Final Report

Ten Mile Creek Water Preserve Area – Updated Water Quality Assessment

Prepared for

South Florida Water Management District

June 2002

Wetland Solutions, Inc.

Contents

Exhibits

Appendices

Executive Summary

Controlling the quantity and timing of water deliveries to the North Fork of the St. Lucie River is the main purpose of the proposed Ten Mile Creek Water Preserve Area (WPA). Quantification of water quality benefits likely to accrue from the proposed project is an important component of project planning and design. A preliminary review of expected water quality improvements for the proposed Ten Mile Creek WPA was conducted in December 1999 (Knight, 1999). This report provides revised estimates of the water quality improvements based on updated system design and operation schedules for this project and on more recently developed tools for treatment wetland performance estimation.

The Ten Mile Creek WPA project will consist of a 213 ha (526 ac) water storage area (reservoir) and a downstream treatment wetland cell encompassing approximately 53 ha (132 ac). A pump station will move water from Ten Mile Creek into the reservoir, from which it will flow downstream into the treatment wetland via gravity with a pump backup. A final control structure will convey water by gravity from the proposed treatment wetland into Ten Mile Creek by way of Canal 96. When water is available, the reservoir will also provide irrigation water supply to local agriculture via a return bay at the main pump station.

Revised water quality performance estimates were made using a variety of methods including the Dynamic Model for Stormwater Treatment Areas (DMSTA) version 4/12/02, the reservoir algorithm in the DMSTA, and a sequential nitrogen model. Results from these analyses were based on an updated long-term (31-year) simulated operational schedule provided by the District for the 60 percent design of the Ten Mile Creek WPA.

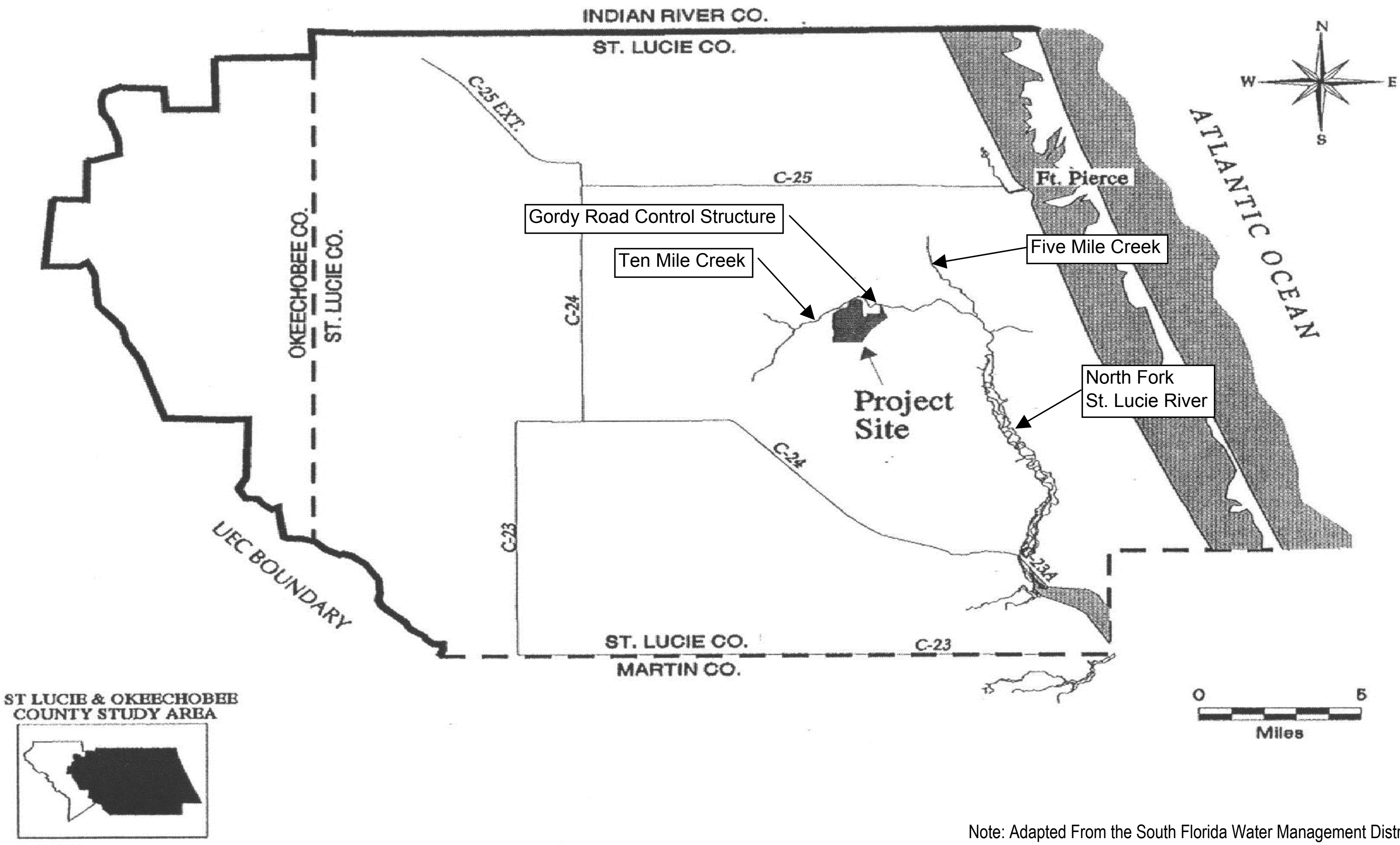
The average flow-weighted inflow total phosphorus (TP) concentration in Ten Mile Creek is projected to be about 245 μg/L and is expected to be reduced by approximately 80 to 89 percent in the combined reservoir/treatment wetland system (based on DMSTA model estimates for the reservoir [estimated average flow-weighted outflow = 91 μg/L] and a treatment wetland dominated by either an emergent marsh [estimated average flow-weighted outflow = 50 μg/L] or by submerged aquatic vegetation [estimated average flow-weighted outflow = 28 μg/L]). Revised model estimates also indicate that the combined reservoir/treatment wetland will lower the average total nitrogen (TN) concentration from about 1.6 to 1.2 mg/L and average inorganic nitrogen concentrations by approximately 70 percent.

Introduction

Controlling the quantity and timing of water deliveries to the North Fork of the St. Lucie River is the main purpose of the proposed Ten Mile Creek Water Preserve Area (WPA). Exhibit 1 presents a location map for the proposed Ten Mile Creek WPA. Benefits to the St. Lucie River may also be realized through reduction in the Ten Mile Creek sediment load and suspended solids concentration and through nutrient assimilation. Quantification of water quality improvements likely to accrue from the proposed project is an important component of project planning and design. A preliminary water quality assessment for the proposed Ten Mile Creek WPA was completed in December 1999 (Knight, 1999). The magnitude of potential water quality benefits is dependent upon system design and operation. This report provides updated estimates of the water quality changes that are likely to result from this project.

The Ten Mile Creek WPA is a project proposed under the Critical Restoration Project Program established by the Water Resources Development Act of 1996. When completed, this project will consist of a water storage area (reservoir) about 213 ha (526 ac) in size and with a maximum depth of water between 3.0 and 4.6 m (10 to 15 ft). In addition to the water storage area, the proposed project includes a pump station to move water from Ten Mile Creek into the reservoir, a 53 ha (132 ac) treatment wetland cell downstream of the reservoir for additional water quality and habitat benefits, auxiliary pumps and control structure to move water from reservoir to wetland, and a discharge control structure back to Ten Mile Creek via Canal 96. Exhibit 2 presents a plan view of the proposed Ten Mile Creek WPA reservoir and treatment wetland.

The primary purpose of the project is to control storm water flow from Ten Mile Creek into the North Fork of the St. Lucie River. Storm water from Ten Mile Creek would be pumped from the creek into the water storage area primarily during the summer rainy season. This water would be released at times favorable to the North Fork, most often in the drier, winter season. A secondary goal of this project is to improve water quality to the Indian River Lagoon and St. Lucie Estuary by reducing nutrients such as total nitrogen (TN) and total phosphorus (TP), total suspended solids (TSS), metals and agrichemicals. Prior to release to the North Fork, the storm water would be passed through a treatment wetland for water quality improvement purposes. This cell is currently planned to hold water with relatively shallow depths averaging 0.46 to 0.6 m (18 to 24 in). It would be densely vegetated by emergent and floating obligate wetland plant species.



Note: Adapted From the South Florida Water Management District

EXHIBIT 1

Location Map for the Proposed Ten Mile Creek Water Preserve Area, St. Lucie County, Florida.

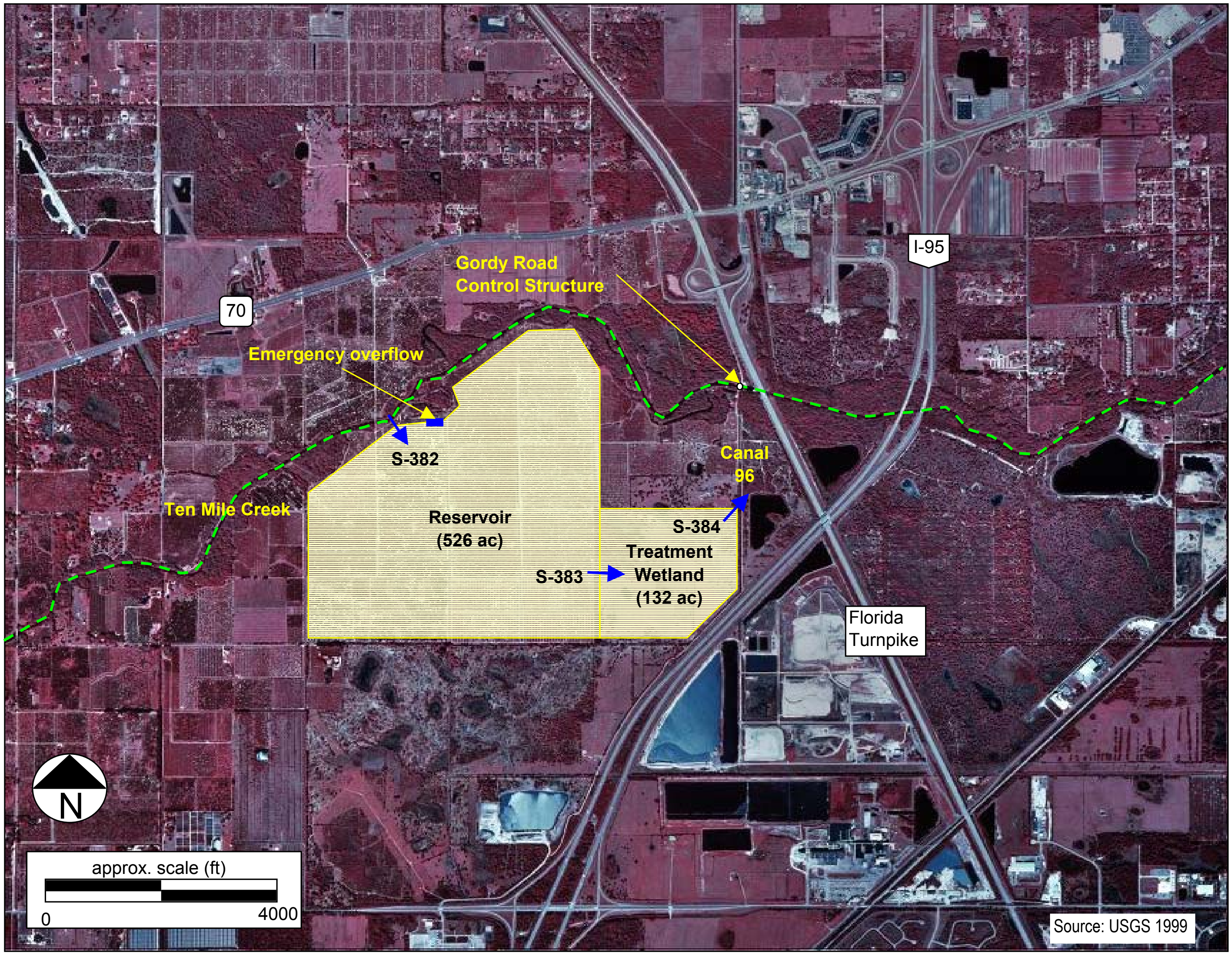


EXHIBIT 2

Color Infrared Aerial Photograph of the Proposed Ten Mile Creek Water Preserve Area, St. Lucie County, Florida.

Summary of Previous Analysis

This section provides a review and summary of the preliminary Ten Mile Creek water quality assessment previously conducted by Knight (1999). Several models for estimating treatment performance of the proposed reservoir and treatment wetland were used during these earlier analyses.

Reservoir Performance Assessment

Knight (1999) used three methods for making water quality performance predictions for the proposed reservoir; the Army Corps of Engineers (COE) reservoir model, EUTROMOD model, and empirical performance estimation techniques. Several of the reservoir assumptions have changed since the preliminary analysis was conducted. Listed below is a summary of the changed assumptions:

- Average TP inflow concentration from Ten Mile Creek was changed from 252 to 245 µg/L
- Average pumping rate was changed from 10.7 to 19.8 hm^3/yr (8,670 to 16,070 ac-ft/yr)
- Wetted-area changed from 1.87 to 2.13 km^2 (462 to 526 acres)
- Operational water depth changed from 0.98 to 3.7 meters (3.2 to 12.1 feet)

The COE Reservoir Model was developed by Walker (1985; 1987; 1998) originally for the U.S. Army Corps of Engineers and is based on data from stormwater wet detention basins in the north central U.S. The COE Reservoir model only predicts changes in the concentration of total phosphorus for annual average conditions.

A second tool used for the reservoir water quality prediction is the EUTROMOD model developed by Kenneth Reckhow and calibrated for Florida lakes (Reckhow et al. 1992). This model predicts changes in the concentrations of total nitrogen, total phosphorus, and chlorophyll a in lakes based on hydraulic residence time. This model was calibrated with data largely from natural lakes and does not include flood control reservoirs.

A third tool used in the preliminary water quality assessment was comparison to data from other south-central Florida water storage reservoirs. These included several systems in the St. Johns River Water Management District. These data sets tend to be broader than the COE and EUTROMOD models and are most useful for estimating the performance of parameters other than nitrogen and phosphorus.

Exhibit 3 provides a summary of the preliminary estimated water quality for the pumped inflow and outflow for the proposed Ten Mile Creek reservoir (Knight, 1999).

Treatment Wetland Performance Assessment

Treatment wetland performance is generally based on empirical methods. The methods used in the preliminary analysis for the Ten Mile Creek WPA are described in Kadlec and Knight (1996) and in Knight (1999) and included:

- Regression models based on data in the North American Treatment Wetland Database (NADB) (Knight et al., 1993; CH2M HILL 1998)
- Pollutant mass loading methods
- A first-order, area based model (k-C* Model) modified for infiltrating/exfiltrating conditions

These performance estimation methods are described in Knight (1999). Exhibit 4 provides a summary of the preliminary estimated inflow and outflow water quality for the proposed treatment wetland and the resulting planned discharge to Ten Mile Creek (Knight, 1999).

Several of the treatment wetland assumptions have changed since the original assessment including:

- Average TP inflow concentration from the proposed Ten Mile Creek Reservoir was changed from 158 to 91 μg/L
- Wetted-area changed from 0.400 to 0.534 km^2 (100 to 132 acres) based on the stage-area table in Exhibit 6.

EXHIBIT 3

Summary of Preliminary Estimates of Water Quality Changes in the Proposed Ten Mile Creek WPA Reservoir (Knight, 1999)

		Pumped Inflow From Ten Mile Creek			Outflow to Polishing Cell		
Parameter	Units	Average	Maximum	Minimum	Average	Maximum	Minimum
Water temperature	deg C	25.0	31.0	15.0	25.0	34.0	13.0
Secchi	meters	1.2	2.4	0.6	1.2	2.4	0.3
Color	CPU	85.0	250.0	30.0	68.0	250.0	40.0
Conductivity	umhos/cm	1700	2600	670	1400	2100	500
Dissolved oxygen	mg/L	5.1	11.0	0.6	6.0	12.0	2.2
BOD_5	mg/L	1.5	2.2	0.8	1.8	7.0	0.6
pH	s.u.	7.2	7.8	6.9	7.3	9.4	6.7
Alkalinity	mg/L	190.0	200.0	180.0	120.0	190.0	60.0
TSS	mg/L	5.0	20.0	2.0	6.0	20.0	0.5
Total NH_4-N	mg/L	0.120	0.260	0.002	0.050	0.300	0.002
TKN	mg/L	1.200	2.800	0.360	1.200	1.800	0.400
NO_2+NO_3-N	mg/L	0.150	0.390	0.002	0.075	0.380	0.002
TN	mg/L	1.600	2.600	0.770	1.300	1.800	1.000
Ortho-P	mg/L	0.190	0.300	0.040	0.060	0.180	0.010
Diss. P	mg/L	0.200	0.500	0.050	0.100	0.300	0.050
TP	mg/L	0.251	0.590	0.055	0.160	0.450	0.150
Chlorides	mg/L	400	690	190	320	550	150
Sulfate	mg/L	150	190	110	100	150	80
Chlorophyll-*a* (corr.)	ug/L	51.0	56.0	46.0	23.0	100.0	10.0
Turbidity	NTU	10.0	25.0	1.1	7.0	25.0	1.5
Fecal coliforms	col/100mL	120	780	5	100	750	5
Copper	ug/L	20	50	5	5	25	1
Zinc	ug/L	30	100	15	15	60	5

Source of estimates:
Inflow estimates from STORET data from Gordy Road Bridge (1972-94) with the exception of TSS, Diss. P, Cu, and Zn
TSS, Dissolved P, Copper and Zinc estimated inflows are from best professional judgment (BPJ) from other central Florida reservoir data
Outflows to polishing cell are BPJ with the exception of TN and TP
Total nitrogen outflow estimates are from EUTROMOD model
Total phosphorus outflow estimates are from COE reservoir model

EXHIBIT 4

Summary of Preliminary Estimates of Water Quality Changes in the Proposed Ten Mile Creek WPA Treatment Wetland (Knight, 1999)

Parameter	Units	Gravity Inflow From Reservoir			Outflow to Ten Mile Creek		
		Average	Maximum	Minimum	Average	Maximum	Minimum
Water temperature	deg C	25.0	34.0	13.0	24.0	32.0	14.0
Secchi	meters	1.2	2.4	0.3	n.a.	n.a.	n.a.
Color	CPU	68.0	250.0	40.0	80.0	200.0	50.0
Conductivity	umhos/cm	1400	2100	500	1400	2100	500
Dissolved oxygen	mg/L	6.0	12.0	2.2	3.3	6.0	0.5
BOD_5	mg/L	1.8	7.0	0.6	1.2	4.5	1.0
pH	s.u.	7.3	9.4	6.7	7.2	8.0	6.0
Alkalinity	mg/L	120.0	190.0	60.0	110.0	150.0	60.0
TSS	mg/L	6.0	20.0	0.5	1.6	6.5	1.0
Total NH_4-N	mg/L	0.050	0.300	0.002	0.020	0.300	0.005
TKN	mg/L	1.200	1.800	0.400	1.100	1.800	1.000
NO_2+NO_3-N	mg/L	0.075	0.380	0.002	0.020	0.110	0.005
TN	mg/L	1.300	1.800	1.000	1.100	2.000	1.000
Ortho-P	mg/L	0.060	0.180	0.010	0.030	0.080	0.005
Diss. P	mg/L	0.100	0.300	0.050	0.060	0.200	0.050
TP	mg/L	0.160	0.450	0.150	0.060	0.170	0.050
Chlorides	mg/L	320	550	150	320	550	150
Sulfate	mg/L	100	150	80	75	100	25
Chlorophyll-*a* (corr.)	ug/L	23.0	100.0	10.0	10.0	20.0	2.0
Turbidity	NTU	7.0	25.0	1.5	4.0	15.0	1.0
Fecal coliforms	col/100mL	100	750	5	10	750	5
Copper	ug/L	5	25	1	7	14	1
Zinc	ug/L	15	60	5	14	40	5

Source of estimates:
Inflows to polishing cell are BPJ with the exception of TN, TP and Chlorophyll-a (average)
Total nitrogen inflow and chlorophyll-a (average) estimates are from EUTROMOD model
Total phosphorus inflow estimates are from COE reservoir model
Outflow estimates to Ten Mile Creek for BOD_5 (Avg, Min), TSS, NH_4-N, TKN, NO_x-N, TN, FC, Cu, and Zn are from k-C* Model
Total phosphorus outflow estimates to Ten Mile Creek are from Infiltrating/Exfiltrating Model
Remaining outflow estimates to Ten Mile Creek are from best professional judgment (BPJ) from other central Florida reservoir data

Updated Project Design and Operation

The revised Ten Mile Creek WPA project (60 percent design, PBS&J, 2001) consists of a 213 ha (526 ac) reservoir with a maximum volume of 7.59 hm^3 (hm^3 = million m^3; 6,160 ac-ft) (emergency overflow at 29 ft NGVD) and a 53 ha (132 ac) treatment wetland cell (PBS&J, 2001). The wetted area for both the reservoir and treatment wetland will increase with depth. Exhibits 5 and 6 summarize the stage vs. volume and area of the proposed reservoir and treatment wetland. The original project footprint was modified when the District agreed to allow approximately 6.9 ha (17 ac) to remain in natural habitat at the request of the Florida Game and Freshwater Fish Commission. In addition, the SFWMD added approximately 30 acres to the wetland area footprint for its final land acquisition purchase. This area is located between Gordy Road and the Florida Turnpike. The site includes a pond and upland scrub habitat in which gopher tortoise burrows have been observed.

A 380 cfs (754 ac-ft/d) pump station (S-382) will move water from Ten Mile Creek into the reservoir. The reservoir will also be used by local agriculture as an irrigation water supply via a return bay at the main pump station (S-382). A control structure (S-383) with 2 auxiliary pumps (15 and 25 cfs [30 and 50 ac-ft/d]) will be located between the reservoir and treatment wetland to provide gravity and/or pumped discharge into the treatment wetland, depending on reservoir stage. A final control structure (S-384) will convey water by gravity from the treatment wetland cell into Ten Mile Creek by way of Canal 96 (Exhibit 2).

The proposed operational schedule will have a significant effect on water quality changes occurring in the reservoir. The planned schedule indicates a highly variable operation based on water availability in Ten Mile Creek and on anticipated water needs downstream. An updated schedule provided by the District was used for this updated analysis (Konyha, 2002). This schedule provides an estimated long-term (31-year) simulated average pumped inflow to the reservoir from Ten Mile Creek of 19.8 hm^3/yr (16,070 ac-ft/yr) with an average return of 0.04 hm^3/yr (31.4 ac-ft/yr) to Ten Mile Creek via an emergency overflow. The estimated rainfall input to the reservoir is 2.88 hm^3/yr (2,330 ac-ft/yr) and 0.72 hm^3/yr (585 ac-ft/yr) for the treatment wetland, respectively. An input of 0.127 hm^3/yr (103 ac-ft/yr) of 'makeup water' is estimated for the treatment wetland. 'Makeup water' refers to water imported into the treatment wetland to keep it wet during extended dry periods. The source of this water and its attendant TP load are not defined. The average estimated annual surface outflow from the reservoir to the treatment wetland is about 9.64 hm^3/yr (7,810 ac-ft/yr) and 4.48 hm^3/yr (3,630 ac-ft/yr) to local agricultural irrigation. The estimated evapotranspiration loss from the reservoir is 2.74 hm^3/yr (2,230 ac-ft/yr) and 0.69 hm^3/yr (559 ac-ft/yr) from the treatment wetland, respectively. The estimated groundwater seepage loss is 5.98 hm^3/yr (4,850 ac-ft/yr) for the reservoir and 1.65 hm^3/yr (1,340 ac-ft/yr) for the treatment wetland, respectively. The estimated average discharge from the proposed treatment wetland to Ten Mile Creek is 8.14 hm^3/yr (6,600 ac-ft/yr). Exhibit 7 presents a summary of the estimated 31-year simulated average surface inflows/outflows for the proposed Ten Mile Creek WPA.

EXHIBIT 5
Proposed Ten Mile Creek Main Reservoir Stage-Area and Stage-Volume Relationship

Stage (ft NGVD)	Area [a] (ac)	Volume (ac-ft)
7.0	5.28	0.00
12.0	18.50	59.44
12.0	94.15	59.44
18.5	110.82	725.58
18.5	508.09	725.58
20.0	511.20	1,490.04
22.0	514.40	2,515.65
24.0	517.59	3,547.64
26.0	**520.79**	**4,586.02**
28.0	523.98	5,630.79
29.0	525.58	6,156.22
30.0	527.18	6,681.96
32.0	530.37	7,739.51
34.0	533.57	8,803.45
34.6	534.53	9,123.88

[a] levee top el. 34.6 ft, 12' width, 3.5 to 1 side slopes, 24' turnarounds, rounded corners

Operational level assumed to be 26.0 ft ngvd

SFWMD estimates were made using CADD-measured areas from 10/02/01 drawing (60% design, PBS&J, 2001)

EXHIBIT 6

Proposed Ten Mile Creek Treatment Wetland Stage-Area and Stage-Volume Relationship

Stage (ft NGVD)	Area [a] (ac)	Volume (ac-ft)
14.0	1.66	0.00
18.5	6.53	18.43
18.5	129.84	18.43
20.0	130.84	213.94
22.0	**132.18**	**476.96**
24.0	133.51	742.65
26.0	134.85	1,011.01
28.5	136.51	1,350.21

[a] levee top el. 28.5 ft, 12' width, 3.5 to 1 side slopes, ditch bottom el. 14.0, rounded corners

Operational level assumed to be 22.0 ft ngvd

SFWMD estimates were made using CADD-measured areas from 10/02/01 drawing (60% design, PBS&J, 2001)

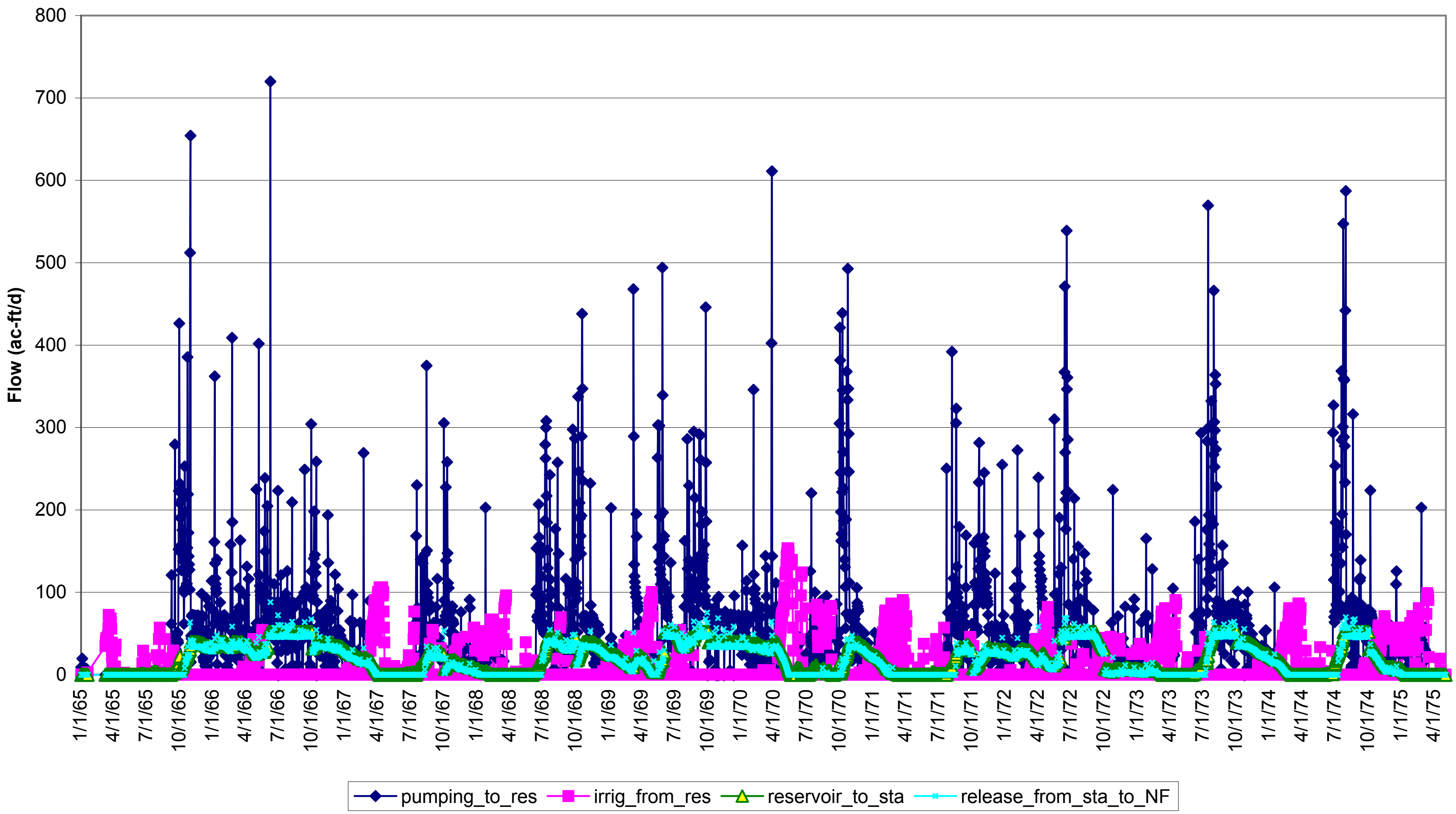


EXHIBIT 7

Estimated Long-Term (31-year) Simulated Average Pumped Inflow/Outflow for the Proposed Ten Mile Creek Reservoir and Treatment Wetland

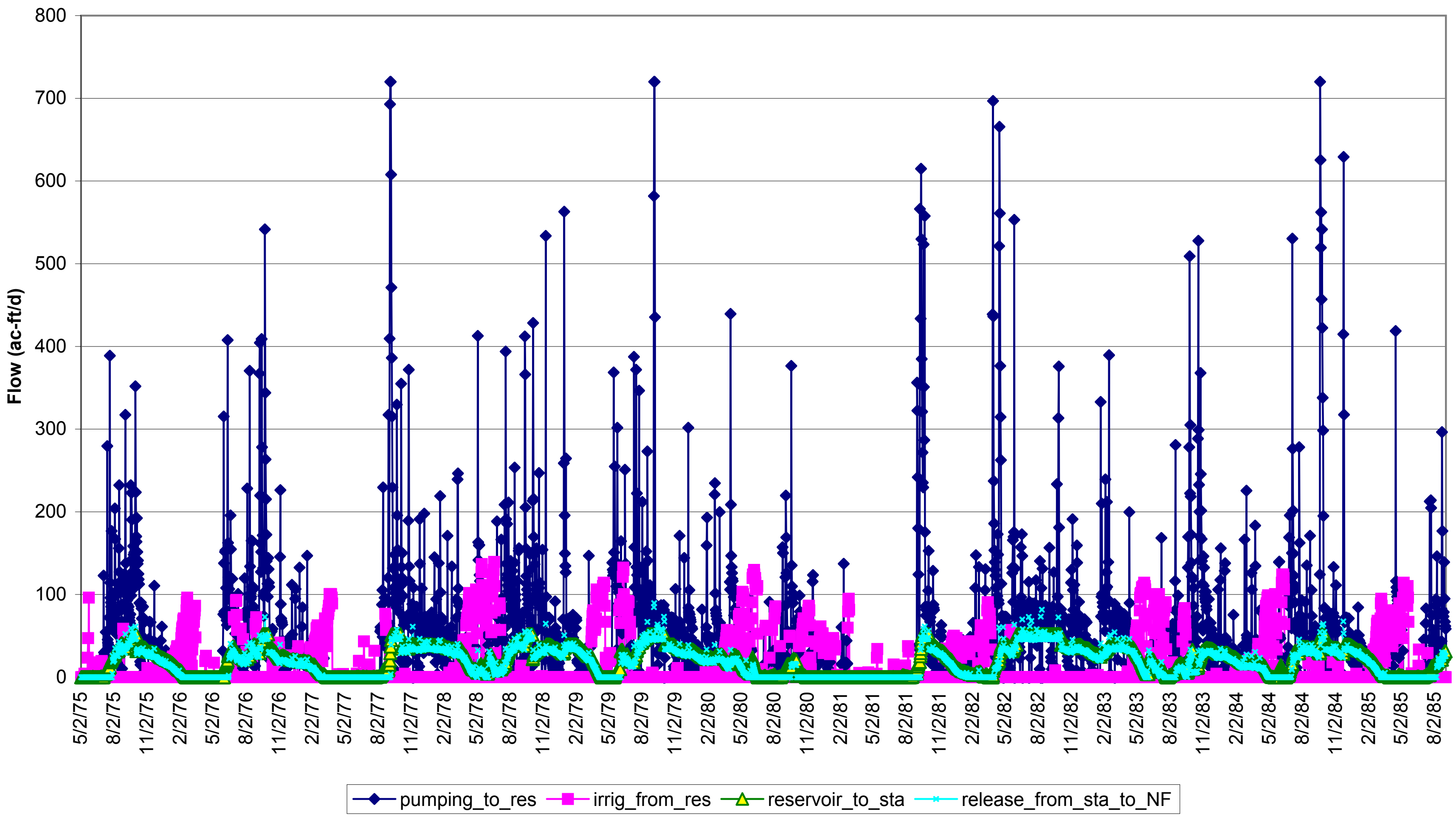


EXHIBIT 7 (cont.)

Estimated Long-Term (31-year) Simulated Average Pumped Inflow/Outflow for the Proposed Ten Mile Creek Reservoir and Treatment Wetland

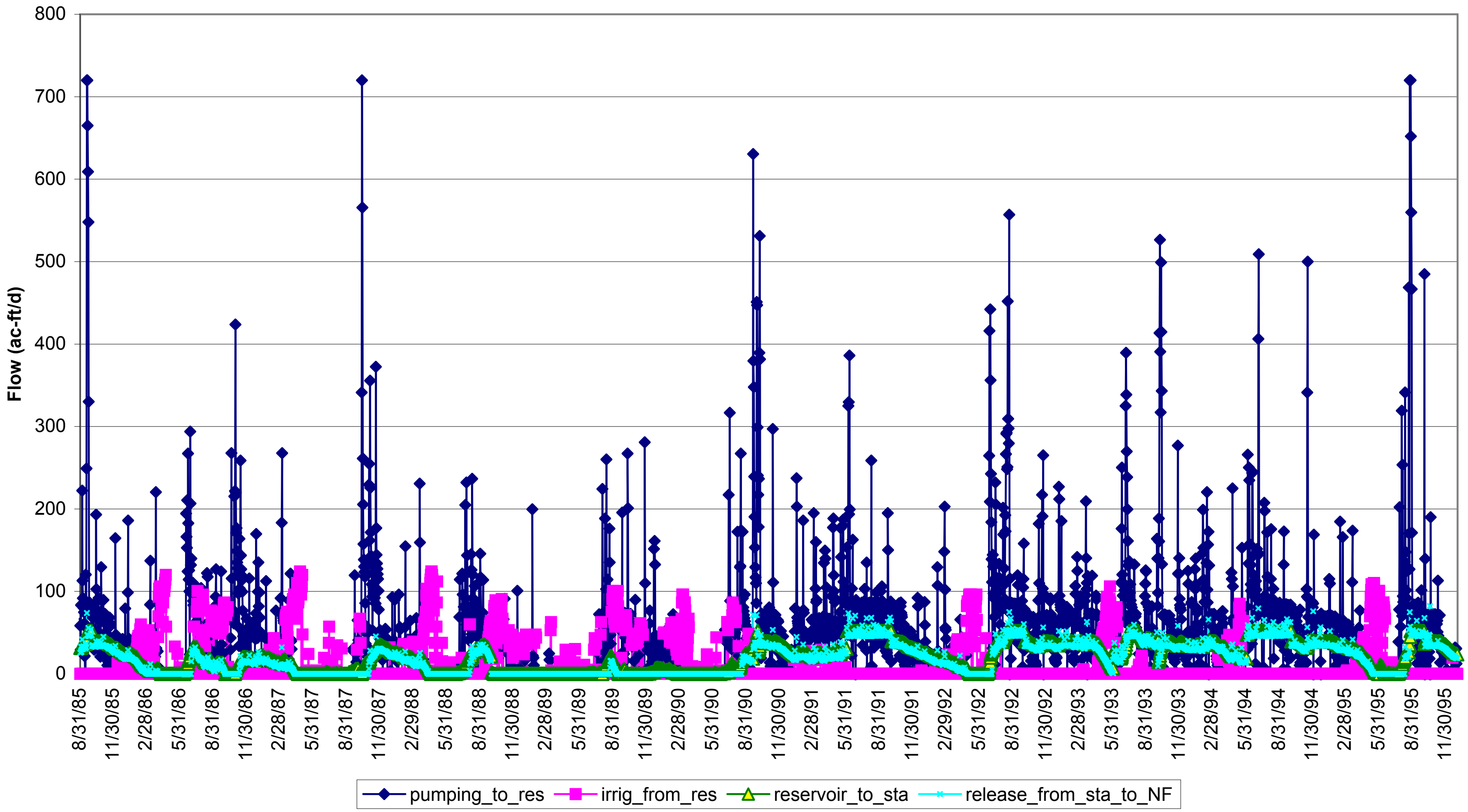


EXHIBIT 7 (cont.)

Estimated Long-Term (31-year) Simulated Average Pumped Inflow/Outflow for the Proposed Ten Mile Creek Reservoir and Treatment Wetland

Description of Additional Water Quality Assessment Methods

Estimation of Ten Mile Creek Loads

Several methods were tested to estimate daily TP concentrations in Ten Mile Creek for use in performance estimates. These alternative methods included:

- Existing TP concentration data from Ten Mile Creek (Gordy Road Bridge) – sinusoidal time series model
- Correlations between actual TP concentration data from Ten Mile Creek (Gordy Road Bridge) and measured stream flow
- TP concentration data from a neighboring basin (C-24) – Julian day model and sinusoidal time series model.

A STORET database search was conducted for TP concentration data from Ten Mile Creek and resulted in 45 data records (1972 to 1994) from the Gordy Road Bridge Station. Daily flow estimates for Ten Mile Creek over a 31-year period-of-record were provided by the District.

Visual examination of the TP data records indicated a possible seasonal cycle in TP concentrations at this location. For this reason a sinusoidal time series model was tested to generate daily TP estimates.

The sinusoidal time series model is defined as:

$$TP = TP_{avg} (1 + A \cos [w (t-t_{max})]) \qquad [1]$$

where:

TP = total phosphorus, mg/L

TP_{avg} = annual average total phosphorus concentration, mg/L

A = fractional half amplitude

w = annual frequency, $w = 2 pi/ 365$, 1/yr

t = time, Julian day

t_{max} = time of maximum TP concentration, Julian day

Solving for TP_{avg}, A, and t_{max} and comparing the resulting modeled TP values to the measured Ten Mile Creek TP data resulted in a correlation coefficient (R^2) of 0.259 (Appendix A-1).

The second method searched for a significant correlation between TP concentrations and stream flows. Since stream flow records are daily, the presence of a significant correlation between these two parameters would allow estimation of daily TP concentrations based on daily flow records. A correlation analysis of TP concentrations and Ten Mile Creek flows was conducted and resulted in an R^2 of 0.104 (Appendix A-2). This method was rejected because of the poor correlation between flows and TP concentrations.

Approximately 10 years (May 1989 – April 1999; 265 records) of TP water quality data from a neighboring watershed (C-24 basin) were also tested for this analysis. The District estimated daily TP data from C-24 by interpolating between measured TP values. These daily estimates were then averaged by Julian day to approximate the seasonal TP pattern for C-24 (Konyha, 2001). The C-24 Julian day averages were correlated to measured TP values from the Gordy Road Station, resulting in an R^2 of 0.258 (Appendix A-3).

The sinusoidal model (Equation 1) was also fit to the measured C-24 TP data and solved for the model parameters, TP_{avg}, A, and t_{max}. A linear regression of modeled TP with measured TP data from C-24 resulted in an R^2 of 0.317 (Appendix A-4). However, using the C-24 model parameters A and t_{max} to predict TP data for Ten Mile Creek, and then correlation to the actual TP data resulted in a R^2 of 0.258 (Appendix A-5).

The sinusoidal time series model, solving for TP_{avg}, A, and t_{max}, using the Gordy Road Station data provided the best correlation with actual data from Ten Mile Creek (Appendix A-1; $R^2 = 0.259$). The resulting model TP = 0.221(1+0.440 cos(0.0172/(t-217.3))) was used to estimate daily TP data for the updated performance modeling of the proposed Ten Mile Creek WPA reservoir and treatment wetland.

Dynamic Model for Stormwater Treatment Areas (DMSTA)[1]

The DMSTA model (version 4/12/02) was available for this updated analysis of TP removal performance by the proposed Ten Mile Creek WPA. This model has been calibrated with a number of existing stormwater treatment area (STA) datasets and has significant flexibility in terms of assumptions needed for treatment wetland design.

The DMSTA model was prepared to provide a single platform for estimating the performance of a variety of treatment wetland options, including wetlands dominated by emergent macrophytes, submerged aquatic vegetation (SAV), and periphytic algae. This model provides a flexible set of options for parameter selection, water balance issues, water flows and internal hydraulics, and cell configurations (Walker and Kadlec, 2001). The DMSTA model only estimates TP removal performance and is not currently expected to be expanded for use for estimating treatment wetland performance for other water quality parameters.

The DMSTA model offers the following factors that are not included in the steady-state design model used previously for STA designs:

- Temporal variations in inflow volume, load, rainfall, and ET
- Hydraulic compartments (cells, internal levees for flow redistribution)
- Hydraulic efficiency (number of stirred tanks in series)

[1] This section has been adapted from the web site hosted by W.W. Walker (http://wwwalker.net/dmsta/index.htm)

- Cell aspect ratio (length/width)
- Water level regulation
- Outflow regulation (discharge vs. water level)
- Compartmentalization of biological communities
- Dry-out frequency and supplemental water needs
- Bypass frequency, quantity, and quality
- Seepage collection and management

DMSTA Treatment Wetland Model Structure

The DMSTA model structure and equations are summarized in Exhibit 8.

At one CSTR and F_Z =1 (depth multiplier for gross uptake):

Storage: $K_1 C = K_2 S + K_3$ [2]

Overall: $L - QC = K_3 S$ [3]

where:

K_1 = maximum uptake rate, m^3/mg-yr

K_2 = recycle rate, m^2/mg-yr

K_3 = burial rate, 1/yr

C = water column concentration, mg/m^3

S = temporary P storage in biota, etc., mg/m^2

L = P load, including atmospheric deposition, mg/m^2-yr

Q = outflow, m/yr

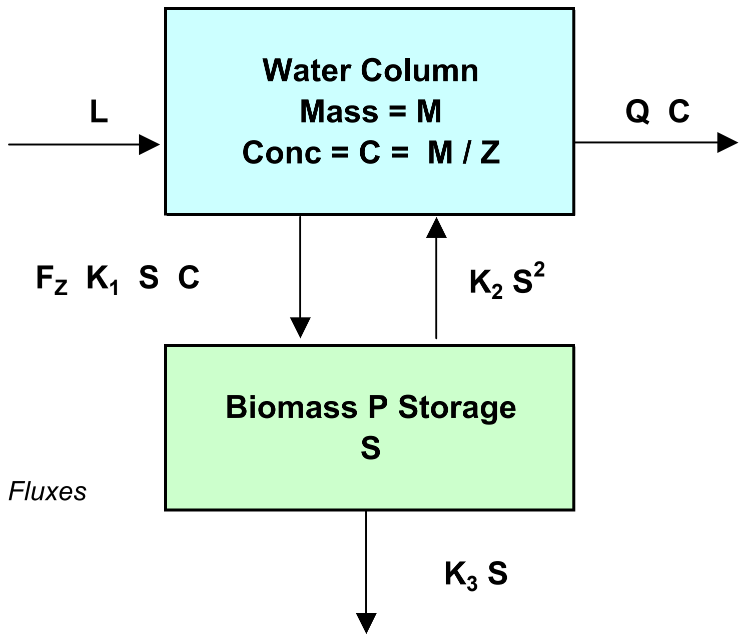
For parameter estimation, the model coefficients can be expressed as follows:

K_s = storage turnover rate at S = 1000 mg/m^2, m^3/mg-yr

C_0 = water column concentration at S = 0 mg/m^2, mg/m^3
(Equivalent to C* in k-C* Model)

C_1 = water column concentration at S = 1000 mg/m^2, mg/m^3

DMSTA Phosphorus Cycling Model



Unit Area Storage & Fluxes
Concs in mg/m^3
Fluxes in mg/m^2-yr
Storage in mg/m^2

F_Z = Min (1, Z / Z_X)

State Variables:

M	Water Column P Storage	mg/m^2
S	Temporary P Storage in Biota, etc.	mg/m^2
Z	Water Column Mean Depth	m
Zx	Water Depth at Maximum Areal Uptake	m

Driving Variables:

L	P Load, Including Atmos. Deposition	mg/m^2-yr
Q	Outflow	m/yr

Parameter Values:

K_1	Maximum Uptake Rate	m^3 / mg - yr
K_2	Recycle Rate	m^2 / mg-yr
K_3	Burial Rate	1/yr

EXHIBIT 8

DMSTA Phosphorus Cycling Model Construction and Variable Definitions

In long term steady-state conditions the above can be expressed as follows:

$$C = (L + K C_0) / (K + Q) \quad [4]$$

$$S = 1000 (C - C_0) / (C_1 - C_0) \quad [5]$$

$$K = 1000 K_S C_0 / C_1 (C_1 - C_0) = K_3 K_1 / K_2 \quad [6]$$

where:

K = settling rate in steady-state k-C* Model, m/yr

A list of the DMSTA input data requirements includes the following:

- Morphometry (length, width, area, cell configuration)
- Hydraulic efficiency (assumed number of stirred tanks in series)
- Daily time series:
  - Inflow and outflow volume
  - Inflow and outflow conc.
  - Mean depth
  - Rainfall
  - Evapotranspiration (ET)
- Descriptive data:
  - Seepage rates
  - Community description
  - P storage in macrophytes, periphyton, and soil

Daily time series data used for model calibration include:

- Outflow volume
- Depth
- Velocity
- Inflow concentration (flow-weighted, un-weighted)
- Outflow load (using observed or predicted flows)

The DMSTA phosphorus cycling model contains three parameters that require calibration to each vegetation type. Two parameters (C_0, C_1) define the effective concentration range and scale of biomass P storage. These are calibrated using biomass P and water column P data from several systems. The remaining parameter (K_s) reflects the turnover rate of biomass P. Turnover rate is calibrated to outflow concentration time series data.

To calibrate turnover rates, a single prototype dataset was selected for each vegetation type (Boney Marsh for Emergent, STA-1W Cell-4 for SAV, and STA-1W South Test Cell 8 for periphyton). Selection criteria included characteristics of vegetation, length and quality of dataset, and spatial scale (larger preferred). Steady-state solutions define rates of turnover and phosphorus uptake as a function of water-column concentration at steady-state.

Factors contributing to variations in calibrated turnover rates include:

- Actual vs. expected vegetation types
  - SAV: *Hydrilla* vs. *Ceratophyllum/Najas* vs. *Chara*
  - periphyton: macrophytes vs. periphyton
- Substrate (peat vs. shell rock)
- Actual vs. assumed hydraulics
- Experimental artifacts - scale and duration
- Startup effects
  - Release from initial substrates
  - Biomass growth
  - Species transitions
- Factors not considered in model structure
  - Inflow P species (SRP vs. Total P)
  - Inflow calcium
- Random variability

DMSTA Storage Reservoir Model Structure

The DMSTA model includes a reservoir model component that allows a reservoir to be placed upstream of the treatment wetland to manage and treat inflows prior to entering the wetland. A reservoir can be used for water storage during peak events and can be used to modify flow rates entering the wetland treatment area.

A list of the DMSTA Reservoir Model input data requirements includes the following:

- Maximum storage reservoir volume (hm^3)
- Hydraulic residence time of reservoir (days)
- Maximum inflow / mean inflow ratio
- Second order phosphorus decay rate in reservoir (1/yr/ppb)
- Daily time series:

- Inflow volume
- Inflow concentration
- Rainfall
- Evapotranspiration

The DMSTA Reservoir Model does not include groundwater exchanges (seepage).

The DMSTA Reservoir Model has several input variables that control how the reservoir is used in managing flows to the wetland treatment cell.

If the hydraulic residence time of the reservoir is greater than zero:

- All pumped basin flow is routed through the reservoir
- Reservoir outflow to the STA is proportional to reservoir storage volume (Outflow = Volume / hydraulic residence time).

If the hydraulic residence time of the reservoir is equal to zero:

- Reservoir is used for peak flow control only (low and average flows go directly to STA)

The ratio of maximum to mean daily inflow to treatment area is used to determine the operating objective for reservoir. If the maximum to mean daily inflow ratio is equal to zero there is no peak flow control.

If the reservoir is full:

- The STA peak inflow constraint is ignored
- All basin flow is routed directly to STA (where it may be bypassed) and continues until storage is available in reservoir

Phosphorus retention in the reservoir is modeled as a second order reaction (proportional to volume and square of TP concentration). The phosphorus mass-balance in the storage reservoir is tracked, so that outflow load equals inflow load on the average unless the specified second order phosphorus decay rate in reservoir is greater than zero. The phosphorus retention model has not been tested regionally. The model was originally developed using data from Corps of Engineer reservoirs outside of Florida. Typical rate coefficients range from 0.1 to 0.2 1/yr/ppb.

Sequential N Model

Nitrogen occurs in a number of different oxidation states in treatment wetlands, and numerous biological and physical-chemical processes can transform nitrogen between these different forms.

Organic nitrogen (ON), ammonia and ammonium nitrogen (AN), nitrate and nitrite nitrogen (NN), and nitrogen gasses are the primary nitrogen forms in surface waters. A fraction of ON is mineralized to AN in aquatic and wetland systems. Water temperature and pH determine the extent to which AN is distributed between ammonium (ionized form) and its volatile form (un-ionized ammonia). AN can in turn be oxidized to NN through aerobic microbial processes (nitrification). Depending on the amount of ON found in the source water, AN can be both produced and consumed in wetlands. The following two-step reaction model from Kadlec and Knight (1996) can be used to estimate the concentration of AN (C_{AN}):

$$C_{AN} = (C_{ANi})e^{-\frac{k_{AN}}{q}} + \left(\frac{k_{ON}}{k_{AN} - k_{ON}}\right)(C_{ONi} - C^*_{ON})\left(e^{-\frac{k_{ON}}{q}} - e^{-\frac{k_{AN}}{q}}\right) \quad [7]$$

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

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

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

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

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

q = hydraulic loading rate, m/yr

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

The three-step plug flow kinetic model from Kadlec and Knight (1996) was used to estimate the combined effects of all processes on NN concentrations (C_{NN}):

$$C_{NN} = (C_{NNi})e^{-\frac{k_{NN}}{q}y} + \psi\left\{\begin{array}{l} \left(\frac{k_{AN}}{k_{NN} - k_{AN}}\right)(C_{ANi})\left(e^{-\frac{k_{AN}}{q}y} - e^{-\frac{k_{NN}}{q}y}\right) \\ + \left(\frac{k_{ON}}{k_{AN} - k_{ON}}\right)\left(\frac{k_{AN}}{k_{NN} - k_{ON}}\right)(C_{ONi} - C^*_{ON})\left(e^{-\frac{k_{ON}}{q}y} - e^{-\frac{k_{NN}}{q}y}\right) \\ - \left(\frac{k_{ON}}{k_{AN} - k_{ON}}\right)\left(\frac{k_{AN}}{k_{NN} - k_{AN}}\right)(C_{ONi} - C^*_{ON})\left(e^{-\frac{k_{AN}}{q}y} - e^{-\frac{k_{NN}}{q}y}\right) \end{array}\right\} \quad [8]$$

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

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

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

An Excel spreadsheet adapted from Kadlec (unpublished) and Kadlec and Knight (1996) was used to estimate the sequential removal of nitrogen forms in the proposed treatment wetland.

Water Quality Assessment – Revised Results

Reservoir

A list of the daily DMSTA reservoir input data requirements includes the following:

- Inflow Volume
- Inflow TP Concentrations
- Rainfall
- Evapotranspiration

The 31-year simulated operational schedule (Exhibit 7), provided by the District, was used to estimate daily flows to the reservoir from Ten Mile Creek. Daily TP inflow water quality to the reservoir was estimated using the sinusoidal time series model as described above. Actual TP values from STORET were used when available. Exhibit 9 presents a summary of the model input parameters and simulation results.

The flow-weighted average TP concentration for Ten Mile Creek was 245µg/L, with individual estimated TP concentrations ranging from 90 to 590 µg/L. Reservoir outflow TP concentrations ranged from 14 to 340 µg/L, with an estimated average flow-weighted concentration of 91 µg/L. Time series plots of the 31-year daily inputs and simulation results are presented in Appendix B.

Knight (1999) used the COE Reservoir model to estimate the average TP outflow concentration from the proposed Ten Mile Creek Reservoir, resulting in an estimate of 158 µg/L. Several of the model parameter estimates have changed since the preliminary analysis was conducted. Listed below is a summary of the changed assumptions:

- Average TP inflow concentration from Ten Mile Creek was changed from 252 to 245 µg/L
- Average pumping rate was changed from 10.7 to 19.8 hm^3/yr (8,670 to 16,070 ac-ft/yr)
- Wetted-area changed from 1.87 to 2.13 km^2 (462 to 526 acres)
- Operational water depth changed from 0.98 to 3.7 meters (3.2 to 12.1 feet)

Using the same COE model with the new assumptions results in an estimated average TP outflow concentration of 90 µg/L (Exhibit 10). These results are similar to the long-term estimates from the DMSTA reservoir model (91 µg/L).

EXHIBIT 9
DMSTA Simulation Results for the Proposed Ten Mile Creek Reservoir

Parameter	Units	Value
Model Input Parameters		
Reservoir Residence Time	Days	104
Maximum Inflow/Mean Inflow	---	16.4
Maximum Reservoir Storage	hm^3	5.66
Reservoir P Decay Rate	1/yr/ppb	0.10
Simulation Results		
Mean Storage Volume	hm^3	4.06
Mean Hydraulic Loading Rate	m/yr	10.1
Mean Inflow	hm^3/day	0.054
Mean TP Load – Inflow	kg/d	13.3
Flow-weighted Mean TP Conc – Inflow	µg/L	245
Flow-weighted Mean TP Conc – Outflow	µg/L	91

Notes:
Reservoir operating water depth at 26 ft NGVD (area 521 ac; volume 4,586 ac-ft)
DMSTA Model version 4/12/02

EXHIBIT 10

Updated Summary of Estimated Water Quality Performance of the Proposed Ten Mile Creek Reservoir using the COE Reservoir Model

Terms	Description	Units	Average Conditions	
			Knight 1999	This Study
P =	Average rainfall	m/yr	1.35	1.35
C_i =	TP concentration in	µg/L	252	245
C_p =	Rainfall TP concentration	µg/L	36	25 (a)
Q_i =	Inflow rate	hm^3/yr	10.7	19.8
Q_o =	Outflow rate	hm^3/yr	9.6	19.8
A =	WPA reservoir surface area	km^2	1.87	2.13
q_i =	Hydraulic loading rate from pumped inflow	m/yr	5.7	9.3
U_s =	Exfiltrating groundwater	m/yr	0.00	0.00
U_o =	Infiltrating groundwater	m/yr	0.94	0.94
Z =	Mean water depth	m	0.98	3.70
F_w =	Fraction of days with surface water	---	1.00	1.00
C_s =	TP concentration in exfiltrating groundwater	µg/L	20	20
C_o=	TP concentration out, calculated:	µg/L	158	90
Eff=	Concentration reduction efficiency, calculated:	%	37	63

Model Equations

C_o =	$[P_i*(-1+4*N)^{0.5}]/(2*N)$	µg/L		
q_o =	$Q_o/A + U_o$	m/yr	6.1	10.2
K_2 =	$0.17*F_w*q_o/(q_o+13.3)$	---	0.053	0.074
P_i =	$[(Q_i*C_i)/A + P*C_p + U_s*C_s]/q_o$	µg/L	244.1	225.8
N =	K_2*P_i*Z/q_o	$mg/m^3/yr$	2.105	6.031

[a] C_p = Dry Atmospheric P Load (20 mg/m2-yr) / Average Rainfall (1.35 m/yr) + Rainfall P Concentration (10 µg/L)

1 hm^3/d (million m^3/d) = 408.7 cfs = 810.7 ac-ft/d

Treatment Wetland

Phosphorus

The DMSTA Model has a number of calibrated parameter sets available. The DMSTA assigns pre-calibrated P cycling parameters based upon vegetation type. Emergent vegetation input model parameters were used in the 'base case' simulation for the proposed Ten Mile Creek Treatment Wetland and are presented in Exhibit 11.

Using the different model calibration parameters results in a range of expected performance estimates for the proposed Ten Mile Creek Treatment Wetland. The 31-year simulated operational schedule (Exhibit 7), provided by the District, was used to estimate daily flows to the proposed treatment wetland from the reservoir. Daily inflow TP concentrations to the treatment wetland were estimated from the DMSTA reservoir simulation summarized above.

Exhibit 12 presents a summary of the estimated performance for the proposed treatment wetland using both emergent and submerged aquatic vegetation (SAV) model calibration parameters. Total phosphorus load reductions ranged from 48 to 70 percent using the Emergent and SAV calibration datasets, respectively. Average flow-weighted outflow TP concentrations ranged from 50 to 28 µg/L for the same simulations.

Exhibit 13 presents the stage frequency curve for the proposed Ten Mile Creek Treatment Wetland using the 31-year simulated operational schedule provided by the District. Depths were estimated using the 'base case' DMSTA model parameters in Exhibit 11. The DMSTA calibrated parameter datasets identify a range of depths for both emergent vegetation and SAV. The calibrated parameter depths ranged from 18 to 98 cm for emergent vegetation and from 30 to 109 cm for SAV datasets, respectively.

Knight (1999) used the steady-state, infiltrating/exfiltrating model with storage to estimate the average TP outflow concentration from the proposed Ten Mile Creek Treatment Wetland. This analysis resulted in an estimate of 64 µg/L under average conditions. Several of the model parameter estimates have changed since this analysis was conducted. Listed below is a summary of the changed assumptions:

- Average TP inflow concentration from the proposed Ten Mile Creek Reservoir was changed from 158 to 91 µg/L
- Wetted-area changed from 0.400 to 0.534 km^2 (100 to 132 acres)
- First-order removal rate constant adjusted downward from 24 m/yr to original STA design value of 10.2 m/yr

Using the same model with the new assumptions results in an estimated average TP outflow concentration of 55 µg/L (Exhibit 14). This estimate is similar to the updated estimate generated from the DMSTA model using the emergent vegetation calibration dataset (50 µg/L).

EXHBIT 11

Model Parameters used in the DMSTA Model Simulations for the Proposed Ten Mile Creek Treatment Wetland

Parameters	Units	Value
Surface Area of Treatment Cell	km^2	0.534
Mean Width of Flow Path (W)	km	0.732
Number of Tanks in Series	---	3
Outflow Control Depth	cm	0
Outflow Coefficient - Exponent (b) [1]	---	3.5
Outflow Coefficient - Intercept (a) [1]	---	0.4
Outflow Seepage Rate	(cm/d)/cm	0.008
Seepage Recycle Fraction	---	0
Maximum Outflow Seepage Conc	ppb	20
Rainfall P Conc	ppb	10
Atmospheric P Load (Dry)	(mg/m^2-yr)	20
Initial Water Column Conc	ppb	30
Initial P Storage Per Unit Area	mg/m^2	500
Initial Water Column Depth	cm	50
C0= WC Conc at 0 g/m2 P storage	ppb	4
C1 =WC Conc at 1 g/m^2 P storage	ppb	22
K = Net Settling Rate at Steady State	m/yr	16
Zx = Depth Scale Factor	cm	60

[1] hydraulic resistance of vegetation as a function of depth; Cell Outflow = $W a Z^b$

DMSTA Model version 4/12/02 - pre-calibrated p cycling parameters based upon emergent vegetation type

EXHIBIT 12

Estimated Performance Summary for Two Alternate Vegetation Types in the Proposed Ten Mile Creek Treatment Wetland Based on the DMSTA Model

Parameter	Units	Vegetation Type	
		Emergent	SAV
Calibration Datasets			
C0= WC Conc at 0 g/m^2 P storage	ppb	4	12
C1 =WC Conc at 1 g/m^2 P storage	ppb	22	22
K = Net Settling Rate at Steady State	m/yr	16	128
Zx = Depth Scale Factor	cm	60	60
Estimated Performance Results			
Inflow	hm^3/d	0.027	0.027
Outflow	hm^3/d	0.025	0.025
Flow weighted TP Inflow	**µg/L**	**91**	**91**
Flow weighted TP Outflow	**µg/L**	**50**	**28**
HLR	m/yr	18.2	18.2
TP Inflow Load	kg/d	2.4	2.4
TP Outflow Load	kg/d	1.3	0.7
TP Load Reduction	%	48	70
Mean Depth	cm	41	34
Maximum Depth	cm	67	55

Notes:

DMSTA Model version 4/12/02

Treatment Wetland operating water depth at 22 ft. NGVD (area 132 ac; volume 477 ac-ft)

Averaging interval = 7 days

1 hm^3/d (million m^3/d) = 408.7 cfs = 810.7 ac-ft/d

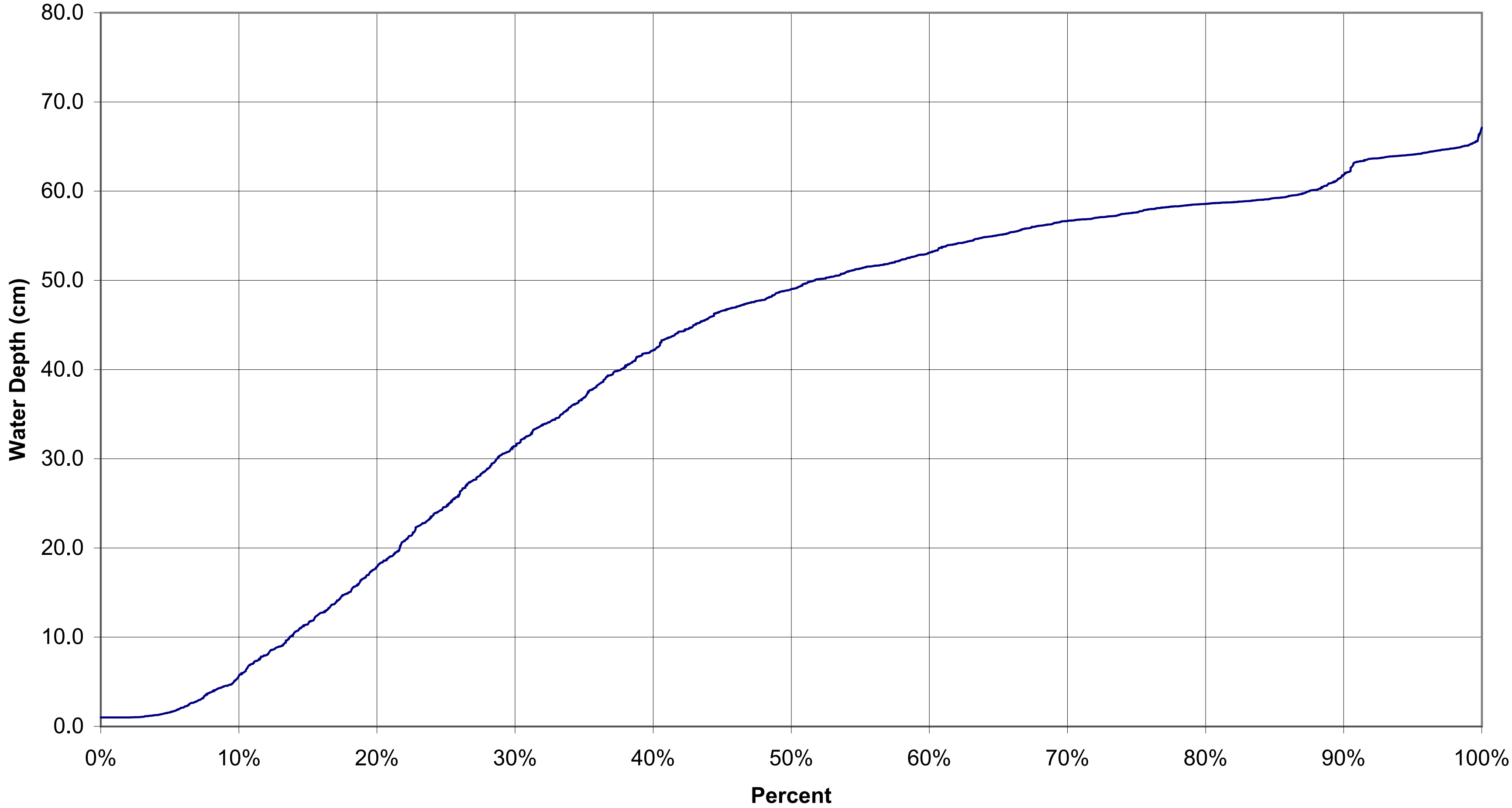


EXHIBIT 13

Stage Frequency Curve of Proposed Ten Mile Creek Treatment Wetland Simulated Water Depths using the DMSTA Model v. 4/12/02

EXHIBIT 14

Updated Summary of Estimated Water Quality Performance of the Proposed Ten Mile Creek Treatment Cell Using Infiltrating/Exfiltrating Model with Storage

Terms	Description	Units	Average Conditions: Knight 1999	Average Conditions: This Study
R =	Average rainfall	m/yr	1.35	1.35
ET =	Average ET	m/yr	1.31	1.31
C_1 =	TP concentration in	mg/L	0.158	0.091
C_r =	Rainfall TP concentration	mg/L	0.036	0.025 (a)
k =	TP settling rate constant	m/yr	24	10.2
Q =	Annual pumped inflow volume	m^3/yr	9,640,000	9,640,000
A =	STA wetland surface area	m^2	396,606	534,000
q =	Hydraulic loading rate from pumped inflow	m/yr	24.31	18.05
I_i =	Exfiltrating groundwater	m/yr	0.00	0.00
I_o =	Infiltrating groundwater	m/yr	0.10	0.10
deltaS =	Change in surface water storage	m/yr	0.00	0.00
C_l =	TP concentration resulting from internal loading	mg/L	0.006	0.006
C_i =	TP concentration in exfiltrating groundwater	mg/L	0.100	0.100
C_2=	TP concentration out, calculated:	mg/L	0.064	0.055
Eff=	Concentration reduction efficiency, calculated:	%	60	39
Model Equations				
C_2 =	$C^* + ((C_1 - C^*)((1+(a/q))^{\wedge}-r))$			
a =	$(R - ET + I_i - I_o - deltaS)$	m/yr	-0.060	-0.060
r =	g/a	---	-400.667	-170.667
g =	$(R - ET + I_i + k)$	m/yr	24.040	10.240
C* =	$(k^*C_l + R^*C_r + I_i^*C_i)/(a+k+deltaS+I_o))$	mg/L	0.008	0.009

[a] C_p = Dry Atmospheric P Load (20 mg/m2-yr) / Average Rainfall (1.35 m/yr) + Rainfall P Concentration (10 µg/L)

1 hm^3/d (million m^3/d) = 408.7 cfs = 810.7 ac-ft/d

The DMSTA design model requires the user to identify the number of stirred tanks in series (TIS) to estimate the hydraulic efficiency of the treatment system. An analysis was conducted to determine the sensitivity of estimated TP removal based on 1 to 6 TIS (Exhibit 15). Varying the TIS assumption between 1 and 6 had little effect on estimated performance, with a range of estimated outflow TP concentrations from 48 to 56 µg/L. Estimated load reductions and net settling rates ranged from 42.1 to 49.6 percent and 8.7 to 11.3 m/yr, respectively.

EXHIBIT 15

Sensitivity of Outflow TP Concentration to the Number of Tanks-in-Series in the DMSTA Model Simulations

Number of TIS	Flow-Weighted Mean TP Outflow (µg/L) [1]	Load Reduction (%)	Net Settling Rate (m/yr)
1	56	42.1	8.7
2	52	46.1	10.1
3	50	47.8	10.6
4	49	48.7	11.0
5	49	49.2	11.2
6	48	49.6	11.3

TIS = tanks-in-series
[1] DMSTA version 4/12/02 - Emergent vegetation model parameter calibration dataset used to estimate outflow TP

Sensitivity analyses were also conduced to estimate the influence of the DMSTA outflow control depth on treatment performance and water depth (Exhibit 16). The outflow control depth had little to no impact on the long-term flow-weighted average TP outlet concentration (48 to 50 µg/L). Adjusting control depth from 0 to 75 cm resulted in average depths of 41 to 65 cm, respectively.

Sensitivity analyses were conducted to determine the influence of outflow seepage rates on model simulation results (Exhibit 17). Seepage rates are reported in centimeters per day per centimeter of head ((cm/d)/cm) and reflect the transmissivity of soils. Seepage rates were adjusted by 25%, 50%, and 100% from the base case (0.008 (cm/d)/cm). Adjusting the outflow seepage rate within this range had little effect on the estimated long-term flow-weighted average TP outlet concentration (50 to 51 µg/L) or on estimated average water depths (40 to 42 cm).

EXHIBIT 16
Sensitivity of Estimated Water Depth and Outflow TP Concentration to Assumed Outflow Control Depth in the DMSTA Model Simulations

Estimated Outflow Control Depth (cm)	Estimated Mean Depth (cm)	Estimated Maximum Depth (cm)	Estimated Flow-Weighted Mean TP Outflow (µg/L) [1]
0	41	67	50
15	41	67	50
30	42	67	50
45	45	67	50
60	52	67	48
75	65	75	48

[1] DMSTA version 4/12/02 - Emergent vegetation model parameter calibration dataset used to estimate outflow TP

The DMSTA design model requires the user to identify the rainfall P concentration (wet deposition) and dry deposition rate (atmospheric P load). The DMSTA calibrations assumed 10 µg/L and 20 mg/m²/yr for the rainfall P concentration and atmospheric dryfall P load, respectively. A sensitivity analysis was conducted for these parameters by adjusting each by ± 25, 50, and 100 percent from the 'base case' (Exhibit 18). The total rainfall / atmospheric P concentration was calculated for each input variable combination using an average rainfall of 1.35 m/yr resulting in a P concentration range of 17 to 40 µg/L. Using the emergent vegetation calibrated model parameters with these rainfall / atmospheric P combination resulted in a range of outflow TP concentrations from 50 to 51 µg/L.

Sensitivity analyses were conduced to estimate the influence of hydraulic loading on treatment wetland performance and water depth (Exhibit 19). Due to the limited range of flows in the 31-year simulated operational schedule for the proposed treatment wetland, the DMSTA design model was run with the reservoir/treatment wetland combination. Flows to the proposed treatment wetland were estimated using the DMSTA platform and not from the operational schedule from the District. This exhibit is intended to show the estimated affect of hydraulic loading on estimated P removal performance and not to suggest new operational rules for the reservoir and treatment wetland. Maximum inflow rates into the treatment wetland were set in the DMSTA model to simulate different hydraulic loading rates to the treatment wetland. Adjusting the maximum inflow rate from 20 to 120 cfs (0.049 to 0.294 hm³/d) resulted in hydraulic loading rates between 26 to 35 m/yr to the treatment wetland (compared to the base case of 18.2 m/yr). Using the emergent vegetation calibrated model parameters with these loading rates resulted in a range of flow-weighted average TP outlet concentrations from 49 to 64 µg/L. Estimated total phosphorus load reductions in the proposed treatment wetland ranged from 41 to 31 percent. Estimated average water depths in the treatment wetland ranged from 53 to 57 cm with maximum depths ranging from 63 to 100 cm, respectively.

EXHIBIT 17

Estimated Performance Summary for Various Outflow Seepage Rates in the Proposed Ten Mile Creek Treatment Wetland based on the DMSTA Model

		Outflow Seepage Rates ((cm/d)/cm)						
		Base Case	-100%	-50%	-25%	+ 25%	+ 50%	+ 100%
Parameter	Units	0.008	0.000	0.004	0.006	0.010	0.012	0.016
Calibration Datasets								
C0= WC Conc at 0 g/m^2 P storage	ppb	4	4	4	4	4	4	4
C1 =WC Conc at 1 g/m^2 P storage	ppb	22	22	22	22	22	22	22
K = Net Settling Rate at Steady State	m/yr	16	16	16	16	16	16	16
Zx = Depth Scale Factor	cm	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Estimated Performance Results								
Inflow	hm^3/d	0.027	0.027	0.027	0.027	0.027	0.027	0.027
Outflow	hm^3/d	0.025	0.026	0.026	0.025	0.024	0.024	0.024
Flow weighted TP Inflow	µg/L	91	91	91	91	91	91	91
Flow weighted TP Outflow	µg/L	50	51	51	50	50	50	50
HLR	m/yr	18.2	18.2	18.2	18.2	18.2	18.2	18.2
TP Inflow Load	kg/d	2.4	2.4	2.4	2.4	2.4	2.4	2.4
TP Outflow Load	kg/d	1.3	1.3	1.3	1.3	1.2	1.2	1.2
TP Load Reduction	%	48	46	46	47	49	50	50
Mean Depth	cm	41	42	42	41	41	40	40
Maximum Depth	cm	67	68	68	67	67	67	66

Notes:

Treatment Wetland operating water depth at 22 ft. NGVD (area 132 ac; volume 477 ac-ft)

Averaging interval = 7 days

DMSTA Model version 4/12/02 - pre-calibrated p cycling parameters based upon emergent vegetation type

1 hm^3/d (million m^3/d) = 408.7 cfs = 810.7 ac-ft/d

EXHIBIT 18

Parameter	Units	Base Case	Sensitivity Analysis: Rainfall P -100%	-50%	-25%	+ 25%	+ 50%	+ 100%	Sensitivity Analysis: Atmospheric P Load (dry) -100%	-50%	-25%	+ 25%	+ 50%	+ 100%
Input Variables														
Rainfall P Concentration	ppb	10	**5**	**6.7**	**8**	**12.5**	**15**	**20**	10	10	10	10	10	10
Atmospheric P Load (dry)	mg/m^2-yr	20	20	20	20	20	20	20	**10**	**13.3**	**16**	**25**	**30**	**40**
Total Rainfall P Concentration [a]	ppb	25	20	22	23	27	30	35	17	20	22	29	32	40
Estimated Performance Results														
Inflow	hm^3/d	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
Outflow	hm^3/d	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Flow weighted TP Inflow	**µg/L**	**91**	**91**	**91**	**91**	**91**	**91**	**91**	**91**	**91**	**91**	**91**	**91**	**91**
Flow weighted TP Outflow	**µg/L**	**50**	**50**	**50**	**50**	**50**	**50**	**51**	**50**	**50**	**50**	**50**	**51**	**51**
HLR	m/yr	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2
TP Inflow Load	kg/d	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
TP Outflow Load	kg/d	1.3	1.2	1.2	1.2	1.3	1.3	1.3	1.2	1.2	1.2	1.3	1.3	1.3
TP Load Reduction	%	48	48	48	48	48	48	47	48	48	48	48	48	47

Notes:

Treatment Wetland operating water depth at 22 ft. NGVD (area 132 ac; volume 477 ac-ft)

Averaging interval = 7 days

Average Rainfall: 1.35 m/yr

[a] Dry Atmospheric P Load / Average Rainfall + Rainfall P Concentration

DMSTA Model version 4/12/02 - pre-calibrated p cycling parameters based upon emergent vegetation type

1 hm^3/d (million m^3/d) = 408.7 cfs = 810.7 ac-ft/d

EXHIBIT 19

Sensitivity Analysis of Estimated Performance Summary Using Various Maximum Inflow Rates in the Proposed Ten Mile Creek Treatment Wetland based on the DMSTA Model

		Maximum Inflow Rate to Treatment Wetland					
Parameter	Units	20 cfs ($0.049\ hm^3/d$)	40 cfs ($0.098\ hm^3/d$)	60 cfs ($0.147\ hm^3/d$)	80 cfs ($0.196\ hm^3/d$)	100 cfs ($0.245\ hm^3/d$)	120 cfs ($0.294\ hm^3/d$)
Ten Mile Creek							
Average Daily Flow	hm^3/d	0.148	0.148	0.148	0.148	0.148	0.148
Maximum Daily Flow	hm^3/d	2.64	2.64	2.64	2.64	2.64	2.64
Flow weighted TP	µg/L	247	247	247	247	247	247
Ten Mile Creek Reservoir [a]							
Inflow	hm^3/d	0.054	0.054	0.054	0.054	0.054	0.054
Maximum Daily Inflow	hm^3/d	0.690	0.690	0.690	0.690	0.690	0.690
TP Inflow Load	kg/d	13.3	13.3	13.3	13.3	13.3	13.3
Flow weighted TP	µg/L	245	245	245	245	245	245
Ten Mile Creek Treatment Wetland [b]							
Inflow	hm^3/d	0.037	0.045	0.048	0.050	0.051	0.052
Outflow	hm^3/d	0.035	0.043	0.046	0.047	0.048	0.049
Flow weighted TP Inflow	µg/L	78	83	86	87	88	89
Flow weighted TP Outflow	µg/L	49	57	60	62	63	64
HLR	m/yr	25.5	31.1	33.0	34.1	34.6	35.2
TP Inflow Load	kg/d	2.9	3.8	4.1	4.3	4.5	4.6
TP Outflow Load	kg/d	1.7	2.5	2.8	2.9	3.1	3.2
TP Load Reduction	kg/d	1.2	1.3	1.4	1.4	1.4	1.4
TP Load Reduction	%	41	35	33	33	31	31
Mean Depth	cm	53	56	56	56	57	57
Maximum Depth	cm	63	74	82	89	95	100
Bypass [b]							
Bypass flow	hm^3/d	0.017	0.009	0.006	0.004	0.003	0.003
Percent of Total Flow Bypass	%	31	16	11	8	6	5
TP Bypass Load	kg/d	2.02	1.14	0.81	0.62	0.48	0.37
Flow weighted TP Bypass	µg/L	120	133	139	142	144	144
Total Downstream							
Outflow	hm^3/d	0.052	0.052	0.052	0.052	0.052	0.052
Total TP Load Downstream	kg/d	3.75	3.61	3.57	3.54	3.54	3.53
TP Load Reduction	kg/d	9.58	9.73	9.76	9.79	9.80	9.81
TP Load Reduction	%	72	73	73	73	73	74
Flow weighted TP Outflow	µg/L	69	66	66	65	65	65

Notes:

[a] Long-term estimated (31-year) simulated average pumped inflow schedule to the reservoir from Ten Mile Creek (Konyha 2002)

[b] Treatment Wetland and Bypass flows and loads estimated using the DMSTA platform with set maximum inflow rates

Treatment Wetland operating water depth at 22 ft. NGVD (area 132 ac; volume 477 ac-ft)

DMSTA Model version 4/12/02 - pre-calibrated p cycling parameters based upon emergent vegetation type

Averaging interval = 7 days

1 hm^3/d (million m^3/d) = 408.7 cfs = 810.7 ac-ft/d

While increasing inflows to the treatment wetland also increases the estimated TP outflow concentrations and reduces estimated percent load reductions in the treatment wetland (an estimated increase of about 30 percent between 20 and 120 cfs [0.049 to 0.294 hm^3/d] maximum inflow rates), this sensitivity analysis indicates that the estimated TP load to the St. Lucie River is slightly reduced. Increasing the HLR to the maximum pumping rate allowed by the existing pump station design capacity, slightly increases the overall estimated TP load reduction from 9.6 to 9.8 kg/d (2 percent increase).

Exhibit 20 presents the stage frequency curve for the proposed Ten Mile Creek Treatment Wetland with the same maximum inflow rates used in Exhibit 19. All the stage frequency curves are within the DMSTA emergent and SAV calibrated parameter dataset range of depths with the exception of 2 percent below the minimum SAV depth. The DMSTA calibrated parameter depths ranged from 18 to 98 cm for emergent vegetation and from 30 to 109 cm for SAV datasets, respectively.

This analysis indicates that the proposed flow regime in the treatment wetland will be compatible with the survival and propagation of either adapted emergent wetland plants or SAV.

Nitrogen

The sequential nitrogen model from Kadlec and Knight (1996) was used to provide an updated estimate of nitrogen removal performance of the proposed Ten Mile Creek Treatment Wetland. Exhibit 21 presents a summary of the results and detailed model profile estimates are presented in Appendix C. Three model scenarios were tested by adjusting the rate constants (k) for each of the nitrogen species. Results from this sensitivity analysis can be used to bracket the likely performance of the treatment wetland.

Average influent nitrogen concentrations to the treatment wetland are best professional judgment estimates using central Florida reservoir data by Knight (1999) (ON = 1.15 mg/L, AN = 0.05 mg/L, NN = 0.08 mg/L, TN = 1.28 mg/L, TKN = 1.20 mg/L). Due to the relatively low influent concentration expected at the treatment wetland, each of the nitrogen species exhibited low estimated removals, averaging 7.8, 50, 8.6, and 5.8 percent for ON, NN, TN, and TKN, respectively (Scenario 1). The estimated AN concentration exhibited a slight increase from 0.05 mg/L to 0.07 mg/L.

The combined reservoir/treatment wetland cell will lower the average estimated TN inflow concentration from 1.60 to an estimated 1.17 mg/L for a 27 percent reduction (Scenario 1). The remaining nitrogen series average estimates and removals for the reservoir / treatment wetland combination are as follows: ON 1.05 – 1.06 mg/L (-1%), AN 0.12 - 0.07 mg/L (42%), NN 0.15 – 0.04 mg/L (73%), and TKN 1.20 – 1.13 mg/L (6%).

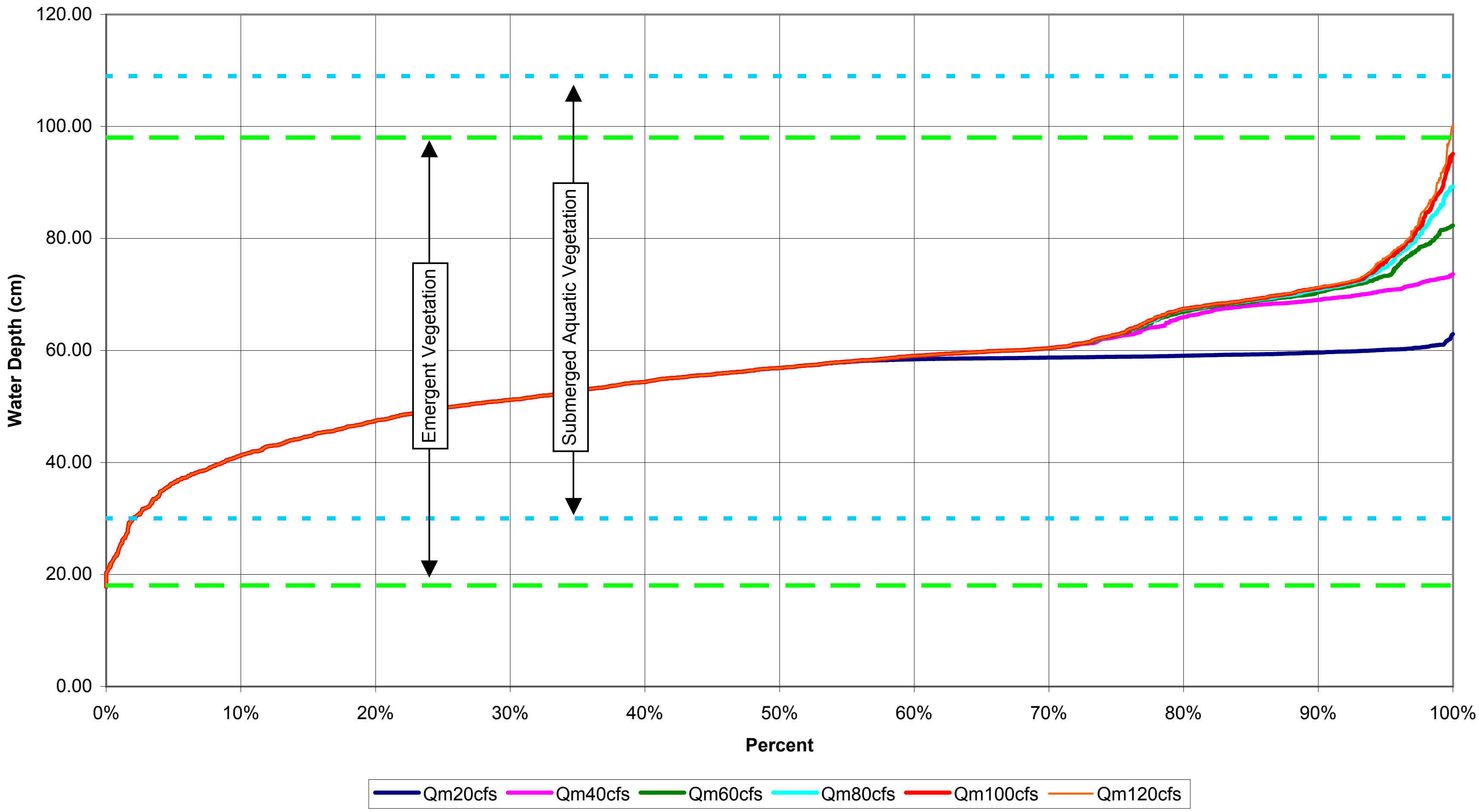


EXHIBIT 20

Estimated Stage Frequency Curves of Proposed Ten Mile Creek Treatment Wetland Simulated Water Depths using Maximum Inflow Rates (Qm) in the DMSTA Model v. 4/12/02

EXHIBIT 21
Estimated Average Nitrogen Concentrations for the Proposed Ten Mile Creek Treatment Wetland

Scenario	Parameter	Organic N	Ammonium-N	Nitrate-N	Total N	TKN
---	C_i (mg/L)	1.15	0.05	0.08	1.28	1.20
1	k (m/yr)	17.0	18.0	35.0	---	---
	C_o (mg/L)	1.06	0.07	0.04	1.17	1.13
2	k (m/yr)	8.5	9.0	18.0	---	---
	C_o (mg/L)	1.09	0.08	0.05	1.22	1.14
3	k (m/yr)	25.5	27.0	53.0	---	---
	C_o (mg/L)	1.03	0.06	0.04	1.13	1.09

C^*_{ON} = 0.995 mg/L
Average Flow = 21.41 ac-ft/d
Area = 132 ac

Summary and Recommendations

Controlling the quantity and timing of water deliveries to the North Fork of the St. Lucie River is the main purpose of the proposed Ten Mile Creek WPA. This proposed project will capture, store, and treat an average of 37 percent of the flow in Ten Mile Creek at this location. The assumed pumped inflow to the reservoir from Ten Mile Creek will average 19.8 hm^3/yr (16,070 ac-ft/yr) with an average surface return of 8.18 hm^3/yr (6,639 ac-ft/yr) to Ten Mile Creek from the treatment wetland discharge and an emergency overflow from the reservoir. Seepage losses from the reservoir and treatment wetland as well as irrigation return flows will also help maintain pre-project average downstream Ten Mile Creek flows.

Estimated outflow concentrations from the proposed reservoir and treatment wetland are a function of hydraulic loading and inflow concentrations. When inflow quality is good (near wetland background values) percent removals and outlet concentrations will be low. When inflow quality is poor and flows are higher, the combination of the proposed reservoir and treatment wetland are likely to result in large pollutant mass removals and maximum benefits to downstream waters.

The average inflow TP concentration from Ten Mile Creek is projected to be about 245 µg/L and is expected to be reduced by approximately 80 to 90 percent in the combined reservoir/treatment wetland system, resulting in a range of estimated flow weighted average outflow concentrations between 28 and 50 µg/L, depending on the selected treatment wetland plant community.

The proposed project is expected to reduce the estimated average inflow inorganic nitrogen concentrations (0.15 mg/L) by approximately 70 percent. The combined reservoir/treatment wetland cell will also lower the estimated average TN inflow concentration from about 1.6 to about 1.2 mg/L for an estimated 27 percent reduction.

EXHIBIT 22
Summary of TP and TN Concentration Estimates for the Proposed Ten Mile Creek Reservoir and Treatment Wetland

Report	Ten Mile Creek		Reservoir		Treatment Wetland	
	TP (µg/L)	TN (mg/L)	TP (µg/L)	TN (mg/L)	TP (µg/L)	TN (mg/L)
Knight (1999)	252	1.56	158	1.34	64	1.10
This Study	245[a]	1.60	91[a]	1.30	50[a]	1.17

[A] FLOW WEIGHTED AVERAGE (EMERGENT VEGETATION PARAMETERS)

Estimated treatment performance for TP was not found to be very sensitive to assumed TIS, seepage rate, or rainfall TP. Estimated treatment wetland performance was sensitive to HLR with higher wetland outflow TP concentrations resulting from higher hydraulic loading rates.

The combined system of reservoir and treatment wetland could possibly assimilate higher inflows from Ten Mile Creek with very slight improvements in TP mass removals downstream. However, potential disadvantages of directing higher loads to the Ten Mile Creek WPA are a loss of control of the timing of downstream flows, as well as higher TP concentrations in the treatment wetland outflow to Ten Mile Creek.

A few design and operational recommendations for the Ten Mile Creek WPA final design follow from this water quality evaluation. First, the level of the reservoir outflow to the treatment wetland should be set to optimize water quality benefits. This release should not be from the surface where particulates and floating plants may predominate, or from the bottom of the reservoir where dissolved nutrients and other pollutants will be highest. Rather the discharge should be near surface with floating materials skimmed by a floating boom or skimmer structure.

The final treatment wetland design should take advantage of several design criteria developed at other sites. The 60 percent design shows a single outlet point at the northeast corner of the treatment wetland. The outflow from the STA should probably not be through a buried culvert for safety reasons. Water level control should be provided at the outlet, if possible, to allow plant community maintenance within the treatment wetland cell. Some typical treatment wetland outfall designs include an adjustable broad-crested horizontal weir. Existing results indicate that treatment wetland colonization by deeper plant communities dominated by submerged aquatic vegetation may be able to increase performance for TP removal. Finally, a skimmer should be provided at the outflow canal to retard the escape of floating and dislodged vegetation.

References

CH2M HILL. 1998. Treatment Wetlands Habitat and Wildlife Use Assessment & North American Treatment Wetland Database v. 2.0. CD ROM. Prepared for U.S. Bureau of Reclamation, U.S. EPA, and City of Phoenix. Available from CH2M HILL, Gainesville, Florida.

Kadlec, R.H. and R.L. Knight 1996. *Treatment Wetlands.* Lewis Publishers, Boca Raton, FL. 896 pp.

Knight, R.L. 1999. Assessment of the Water Quality and Environmental Benefits of the Proposed Ten Mile Creek Water Preserve Area. Prepared for the South Florida Water Management District, West Palm Beach, FL.

Knight, R.L., R.W. Ruble, R.H. Kadlec, and S. Reed. 1993. Wetlands for Wastewater Treatment Performance Database. Chapter 4, pp. 35-58 in G.A. Moshiri (ed.), Constructed Wetlands for Water Quality Improvement. Lewis Publishers, Boca Raton, FL.

Knight, R.L. and CH2M HILL. 1999. Section 3. Treatment System Parameters for STA 3/4 Design. Report section to Burns & McDonnell, Kansas City, Kansas. 15 pp.

Konyha, D. 2001. Responses to Information Requests, South Florida Water Management District, West Palm Beach, FL.:

- TenMile_Res_STA_dailydata.xls
- Tenmile_stage_storage.xls
- Gordy_Road_data_090501.xls
- TMC_ResSTA_model.zip
- C24_hydrologic_dat.zip
- C24_tp_tn_flow_data.xls

Konyha, D. 2002. Responses to Information Requests, South Florida Water Management District, West Palm Beach, FL.:

- TenMile_Res_STA_dailydata_040102.xls
- WPA_sta_analysis_RULES_Apr1.xls

Post Buckley, Shuh & Jernigan (PBS&J). 2001. Alternative Project Study. 10 Mile Creek Project. Miami, FL. April 2001.

Post Buckley, Shuh & Jernigan (PBS&J). 2001. 60% Plans and Specifications. 10 Mile Creek Project, St. Lucie County, FL. Miami, FL. October 2001.

South Florida Water Management District (District). 2001. Draft Technical Documentation to Support Development of Minimum Flows for the St. Lucie River and Estuary. Water Supply Department. West palm Beach, FL. October 2001.

U.S. Army Corps of Engineers (COE) and South Florida Water Management District (District). 2001. Draft Integrated Feasibility Report and Supplemental Environmental Impact Statement. Central and Southern Florida Project Indian River Lagoon-South Feasibility Study. Jacksonville, FL. October 2001.

Walker, W.W. 1985. Empirical Methods for Predicting Eutrophication in Impoundments. Report 3, Phase II, Model Refinements. Prepared for U.S. Army Corps of Engineers, Waterways Experiment Station, Report E-81-9.

Walker, W.W. 1987. Phosphorus Removal by Urban Runoff Detention Basins. Lake and Reservoir Management 3: 314-328.

Walker, W.W. 1998. STA & Reservoir Performance Measures for the Everglades Restudy. Equations Used for Predicting Phosphorus Retention in Stormwater Treatment Areas & Storage Reservoirs. (http://wwwalker.net)

Walker, W.W. and R. H. Kadlec 2001. Development of the Dynamic Model for Stormwater Treatment Areas. Presentations in February, August and December, 2001.

APPENDIX A

Gordy Road Bridge TP Sinusoidal Timeseries Model /

C-24 Basin Julian Day TP Averages

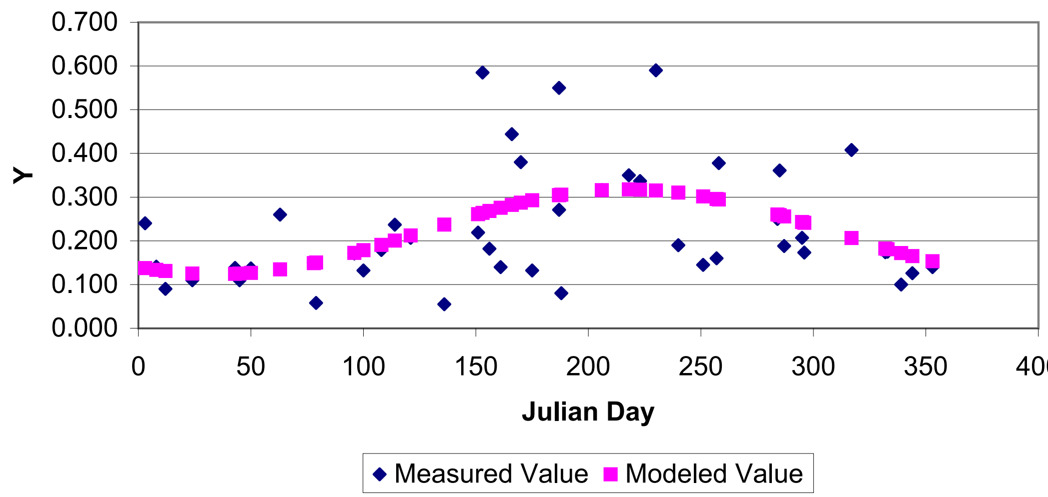
Appendix A-1
Sinusoidal Model Fit for Ten Mile Creek (Gordy Rd. Bridge)

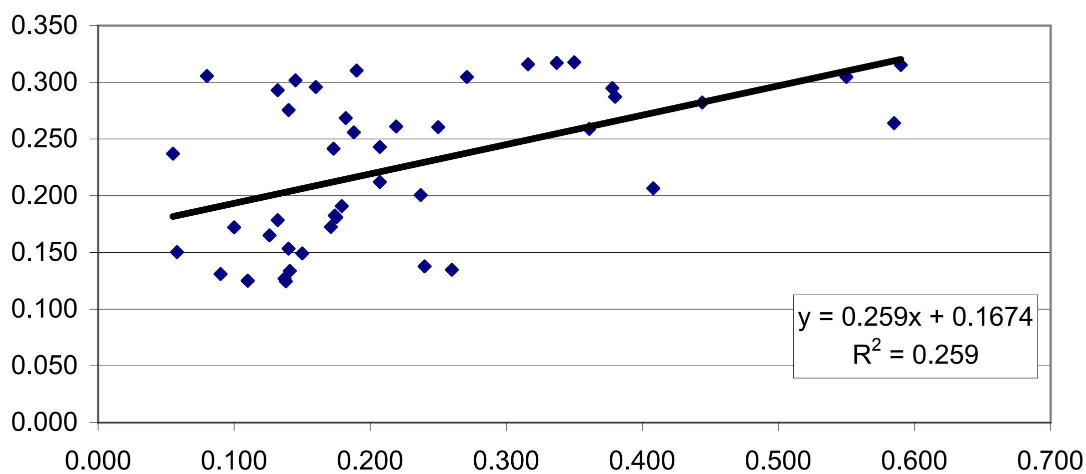
$Y = Y_{avg} (1+A \cos [(2 pi() / 365)(t-t_{max})])$

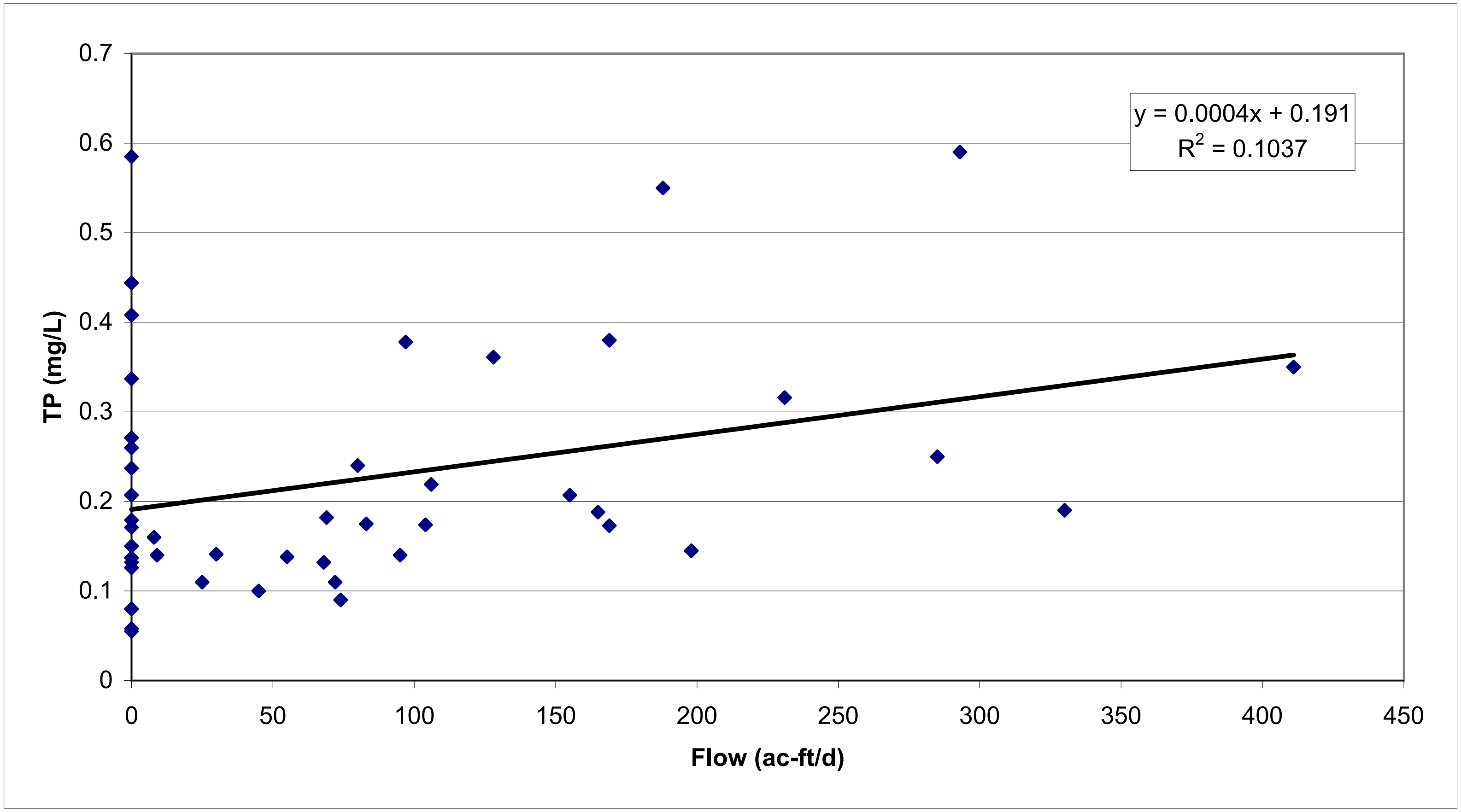
Y_{avg}:	0.221	<--- solver
half amplitude (A):	0.440	<--- solver
t_{max}:	217.3	<--- solver

Statistics	Measured Value	Modeled Value	Measured - Modeled	(Measured - Modeled)^2
Sum	---	---	---	0.588
Average	0.226	0.226	0.000	0.013
Median	0.179	0.241	-0.010	0.002
Maximum	0.590	0.318	0.321	0.103
Minimum	0.055	0.125	-0.226	0.000
Std Dev	0.134	0.068	0.116	0.022
Count	45	45	45	45

Period of Record: 12/1972 - 8/1994

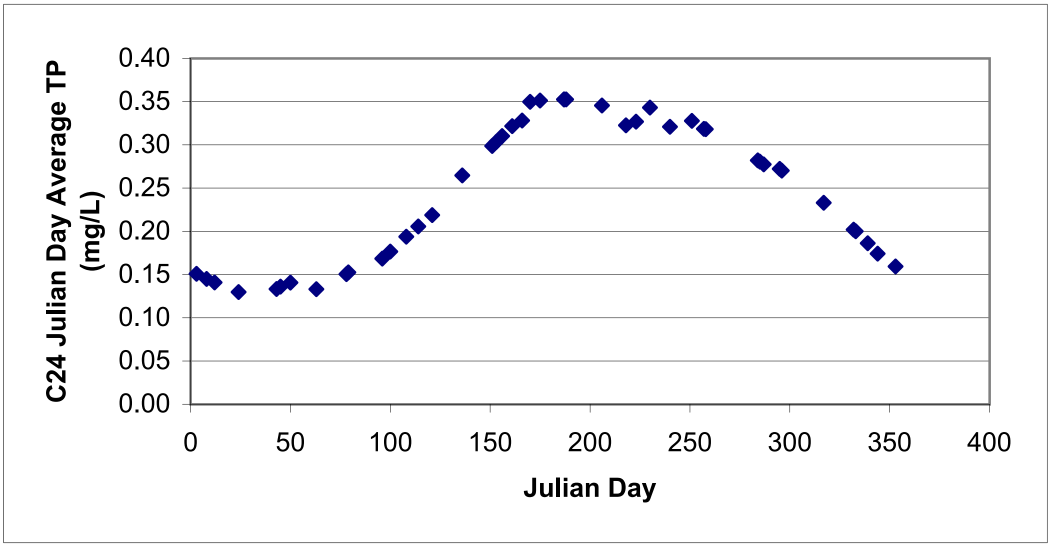


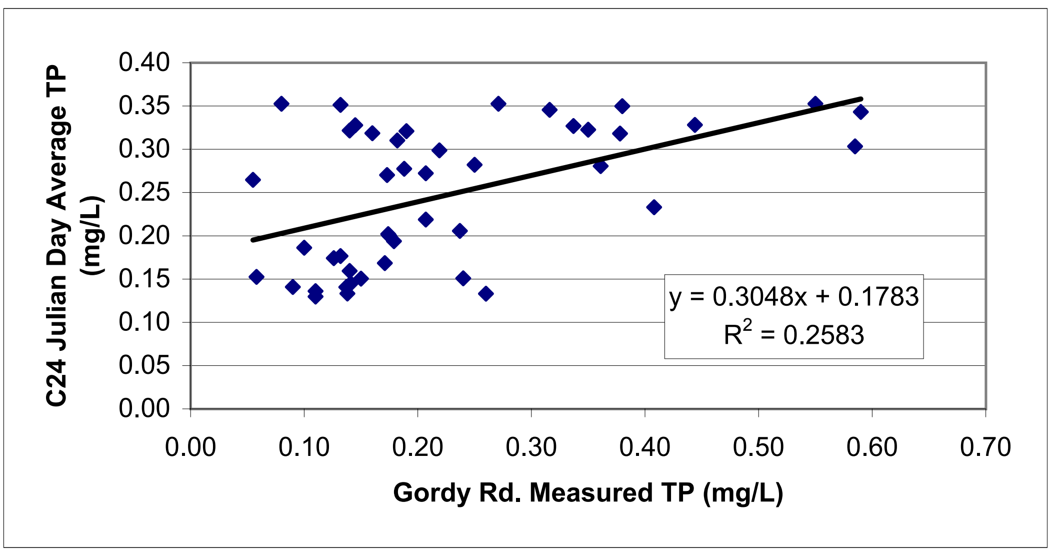




Appendix A-2
Correlation Between Gordy Road Bridge TP Concentrations and Flows

Appendix A-3
Gordy Road Bridge Correlation to Julian Day TP Averages from the C-24 Basin





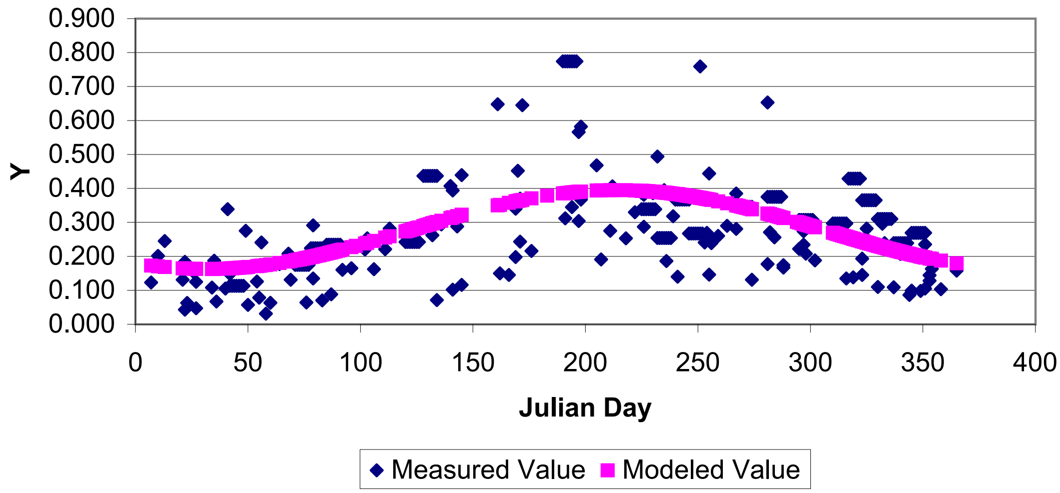
Appendix A-4
Sinusoidal Model Fit for C-24 Basin

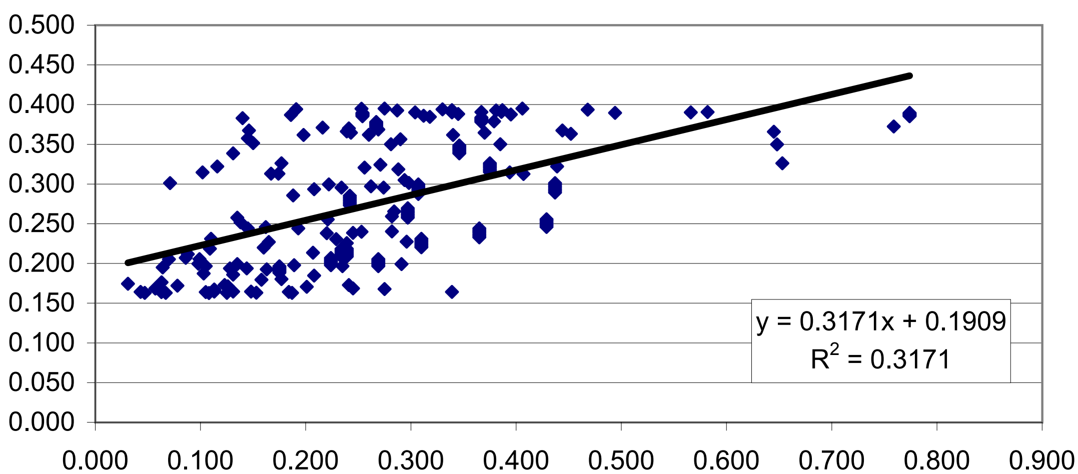
$Y = Y_{avg}$ (1+A cos [(2 pi() / 365)(t-t_{max})])

Y_{avg}:	0.279	<--- solver
half amplitude (A):	0.417	<--- solver
t_{max}:	214.1	<--- solver

Statistics	Measured Value	Modeled Value	Measured - Modeled	(Measured - Modeled)^2
Sum	---	---	---	3.569
Average	0.280	0.280	0.000	0.013
Median	0.267	0.275	-0.010	0.004
Maximum	0.774	0.395	0.389	0.151
Minimum	0.031	0.163	-0.243	0.000
Std Dev	0.141	0.079	0.116	0.028
Count	265	265	265	265

Period of Record: 5/1989 - 4/1999





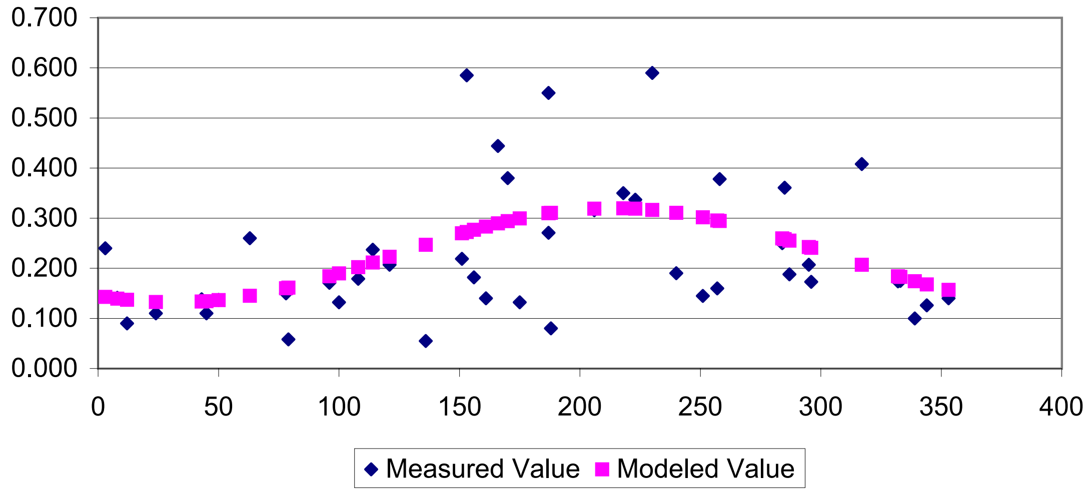
Appendix A-5
Sinusoidal Model Fit for Ten Mile Creek (Gordy Rd. Bridge) with C-24 Model Parameters

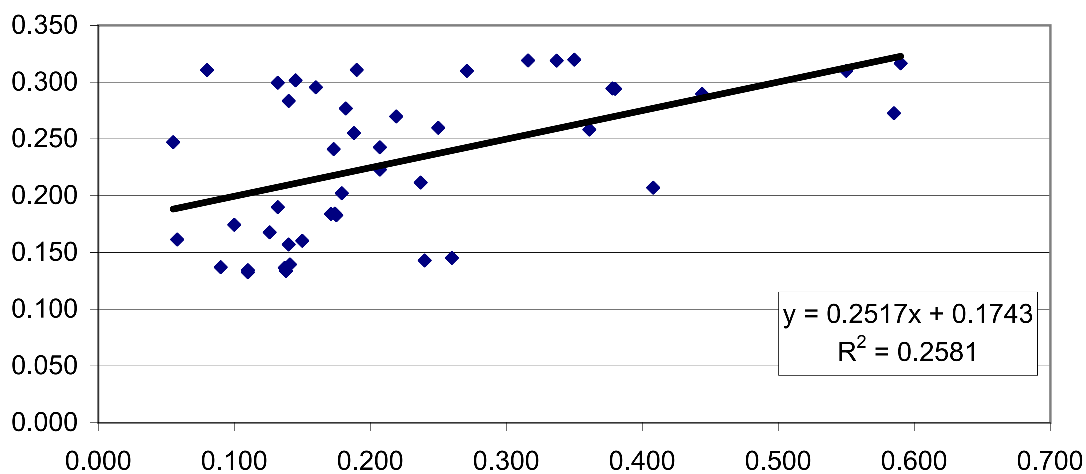
$Y = Y_{avg} (1+A \cos [(2 \, pi() / 365)(t-t_{max})])$

Y_{avg}:	0.226	<--- measured avg
half amplitude (A):	0.417	<--- from C24 fitted values
t_{max}:	214.1	<--- from C24 fitted values

Statistics	Measured Value	Modeled Value	Measured - Modeled	(Measured - Modeled)^2
Sum	---	---	---	0.590
Average	0.226	0.231	-0.005	0.013
Median	0.179	0.243	-0.016	0.003
Maximum	0.590	0.320	0.312	0.098
Minimum	0.055	0.133	-0.231	0.000
Std Dev	0.134	0.066	0.116	0.021
Count	45	45	45	45

Period of Record: 12/1972 - 8/1994





APPENDIX B

DMSTA Storage Reservoir Model Results

DMSTA Reservoir Model Parameters

Reservoir H2O Residence Time	days	**104.3**	
Max Inflow / Mean Inflow	-	**16.4**	ratio of maximum to mean daily inflow to treatment area; operating objective for reservoir (0 = no peak flow control)
Max Reservoir Storage	hm3	**5.66**	maximum reservoir volume (0 = no constraint)
Reservoir P Decay Rate	1/yr/ppb	**0.1**	second order p removal rate in storage reservoir, nominal value ~ .15 1/yr/ppb; not tested on south florida systems
Rainfall P Conc	ppb	**10**	
Atmospheric P Load (Dry)	mg/m2-yr	**20**	dry deposition rate (20 mg/m^2-yr assumed in calibrations)

Assumptions:
operating depth of 26 feet = 4586.02 ac-ft (5.66 hm3)
Avg inflow (pump from ten mile crk) 44.0 ac-ft/d (0.0543 hm3/d)
results in HRT of 104 days (5.66 hm3/0.0543 hm3/d)

Storage Reservoir Simulation File: TenMile_RES_OR.xls Case: Res_OR

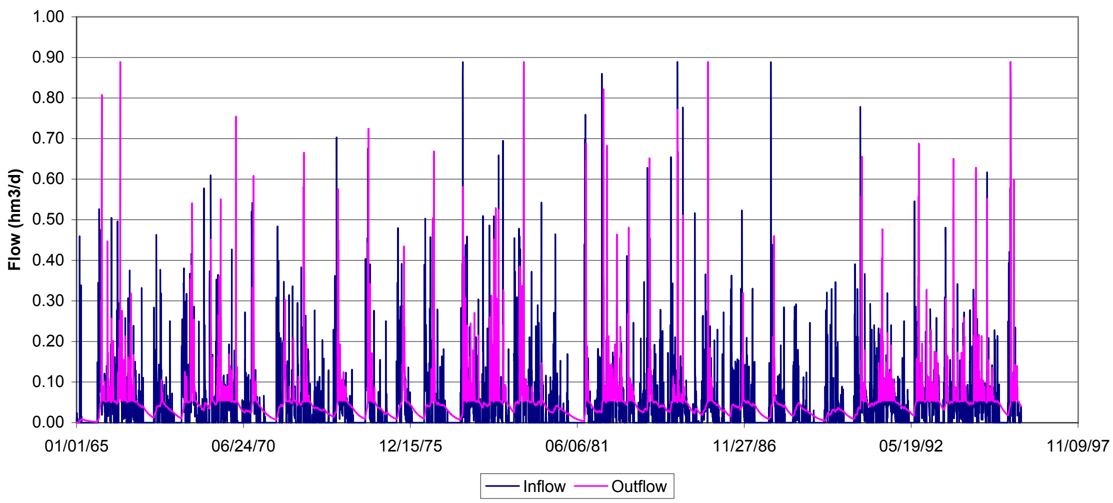
Input Design Values:

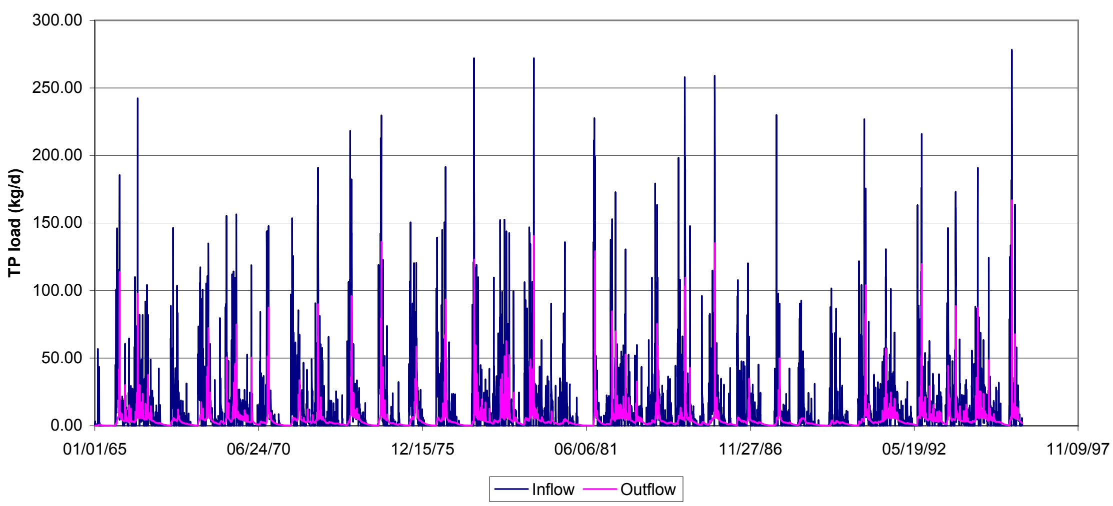
Hydraulic Residence Time	104	days	Load Reduction in Reservoir	63%
Max Inflow / Mean Inflow	16.4	-		
Maximum Storage	5.66	hm3		

Simulation Results:

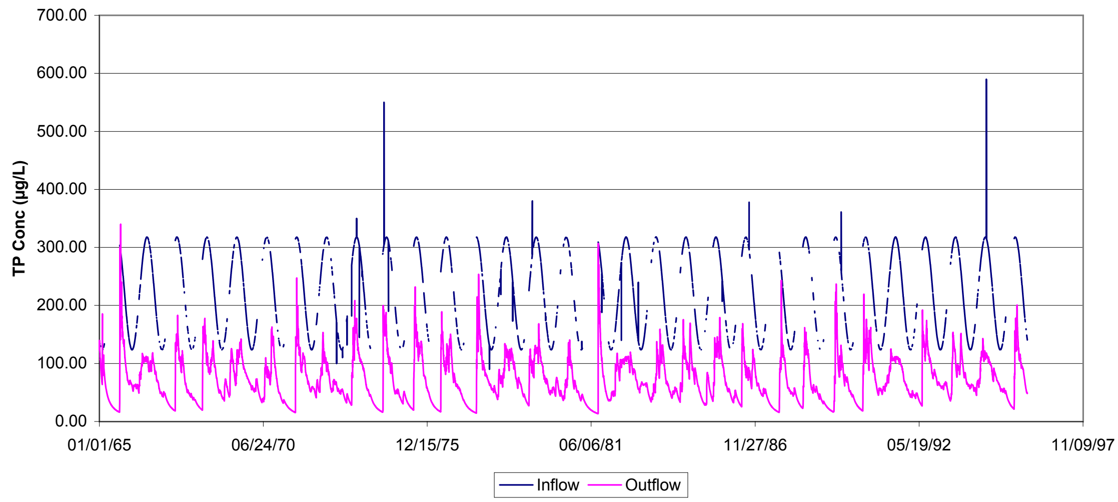
Reservoir ------>

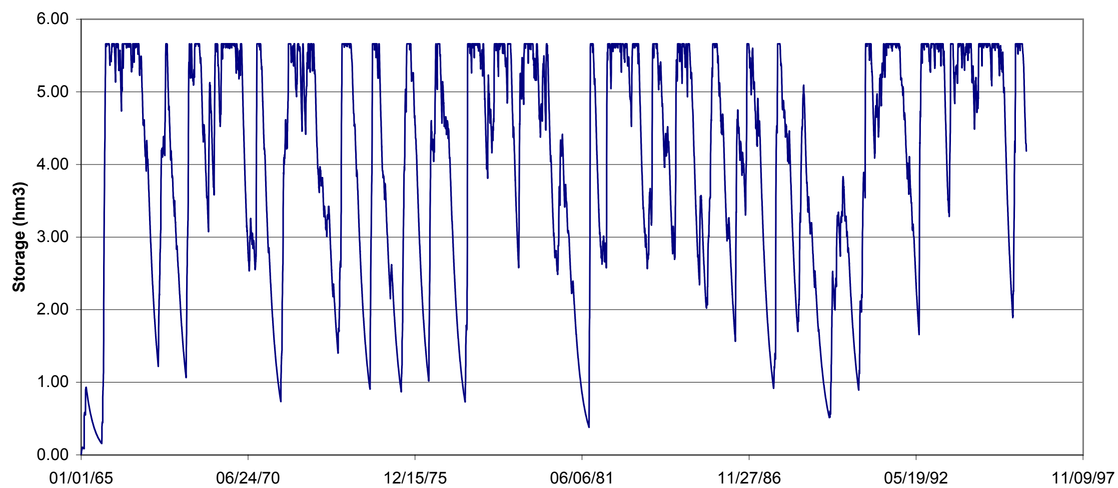
	Flow (hm3/day)		TP Load (kg/d)		Conc (ppb)		Storage (hm3)
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Volume
Mean	0.054	0.054	13.3	4.9	226.5	71.7	4.06
Flow-Wt	---	---	---	---	245.0	91.3	---
Max	0.889	0.889	278.4	167.0	590.0	340.1	5.66
Min	0.000	0.000	0.0	0.0	90.0	13.5	0.01

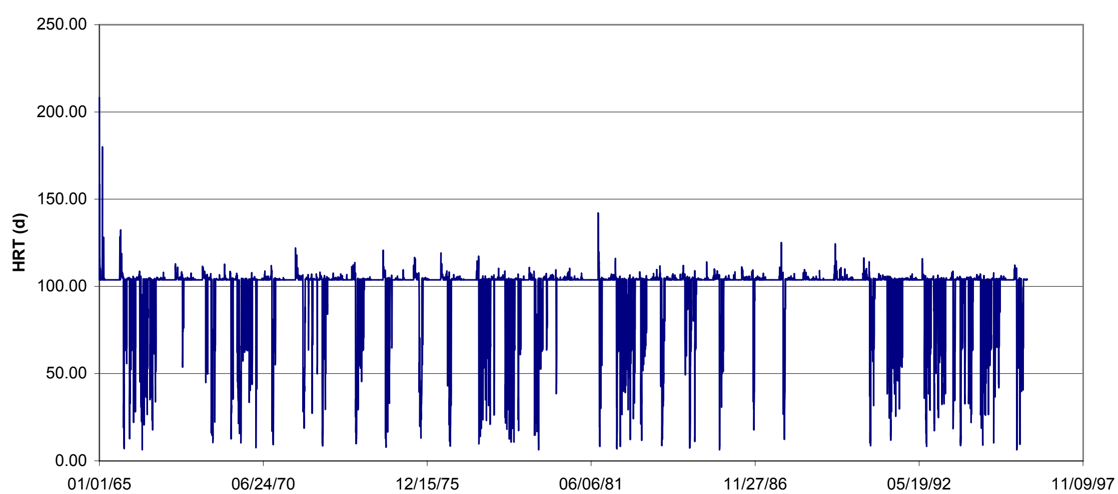




Storage Reservoir Simulation File: TenMile_RES_OR.xls Case: Res_OR







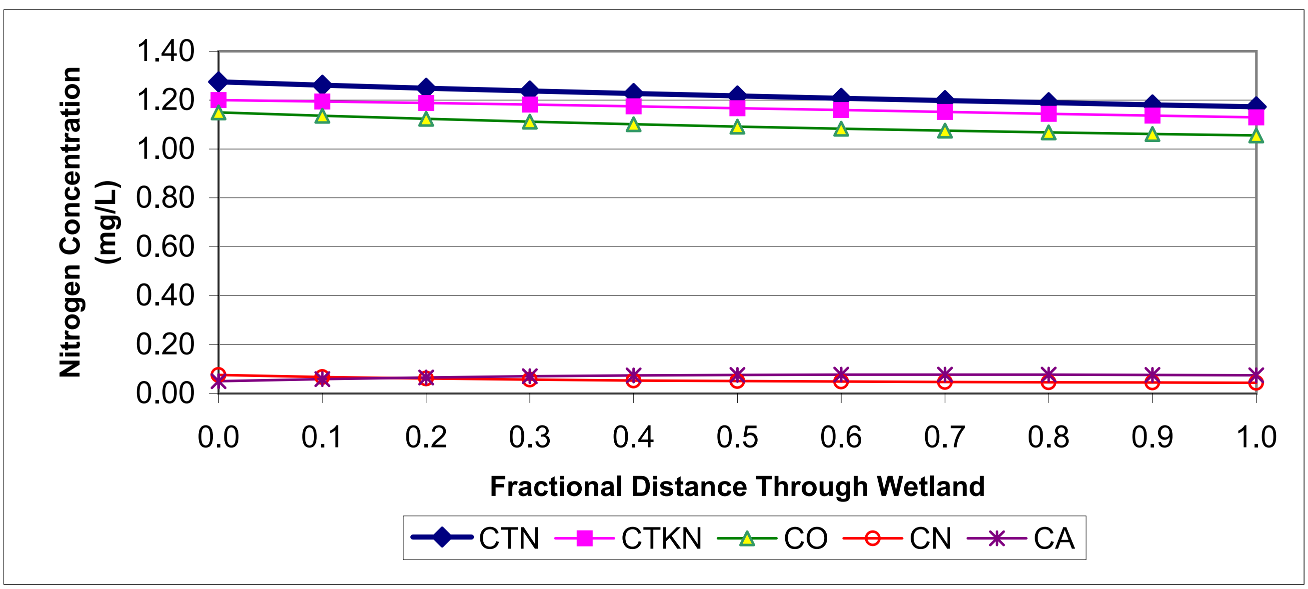
APPENDIX C

Treatment Wetland Nitrogen Species Profile

Nitrogen Species Profile Solver - Base Case

Q=	**26409.02** m3/d	10.794 cfs	6.977 mgd	21.410 ac-ft/d	
CO*=	**0.995** mg/l				
kO =	**17** m/yr		COi-CO*=	0.155	
kA =	**18** m/yr		exp(-kO/q)=	0.38994	
kN =	**35** m/yr		exp(-kA/q)=	0.36892	
kO/(kA-kO)=	17.00		exp(-kN/q)=	0.14386	
kA/(kN-kA)=	1.06		COo=	1.06	mg/l
kA/(kN-kO)=	1.00		CAo=	0.07	mg/l
COi=	**1.15** mg/l		CNo=	0.04	mg/l
CAi=	**0.05** mg/l		CTNo=	1.17	mg/l
CNi=	**0.075** mg/l				
ψ=	**1**		CNi'=	0.010789238	
A=	**534,000** m2	131.96 acres			
q=	18.05 m/yr	4.95 cm/d			

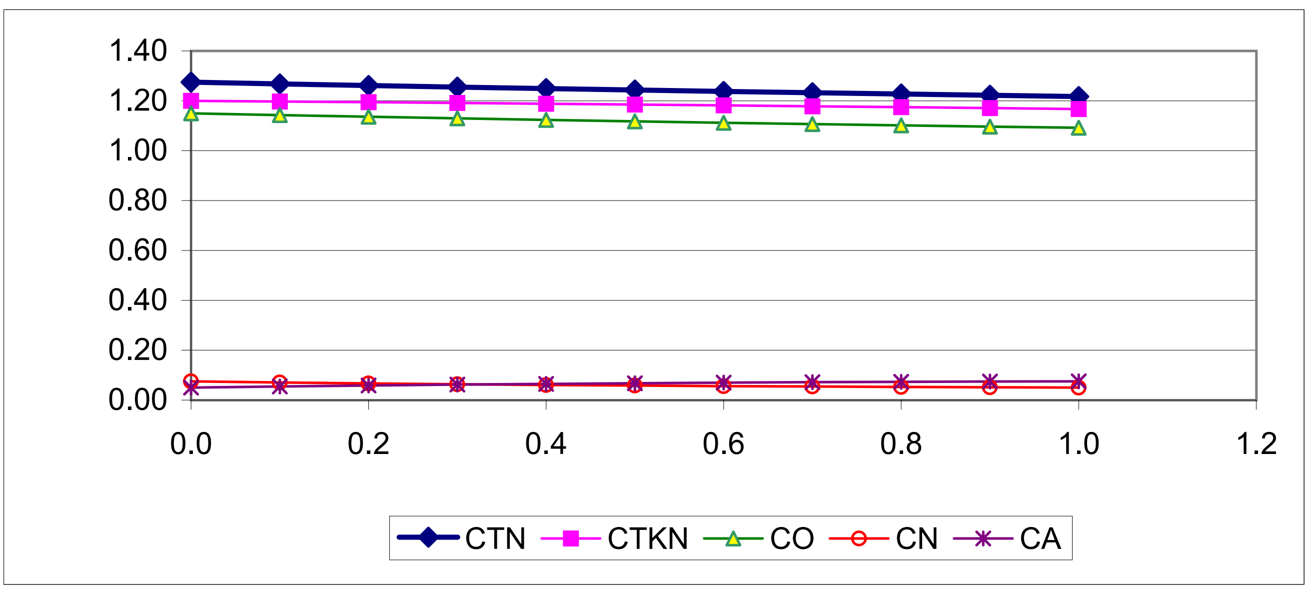
y	CO mg/l	CA mg/l	CN mg/l	CTKN mg/l	CTN mg/l	AD HOC **1.5** TKN-1.5 CA mg/l
0.0	1.15	0.05	0.08	1.20	1.28	-0.30
0.1	1.14	0.06	0.07	1.19	1.26	-0.27
0.2	1.12	0.07	0.06	1.19	1.25	-0.25
0.3	1.11	0.07	0.06	1.18	1.24	-0.22
0.4	1.10	0.07	0.05	1.17	1.23	-0.20
0.5	1.09	0.08	0.05	1.17	1.22	-0.18
0.6	1.08	0.08	0.05	1.16	1.21	-0.16
0.7	1.08	0.08	0.05	1.15	1.20	-0.15
0.8	1.07	0.08	0.05	1.14	1.19	-0.14
0.9	1.06	0.08	0.04	1.14	1.18	-0.12
1.0	1.06	0.07	0.04	1.13	1.17	-0.11



Nitrogen Species Profile Solver (k - 50%)

Q=	**26409.02**	m3/d	10.794 cfs	6.977 mgd	21.410 ac-ft/d		
CO*=	**0.995**	mg/l					
kO =	**8.5**	m/yr		COi-CO*=	0.155		
kA =	**9**	m/yr		exp(-kO/q)=	0.62445		
kN =	**18**	m/yr		exp(-kA/q)=	0.60739		
kO/(kA-kO)=	17.00			exp(-kN/q)=	0.37928		
kA/(kN-kA)=	1.06			COo=	1.09	mg/l	
kA/(kN-kO)=	1.00			CAo=	0.08	mg/l	
COi=	**1.15**	mg/l		CNo=	0.05	mg/l	
CAi=	**0.05**	mg/l		CTNo=	1.22	mg/l	
CNi=	**0.075**	mg/l					
ψ=	**1**			CNi'=	0.028446315		
A=	**534,000**	m2	131.96 acres				
q=	18.05	m/yr	4.95 cm/d				

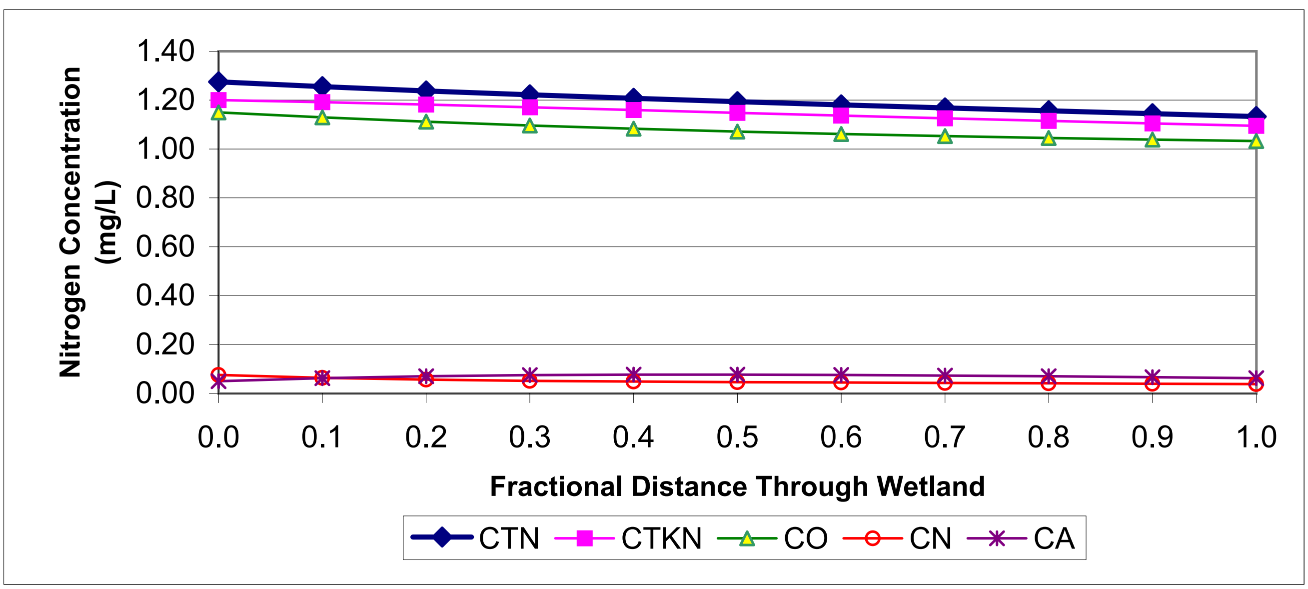
y	CO mg/l	CA mg/l	CN mg/l	CTKN mg/l	CTN mg/l	AD HOC **1.5** TKN-1.5 CA mg/l
0.0	1.15	0.05	0.08	1.20	1.28	-0.30
0.1	1.14	0.05	0.07	1.20	1.27	-0.29
0.2	1.14	0.06	0.07	1.19	1.26	-0.27
0.3	1.13	0.06	0.06	1.19	1.25	-0.26
0.4	1.12	0.07	0.06	1.19	1.25	-0.25
0.5	1.12	0.07	0.06	1.19	1.24	-0.23
0.6	1.11	0.07	0.06	1.18	1.24	-0.22
0.7	1.11	0.07	0.05	1.18	1.23	-0.21
0.8	1.10	0.07	0.05	1.17	1.23	-0.20
0.9	1.10	0.07	0.05	1.17	1.22	-0.19
1.0	1.09	0.08	0.05	1.17	1.22	-0.18



Nitrogen Species Profile Solver (k + 50%)

Q=	**26409.02** m3/d	10.794 cfs	6.977 mgd	21.410 ac-ft/d		
CO*=	**0.995** mg/l					
kO =	**25.5** m/yr		COi-CO*=	0.155		
kA =	**27** m/yr		exp(-kO/q)=	0.24350		
kN =	**53** m/yr		exp(-kA/q)=	0.22408		
kO/(kA-kO)=	17.00		exp(-kN/q)=	0.05456		
kA/(kN-kA)=	1.06		COo=	1.03	mg/l	
kA/(kN-kO)=	1.00		CAo=	0.06	mg/l	
COi=	**1.15** mg/l		CNo=	0.04	mg/l	
CAi=	**0.05** mg/l		CTNo=	1.13	mg/l	
CNi=	**0.075** mg/l					
ψ=	**1**		CNi'=	0.004092188		
A=	**534,000** m2	131.96 acres				
q=	18.05 m/yr	4.95 cm/d				

y	CO mg/l	CA mg/l	CN mg/l	CTKN mg/l	CTN mg/l	AD HOC **1.5** TKN-1.5 CA mg/l
0.0	1.15	0.05	0.08	1.20	1.28	-0.30
0.1	1.13	0.06	0.06	1.19	1.25	-0.26
0.2	1.11	0.07	0.06	1.18	1.24	-0.22
0.3	1.10	0.07	0.05	1.17	1.22	-0.19
0.4	1.08	0.08	0.05	1.16	1.21	-0.16
0.5	1.07	0.08	0.05	1.15	1.19	-0.14
0.6	1.06	0.08	0.04	1.14	1.18	-0.12
0.7	1.05	0.07	0.04	1.13	1.17	-0.11
0.8	1.05	0.07	0.04	1.11	1.16	-0.09
0.9	1.04	0.07	0.04	1.10	1.14	-0.08
1.0	1.03	0.06	0.04	1.10	1.13	-0.07



APPENDIX D

Example Spreadsheets

Example Spreadsheets

Below is a list of the water quality models used to generate performance estimates for the Ten Mile Creek WPA in this report. Example spreadsheets are attached for the models noted otherwise the sources are identified.

- COE Reservoir Model - attached
- Infiltrating/Exfiltrating Wetlands with Storage - attached
- DMSTA version 4/12/02 – source W.W. Walker
- Sinusoidal Timeseries Model - attached
- Nitrogen Species Profile – source R.H. Kadlec

COE Reservoir Model

The COE Reservoir Model is based on empirical data collected from COE water impoundment reservoirs and from natural and man-made stormwater wet detention ponds in Michigan, New York, Washington, D.C., Illinois, Minnesota, Missouri, and Florida (Walker 1987). The model was originally developed for predicting water quality changes in COE reservoirs (Walker, 1985) and adapted for the use with wet detention systems receiving urban stormwaters. Agreement between data sets and in different climatic regions was satisfactory to allow use of the model for the analysis in south Florida. An electronic spreadsheet (Excel) copy of Exhibit 10 has been included with this report. Input parameters have been highlighted and include the following:

- P = Average rainfall (m/yr)
- C_i = TP concentration in (μg/L)
- C_p = Rainfall TP concentration (μg/L)
- Q_i = Inflow rate (hm^3/yr)
- Q_o = Outflow rate (hm^3/yr)
- A = WPA reservoir surface area (km^2)
- q_i = Hydraulic loading rate from pumped inflow (m/yr)
- U_s = Exfiltrating groundwater (m/yr)
- U_o = Infiltrating groundwater (m/yr)
- Z = Mean water depth (m)
- F_w = Fraction of days with surface water
- C_s = TP concentration in exfiltrating groundwater (μg/L)

Infiltrating/Exfiltrating Wetlands with Storage

The Infiltrating/Exfiltrating model includes the possible effects of complex water budget considerations. For example, the annual quantity of water gained and lost by a wetland due to rainfall and ET is rarely equal. Thus surface water in a wetland is either diluted or concentrated, depending upon the net effect of rain and ET. Similarly, the stored volume of water in a wetland is not constant and this change in storage alters the steady state, plug flow assumption. Finally, wetlands in south Florida are often subject to significant groundwater exchanges resulting in potential inflows of groundwater and seepage of surface waters out of the wetland to adjacent lands. All of these water balance factors can be incorporated in a steady-state treatment wetland performance estimation model assuming plug flow hydraulics:

$$(C_2-C^*)/(C_1-C^*) = (1+\alpha/q)^{-r} \quad [1]$$

$$\alpha = (R-ET+I_i-I_o-\Delta S) \quad [2]$$

$$r = \gamma/\alpha \quad [3]$$

$$\gamma = R-ET+I_i+k \quad [4]$$

where:

I_i = infiltration into the wetland from the groundwater, m/yr

I_o = infiltration out from the wetland to the groundwater, m/yr

ΔS = change in storage, m/yr

C* in this model combines the effects of internal loading, rainfall, and infiltration on the irreducible wetland outlet concentration. For example, groundwater upwelling in the wetland may carry higher TP concentrations and result in a higher background just as higher rainfall TP can result in a higher background. In this case, C* can be estimated from the following expression:

$$C^* = (kC_\lambda+RC_R+I_iC_i)/(\alpha+k+\Delta S+I_o) \quad [5]$$

where:

C_λ = the TP concentration resulting from internal loading by soils and ecological processes, mg/L

C_i = the TP concentration in the upwelling groundwater, mg/L

This formulation of the k-C* plug flow model can be used for estimating performance of a treatment wetland if seepage and associated TP concentrations are significant.

An electronic copy of Exhibit 14 has been included with this report. Input parameters have been highlighted and include the following:

- R = Average rainfall (m/yr)
- ET = Average ET (m/yr)
- C_1 = TP concentration in (mg/L)
- C_r = Rainfall TP concentration (mg/L)
- k = TP settling rate constant (m/yr)
- Q = Annual pumped inflow volume (m3/yr)
- A = STA wetland surface area (m2)
- I_i = Exfiltrating groundwater (m/yr)
- I_o = Infiltrating groundwater (m/yr)
- deltaS = Change in surface water storage (m/yr)
- C_l = TP concentration resulting from internal loading (mg/L)
- C_i = TP concentration in exfiltrating groundwater (mg/L)

Sinusoidal Time Series Model

The sinusoidal time series model is defined as:

$$TP = TP_{avg} (1 + A \cos [w (t-t_{max})]) \quad [6]$$

where:

TP = total phosphorus (mg/L)

TP_{avg} = annual average total phosphorus concentration (mg/L)

A = fractional half amplitude

w = annual frequency, w = 2 pi/ 365 (1/yr)

t = time (Julian day)

t_{max} = time of maximum TP concentration (Julian day)

An electronic copy of Appendix A-1 has been included with this report. Using the solver routine in Microsoft Excel, the user solves for the parameters TP_{avg}, A, and t_{max} to result the least sum of squares difference between the measured and modeled value.