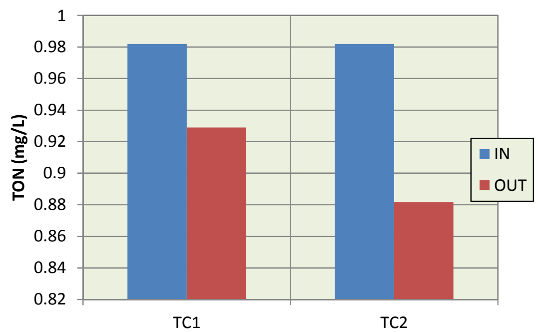
The C-44 Reservoir/Stormwater Treatment Area Project is one component of the proposed Comprehensive Everglades Restoration Plan Indian River Lagoon South Integrated Project Implementation Report and Environmental Impact Statement (USACE and SFWMD 2004). The proposed C-44 Storage Reservoir/ STA Project is expected to retain and treat watershed runoff flows from the C-44 Canal (St. Lucie Canal) and possibly the C-23 Canal prior to discharge either to the St. Lucie River through S-80 or to Lake Okeechobee through S-308. The site for the C-44 Storage Reservoir/STA project is located north of the C-44 Canal about mid-way between Lake Okeechobee and the St. Lucie River in Martin County.

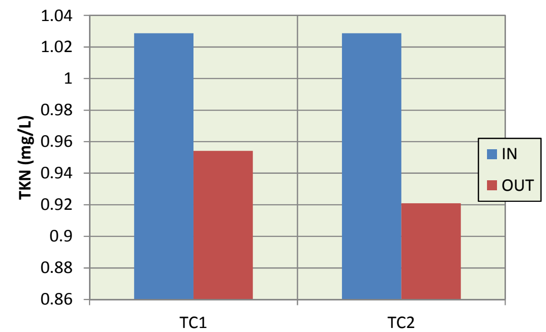
A test cell program was implemented in early 2006 to achieve the following objectives; assessment of storage reservoir seepage rates, water quality conditions during storage reservoir startup (initial flooding response), storage reservoir nutrient removal rates in response to reservoir water depth and hydraulic residence time, STA seepage rates, STA vegetation establishment from planting vs. natural recruitment, water quality conditions during STA startup (initial flooding response), and STA nutrient removal performance.

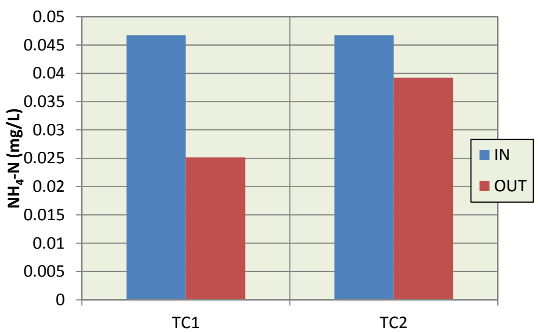
Two reservoir test cells and two STA test cells were constructed between March 2006 and June 2006 (Exhibit 35). Initial pumping began between mid-May and mid-June 2006, with the actual dates varying by cell. The reservoir test cells were constructed with a wetted area of approximately 2.2 acres (0.9 ha) at the inside toe of slope and 3.7 acres (1.5 ha) at the target maximum water depth of 15 feet (4.6 m). The STA cells were constructed with a wetted area of about 4.3 acres (1.7 ha) each at a target depth of about 1 foot (0.3 m) in the marsh zones (WSI 2007b). These test cells were operated with no surface outflows (pumping was controlled within a target range of stages and all outflows were by evapotranspiration and leakage).

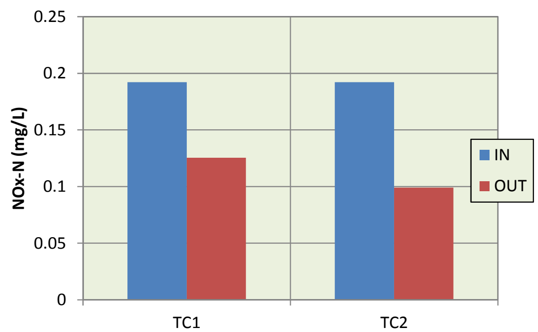
Exhibit 36 shows POR (July 2006 to June 2007) monthly average inflow and outflow concentrations for nutrients and solids with monthly time series data presented in Appendix B. Nutrient concentrations were generally low in the Test Cells with an average TN concentration of 0.87 mg/L (3 percent reduction) and a TP average of 0.022 mg/L (58 percent reduction). TSS concentrations were reduced but still fairly high with an average inflow concentration of 29.3 mg/L and an outflow average of 14.3 mg/L (51 percent reduction). The C-44 STA-2 was the only STA cell that displayed a long-term average TP and TSS reduction [TP - 0.060 to 0.031 mg/L (48 percent), TSS – 11.6 to 8.1 mg/L (30 percent)]. The TN concentration was unchanged or increased in both STA Cells, apparently as a result of TN release from the pre-existing site soils.

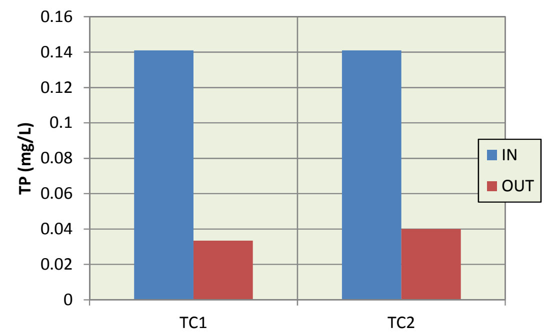


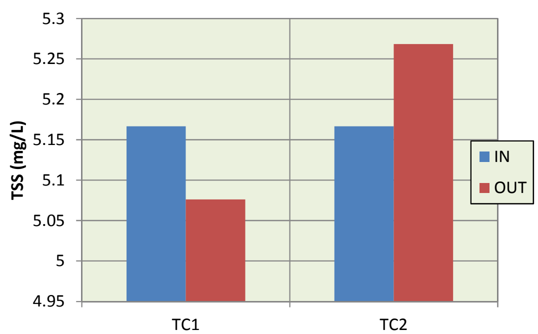












C-43 West Storage Reservoir Test Cells

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
TC1	1.821	937.92	0.00	5.15	SAND	OPEN
TC2	1.821	937.92	0.00	5.15	SAND	OPEN
Period of Record	Jun-06	May-07				

Exhibit 34 - C-43 West Storage Reservoir Test Cells Long-term Average Water Quality Summary

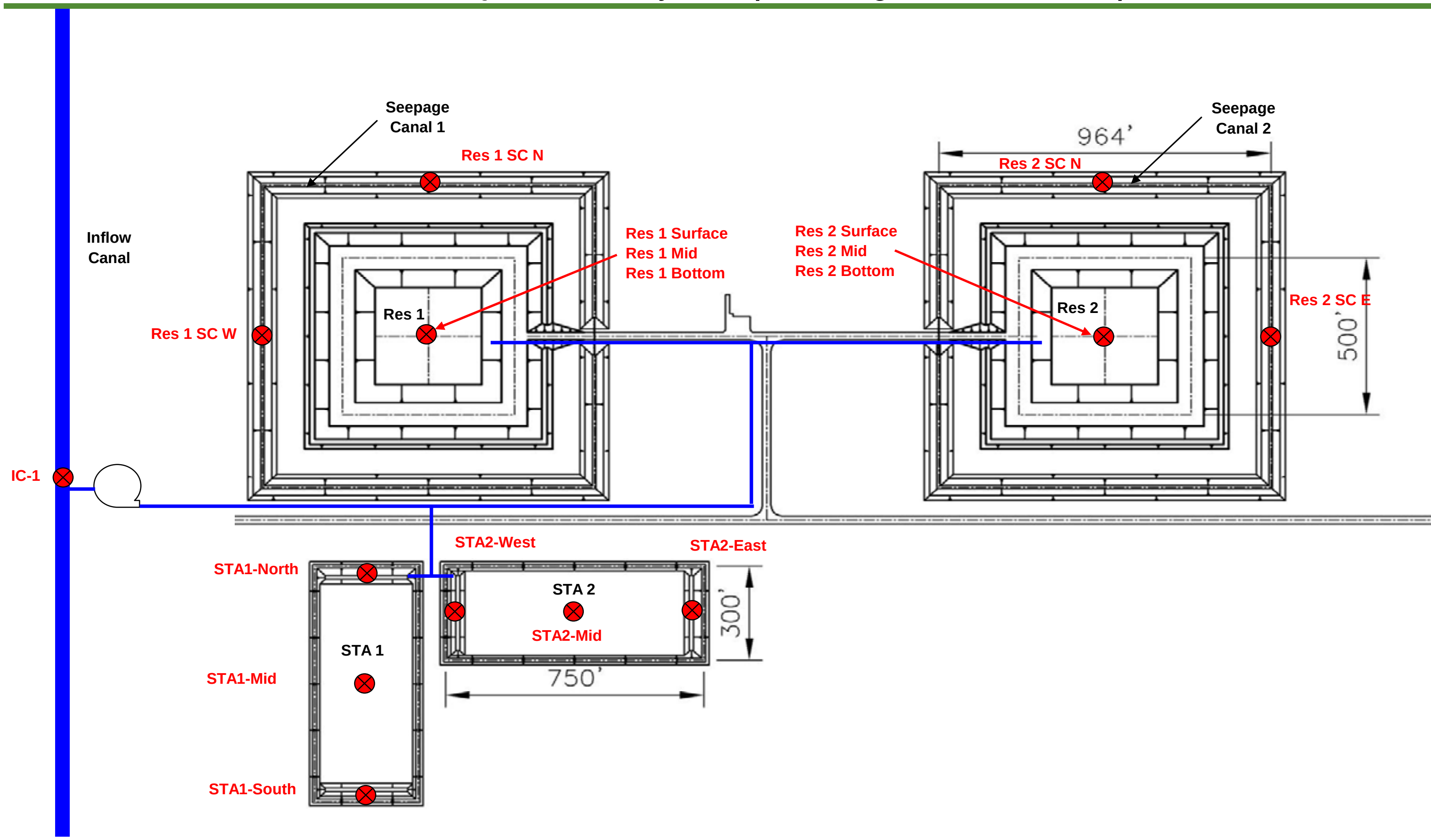
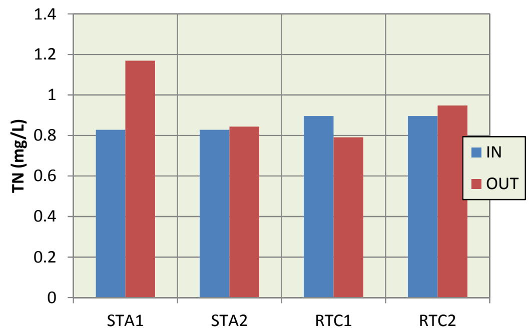
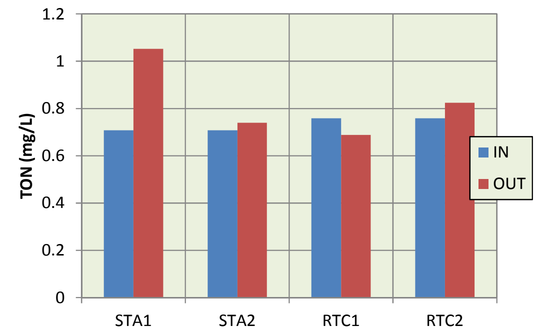
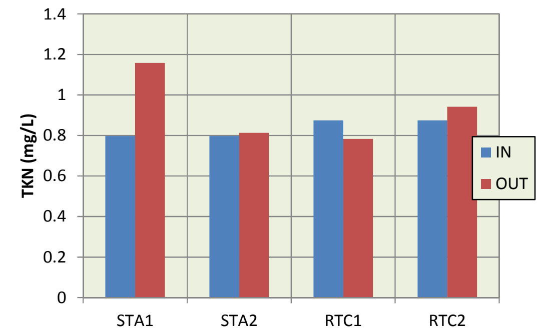
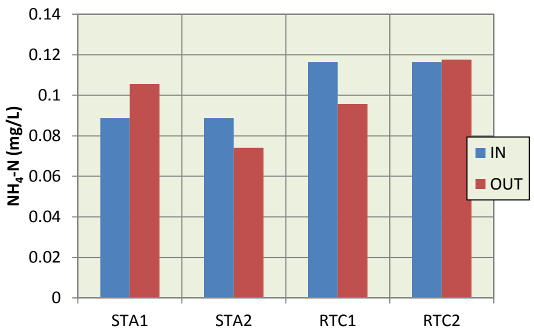


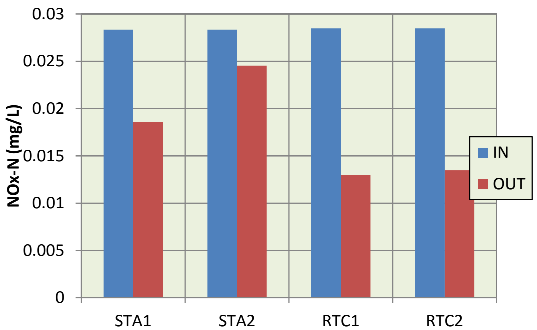
Exhibit 35 - Site Plan of the C-44 Reservoir/Stormwater Treatment Area Test Cells

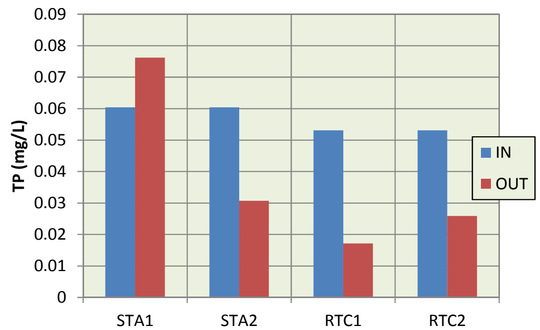


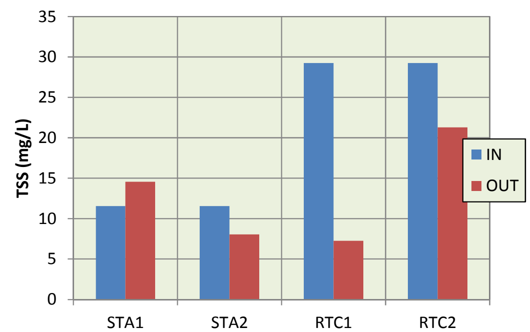












C-44 Reservoir/Stormwater Treatment Area Test Cells

Cell	Area (ha)	Avg Flow (m^3/d) In	Avg Flow (m^3/d) Out	HLR (cm/d)	Substrate	Vegetation
STA1	1.740	582.31	0.00	3.35	SAND	EMERGENT
STA2	1.740	1,361.25	0.00	7.82	SAND	EMERGENT
RTC1	1.497	537.83	0.00	3.59	SAND	OPEN
RTC2	1.497	688.32	0.00	4.60	SAND	OPEN
Period of Record	Jul-06	Jun-07				

Exhibit 36 - C-44 Reservoir/Stormwater Treatment Area Test Cells Long-term Average Water Quality Summary

3.3 Analysis of Design Factors Affecting Treatment Wetland Removal of Nitrogen Fractions

3.3.1 Site

Exhibit 37 summarizes the average inflow and outflow concentrations for nitrogen, phosphorus, and total suspended solids for each of the Florida treatment wetland systems included in this performance summary. The long-term average inflow TN concentrations for these systems ranged from 0.83 to 10.1 mg/L and the POR outflow TN concentrations ranged from 0.79 to 3.5 mg/L. The long-term average inflow total Kjeldahl nitrogen (TKN) concentrations for these systems ranged from 0.80 to 3.98 mg/L and the POR outflow TKN concentrations ranged from 0.78 to 3.14 mg/L. The long-term average inflow TON concentrations for these systems ranged from 0.71 to 3.90 mg/L and the POR outflow TON concentrations ranged from 0.69 to 2.88 mg/L. The long-term average inflow AN concentrations for these systems ranged from 0.03 to 1.08 mg/L and the POR outflow AN concentrations ranged from 0.01 to 0.76 mg/L. The long-term average inflow NO_x-N concentrations for these systems ranged from 0.02 to 6.29 mg/L and the POR outflow NO_x-N concentrations ranged from 0.00 to 1.53 mg/L. The long-term average inflow TP concentrations for these systems ranged from 0.02 to 5.42 mg/L and the POR outflow TP concentrations ranged from 0.01 to 5.00 mg/L. The long-term average inflow TSS concentrations for these systems ranged from 0.60 to 29.2 mg/L and the POR outflow TSS concentrations ranged from 0.20 to 21.3 mg/L.

Exhibit 37 - Average Inflow / Outflow Water Quality Concentrations by Treatment Wetland Site

			TP (mg/L)		NOx-N (mg/L)		NH_4-N (mg/L)		TKN (mg/L)		TON (mg/L)		TN (mg/L)		TSS (mg/L)			
System	**Substrate**	**Vegetation**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**Period-of-Record**	
Phase I Apopka Marsh Flow-Way																		
Cell B1	PEAT	EMERGENT	0.119	0.087	0.027	0.010	0.081	0.660	3.98	2.94	3.90	2.29	4.00	2.96	21.50	1.47	Nov-03	Dec-09
Cell B2	PEAT	EMERGENT	0.101	0.074	0.026	0.012	0.159	0.761	3.68	3.06	3.52	2.30	3.71	3.07	11.32	1.68	Nov-03	Dec-09
Cell C1	PEAT	EMERGENT	0.116	0.096	0.028	0.016	0.104	0.759	3.93	3.14	3.83	2.38	3.96	3.16	19.48	1.17	Nov-03	Dec-09
Cell C2	PEAT	EMERGENT	0.111	0.109	0.031	0.024	0.122	0.533	3.62	3.08	3.50	2.54	3.65	3.10	13.03	1.56	Nov-03	Dec-09
C-43 West Storage Reservoir Test Cell																		
Cell 1	SAND	OPEN	0.141	0.033	0.192	0.126	0.047	0.025	1.03	0.95	0.98	0.93	1.22	1.08	5.17	5.08	Jun-06	May-07
Cell 2	SAND	OPEN	0.141	0.040	0.192	0.099	0.047	0.039	1.03	0.92	0.98	0.88	1.22	1.02	5.17	5.27	Jun-06	May-07
C-44 Reservoir / Stormwater Treatment Area Test Cell 1																		
STA Cell 1	SAND	EMERGENT	0.060	0.076	0.028	0.019	0.089	0.106	0.80	1.16	0.71	1.05	0.83	1.17	11.55	14.58	Jul-06	Dec-06
STA Cell 2	SAND	EMERGENT	0.060	0.031	0.028	0.025	0.089	0.074	0.80	0.81	0.71	0.74	0.83	0.84	11.55	8.07	Jul-06	Dec-06
Test Cell 1	SAND	OPEN	0.053	0.017	0.028	0.013	0.116	0.096	0.88	0.78	0.76	0.69	0.90	0.79	29.25	7.27	Jul-06	Jun-07
Test Cell 2	SAND	OPEN	0.053	0.026	0.028	0.013	0.116	0.118	0.88	0.94	0.76	0.82	0.90	0.95	29.25	21.29	Jul-06	Jun-07
City of Lakeland Wetland Treatment System Cells																		
Cell 1	CLAY	EMERGENT	5.416	5.001	6.289	1.528	1.081	0.641	3.83	2.01	2.68	1.42	10.11	3.50	8.25	1.49	Jan-87	Sep-08
Cell 2	CLAY	EMERGENT	4.995	4.406	1.530	0.730	0.643	0.246	2.01	1.16	1.42	0.91	3.50	1.84	1.49	1.52	Jan-87	Sep-08
Cell 3	CLAY	EMERGENT	4.406	4.192	0.730	0.194	0.246	0.182	1.16	1.06	0.91	0.88	1.84	1.87	1.52	3.19	Jan-87	Sep-08
Cell 4	CLAY	EMERGENT	4.192	4.085	0.194	0.169	0.182	0.127	1.06	1.06	0.88	0.93	1.87	1.21	3.19	3.27	Jan-87	Sep-08
Cell 5	CLAY	SAV	3.862	3.412	0.210	0.205	0.171	0.166	1.14	1.46	0.97	1.30	1.29	1.64	3.03	20.71	Jan-87	Sep-08
Cell 6	CLAY	FAV	3.412	3.034	0.205	0.220	0.166	0.302	1.46	1.57	1.30	1.27	1.64	1.79	20.71	7.87	Jan-87	Sep-08
Cell 7	CLAY	FAV	3.034	2.898	0.220	0.181	0.302	0.178	1.57	1.32	1.27	1.14	1.79	1.51	7.87	5.97	Jan-87	Sep-08
Orlando Easterly Wetlands	SAND	EMERGENT	0.265	0.064	0.850	0.038	0.523	0.058	1.38	0.85	0.85	0.80	2.23	0.87	1.93	2.65	Jan-88	Nov-11
SFWMD Field-Scale PSTA Cells																		
FS-1	LIME ROCK	PSTA	0.030	0.022	0.163	0.104	0.103	0.082	1.45	1.89	1.43	1.81	1.48	1.92	8.01	1.99	Aug-01	Dec-02
FS-2	LIME ROCK	PSTA	0.031	0.015	0.180	0.133	0.097	0.071	1.61	1.61	1.63	1.65	1.72	1.75	9.67	4.19	Sep-01	Dec-02
FS-3	LIME ROCK	PSTA	0.030	0.015	0.155	0.113	0.099	0.134	1.69	1.77	1.69	1.76	1.73	1.81	5.00	3.35	Aug-01	Dec-02
FS-4	PEAT	PSTA	0.033	0.026	0.203	0.193	0.127	0.101	1.42	1.55	1.41	1.60	1.56	1.61	3.04	4.47	Nov-01	Dec-02
SFWMD Porta-PSTA Mesocosms Treatments																		
Treatment 1	PEAT	PSTA	0.021	0.018	0.064	0.022	0.029	0.026	1.17	1.17	1.14	1.14	1.24	1.17	2.02	3.72	Apr-99	Jan-00
Treatment 2	LIME ROCK	PSTA	0.022	0.018	0.061	0.035	0.037	0.028	1.24	1.22	1.20	1.20	1.30	1.27	2.12	4.48	Apr-99	Jan-00
Treatment 3	PEAT	PSTA	0.025	0.018	0.047	0.014	0.033	0.024	1.52	1.47	1.48	1.21	1.57	1.49	2.49	2.93	Apr-99	Feb-01
Treatment 4	LIME ROCK	PSTA	0.025	0.016	0.046	0.020	0.034	0.025	1.58	1.57	1.55	1.38	1.63	1.60	2.66	3.47	Apr-99	Feb-01
Treatment 5	LIME ROCK	PSTA	0.023	0.018	0.059	0.020	0.034	0.026	1.33	1.30	1.29	1.14	1.39	1.31	1.99	3.17	Apr-99	Mar-00
Treatment 6	LIME ROCK	PSTA	0.023	0.018	0.059	0.026	0.035	0.029	1.34	1.29	1.31	1.19	1.41	1.32	1.86	3.56	Apr-99	Mar-00
Treatment 7	SAND	PSTA	0.025	0.018	0.044	0.096	0.034	0.029	1.48	1.66	1.45	1.41	1.53	1.74	2.85	2.33	Apr-99	Feb-01
Treatment 8	SAND	PSTA	0.020	0.021	0.062	0.023	0.032	0.023	1.33	1.14	1.30	1.12	1.40	1.15	2.01	3.84	Apr-99	Jan-00
Treatment 9	PEAT	OPEN	0.024	0.019	0.063	0.025	0.032	0.077	1.32	1.42	1.29	1.25	1.39	1.42	1.71	4.15	Apr-99	Mar-00
Treatment 10	LIME ROCK	OPEN	0.024	0.016	0.053	0.017	0.035	0.069	1.32	1.28	1.29	1.16	1.38	1.28	2.94	5.09	Apr-99	Mar-00
Treatment 11	LIME ROCK	PSTA	0.025	0.020	0.045	0.027	0.035	0.026	1.60	1.66	1.57	1.45	1.65	1.67	2.47	4.80	Apr-99	Feb-01
Treatment 12	PEAT	PSTA	0.025	0.020	0.043	0.013	0.034	0.026	1.53	1.49	1.50	1.30	1.58	1.49	2.60	4.70	Apr-99	Feb-01
Treatment 13	PEAT	PSTA	0.028	0.017	0.022	0.010	0.032	0.121	1.99	2.15	1.96	2.32	2.01	2.16	4.90	4.39	Apr-00	Feb-01
Treatment 14	LIME ROCK	PSTA	0.028	0.015	0.023	0.010	0.032	0.014	2.11	1.71	2.07	2.02	2.13	1.68	5.47	2.60	Apr-00	Feb-01
Treatment 15	LIME ROCK	PSTA	0.028	0.017	0.023	0.012	0.032	0.024	2.01	2.10	1.98	2.41	1.97	2.11	4.67	3.33	Apr-00	Feb-01
Treatment 16	LIME ROCK	PSTA	0.025	0.017	0.034	0.008	0.042	0.020	2.16	2.33	2.12	2.32	2.20	2.33	2.67	2.50	May-00	Feb-01
Treatment 17	SAND	PSTA	0.028	0.016	0.020	0.002	0.033	0.012	2.10	2.03	2.07	2.09	2.12	2.06	4.00	3.13	Apr-00	Feb-01
Treatment 18	NONE	OPEN	0.028	0.016	0.021	0.002	0.033	0.036	2.62	2.01	2.58	2.16	2.64	2.01	4.00	2.60	Apr-00	Feb-01
Treatment 19	NONE	PSTA	0.027	0.014	0.021	0.003	0.034	0.027	2.11	2.34	2.07	1.96	2.13	2.34	3.80	4.22	Apr-00	Feb-01

Exhibit 37 (Cont.) Average Inflow / Outflow Water Quality Concentrations by Treatment Wetland Site

			TP (mg/L)		NOx-N (mg/L)		NH_4-N (mg/L)		TKN (mg/L)		TON (mg/L)		TN (mg/L)		TSS (mg/L)			
System	**Substrate**	**Vegetation**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**Period-of-Record**	
SFWMD PSTA Test Cells Treatments																		
Treatment 1	PEAT	PSTA	0.025	0.026	0.068	0.028	0.068	0.022	1.93	1.17	1.86	1.15	1.96	1.18	2.94	2.68	Feb-99	Jan-00
Treatment 2	LIME ROCK	PSTA	0.024	0.018	0.068	0.019	0.069	0.027	1.86	1.47	1.79	1.30	1.89	1.42	3.11	4.13	Feb-99	Mar-00
Treatment 3	LIME ROCK	PSTA	0.024	0.023	0.072	0.022	0.064	0.021	1.90	1.53	1.83	1.28	1.95	1.47	2.82	6.02	Feb-99	Mar-00
Treatment 4	PEAT	PSTA	0.023	0.032	0.071	0.010	0.086	0.028	2.38	2.34	2.30	2.41	2.45	2.50	3.35	4.48	Apr-00	Mar-01
Treatment 5	LIME ROCK	PSTA	0.023	0.012	0.071	0.002	0.086	0.017	2.37	2.36	2.29	2.39	2.44	2.37	3.36	3.86	Apr-00	Mar-01
Treatment 6	LIME ROCK	PSTA	0.023	0.019	0.057	0.002	0.098	0.030	2.57	2.58	2.47	2.88	2.63	2.58	2.77	2.67	May-00	Mar-01
STA-1E																		
Cell 3	SAND	EMERGENT	0.139	0.155	0.173	0.021	0.099	0.035	1.32	1.32	1.22	1.28	1.49	1.34	11.41	4.22	May-06	Jan-12
Cell 4N	SAND	SAV	0.155	0.066	0.021	0.020	0.035	0.043	1.32	1.63	1.28	1.58	1.34	1.65	4.22	4.84	May-06	Jan-12
Cell 4S	PEAT	SAV	0.070	0.030	0.058	0.031	0.183	0.052	1.62	1.37	1.44	1.32	1.68	1.40	4.80	3.30	May-06	Jan-12
Cell 5	SAND	EMERGENT	0.217	0.241	0.396	0.068	0.193	0.122	2.26	2.26	2.06	2.13	2.65	2.32	9.76	9.75	May-06	Jan-12
Cell 6	PEAT	SAV	0.170	0.147	0.126	0.120	0.124	0.134	2.55	3.00	2.43	2.86	2.68	3.12	8.79	7.89	May-06	Jan-12
Cell 7	PEAT	EMERGENT	0.172	0.134	0.716	0.185	0.297	0.131	2.88	2.68	2.58	2.55	3.60	2.87	16.96	8.31	May-06	Jan-12
STA-1W																		
Cell 1	PEAT	EMERGENT	0.133	0.109	0.533	0.325	0.598	0.202	2.92	2.72	2.32	2.52	3.45	3.04	0.60	0.20	Jun-00	Jan-08
Cell 1A	PEAT	EMERGENT	0.135	0.110	0.926	0.244	0.499	0.149	2.74	2.39	2.24	2.24	3.67	2.64	11.97	9.60	May-08	Jan-12
Cell 1B+3	PEAT	SAV	0.109	0.031	0.087	0.050	0.093	0.136	2.27	2.22	2.18	2.08	2.36	2.27	3.80	3.17	May-08	Jan-12
Cell 2	PEAT	EMERGENT	0.128	0.110	0.842	0.411	0.485	0.125	3.05	2.72	2.56	2.59	3.89	3.13	17.40	8.63	Jun-00	Nov-04
Cell 3	PEAT	EMERGENT	0.102	0.078	0.248	0.135	0.149	0.184	2.60	2.21	2.45	2.02	2.85	2.34	8.69	3.33	Jun-00	Jan-08
Cell 4	PEAT	SAV	0.110	0.053	0.411	0.146	0.125	0.040	2.72	2.09	2.59	2.05	3.13	2.23	8.63	3.14	Jun-00	Nov-04
North Flow-way	PEAT	SAV	0.154	0.087	0.773	0.143	0.354	0.086	2.60	2.59	2.25	2.51	3.37	2.74	16.39	11.00	Jun-00	Feb-12
West Flow-way	PEAT	SAV	0.145	0.043	0.216	0.128	0.216	0.128	2.58	2.45	2.37	2.32	2.80	2.57	14.26	3.13	Feb-08	Feb-12
STA-2																		
Cell 1A	PEAT	EMERGENT	0.060	0.013	0.685	0.018	0.380	0.032	2.45	2.13	2.07	2.10	3.14	2.15	8.55	2.96	Mar-02	May-05
Cell 1B	PEAT	EMERGENT	0.090	0.017	0.840	0.033	0.315	0.027	2.54	1.99	2.22	1.96	3.38	2.02	8.12	3.00	Jun-05	Feb-12
Cell 2	PEAT	EMERGENT	0.089	0.029	0.844	0.147	0.315	0.076	2.61	2.19	2.30	2.12	3.46	2.34	9.81	3.13	Mar-02	Feb-12
Cell 3	PEAT	SAV	0.084	0.019	0.824	0.190	0.270	0.046	2.54	2.22	2.27	2.18	3.36	2.41	7.22	3.02	Mar-02	Feb-12
Cell 4	PEAT	SAV	0.095	0.028	0.633	0.069	0.190	0.229	2.51	2.73	2.32	2.50	3.15	2.80	11.13	4.51	Feb-08	Feb-12
STA-3/4																		
Cell 1A	PEAT	EMERGENT	0.084	0.042	1.052	0.077	0.230	0.069	2.26	2.13	2.03	2.07	3.32	2.21	10.29	3.19	May-05	Jan-12
Cell 1B	PEAT	SAV	0.036	0.019	0.078	0.022	0.070	0.071	2.14	2.05	2.07	1.98	2.22	2.08	3.13	3.09	May-05	Feb-12
Cell 2A	PEAT	EMERGENT	0.066	0.030	1.490	0.135	0.150	0.073	2.16	2.03	2.01	1.95	3.64	2.16	8.35	3.06	May-05	Jan-12
Cell 2B	PEAT	SAV	0.028	0.021	0.134	0.028	0.072	0.084	2.05	1.95	1.98	1.87	2.18	1.98	3.08	3.02	May-05	Feb-12
Cell 3A	PEAT	EMERGENT	0.051	0.025	1.562	0.148	0.112	0.052	2.08	2.04	1.97	1.99	3.64	2.19	7.55	3.00	Apr-08	Feb-12
Cell 3B	PEAT	SAV	0.025	0.018	---	---	---	---	---	---	---	---	---	---	---	---	Apr-08	Nov-11
STA-5																		
Cell 1A	PEAT	EMERGENT	0.128	0.131	0.056	0.021	0.396	0.057	1.89	1.69	1.50	1.63	1.95	1.71	4.28	3.57	Apr-08	Feb-12
Cell 1B	PEAT	SAV	0.090	0.049	0.017	0.017	0.074	0.220	1.72	1.97	1.64	1.75	1.74	1.98	3.67	3.69	Apr-08	Jan-12
Cell 2A	PEAT	EMERGENT	0.137	0.063	0.078	0.015	0.110	0.046	1.57	1.45	1.46	1.41	1.64	1.47	4.88	3.07	Apr-08	Feb-12
Cell 2B	PEAT	SAV	0.101	0.072	---	---	---	---	---	---	---	---	---	---	---	---	Apr-08	Feb-12
Cell 3A	PEAT	EMERGENT	0.223	0.101	0.078	0.040	0.078	0.061	1.52	1.86	1.44	1.80	1.60	1.90	4.15	5.63	Apr-08	Feb-12
Cell 3B	PEAT	SAV	0.079	0.042	0.029	0.005	0.047	0.022	1.35	1.52	1.30	1.50	1.38	1.53	3.98	4.07	Apr-08	Feb-12
Center Flow-way	PEAT	EMERGENT	0.152	0.143	0.047	0.018	0.241	0.051	1.65	1.52	1.41	1.47	1.70	1.54	2.80	1.78	May-00	Mar-08
North Flow-way	PEAT	EMERGENT	0.106	0.123	0.063	0.027	0.326	0.067	1.67	1.58	1.35	1.51	1.74	1.61	1.68	3.00	May-00	Mar-08

Exhibit 37 (Cont.) Average Inflow / Outflow Water Quality Concentrations by Treatment Wetland Site

System	Substrate	Vegetation	TP (mg/L) In	TP (mg/L) Out	NOx-N (mg/L) In	NOx-N (mg/L) Out	NH_4-N (mg/L) In	NH_4-N (mg/L) Out	TKN (mg/L) In	TKN (mg/L) Out	TON (mg/L) In	TON (mg/L) Out	TN (mg/L) In	TN (mg/L) Out	TSS (mg/L) In	TSS (mg/L) Out	Period-of-Record	
STA-6																		
Cell 3	PEAT	EMERGENT	0.068	0.033	0.105	0.008	0.099	0.030	1.56	1.36	1.47	1.34	1.67	1.37	4.26	2.99	Oct-02	Feb-12
Cell 5	PEAT	EMERGENT	0.080	0.023	0.112	0.008	0.133	0.049	1.63	1.48	1.49	1.43	1.74	1.49	4.98	3.03	Oct-02	Feb-12
Section 2	PEAT	SAV	0.105	0.044	0.100	0.006	0.176	0.043	1.60	1.41	1.43	1.37	1.70	1.42	6.22	3.13	May-08	Oct-11
Taylor Creek Pilot STA	SAND	EMERGENT	0.320	0.229	0.172	0.009	0.100	0.120	1.57	1.55	1.47	1.43	1.74	1.56	5.19	3.27	Jun-08	Jan-12
City of Titusville, Blue Heron Wetland	SAND	EMERGENT	0.493	0.077	2.485	0.042	0.438	0.284	1.60	1.16	1.16	0.87	4.02	1.19	0.97	1.30	Jan-97	Dec-11
Wellington Aquatics Pilot Test Facility																		
Cell E1	SAND	EMERGENT	0.348	0.209	0.094	0.080	---	---	1.33	1.07	---	---	1.42	1.15	27.9	1.56	Nov-01	Feb-03
Cell E2	SAND	SAV	0.209	0.090	0.080	0.080	---	---	1.07	1.01	---	---	1.15	1.09	1.56	1.81	Nov-01	Feb-03
Cell E3	LIME ROCK	PSTA	0.090	0.043	0.080	0.062	---	---	1.01	1.02	---	---	1.09	1.09	1.81	2.40	Nov-01	Feb-03
Cell W1	SAND	FAV	0.348	0.081	0.094	0.085	---	---	1.33	0.84	---	---	1.42	0.93	27.9	1.13	Nov-01	Feb-03
Cell W2	SAND	EMERGENT	0.081	0.029	0.085	0.083	---	---	0.84	0.83	---	---	0.93	0.91	1.13	0.94	Nov-01	Feb-03
Cell W3	LIME ROCK	PSTA	0.029	0.022	0.083	0.062	---	---	0.83	0.96	---	---	0.91	1.02	0.94	1.15	Nov-01	Feb-03

Notes:
Period of record averages are reported as arithmetic means; Monthly time series data presented in Appendix B are arithmetic means with the exception of the following sites which are reported as flow-weighted means: STA-1E, STA-1W, STA-2, STA-3/4, STA-5, STA-6, Taylor Creek Pilot STA

Exhibit 38 summarizes the annual average mass loading rate vs. outflow concentrations for TP in the Florida treatment wetlands included in this evaluation. All annual data presented below are arithmetic means by calendar year. Outflow TP concentration appears to be a function of TP mass loading rate with considerable intra-site and year-to-year variability. The Lakeland system built on a former phosphate mine had the highest TP loading rates and resulting outflow TP concentrations. The PSTA test systems, STA-2, STA-3/4, and the open-water reservoir test cells typically had the lowest TP inflow loads and TP outflow concentrations.

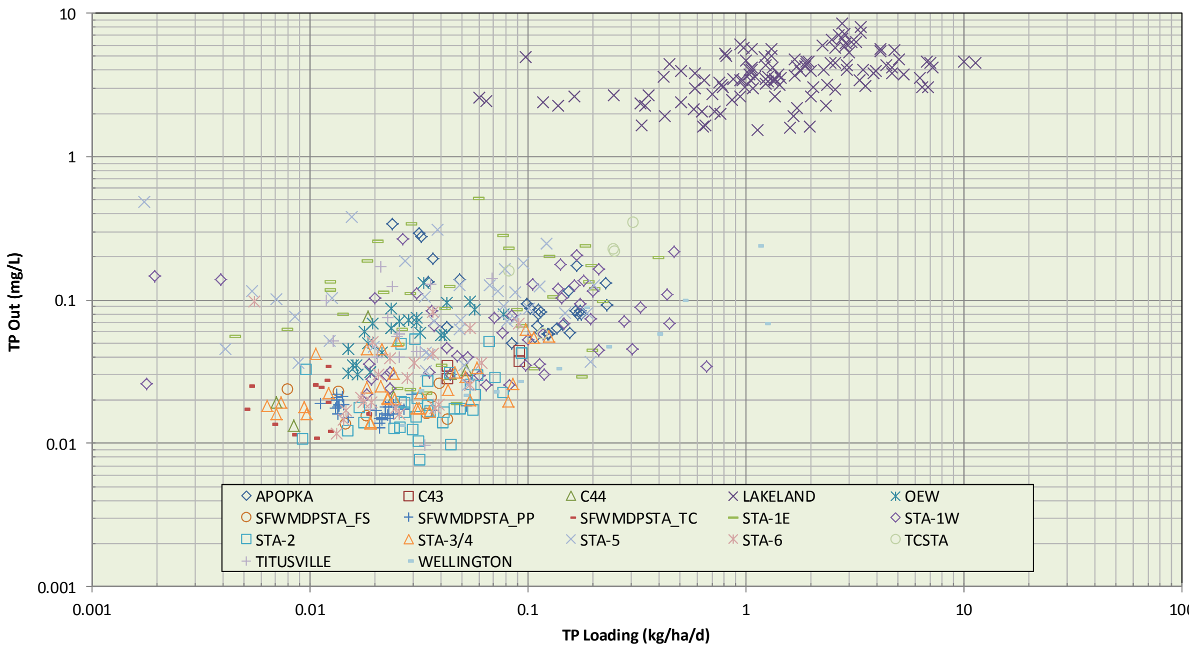


Exhibit 38 - Annual TP Mass Loading vs. Outlet Concentration by Site

Exhibit 39 summarizes the annual average mass loading rate vs. outflow concentrations for NO_x-N in the Florida treatment wetlands included in this evaluation. Outflow NO_x-N concentration is clearly a function of NO_x-N mass loading rate with considerable intra-site and year-to-year variability. The Lakeland treatment wetland system built on a former phosphate mine had the highest NO_x-N loading rates and resulting outflow NO_x-N concentrations. The majority of the treatment wetland systems evaluated were able to achieve very low NOx-N concentrations, often below 0.01 mg/L.

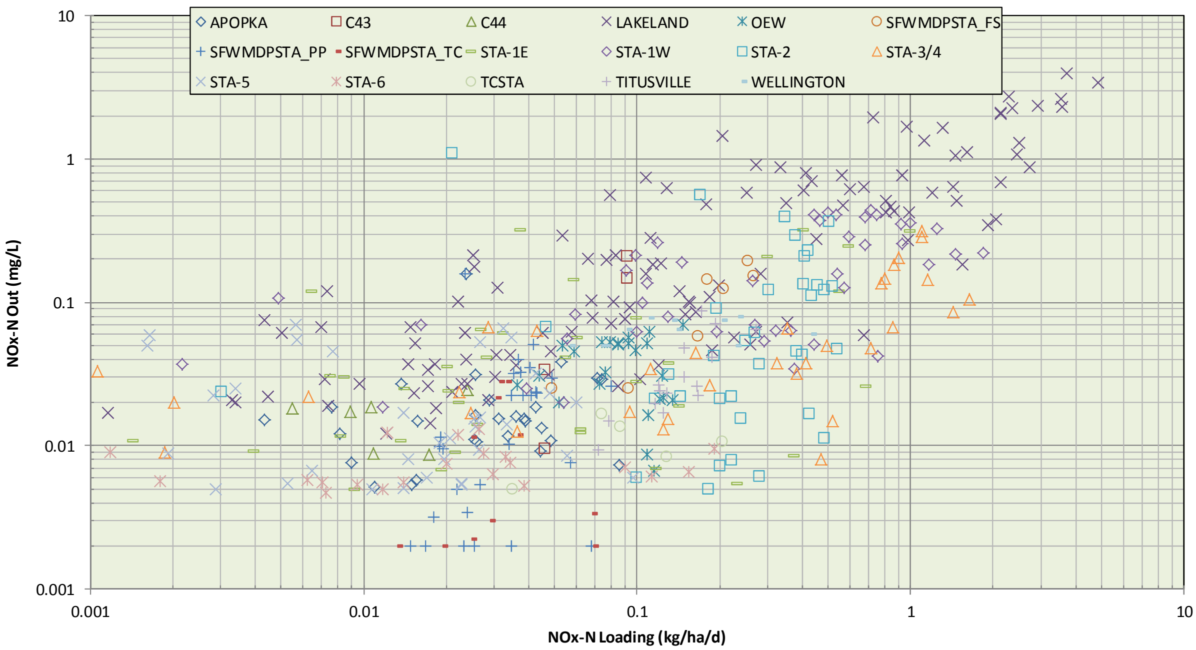


Exhibit 39 - Annual NOx-N Mass Loading vs. Outlet Concentration by Site

Exhibit 40 summarizes the annual average mass loading rate vs. outflow concentrations for AN in the Florida treatment wetlands included in this evaluation. At the inflow loads included in this analysis there does not appear to be a strong effect on outflow AN concentration. However, there is a considerable intra-site and year-to-year variability for AN performance at these sites. The Lakeland and Apopka wetland systems generally have the highest AN loading rates and resulting outflow AN concentrations. Very low outflow AN concentrations (<0.1 mg/L) were typical of the remaining wetland systems across the range of AN mass loading rates summarized.

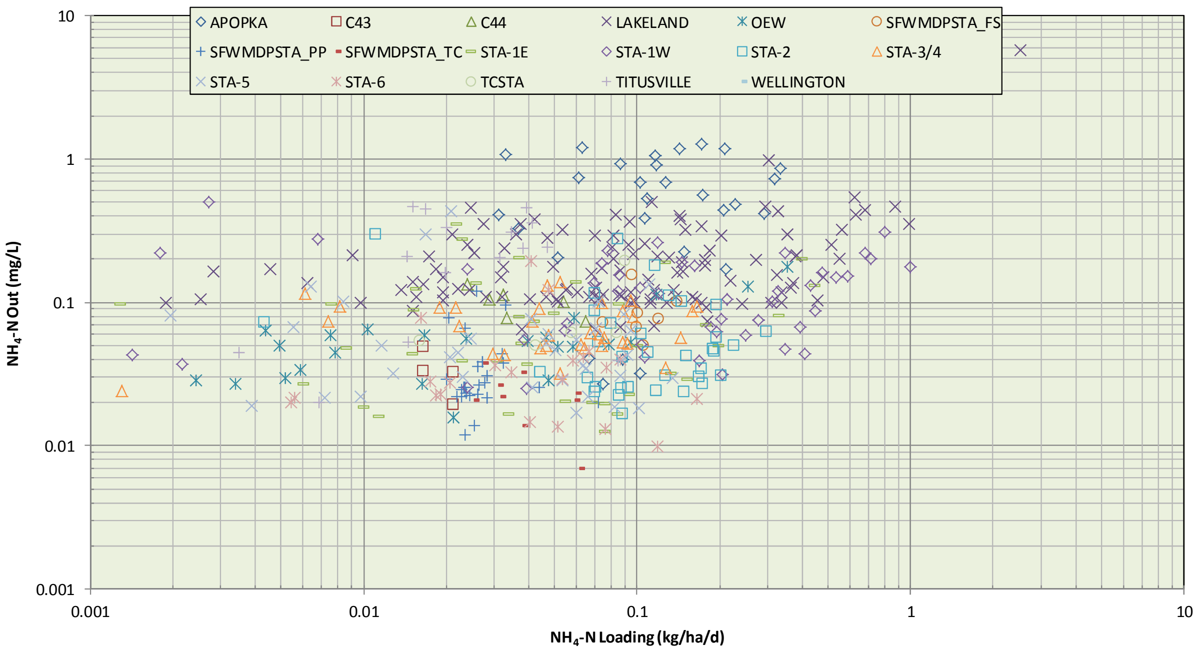


Exhibit 40 - Annual AN Mass Loading vs. Outlet Concentration by Site

Exhibit 41 summarizes the annual average mass loading rate vs. outflow concentrations for TKN in the Florida treatment wetlands included in this evaluation. Above a TKN loading rate of about 0.1 kg/ha/d, outflow TKN concentration is a function of TKN mass loading rate with considerable intra-site and year-to-year variability. The Lake Apopka treatment wetland system built on a former muck farm had the highest TKN loading rates and resulting outflow TKN concentrations. The wetlands with the lowest outflow TKN concentrations included the PSTA test systems, the Orlando Easterly wetland, the C-43 and C-44 test cells, Lakeland, and STA-1E.

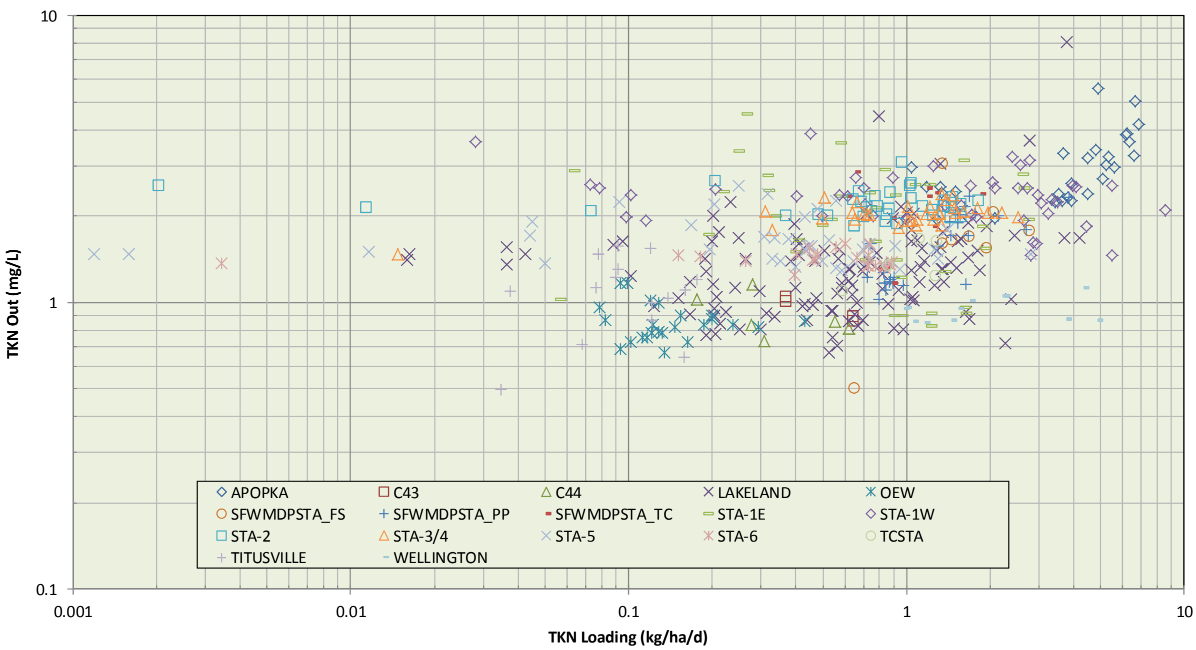


Exhibit 41 - Annual TKN Mass Loading vs. Outlet Concentration by Site

Exhibit 42 summarizes the annual average mass loading rate vs. outflow concentrations for TON in the Florida treatment wetlands included in this evaluation. Organic N loading rates do not exceed about 10 kg TON/ha/d for these data and within this range, most of the wetland TON outflow concentrations are in the range of 1 to 2 mg/L. This is the general TON background typical of treatment wetlands worldwide. Kadlec and Knight (1996) recommend an TON C* value (irreducible or wetland background concentration) of 1.5 mg/L. Of particular interest to the C-43 WQTA project is the observation that some of the Florida systems consistently achieve TON concentrations consistently lower than 1.5 mg/L. These systems include the Orlando Easterly Wetland, Lakeland, and the C-43 and C-44 reservoir test cell projects. Of the EAA STAs, STA-1E and STA-6 achieve the lowest TON concentrations, typically less than 1.5 mg/L. Three of these wetland cells were constructed on sandy or clayey soils. The effects of soil type on TON C* values is examined further below.

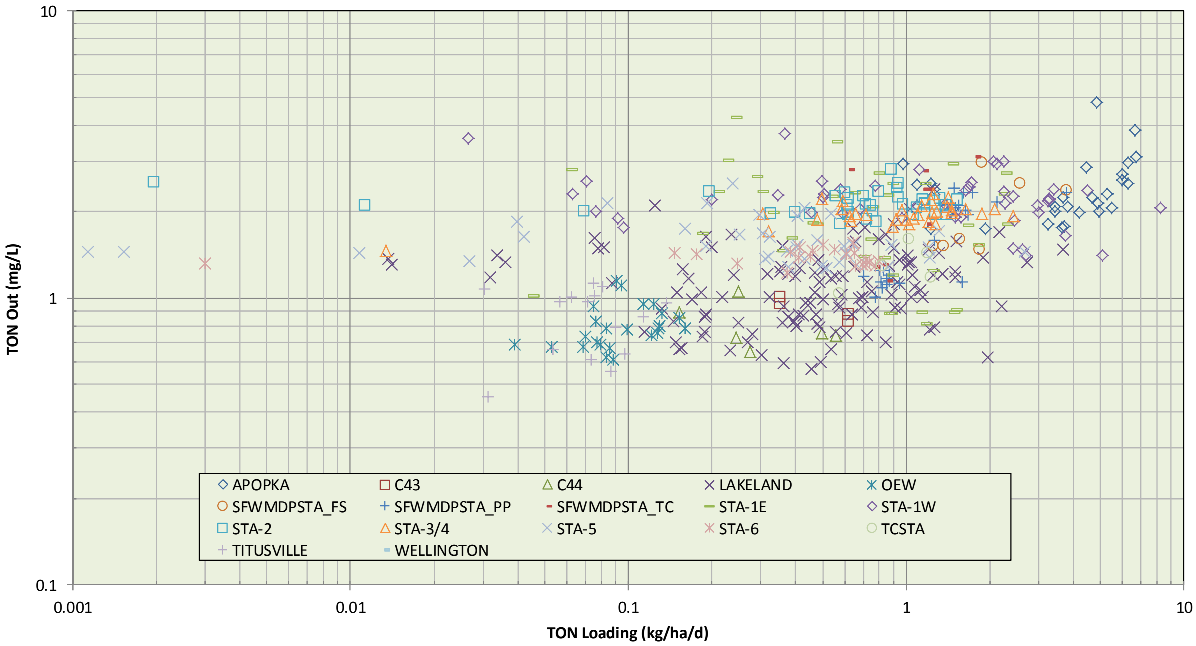


Exhibit 42 - Annual TON Mass Loading vs. Outlet Concentration by Site

Exhibit 43 summarizes the annual average mass loading rate vs. outflow concentrations for TN in the Florida treatment wetlands included in this evaluation. Due to the generally low inorganic N fraction remaining in wetland outflows, outflow TN concentrations are similar to the TON data reviewed above. Kadlec and Knight (1996) estimated a TN C* of 1.5 mg/L. These data support that estimate for wetland systems loaded less than about 2 kg TN/ha/d. However, these data also clearly illustrate the potential to lower TN concentrations to less than 1 mg/L (as low as 0.6 mg/L on an annual average basis) in a variety of full-scale constructed aquatic and wetland treatment systems

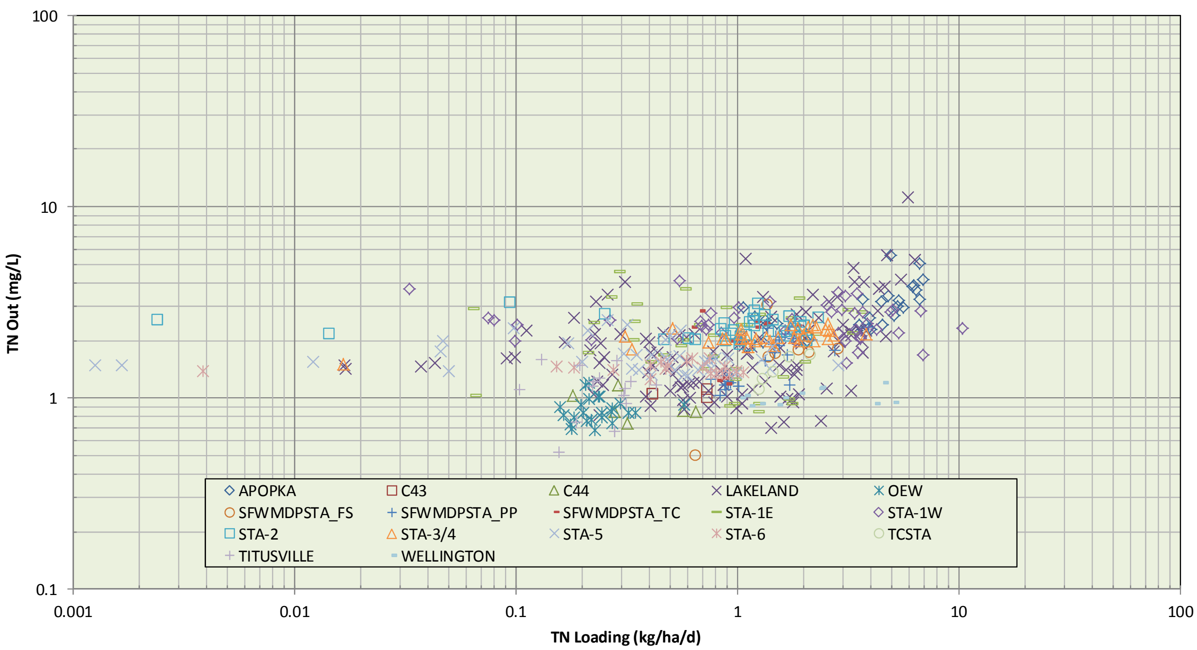


Exhibit 43 - Annual TN Mass Loading vs. Outlet Concentration by Site

Exhibit 44 summarizes the annual average mass loading rate vs. outflow concentrations for TSS in the Florida treatment wetlands included in this evaluation. Within the range of TSS loadings included in this analysis, outflow TSS concentration is largely independent of inflow loads. The central tendency of these TSS data is an outflow concentration of about 5 mg/L, with a range from 1 to 10 mg/L. The wetland systems with the lowest TSS outflow concentrations include Wellington, STA-1W, and the Porta PSTAs. These reported TSS concentrations may be an artifact of differing minimum reporting methods since they are below the typical analytical TSS detection level of 3 mg/L.

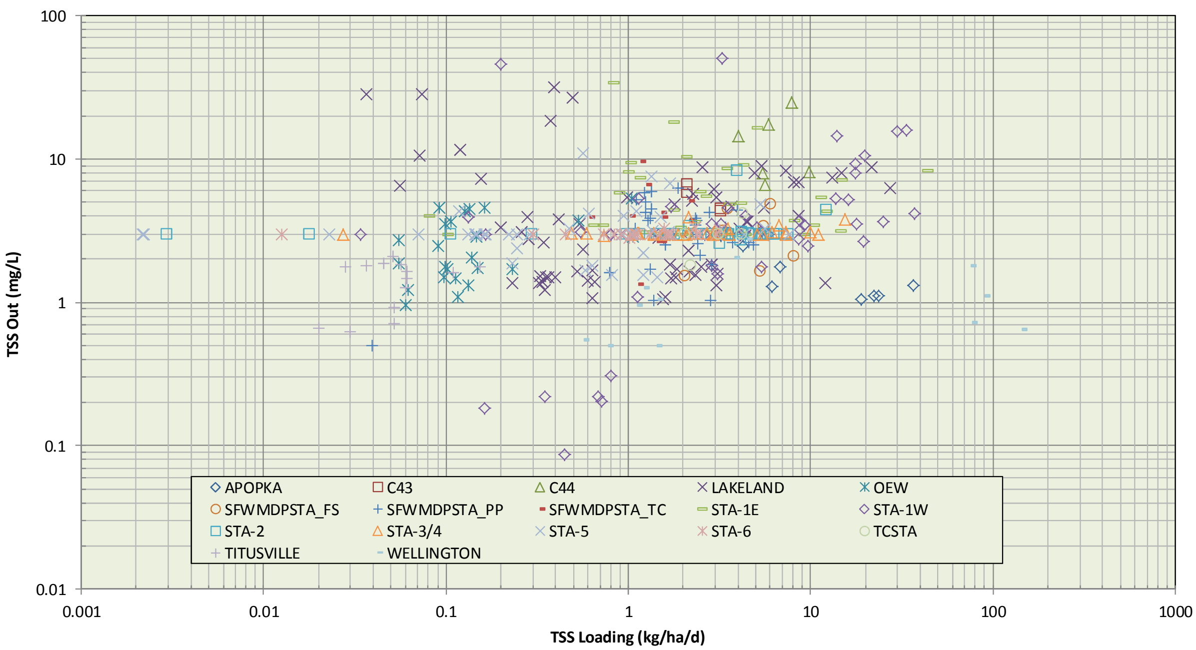


Exhibit 44 - Annual TSS Mass Loading vs. Outlet Concentration by Site

3.3.2 Inflow Concentration

Kadlec and Wallace (2009) note that C* values are sometimes related to inflow concentrations for most pollutants in treatment wetlands. The apparent explanation for this phenomenon is that in most treatment systems there is some water that short circuits and has shorter effective hydraulic residence times and receives less treatment. Exhibit 45 through Exhibit 51 illustrate the effect of higher inflow pollutant concentrations on observed outflow concentrations for Florida systems. The effect is most notable for pollutants with slower reaction rates such as TP. Exhibit 45 illustrates that the achievable outflow TP is about 10 to 20 ppb lower for wetlands receiving the lowest inflow TP concentrations. Exhibit 46 for NO_x-N does not show this effect as strongly as TP since wetland systems receiving higher inflow NO_x-N concentrations can often attain outflow concentrations as low as the systems receiving lower inflow concentrations. For the more resistant N fractions (AN [Exhibit 47] and TON [Exhibit 49]) and for TN (Exhibit 50) there is an apparent effect of inflow concentration on achievable outflow C* values. From these data it is concluded that as long as treatment wetland inflow TON and TN values are generally less than about 3 to 6 mg/L it is possible to achieve even the lowest outflow concentrations.

Exhibit 45 - Annual TP Mass Loading vs. Outlet Concentration by Inlet Concentration Range (TP < 0.561 mg/L)

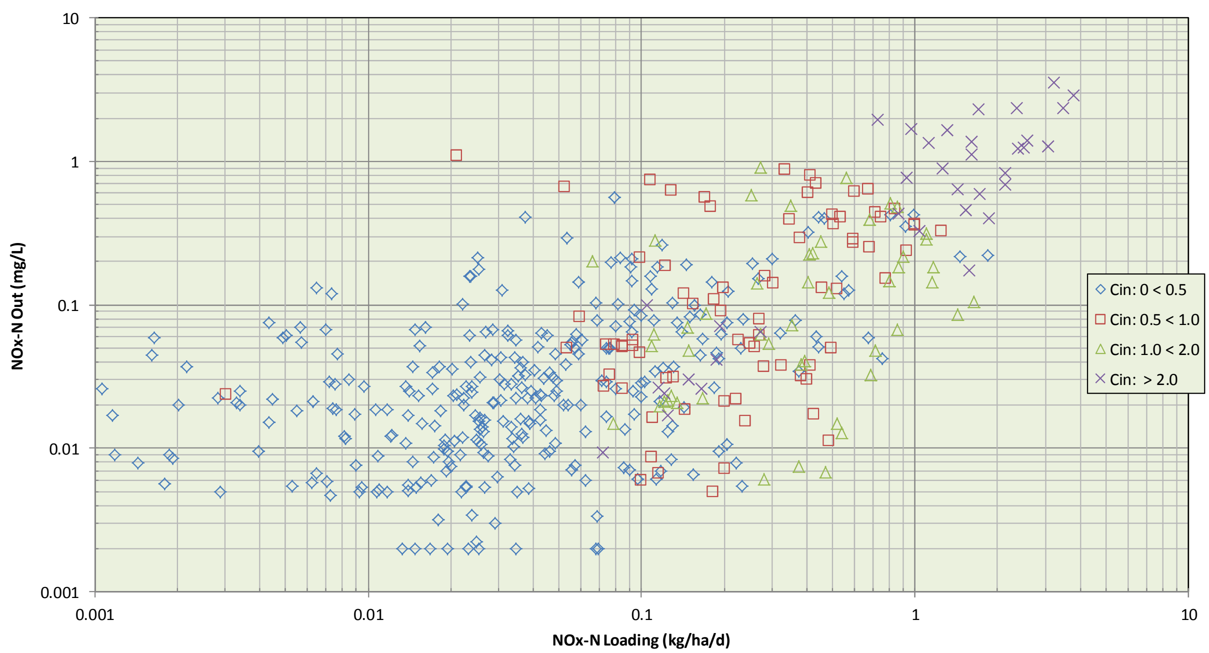


Exhibit 46 - Annual NOx-N Mass Loading vs. Outlet Concentration by Inlet Concentration Range (TN < 11 mg/L)

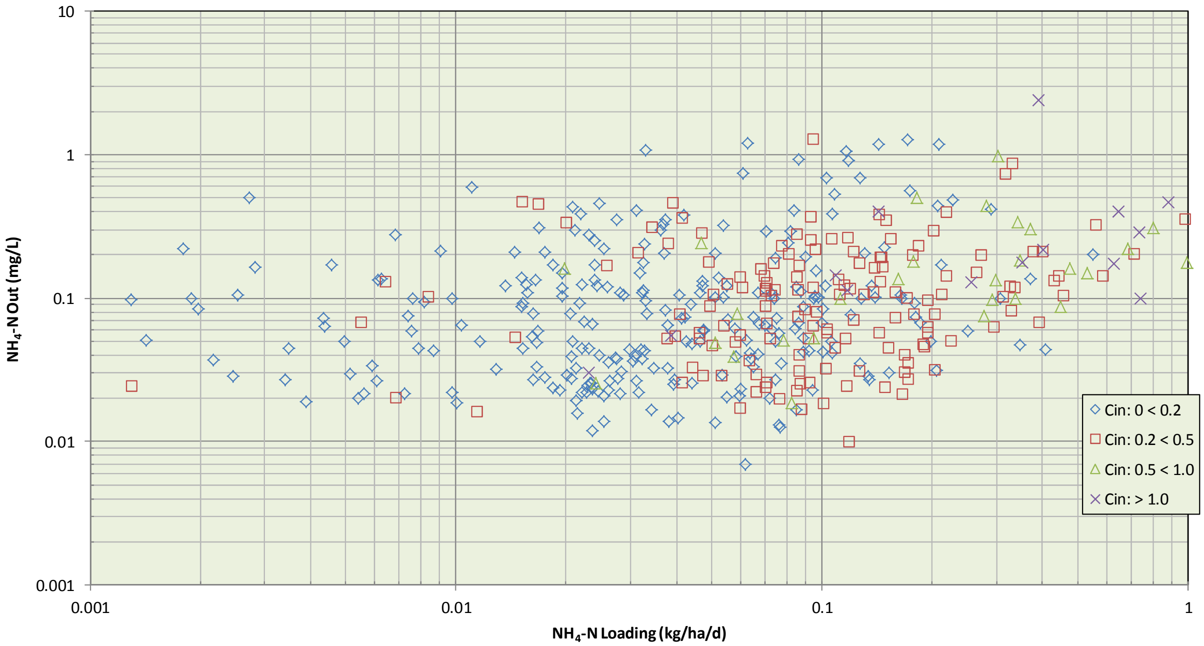


Exhibit 47 - Annual AN Mass Loading vs. Outlet Concentration by Inlet Concentration Range (TN < 11 mg/L)

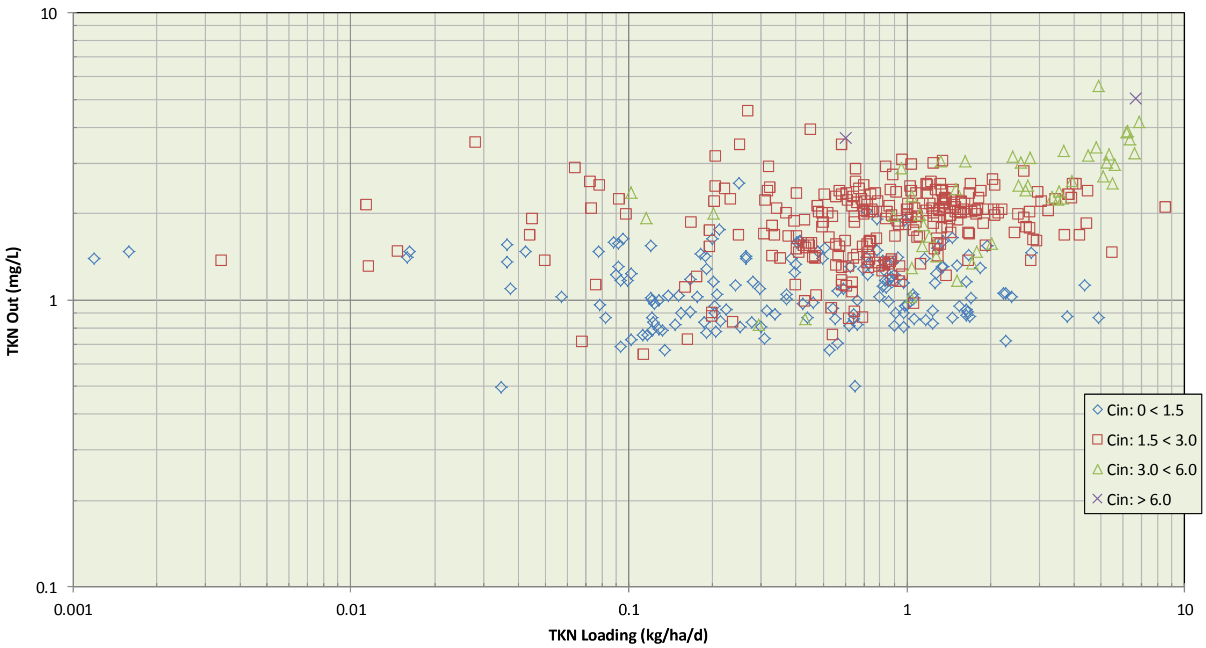


Exhibit 48 - Annual TKN Mass Loading vs. Outlet Concentration by Inlet Concentration Range (TN < 11 mg/L)

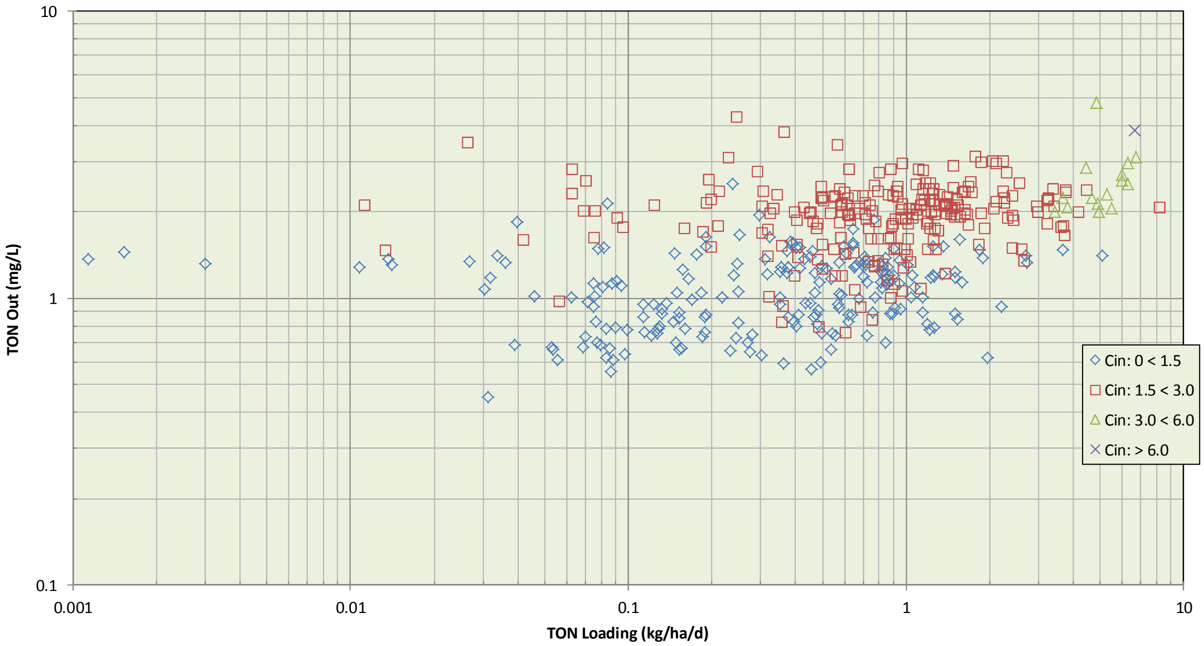


Exhibit 49 - Annual TON Mass Loading vs. Outlet Concentration by Inlet Concentration Range (TN < 11 mg/L)

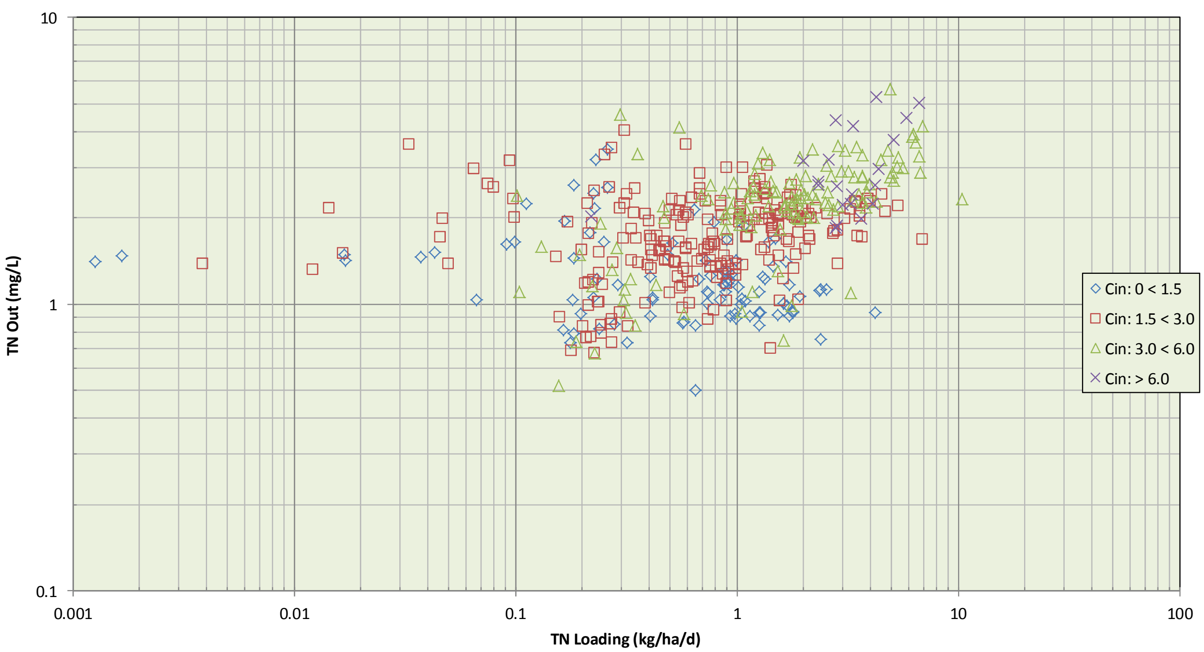


Exhibit 50 - Annual TN Mass Loading vs. Outlet Concentration by Inlet Concentration Range (TN < 11 mg/L)

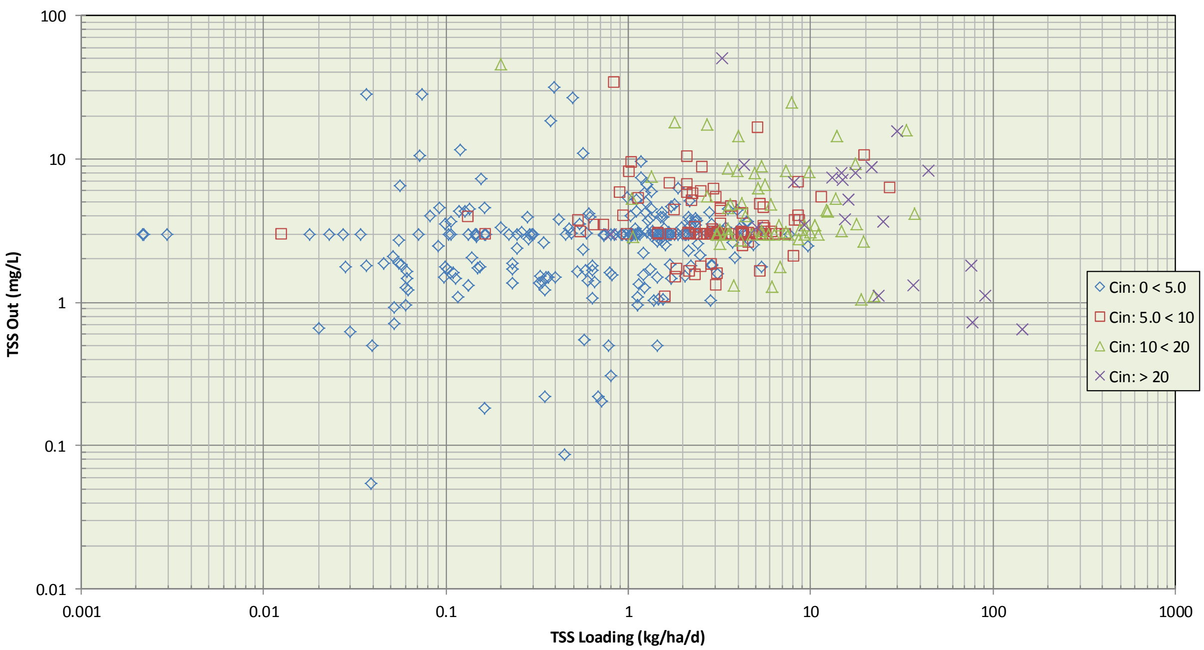


Exhibit 51 - Annual TSS Mass Loading vs. Outlet Concentration by Inlet Concentration Range (TSS < 103 mg/L)

3.3.3 Vegetation

Exhibit 52 shows the relationship between TP loading and TP outflow concentration by vegetation type. The data show that the lowest outflow concentrations were observed in the PSTA and Open Water (OW) systems. It should be noted however, that the OW systems were all from relatively short-duration studies with mostly low inflow TP concentrations. The OW systems from the Porta-PSTA and C-44 projects received water with average inflow TP concentrations of 0.053 mg/L and 0.028 mg/L, respectively, while the C-43 test cells received water with 0.141 mg/L TP. Based on these short-term studies, it is more likely that the TP performance of the OW systems is a function of the low TP loading rate and start-up phenomena (e.g., adsorption to sediments) than it is to an inherently superior removal rate. The general performance curves support previous work that has shown the lowest TP concentrations are achieved in PSTA systems, followed by SAV and EMV.

Exhibit 53 shows cumulative frequency distributions of the monthly average outflow TP concentrations by vegetation type and indicates that the general order of performance (from highest to lowest outflow TP concentration) is FAV>EMV>SAV>OW>PSTA. A significant difference was found between vegetation types with the highest and lowest median outflow concentrations (Kruskal–Wallis test, $P<0.001$). Again, the data for the OW systems are only reflective of relatively lightly loaded systems.

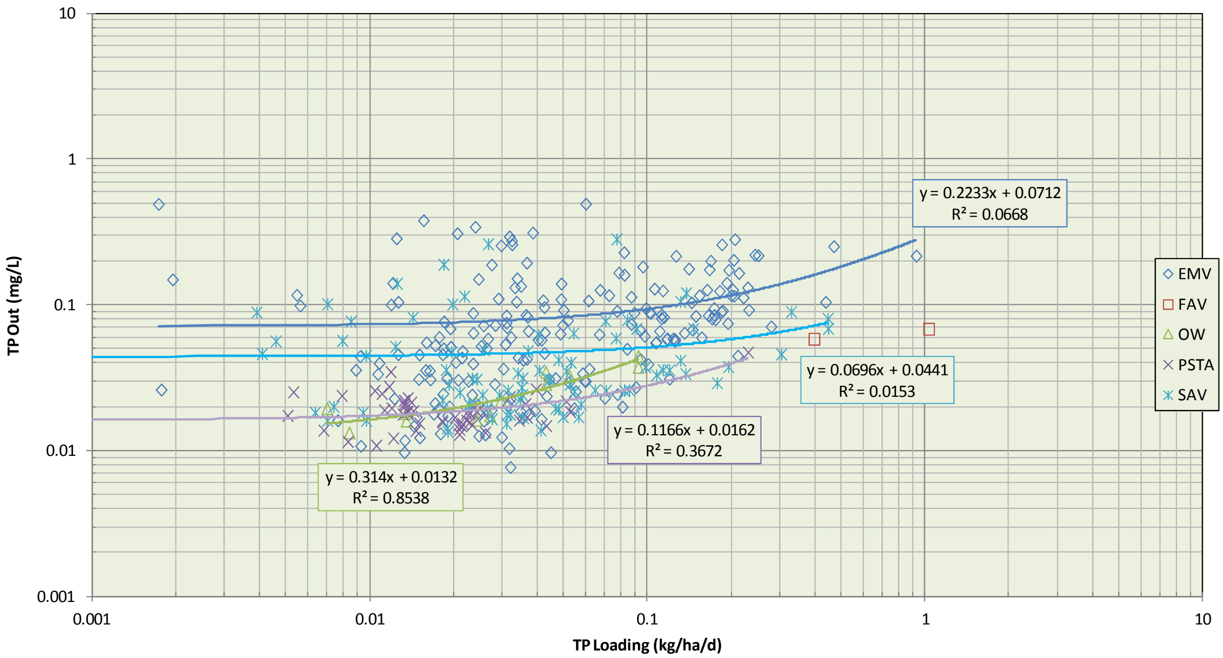
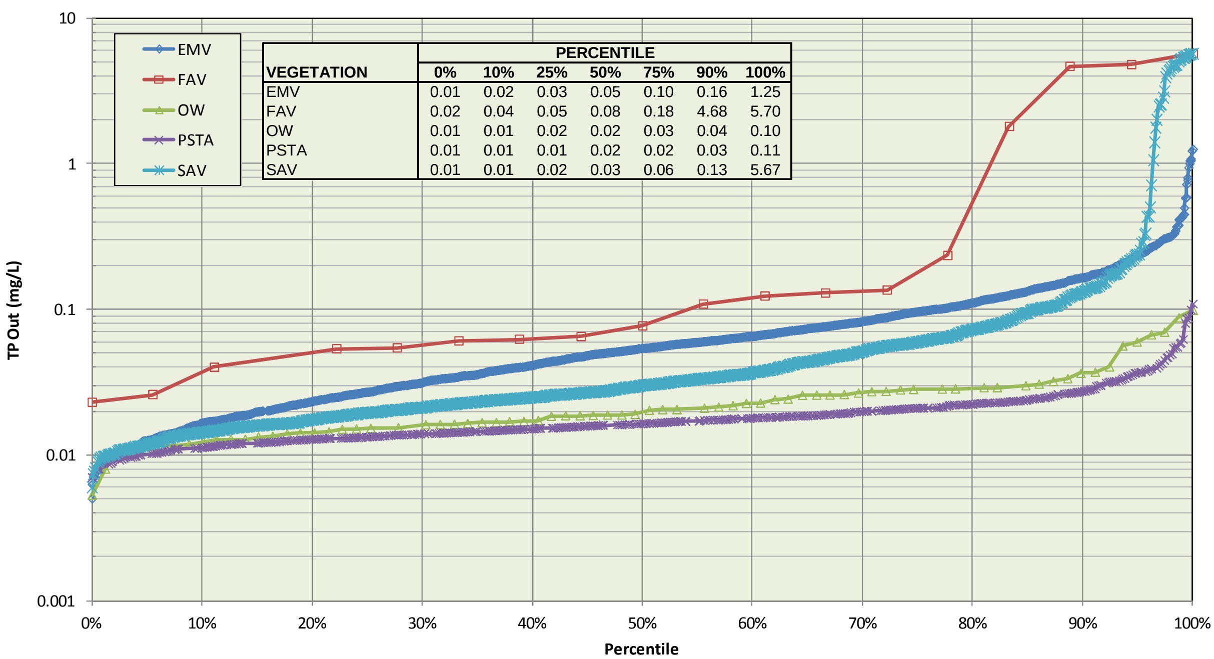


Exhibit 52 - Annual TP Mass Loading vs. Outlet Concentration by Vegetation Type (Inlet TP < 0.561 mg/L)



VEGETATION	PERCENTILE 0%	10%	25%	50%	75%	90%	100%
EMV	0.01	0.02	0.03	0.05	0.10	0.16	1.25
FAV	0.02	0.04	0.05	0.08	0.18	4.68	5.70
OW	0.01	0.01	0.02	0.02	0.03	0.04	0.10
PSTA	0.01	0.01	0.01	0.02	0.02	0.03	0.11
SAV	0.01	0.01	0.02	0.03	0.06	0.13	5.67

Exhibit 53 - Monthly Average TP Outflow Concentration Percentiles by Vegetation Type (Inlet TP < 0.561 mg/L)

Exhibit 54 shows the relationship between NOx-N loading and outflow concentration by vegetation type. These data show that the lowest NOx-N outflow concentrations were observed in the EMV, PSTA, and SAV treatment wetland systems. The highest NOx-N concentrations were typically measured in the FAV treatment wetland systems. Exhibit 55 shows frequency distributions of the monthly average outflow NOx-N concentrations by vegetation type and indicates that the general order of performance (from highest to lowest outflow concentration) is FAV>SAV>EMV>OW>PSTA. A significant difference was found between vegetation types with the highest and lowest median outflow concentrations (Kruskal–Wallis test, $P<0.001$). Again, the data for the OW systems are only reflective of relatively lightly loaded systems.

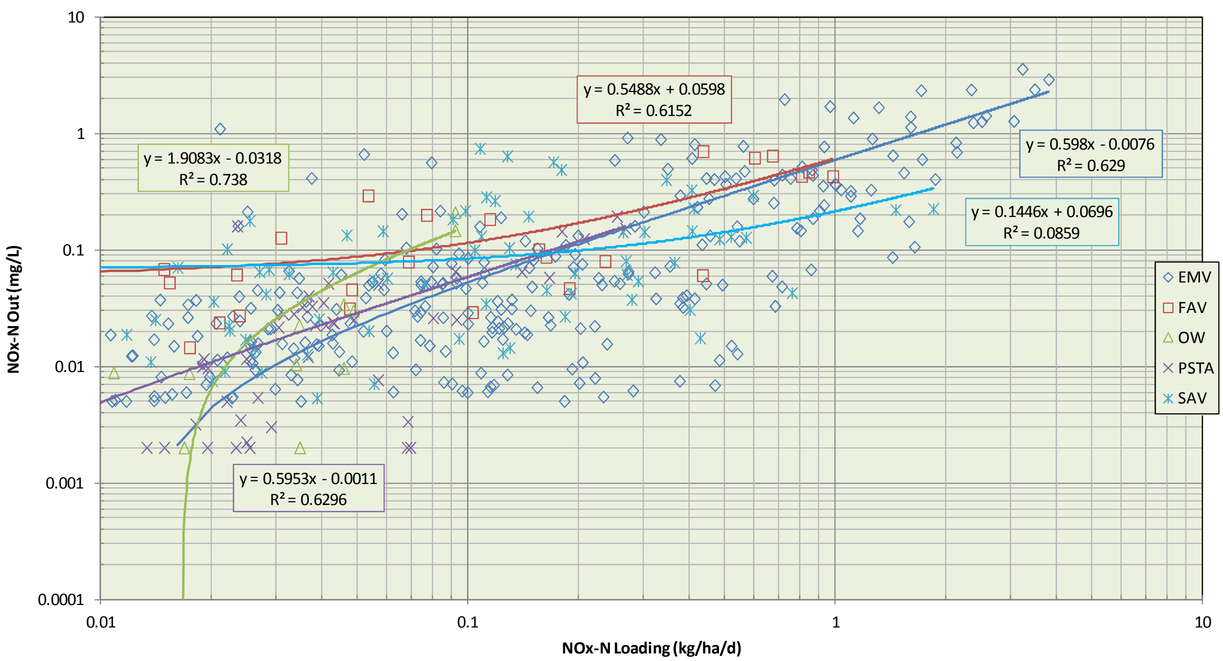


Exhibit 54 - Annual NOx-N Mass Loading vs. Outlet Concentration by Vegetation Type (Inlet TN < 11 mg/L)

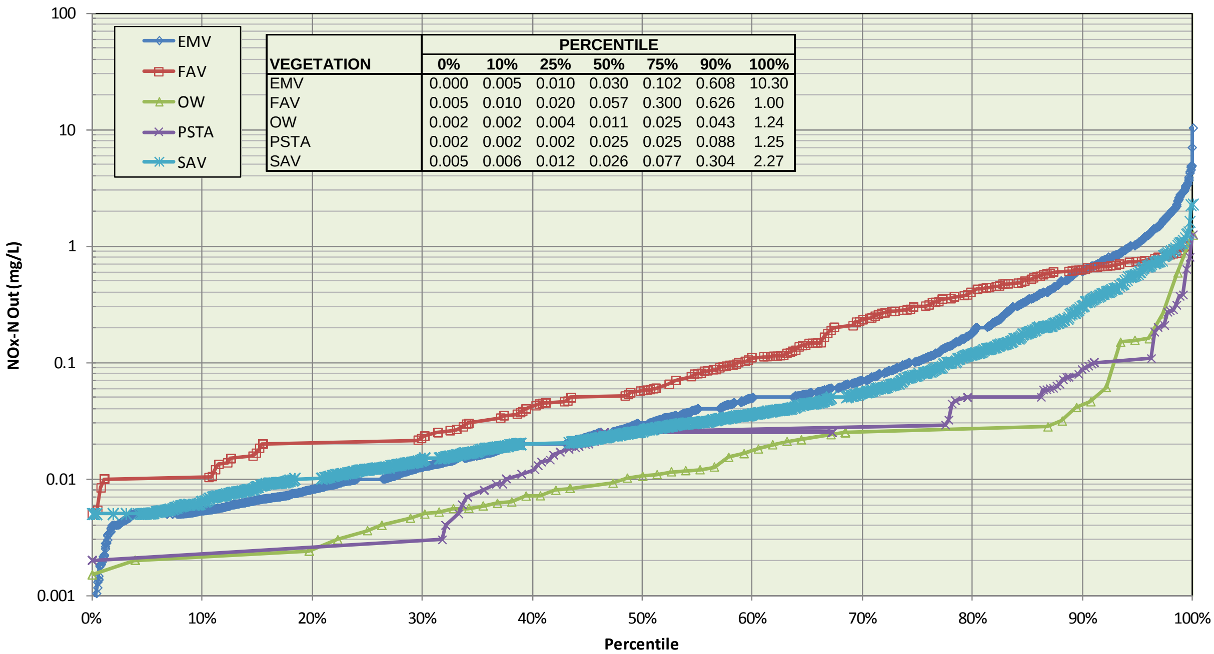


Exhibit 55 - Monthly Average NOx-N Outflow Concentration Percentiles by Vegetation Type (Inlet TN < 11 mg/L)

Exhibit 56 shows the relationship between AN loading and outflow concentration by vegetation type. These data show that the lowest AN outflow concentrations were observed in the PSTA and SAV treatment wetland systems. The highest AN concentrations were typically measured in the FAV treatment wetland systems. EMV treatment wetlands were intermediate in their ability to reduce AN concentrations. Exhibit 57 shows frequency distributions of the monthly average outflow AN concentrations by vegetation type and indicates that the general order of performance (from highest to lowest outflow concentration) is FAV>EMV>SAV>OW>PSTA. A significant difference was found between vegetation types with the highest and lowest median outflow concentrations (Kruskal–Wallis test, P<0.001). Again, the data for the OW systems are only reflective of relatively lightly loaded systems.

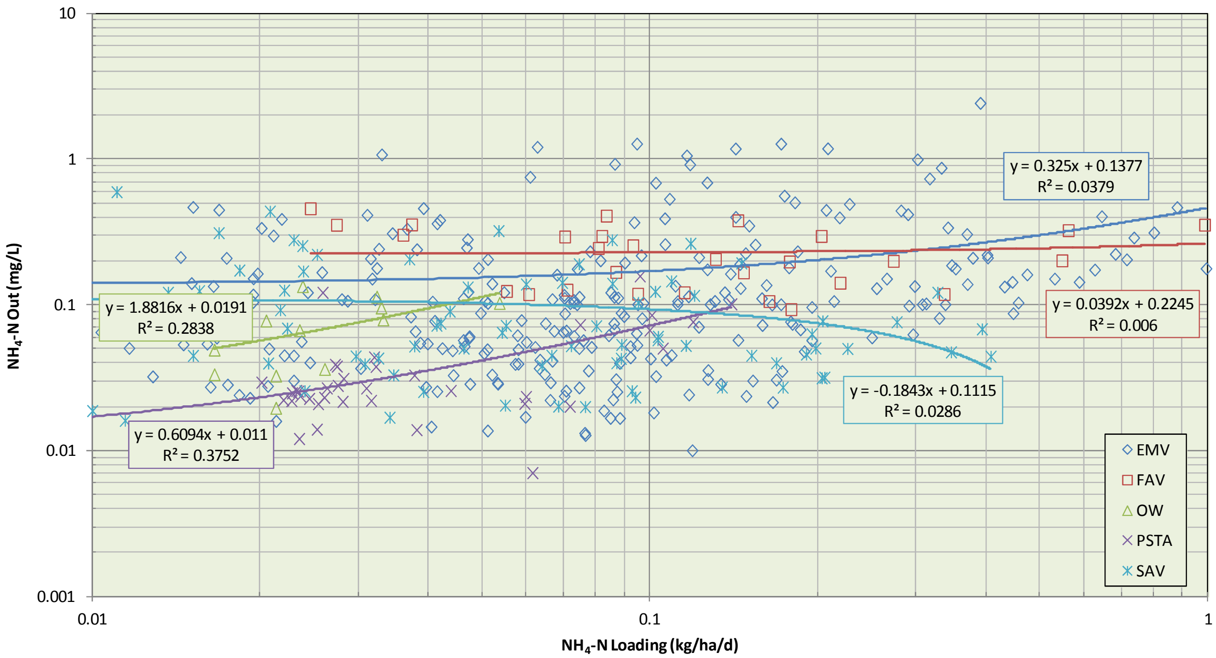
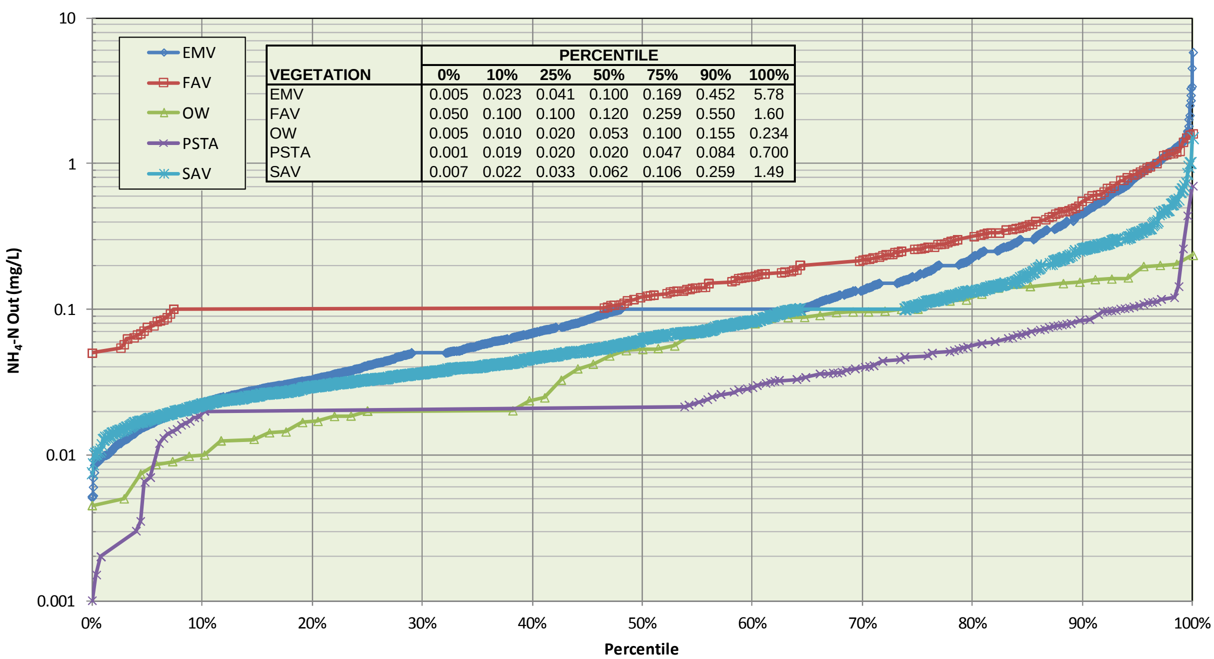


Exhibit 56 - Annual AN Mass Loading vs. Outlet Concentration by Vegetation Type (Inlet TN < 11 mg/L)



VEGETATION	PERCENTILE						
	0%	10%	25%	50%	75%	90%	100%
EMV	0.005	0.023	0.041	0.100	0.169	0.452	5.78
FAV	0.050	0.100	0.100	0.120	0.259	0.550	1.60
OW	0.005	0.010	0.020	0.053	0.100	0.155	0.234
PSTA	0.001	0.019	0.020	0.020	0.047	0.084	0.700
SAV	0.007	0.022	0.033	0.062	0.106	0.259	1.49

Exhibit 57 - Monthly Average AN Outflow Concentration Percentiles by Vegetation Type (Inlet TN < 11 mg/L)

Exhibit 58 shows the relationship between TKN loading and outflow concentration by vegetation type. These data show that the lowest TKN outflow concentrations were observed in the OW and EMV treatment wetland systems. The highest TKN concentrations were typically measured in the SAV treatment wetland systems. This may be due to the fact that most existing SAV treatment wetlands are located in the EAA and are typically sited on organic soils. The PSTA and FAV treatment wetlands were intermediate in their ability to reduce TKN concentrations. Exhibit 59 shows frequency distributions of the monthly average outflow TKN concentrations by vegetation type and indicates that the general order of performance (from highest to lowest outflow concentration) is SAV>FAV>PSTA>EMV>OW. A significant difference was found between vegetation types with the highest and lowest median outflow concentrations (Kruskal–Wallis test, P<0.001). Again, the data for the OW systems are reflective of relatively lightly loaded systems.

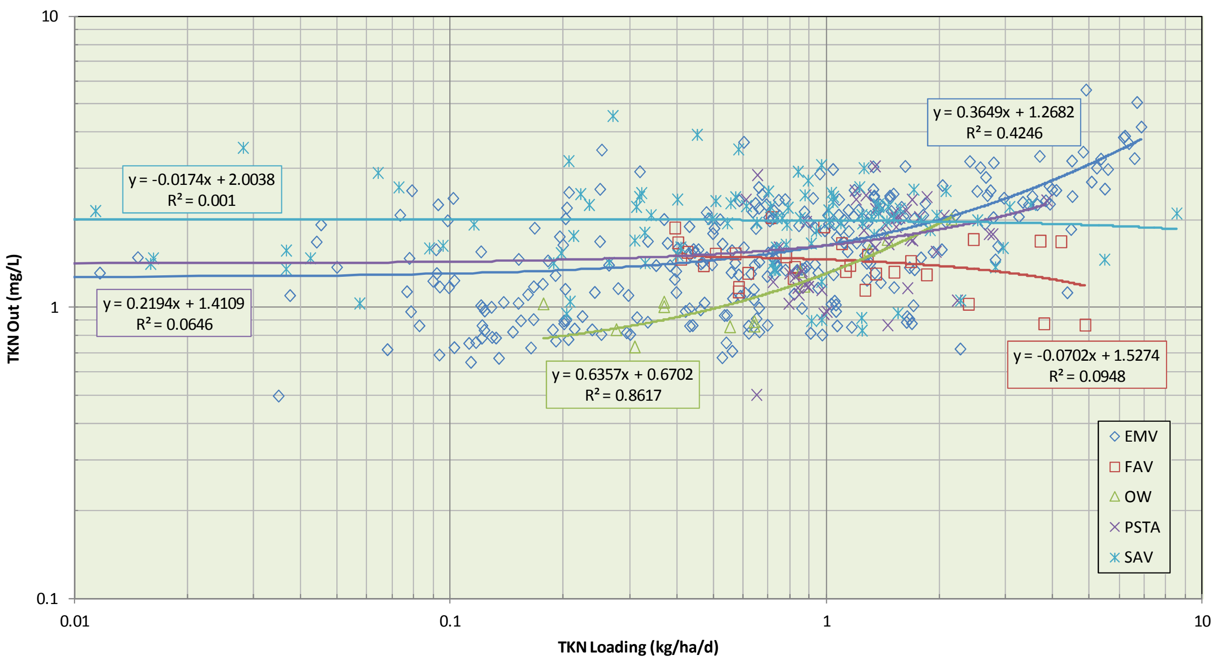


Exhibit 58 - Annual TKN Mass Loading vs. Outlet Concentration by Vegetation Type (Inlet TN < 11 mg/L)

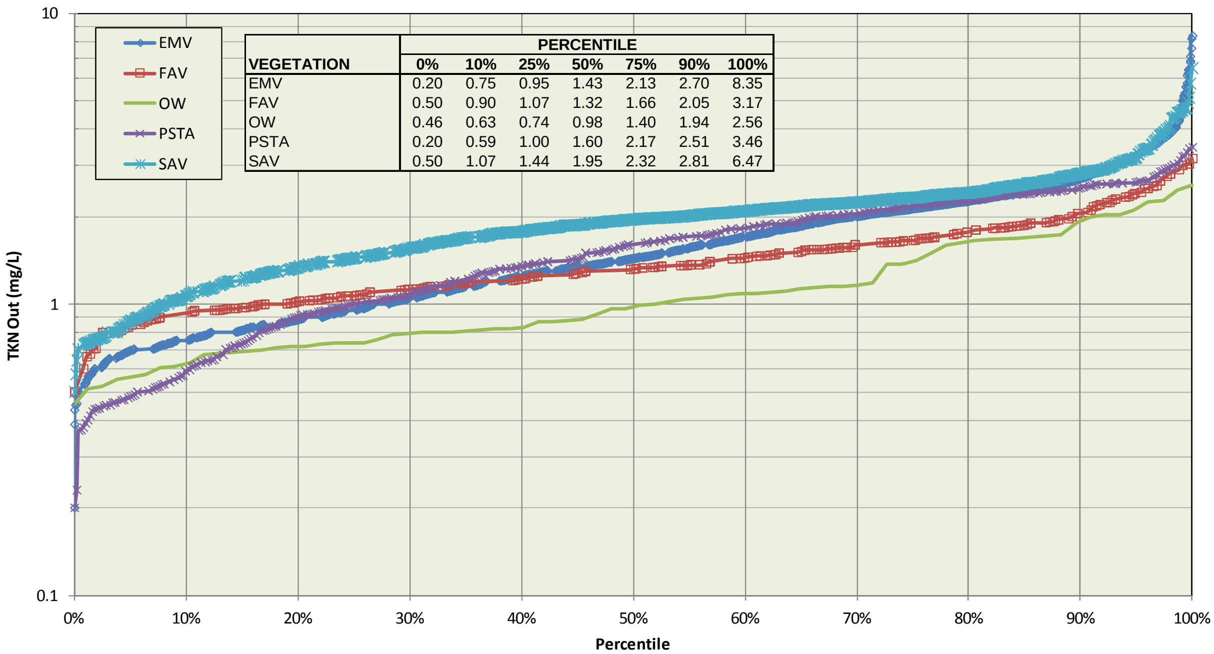


Exhibit 59 - Monthly Average TKN Outflow Concentration Percentiles by Vegetation Type (Inlet TN < 11 mg/L)

Exhibit 60 shows the relationship between TON loading and outflow concentration by vegetation type. These data show that the lowest TON outflow concentrations were observed in the OW and EMV treatment wetland systems. The highest TON concentrations were typically measured in the SAV treatment wetland systems. The PSTA and FAV treatment wetlands were intermediate in their ability to reduce TON concentrations. Exhibit 61 shows frequency distributions of the monthly average outflow TON concentrations by vegetation type and indicates that the general order of performance (from highest to lowest outflow concentration) is SAV>PSTA>FAV>EMV>OW. A significant difference was found between vegetation types with the highest and lowest median outflow concentrations (Kruskal–Wallis test, $P<0.001$). Again, the data for the OW systems are reflective of relatively lightly loaded systems.

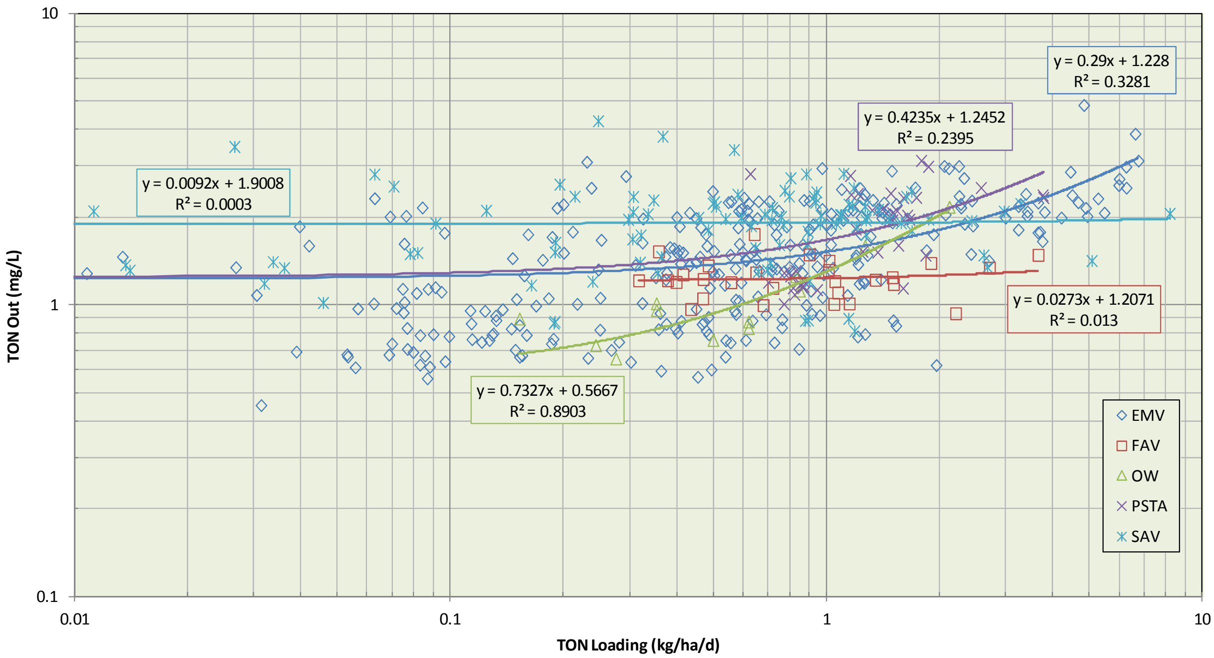
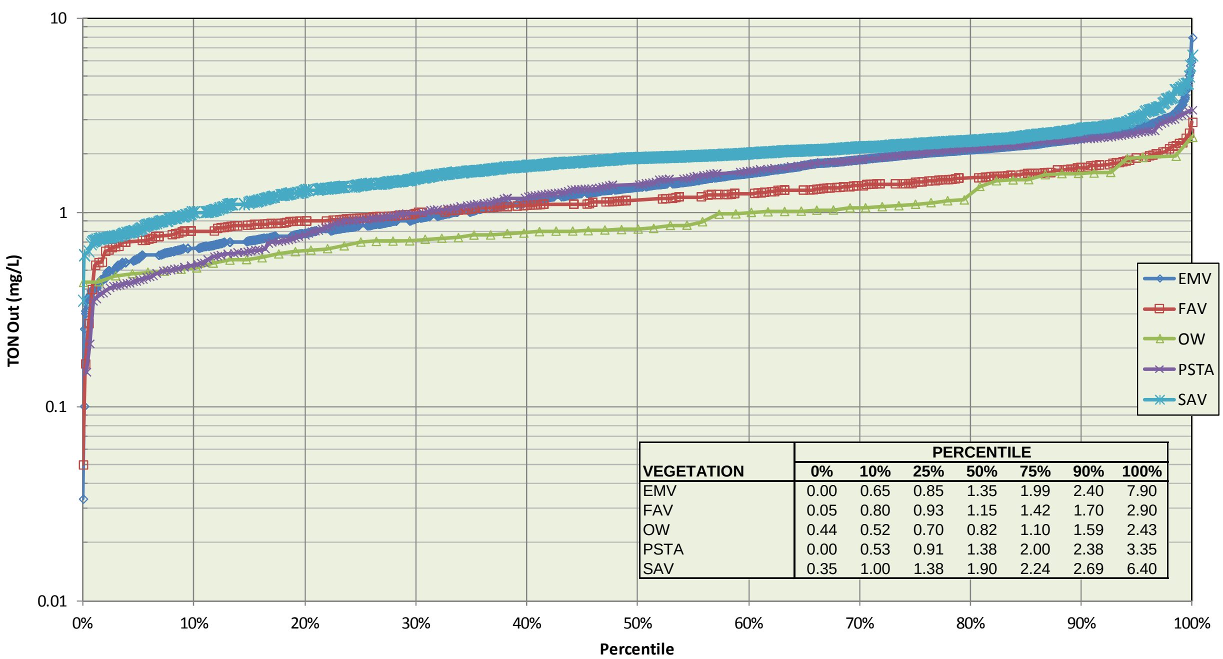


Exhibit 60 - Annual TON Mass Loading vs. Outlet Concentration by Vegetation Type (Inlet TN < 11 mg/L)



VEGETATION	PERCENTILE 0%	10%	25%	50%	75%	90%	100%
EMV	0.00	0.65	0.85	1.35	1.99	2.40	7.90
FAV	0.05	0.80	0.93	1.15	1.42	1.70	2.90
OW	0.44	0.52	0.70	0.82	1.10	1.59	2.43
PSTA	0.00	0.53	0.91	1.38	2.00	2.38	3.35
SAV	0.35	1.00	1.38	1.90	2.24	2.69	6.40

Exhibit 61 - Monthly Average TON Outflow Concentration Percentiles by Vegetation Type (Inlet TN < 11 mg/L)

Exhibit 62 shows the relationship between TN loading and outflow concentration by vegetation type. These data show that the lowest TN outflow concentrations were observed in the OW and EMV treatment wetland systems. The highest TN concentrations were typically measured in the SAV treatment wetland systems. The PSTA and FAV treatment wetlands were intermediate in their ability to reduce TN concentrations. Exhibit 63 shows frequency distributions of the monthly average outflow TN concentrations by vegetation type and indicates that the general order of performance (from highest to lowest outflow concentration) is SAV>PSTA>FAV>EMV>OW. A significant difference was found between vegetation types with the highest and lowest median outflow concentrations (Kruskal–Wallis test, P<0.001). Again, the data for the OW systems are reflective of relatively lightly loaded systems.

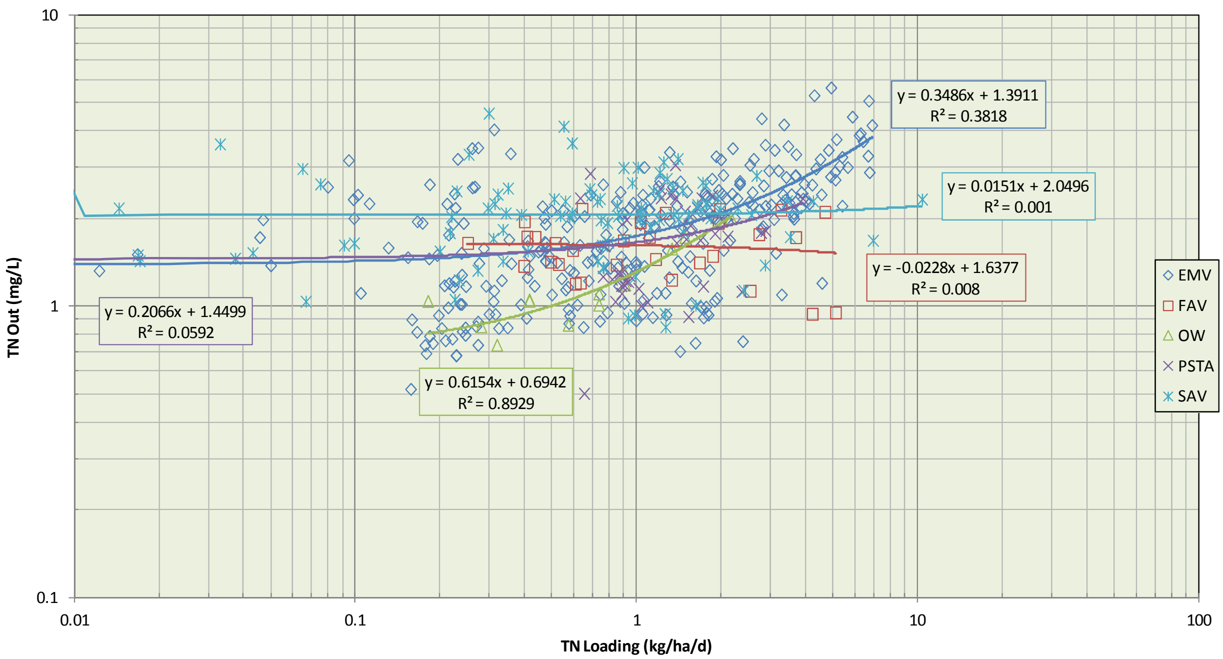
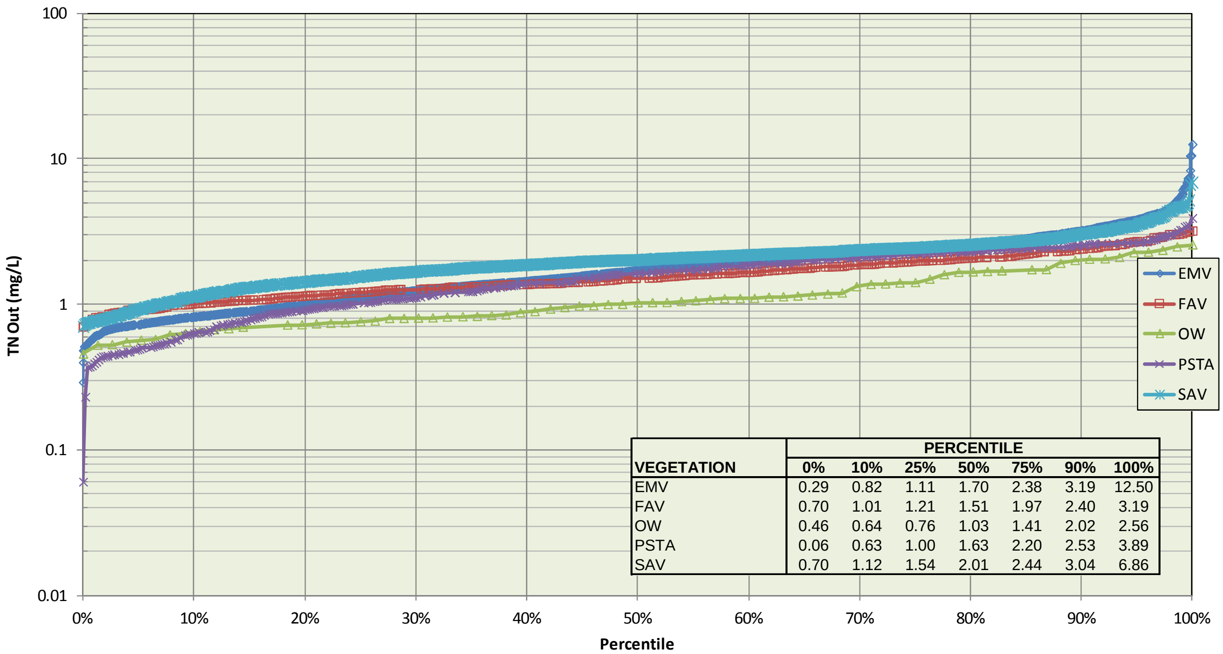


Exhibit 62 - Annual TN Mass Loading vs. Outlet Concentration by Vegetation Type (Inlet TN < 11 mg/L)



VEGETATION	PERCENTILE 0%	10%	25%	50%	75%	90%	100%
EMV	0.29	0.82	1.11	1.70	2.38	3.19	12.50
FAV	0.70	1.01	1.21	1.51	1.97	2.40	3.19
OW	0.46	0.64	0.76	1.03	1.41	2.02	2.56
PSTA	0.06	0.63	1.00	1.63	2.20	2.53	3.89
SAV	0.70	1.12	1.54	2.01	2.44	3.04	6.86

Exhibit 63 - Monthly Average TN Outflow Concentration Percentiles by Vegetation Type (Inlet TN < 11 mg/L)

Exhibit 64 shows the relationship between TSS loading and outflow concentration by vegetation type. These data show that the lowest TSS outflow concentrations were observed in the PSTA and EMV treatment wetland systems. The highest TSS concentrations were typically measured in the FAV and OW treatment wetland systems. The SAV treatment wetlands were intermediate in their ability to reduce TSS concentrations. Exhibit 65 shows frequency distributions of the monthly average outflow TSS concentrations by vegetation type and indicates that the general order of performance (from highest to lowest outflow concentration) is FAV>OW>SAV>PSTA>EMV. A significant difference was found between vegetation types with the highest and lowest median outflow concentrations (Kruskal–Wallis test, $P<0.001$).

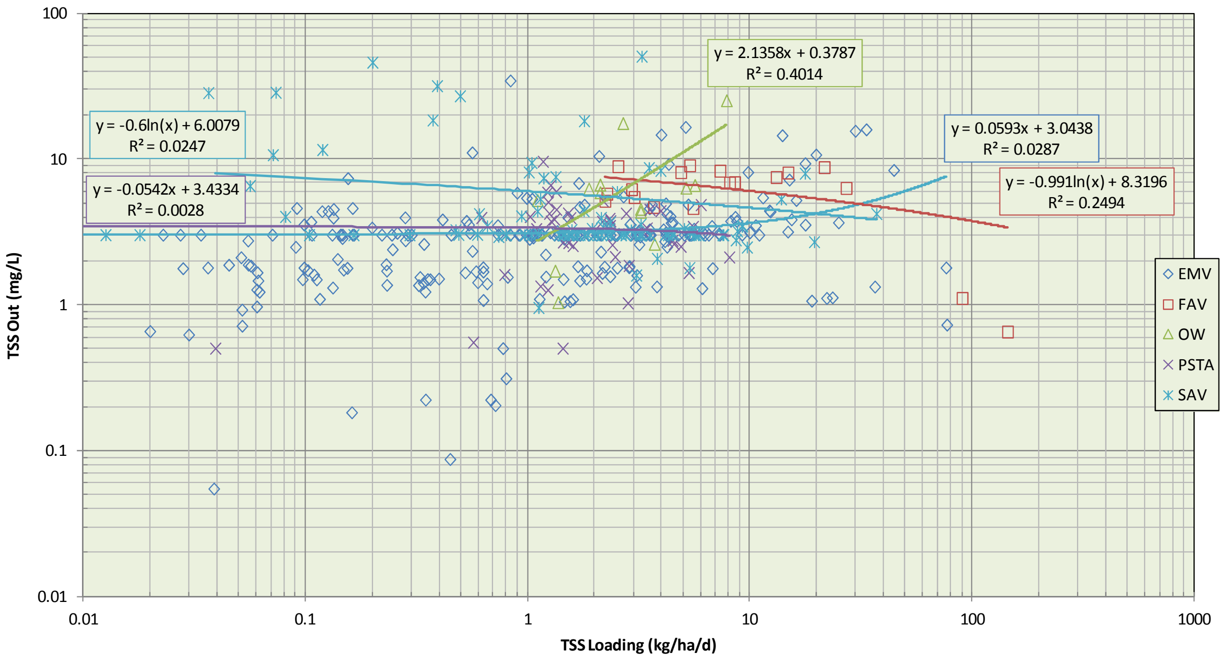
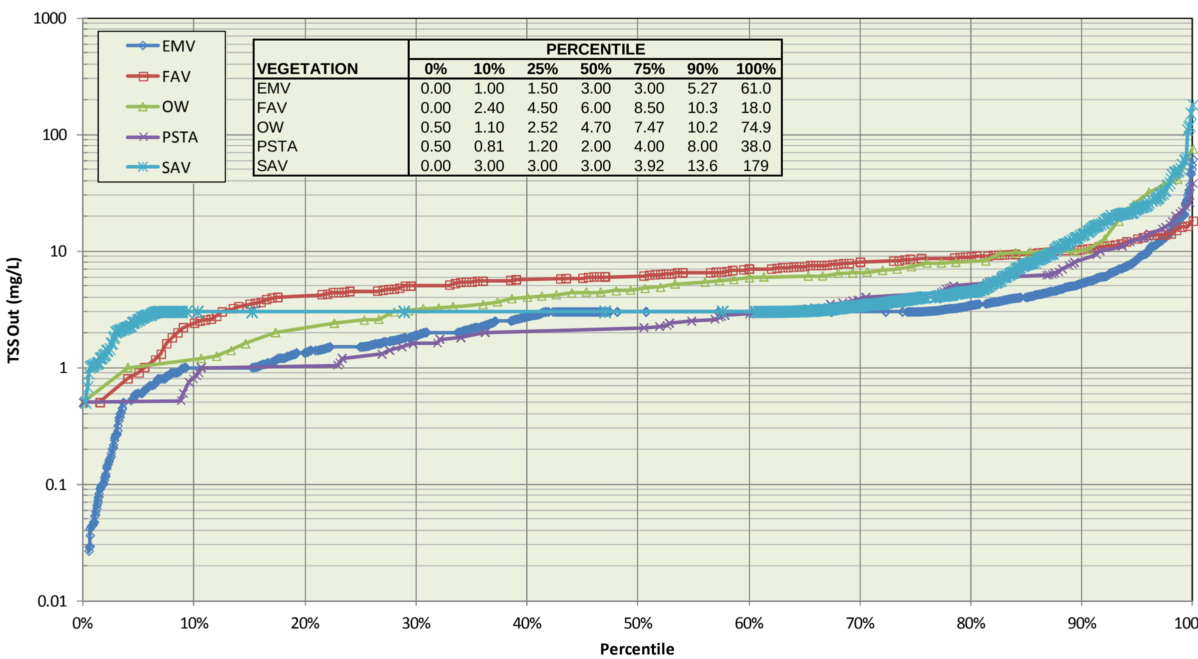


Exhibit 64 - Annual TSS Mass Loading vs. Outlet Concentration by Vegetation Type (Inlet TN < 103 mg/L)



VEGETATION	PERCENTILE 0%	10%	25%	50%	75%	90%	100%
EMV	0.00	1.00	1.50	3.00	3.00	5.27	61.0
FAV	0.00	2.40	4.50	6.00	8.50	10.3	18.0
OW	0.50	1.10	2.52	4.70	7.47	10.2	74.9
PSTA	0.50	0.81	1.20	2.00	4.00	8.00	38.0
SAV	0.00	3.00	3.00	3.00	3.92	13.6	179

Exhibit 65 - Monthly Average TSS Outflow Concentration Percentiles by Vegetation Type (Inlet TSS < 103 mg/L)

3.3.4 Substrate

Examination of these Florida treatment wetland operational performance data indicate a possible relationship between TON C* concentrations and soil type. This section explores that phenomenon for each of the pollutants of interest.

Exhibit 66 illustrates the observed relationship between TP mass loading to Florida treatment wetlands vs. TP outflow concentrations for three basic substrate types: peat or organic soils, sandy soils (low organic), and calcareous soils. This graph and the cumulative probability distribution illustrated in Exhibit 67 clearly show the beneficial effect of using a calcium-rich substrate in treatment wetlands designed for TP reduction. Somewhat surprisingly, peat-based soils had slightly lower TP outflow concentrations as a function of TP loading rates than sandy soils.

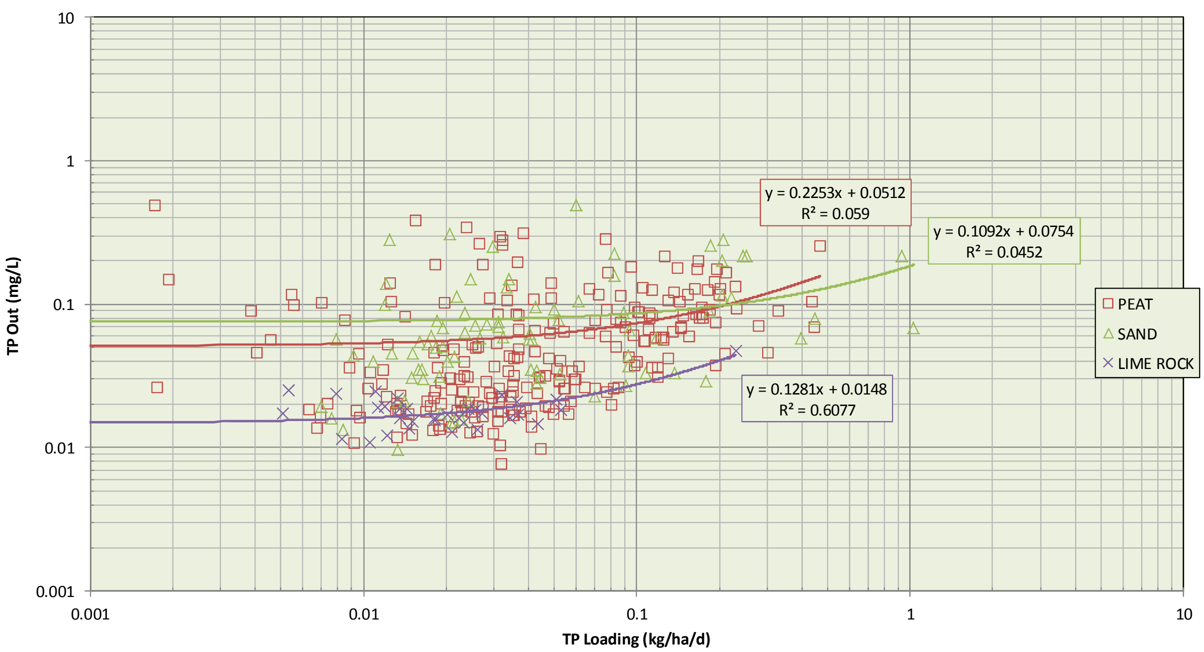


Exhibit 66 - Annual TP Mass Loading vs. Outlet Concentration by Substrate Type (Inlet TP < 0.561 mg/L)

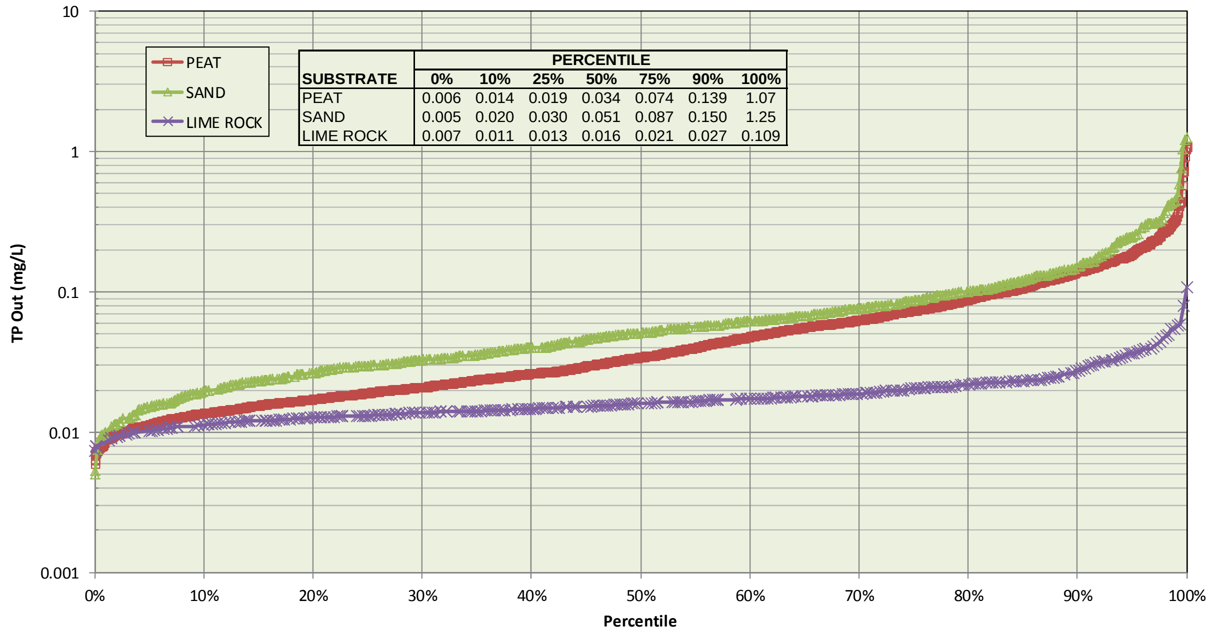


Exhibit 67 - Monthly Average TP Outflow Concentration Percentiles by Substrate Type (Inlet TP < 0.561 mg/L)

Exhibit 68 and Exhibit 69 provide the same information about the effect of substrate type on NOx-N removal in Florida treatment wetlands. These data indicate that peat, sand, and limerock substrates have about equal potential to achieve low NOx-N concentrations. Clayey soils appear to have a much lower potential for NOx-N concentration reduction.

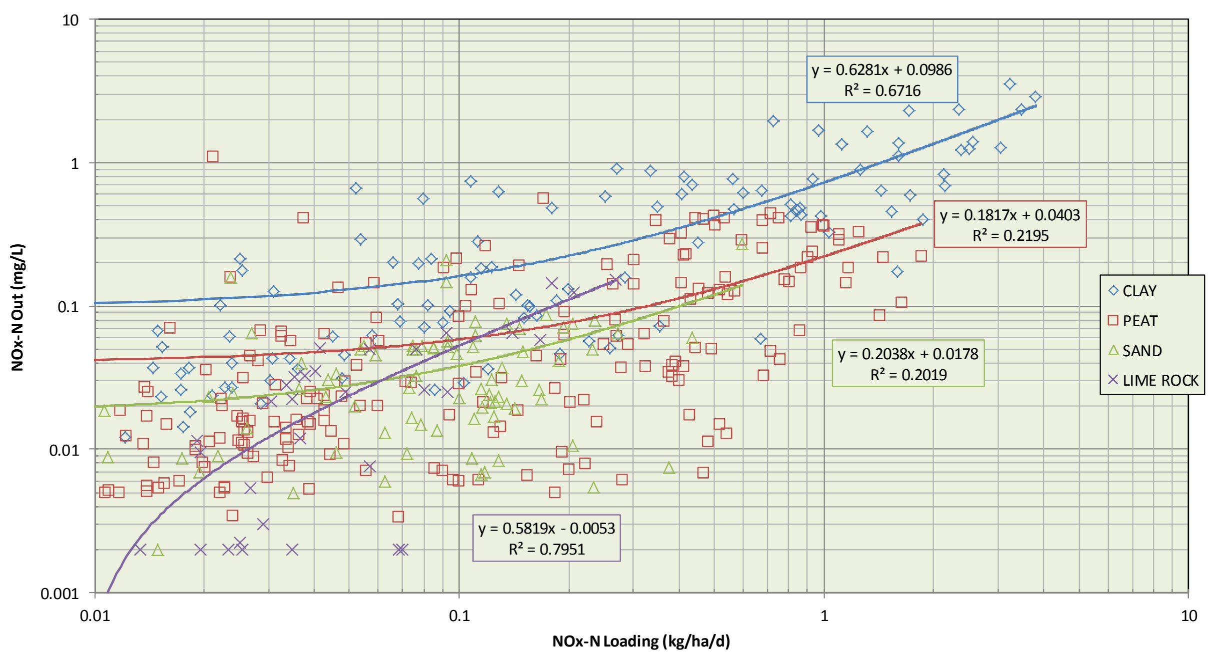


Exhibit 68 - Annual NOx-N Mass Loading vs. Outlet Concentration by Substrate Type (Inlet TN < 11 mg/L)

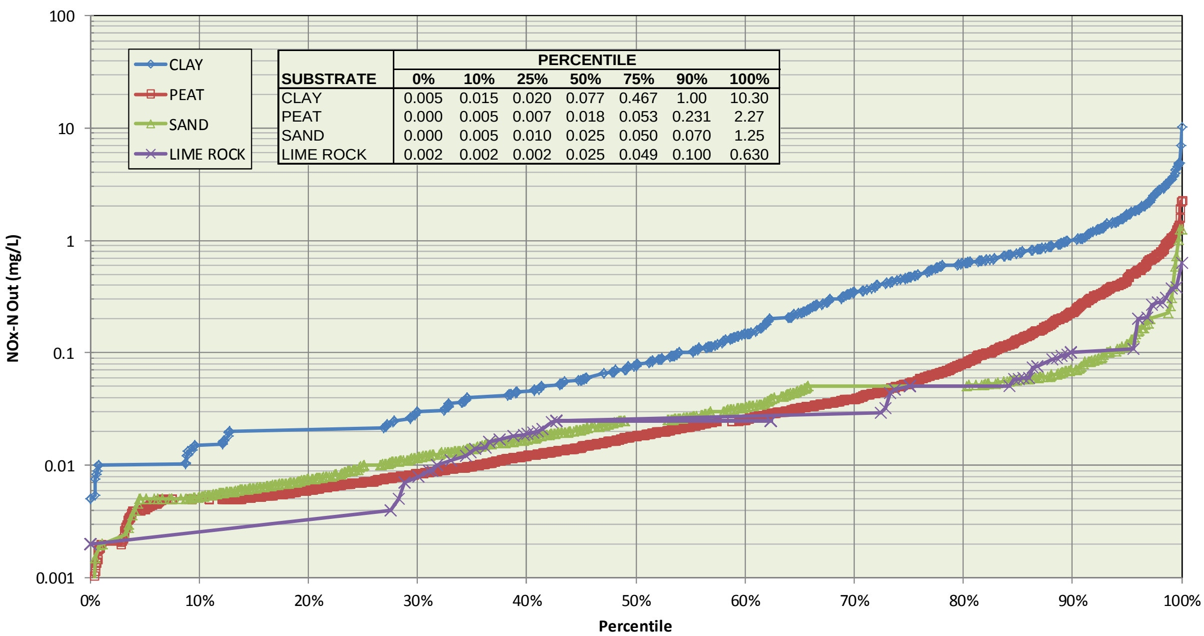


Exhibit 69 - Monthly Average NOx-N Outflow Concentration Percentiles by Substrate Type (Inlet TN < 11 mg/L)

Exhibit 70 and Exhibit 71 provide the same analysis for AN in Florida treatment wetlands. The limerock-based systems achieved the lowest AN concentration. Peat and sand-based treatment wetlands were somewhat less effective and the clay-based system had the highest AN outflow concentrations at a given AN mass loading rate.

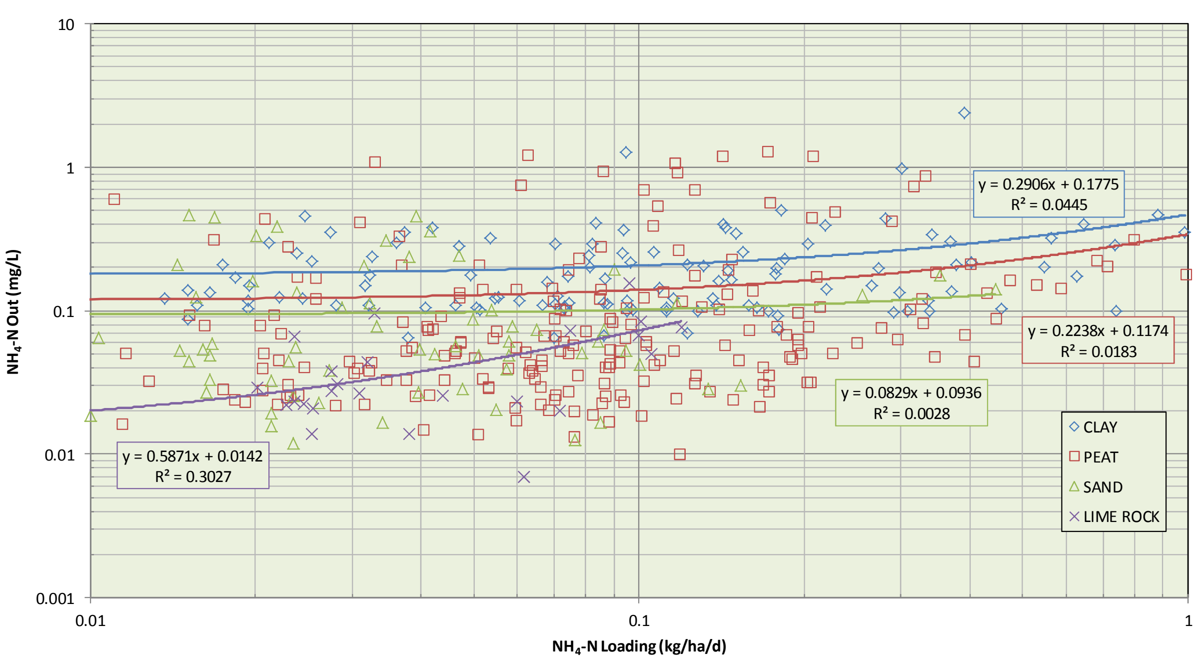


Exhibit 70 - Annual NH_4-N Mass Loading vs. Outlet Concentration by Substrate Type (Inlet TN < 11 mg/L)

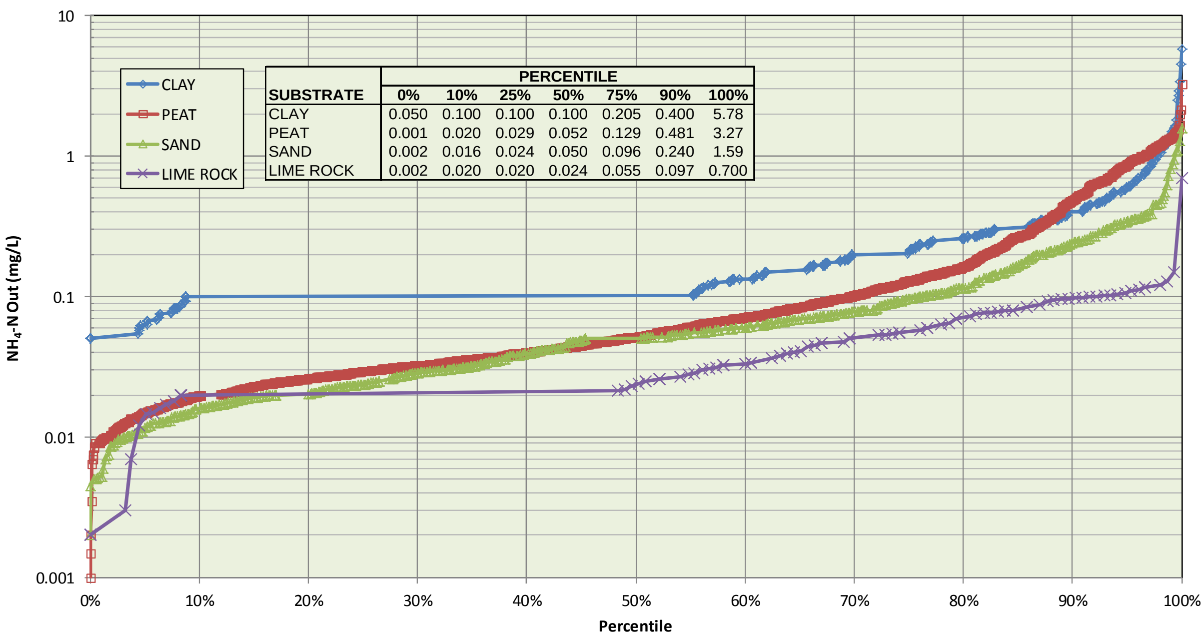


Exhibit 71 - Monthly Average NH_4-N Outflow Concentration Percentiles by Substrate Type (Inlet TN < 11 mg/L)

Exhibit 72 and Exhibit 73 provide the same analysis for TKN removal in Florida treatment wetlands. There appears to be a clear substrate effect on the removal of this pollutant with lowest TKN concentrations obtained in wetlands built on sandy soils, followed in order by clay, limerock, and peat substrates.

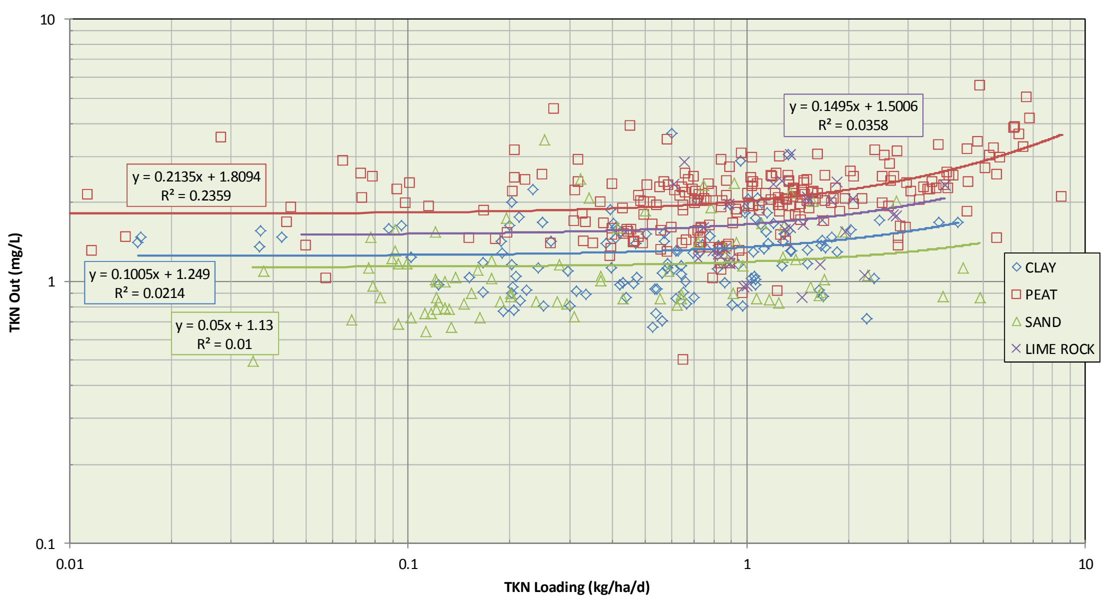


Exhibit 72 - Annual TKN Mass Loading vs. Outlet Concentration by Substrate Type (Inlet TN < 11 mg/L)

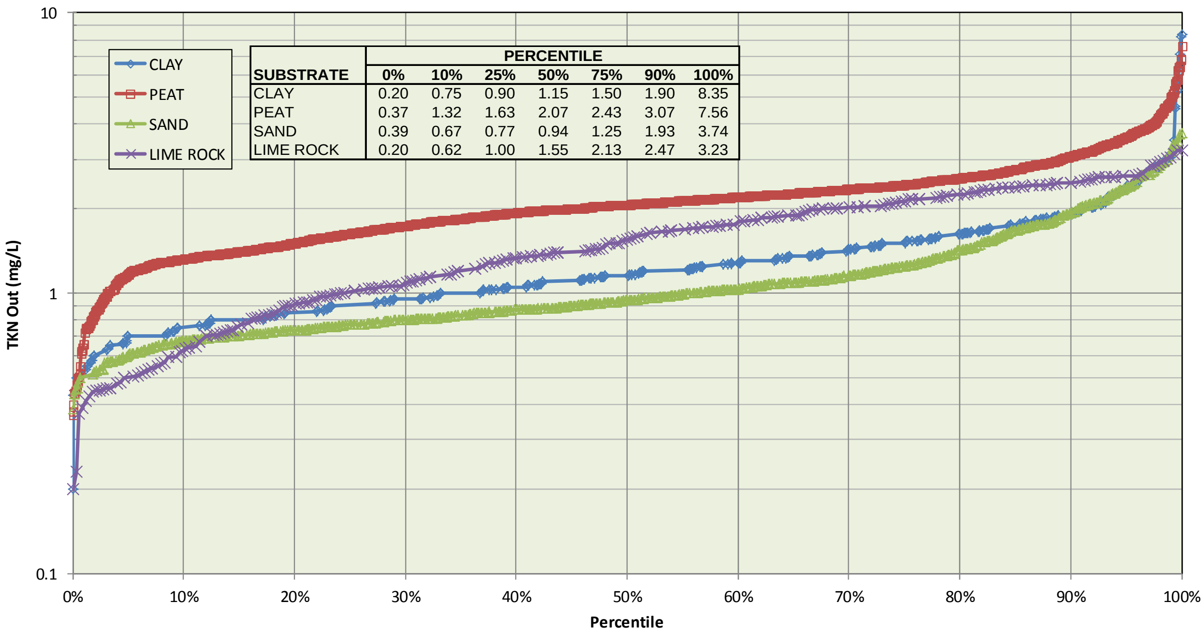


Exhibit 73 - Monthly Average TKN Outflow Concentration Percentiles by Substrate Type (Inlet TN < 11 mg/L)

Exhibit 74 and Exhibit 75 provide the same analysis for TON removal in Florida treatment wetlands. The effect of substrate on TON is similar to that described above for TKN. The lowest TON concentrations are obtained in wetlands built on sandy soils, followed in order by clay, limerock, and peat substrates. There is not as much difference between the sandy and the clayey soils for TON as there was for TKN.

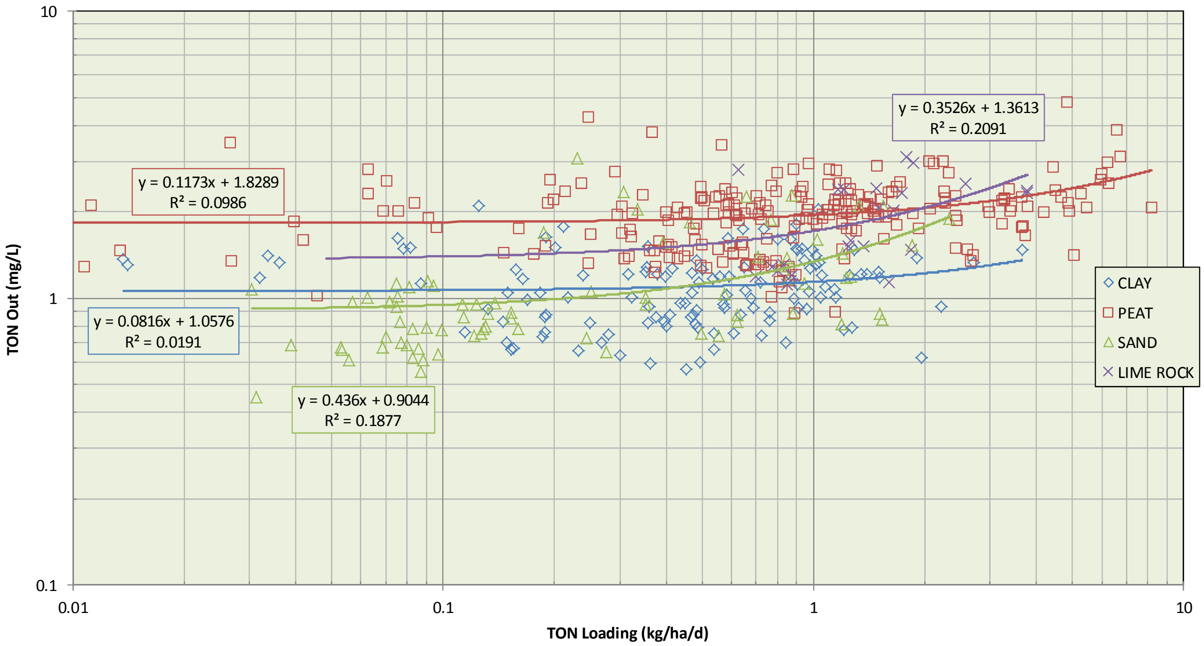
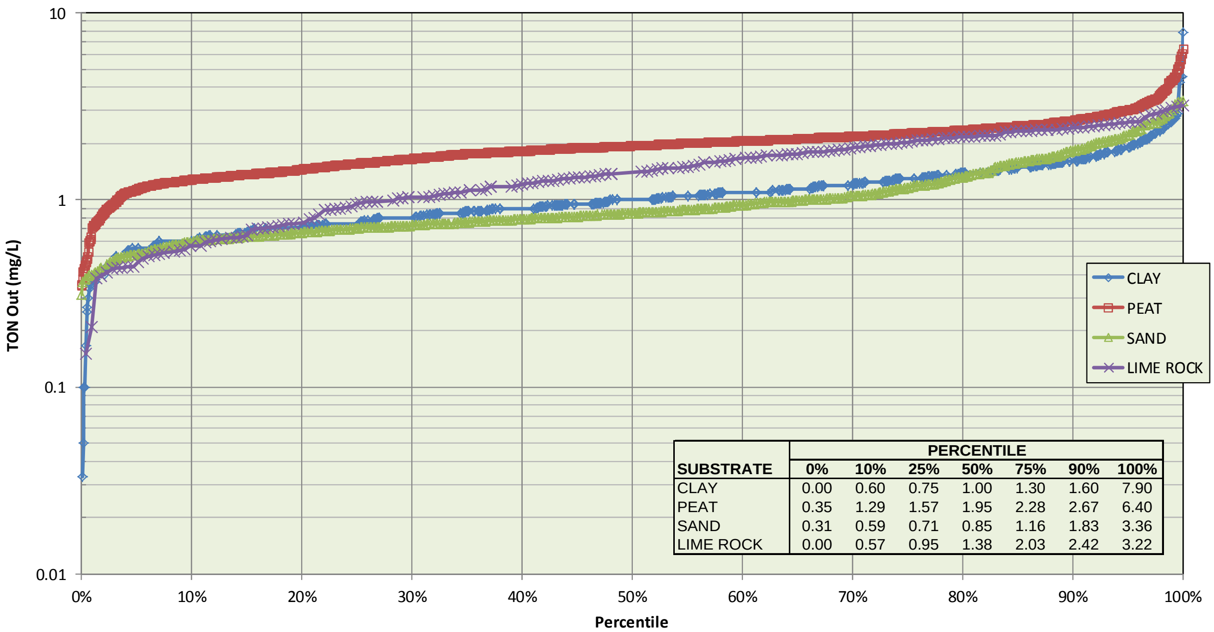


Exhibit 74 - Annual TON Mass Loading vs. Outlet Concentration by Substrate Type (Inlet TN < 11 mg/L)



SUBSTRATE	PERCENTILE						
	0%	10%	25%	50%	75%	90%	100%
CLAY	0.00	0.60	0.75	1.00	1.30	1.60	7.90
PEAT	0.35	1.29	1.57	1.95	2.28	2.67	6.40
SAND	0.31	0.59	0.71	0.85	1.16	1.83	3.36
LIME ROCK	0.00	0.57	0.95	1.38	2.03	2.42	3.22

Exhibit 75 - Monthly Average TON Outflow Concentration Percentiles by Substrate Type (Inlet TN < 11 mg/L)

Exhibit 76 and Exhibit 77 provide the same analysis for TN removal in Florida treatment wetlands. As with TKN and TON, there appears to be a fairly clear substrate effect on the removal of this pollutant with lowest TN concentrations obtained in wetlands built on sandy soils, followed by similar TN concentrations for limerock and clayey soils, and highest concentrations over peat soils.

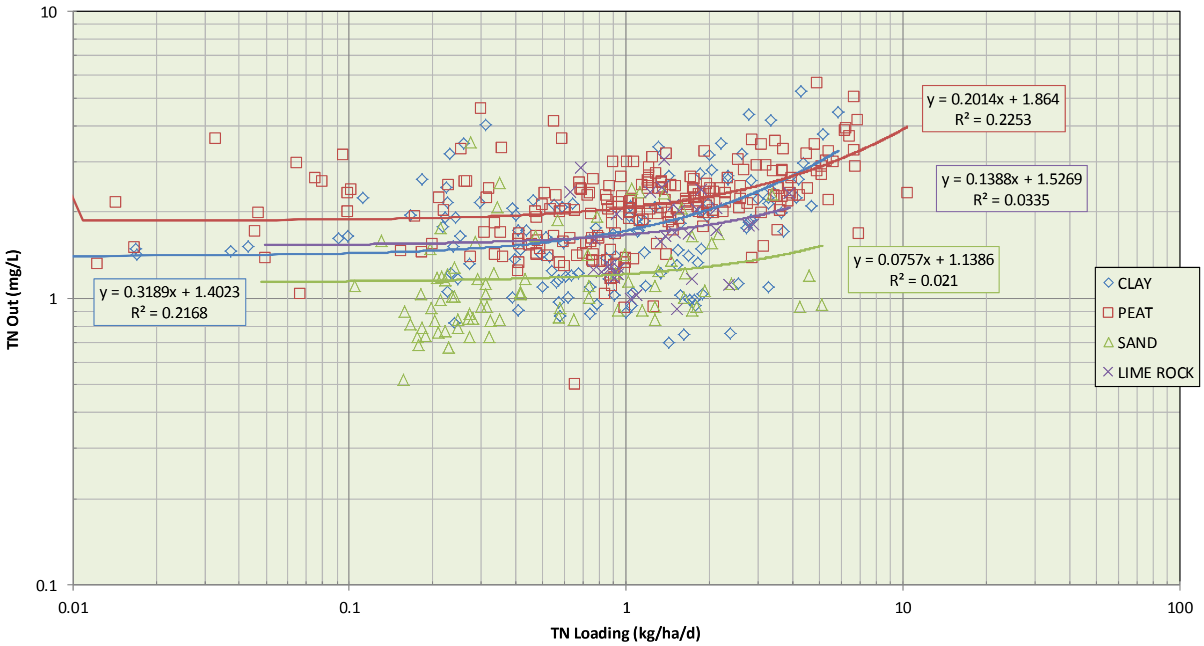
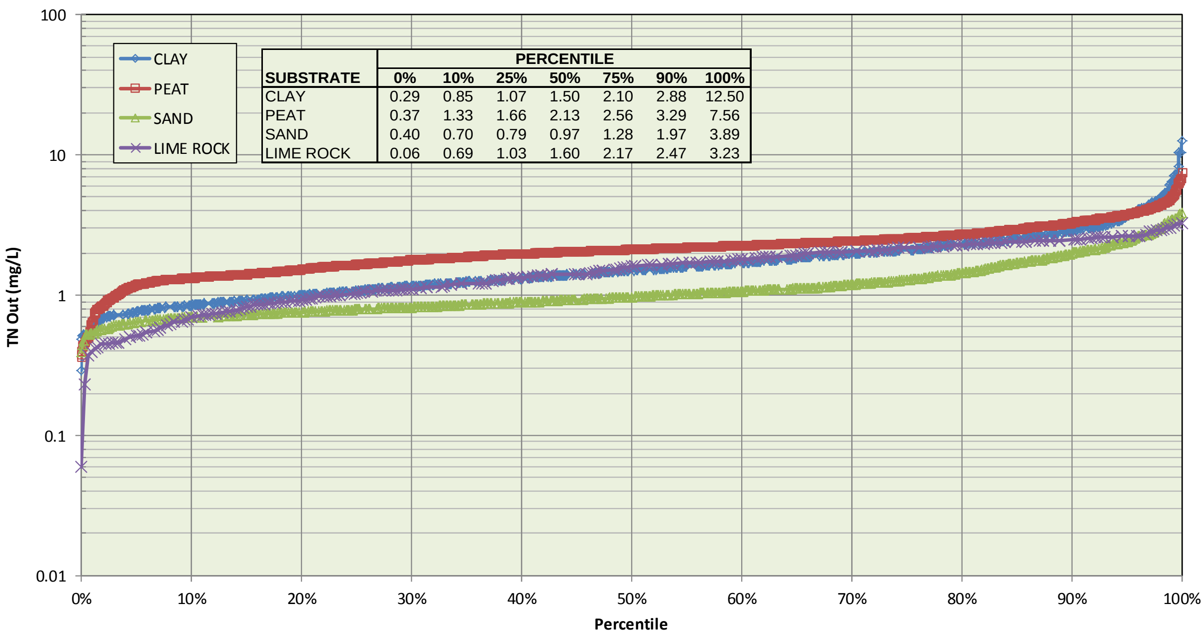


Exhibit 76 - Annual TN Mass Loading vs. Outlet Concentration by Substrate Type (Inlet TN < 11 mg/L)



SUBSTRATE	PERCENTILE 0%	10%	25%	50%	75%	90%	100%
CLAY	0.29	0.85	1.07	1.50	2.10	2.88	12.50
PEAT	0.37	1.33	1.66	2.13	2.56	3.29	7.56
SAND	0.40	0.70	0.79	0.97	1.28	1.97	3.89
LIME ROCK	0.06	0.69	1.03	1.60	2.17	2.47	3.23

Exhibit 77 - Monthly Average TN Outflow Concentration Percentiles by Substrate Type (Inlet TN < 11 mg/L)

Exhibit 78 and Exhibit 79 illustrate that substrate does not have a very significant effect on the ability of treatment wetlands to achieve low TSS concentrations. The peat substrate best-fit line at low TSS concentrations is a model artifact.

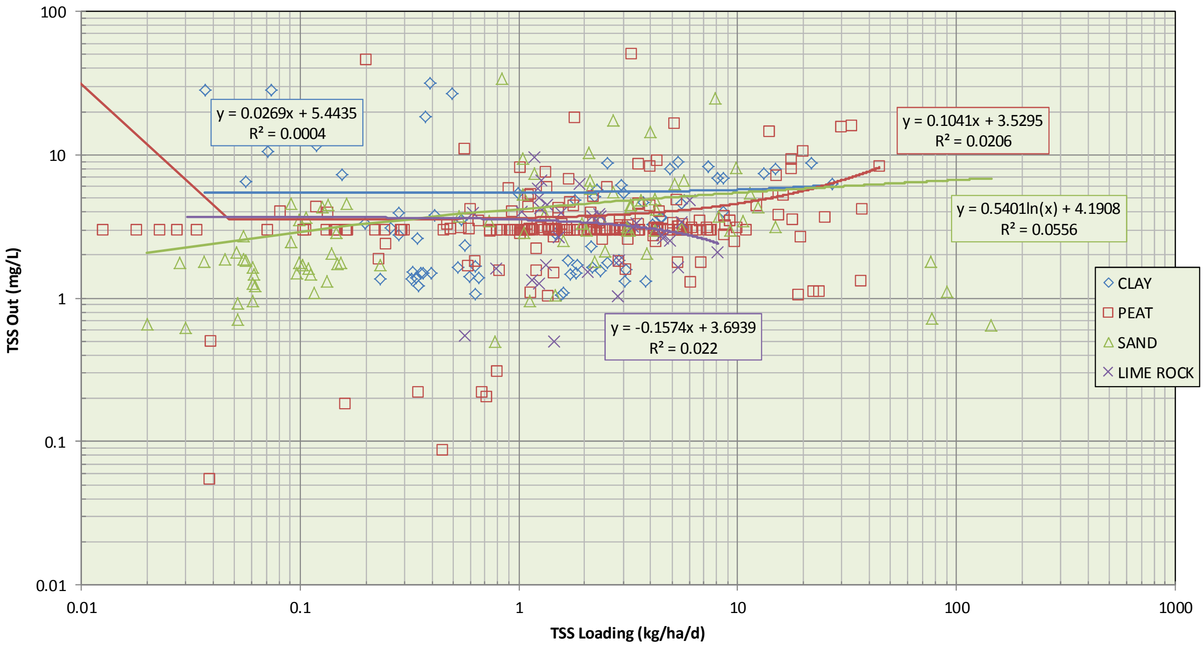


Exhibit 78 - Annual TSS Mass Loading vs. Outlet Concentration by Substrate Type (Inlet TSS < 103 mg/L)

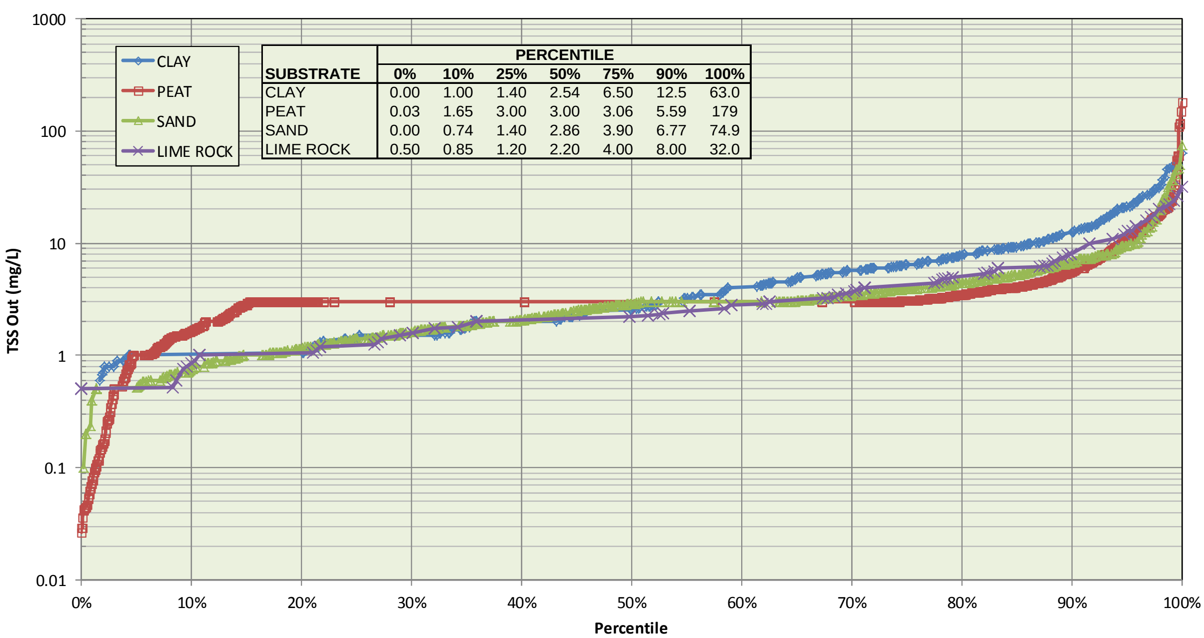


Exhibit 79 - Monthly Average TSS Outflow Concentration Percentiles by Substrate Type (Inlet TSS < 103 mg/L)

3.4 Summary of Design Factors Affecting Treatment Wetland Performance

This section provides a review of extensive operational data from existing constructed treatment wetlands in central and south Florida. This data summary leads to the following general conclusions for each of the parameter groups of interest in this report:

3.4.1 Total Phosphorus

There is considerable evidence that TP is most effectively removed by SAV-dominated wetlands at intermediate TP concentrations in the range between about 50 and 300 ppb (Walker 2010). Emergent wetlands are likely more effective for TP removal at higher inlet TP concentrations (>300 ppb) and periphyton-dominated wetlands are more effective than SAV systems at lower inlet TP concentrations (<50 ppb). The lowest TP concentrations practically achievable in any type of treatment wetlands are in the range of 10 to 15 ppb. The most favorable substrate for achieving very low TP concentrations and for the highest removal rates appears to be calcareous substrates such as limerock. Organic substrates appear to be next most favorable for effective TP reduction, followed in last place by sandy soils. The relationship between lower TP outflow concentrations and the presence of organic soils may just be a result of the SFWMD's preference for use of this plant community within the EAA where incoming TP concentrations tend to be lower than in other Florida treatment marshes.

3.4.2 Nitrate + Nitrite Nitrogen

Most treatment wetlands are successful at removal of NO_x-N. Baseline or C* concentration are close to analytical detection limits (less than 0.01 mg/L). In terms of optimal plant community type, EMV, PSTA, OW, and SAV wetlands appear to be similar for removal of NO_x-N while FAV is least effective. In terms of optimal substrate for NO_x-N removal peat, sand, and limerock appear to be similar while clay was inferior.

3.4.3 Ammonia Nitrogen

Ammonia nitrogen is effectively removed in lightly-loaded treatment wetlands. Typical C* concentrations are approximately 0.02 mg/L. In terms of optimal plant communities, PSTA appeared to be the best, followed by OW, SAV, and EMV, and FAV was the least effective plant community. Substrate type had a noticeable effect of AN removal with limerock performing the best, followed by similar effects for peat and sandy soils, and with clay least effective.

3.4.3 Total Kjeldahl Nitrogen

The lowest typical TKN outflow concentrations observed in these Florida treatment wetlands was approximately 0.7 mg/L, considerably lower than the Global C* value of 1.5 mg/L reported by Kadlec and Knight (1996). The most effective plant communities for TKN reduction appear to be OW and EMV. PSTA and FAV were less effective, followed by SAV as the least effective wetland category. In terms of substrate, sand was clearly better than clay, followed by limerock, and finally by peat.

3.4.4 Organic Nitrogen

The lowest TON outflow concentrations typically observed in these treatment wetlands were about 0.6 mg/L. These low concentrations were most likely to be observed in EMV and OW systems built on sandy soils. PSTA and FAV were less effective especially on clay and limerock soils. SAV and peat soils were the least effective combination to achieve low TON concentrations.

3.4.5 Total Nitrogen

The lowest TN outflow concentrations observed were essentially all in the reduced forms (TON and AN) and equal to about 0.7 mg/L. As with TKN and TON, TN was most efficiently reduced in EMV and OW systems built on sandy soils. Periphyton, FAV, and SAV were less effective plant communities and clay, limerock, and organic peat were less effective substrates to efficiently achieve low TN outflow concentrations.

3.4.6 Total Suspended Solids

The lowest TSS concentration typically attained by these Florida treatment wetlands was about 1 mg/L. For TSS reduction PSTA and EMV were the most effective plant communities, followed by SAV, with OW and FAV least favorable. There was essentially no observed effect of substrate type on TSS reduction effectiveness.

Section 4.0 Summary of Treatment Wetland System Merits and Limitations

4.1 Introduction

This section summarizes evaluation criteria for the effectiveness of various treatment wetland options for removal of TN, TP, and TSS in the C-43 Basin in southwest Florida. The five treatment wetland alternatives that are evaluated include the following categories: EMV, FAV, SAV, PSTA, and OW.

Evaluation factors include:

- TN, TP, and TSS removal rates;
- Estimated C* values by pollutant and sediment type; and
- Order-of-magnitude cost per unit treatment area and volume.

It is expected that each of the five basic wetland plant community types will have a range of positive and negative attributes for specific treatment functions of importance. This section gives a general ranking for these options based on each of the evaluation factors listed above. These rankings are intended to support selection of alternative test facility configurations and are not intended to provide a final alternative evaluation for full-scale project implementation. That evaluation should be conducted later once additional operational, performance, and cost data are developed at the C-43 WQTA Test Facility for each of the highest ranked alternatives.

4.2 Estimated Construction Costs

Kadlec and Wallace (2009) report a median cost of about $100,000 per hectare for surface flow constructed treatment wetlands. However, economy of scale greatly reduces the cost per acre for larger wetlands. Kadlec and Wallace (2009) report a surface flow wetland capital cost relationship with wetland area:

$C = 194A^{0.690}$ $\qquad$ $R^2 = 0.29$

Where:

C = cost in $1,000 U.S.

A = effective wetted area in hectares

This cost curve indicates that a 405-ha (1,000-acre) constructed surface flow wetland would have an estimated capital cost of about $12,220,000 or $30,164 per ha ($12,207 per acre). Actual STA construction costs in south Florida may be greater or lower than this number for a number of site-specific reasons, including site topography and local earthwork costs.

To date, two STAs (Taylor Creek and Nubbin Slough) have been constructed in the Lake Okeechobee Watershed and a third is currently under construction (Lakeside Ranch). Six STAs have been constructed in the EAA in various phases and others are constructed (Ten Mile Creek) or planned (C-44 and C-43) in other watersheds. Cost data were previously compiled by WSI (WSI 2009) from Basis of Design Reports (BODRs) and bid tabulations for Nubbin Slough (USACE 2004), C-44 (HDR 2006), STA-2 Cell 4 (Brown and Caldwell 2005), STA-5 Cell 3 (URS 2005a), STA-6 Section 2 (URS 2005), and Lakeside Ranch (CDM 2007), and used to estimate order-of-magnitude unit costs for key components of STA construction. These costs provide a useful range of unit costs for comparing STA cost-effectiveness as a function of the design variables discussed in this document. It is recognized that these costs are dated and have not been normalized (to 2012 dollars for example). It is also recognized that BODR-level costs may vary significantly from the final engineer's estimates or bid tabulations and are somewhat dependent on total treatment wetland area (economy of scale). Based on the WSI (2009) review of South Florida STA construction costs and recognition of the differences between projects, the average unit cost for STA wetland construction (excluding the cost of land) was approximately \$38,000 per ha (\$15,300 per acre). This is the estimated average cost for an STA with a design water depth of about 2 feet.

WSI (2009) also estimated unit costs for various construction items related to the STAs described above. The average cost of excavation was estimated by WSI (2009) to be about \$4.60 per m^3 (\$3.50 per cubic yard). For deeper wetland alternatives, these crude cost estimates can be extrapolated for the range of deeper wetland alternatives considered in this report. Each additional foot of design water depth greater than 60 cm (2 feet) over an area of 0.4 ha (one acre) will add about 1,233 m^3 (one ac-ft or 1,613 cubic yards) of additional excavation at an estimated cost of about \$14,000 per ha (\$5,650 per acre). This estimate does not account for the possible need for de-watering during deeper excavations and therefore is probably low. While hydraulic residence time in these treatment wetlands is directly related to effective hydraulic volume, Kadlec and Knight (1996) conclude that treatment performance in a variety of wetland systems is more a function of wetted surface area than volume.

4.3 Performance Comparison

The detailed Florida treatment wetland data summarized in Section 3 of this report were compared on the basis of cost and expected effectiveness (Exhibit 80). These comparisons are based on the assumption that site soils for the C-43 WQTA Project will be sandy or calcareous in nature and will therefore avoid the potentially high C* effect for TON resulting from organic and clayey soils. The subsurface profiles, which are limited to the southeast portion of the site and are included in the site exploration report by Dunkelberger Engineering (2009), support this assumption.

The comparison leads to a general order of preference based on cost and pollutant removal performance of EMV>SAV>PSTA>>FAV>>OW. This comparison also indicates that there is not likely to be a large difference in overall TN cost effectiveness between the top three wetland plant community types: EMV, PSTA, and SAV. Each of these types of wetlands has somewhat similar biogeochemical cycles, dependence on adequate surface area for treatment, and production of ample organic carbon required for effective denitrification of NO_x-N. However, where there are differences in performance and cost between wetland alternatives, those differences will be used to prioritize testing resources.

The C-43 WQTA Expert Panel report (WSI 2010) came to a similar conclusion that, if the District was limited to a single wetland technology, the EMV would be most likely to achieve the lowest TN, TP, and TSS concentrations with the smallest footprint and the lowest construction cost. It is too early however for the District to determine what limit, if any, ought to exist for the number of wetland technologies to be used in the WQTA. A full-scale nitrogen-removal WQTA facility may be a combination of technologies in series with each sized to provide the greatest overall cost effectiveness for the reduction of TN in the CRE.

The next task in this project will develop a test facility design that evaluates each of the promising wetland technologies, both individually and in combination.

Exhibit 80 - C-43 WQTA Wetland Plant Community Alternatives Comparison including Pros and Cons

Wetland Type	Target Water Depth (ft)	Est. Cost w/o Land ($/ha)	PROS	CONS
EMV	2	$38,000	Highly complex microbial community, high TON mineralization, high denitrification, moderate P removal, high TSS removal, lowest cost, wide experience and applicability	Limited aerobic zone, limited photodegradation
PSTA	3	$52,00	Aerobic water column including DO supersaturation, potential for photodegradation, able to achieve very low P	Lower removal rates for all N and P forms, requires adequate calcium availability for P removal
SAV	4	$66,000	Highly complex microbial community, high P removal, aerobic water column	Susceptible to vegetation loss due to high wind and extended drought conditions, limited data available for N removal on sandy soils
FAV	6	$94,000	Moderate to high levels of N and P removal	Limited reaeration, highly anaerobic water column, may require plant harvesting, high cost
OW	8	$121,500	Optimal photodegradation for TON mineralization, highly aerobic	Lowest N and P removal rates, limited experience for achieving low N concentrations, high cost

Section 5.0 References

Bailey, N., W. Magley, J. Mandrup-Poulsen, K. O'Donnell and R. Peets. 2009 Nutrient TMDL for the Caloosahatchee Estuary (WBIDs 3240A, 3240B, and 3240C). Florida Department of Environmental Protection. TMDL Report. 119 pp.

Brown and Caldwell. 2005. STA-2/Cell 4 Expansion Project Basis of Design Report. May 2005.

CDM. 2007. Lake Okeechobee Fast Track Project Basis of Design Report – Lakeside Ranch STA. Prepared for the South Florida Water Management District.

CH2M Hill. 2003a. Phase 1, 2, and 3 Summary Report (February 1999 – September 2002) PSTA Research and Demonstration Project. Prepared for the South Florida Water Management District. Prepared by CH2M Hill, Deerfield Beach, FL.

CH2M Hill. 2003b. Village of Wellington Aquatics Pilot Program. Prepared for the Village of Wellington. Prepared by CH2M Hill.

CH2MHill. 2009. Organic Nitrogen Methodology Screening Analysis (Draft). Technical Memorandum prepared for the South Florida Water Management District. 32 pp.

CH2MHill. 2008. Total Nitrogen Reduction Technologies Review. Technical Memorandum prepared for the South Florida Water Management District. 43 pp.

Chimney, M.J. 2012. The macrophyte assemblage of constructed treatment wetlands in south Florida used for Everglades restoration. Florida Scientist In press.

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 Ecosystems Division.

Gary Goforth, Inc. (GGI) 2005. Summary of STA Vegetation Management Practices. Prepared for the South Florida Water Management District, West Palm Beach, FL.

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

Goforth, G. 2011. Written Testimony in Case No. 88-1886-Civ-Moreno in the US. District Court, Southern District of Florida. Prepared as an expert witness for the South Florida Water Management District. Prepared by Gary Goforth, Inc., Stuart, FL.

HDR 2006. C-44 Reservoir/STA final basis for design, Prepared for the U.S. Army Corps of Engineers and South Florida Water Management District.

Janicki Environmental, Inc. (JEI). 2003. Development of critical loads for the C-43 Basin, Caloosahatchee River. Prepared for the Florida Department of Environmental Protection. St. Petersburg, FL.

Kadlec, R.H. and R.L. Knight. 1996. Treatment Wetlands. CRC Press/Lewis Publishers, Boca Raton, FL. 893 pp.

Kadlec, R.H. and S. Newman 1992. Phosphorus removal in wetland treatment areas. Principles and Data. Everglades Protection. Stormwater Treatment Area Design Support Document. South Florida Water Management District.

Kadlec, R.H. and S.D. Wallace. 2009. Treatment Wetlands. Second Edition. CRC Press. Boca Raton, FL. 1,016 pp.

Kadlec, R.H. and W.W. Walker. 2003. Technology Review of Periphyton Stormwater Treatment. Prepared for the U.S. Department of Interior.

Knight, R.L. and J. Steele 2005. Caloosahatchee River/Estuary Nutrient Issues. White Paper. Prepared for the South Florida Water Management District. Prepared by Wetland Solutions, Inc., Gainesville, FL.

Metcalf and Eddy, Inc. 1991. Wastewater Engineering, Treatment, Disposal, and Reuse. Third Edition. McGraw-Hill, New York, NY.

Reddy, K.R. and R.D. DeLaune. 2008. Biogeochemistry of Wetlands. Science and Applications. CRC Press. Boca Raton, FL. 774 pp.

South Florida Water Management District. 2011. South Florida Environmental Report. March 1, 2011.

URS 2005. Basis of Design Report Stormwater Treatment Area 5 3rd Flow-way. June 2005

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

U.S. Army Corps of Engineers (USACE). 2004. Central and South Florida Indian River Lagoon – South, Final Integrated Project Implementation Report and Environmental Impact Statement. Jacksonville District.

USACE and SFWMD 2004. Central and Southern Florida Project, Indian River Lagoon – South. Final Integrated Project Implementation Report Environmental Impact Statement. March 2004.

Vymazal, J., H. Brix, P.F. Cooper, M.B. Green, and R. Haberl. 1998. Constructed Wetlands for Wastewater Treatment in Europe. Backhuys Publishers, Leiden. 366 pp.

Walker, W.W. 2010. Evaluation of Alternatives to Achieve Phosphorus WQBELs in Discharges to the Everglades Protection Area. Prepared for the U.S. Environmental Protection Agency. September 2, 2010.

Walker, W.W., and R.H. Kadlec. 2008. Dynamic Model for Stormwater Treatment Areas Version 2. (available at http://www.wwwalker.net/dmsta) [computer program]

Wetland Solutions, Inc. (WSI). 2007a. C-43 West Storage Reservoir Test Cell Water Quality Summary. Prepared for Stanley Consultants, Inc. August 2007

Wetland Solutions, Inc. (WSI). 2007b. C-44 Reservoir/Stormwater Treatment Area Test Cell Monitoring Program – Surface Water Quality Summary. Prepared for HDR Inc. July 2007

Wetland Solutions, Inc. (WSI). 2009. Development of Design Criteria for Stormwater Treatment Areas (STAs) in the Northern Lake Okeechobee Watershed. Prepared for the South Florida Water Management District. September 2009. 103 pp.

Wetland Solutions, Inc. (WSI). 2010. Inc. 2010 C-43 Water Quality Treatment Area-Technical Expert Review Panel Consolidated Report. Prepared for the South Florida Water Management District. August 2010. 13pp.

Wetland Solutions, Inc. (WSI) and ANAMAR. 2011. STA-1E Periphyton Stormwater Treatment Area (PSTA) Final Report (W912-EP-09-E-0013). Prepared for the U.S. Army Corps of Engineers. October 24, 2011.

Appendix A

USDA Natural Resources Conservation Service - Soil Survey

Appendix B

Florida Treatment Wetlands Monthly Water Quality Data