Design of Treatment Wetlands to Improve Everglades Water Quality

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The South Florida Water Management District (SFWMD) has finalized the construction of 12,000 acres of additional constructed wetlands, known as stormwater treatment areas (STAs), on former agricultural sites. The design and results of the water quality analysis conducted for an expansion of STA 5/6, known as the Compartment C buildout project, is discussed.

The additional STAs are located in western Palm Beach County (part of the Compartment B buildout project) and in Hendry County (Compartment C buildout project). These STAs treat stormwater from the contributing agricultural basins and assist existing STA-2 and STA-5/6 in reducing total phosphorus (TP) from runoff water before entering the Everglades Protection Area (EPA). The Compartment C buildout project is located in the southwest corner of Hendry County at the intersection of the Palm Beach, Broward, and Hendry County lines and is between the former STA-5 and STA-6 and between the C-139 Annex and the Rotenberger Wildlife Management Area (RWMA), as shown in Figure 1.

The two projects are components of the long-term plan for achieving water quality goals for Everglades Protection Area Tributary Basins and will assist the state of Florida and the SFWMD in fulfilling their obligations under the Everglades Forever Act (EFA, F.S. 373.4592). The projects also help achieve compliance with the phosphorous limits and levels established under Florida law, Rule 62-302.540, F.A.C. (the Phosphorous Rule), and the consent decree entered in United States v. SFWMD, et al., Case No. 88-1886-CIV-Moreno (S.D. Fla.).

The SFWMD began operating its first STA, called the Everglades Nutrient Removal Project, in 1994 and has gradually been expanding the acreage of STAs since that time. The completion of Compartments B and C bring the total footprint of STA effective treatment area to approximately 57,000 acres.

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The SFWMD's expansion of STAs continues to evolve. In 2012, subsequent to the completion of the Compartment C buildout project, the state of Florida and the U.S. Environmental Protection Agency reached a consensus on new strategies for improving water quality in the Everglades. This historic undertaking will expand water quality improvement projects to achieve the ultra-low phosphorus water quality standard established for the Everglades. Specifically, an additional 800 acres of effective treatment area will be added within STA-5/6, and an 11,000 acre-ft flow equalization basin will be constructed on the north portion of the C-139 annex. Flow equalization basins attenuate peak stormwater flows and provide a more steady flow of water to STAs, helping to maintain desired water levels needed to achieve optimal water quality treatment performance. Design and construction of the treatment and storage projects will be completed in three phases over a 12-year timeframe, with completion set for 2024.

Figure 1. Compartments B and C Buildout Project Location

Project Description

The Compartment C buildout project is approximately 5,000 acres and includes STA-5/6 and cells 5-4A, 5-4B, 5-5A, 5-5B, and 6-4. This phase will further improve the quality of water entering the EPA. The former STA-5 and STA-6 provided a total effective treatment area of approximately 8,700 acres and were modified during the buildout to work as integral parts of the complete STA-5/6 system. The overall STA-5/6 system has approximately 13,700 acres of effective treatment area. The STA-5/6 effective treatment areas in chronological order of development are shown in Figure 2.

The effective treatment area for an STA is defined as the area that contains treatment wetland vegetation. In general, the goal is to maintain STA water depths at approximately 1.25 ft. The minimum water depth for an STA is 0.5 ft to avoid dryout, while the maximum static water depth is 4.0 ft to avoid damaging the wetland vegetation.

Like most other STAs, the Compartment C buildout project was divided into two cell types: emergent aquatic vegetation (EAV) cells (or cell A) and submerged aquatic vegetation (SAV) cells (or cell B). As water flows from the west to the east, EAV cells were positioned on the west side of the project and SAV cells were positioned on the east side. The EAV cells perform primary phosphorus removal on the upstream end of the flow-way, and the SAV cells provide polishing treatment on the downstream end of the flow-way. The topographic relief of the EAV cells within the Compartment C buildout project required that intermediate weirs be constructed to subdivide the EAV cells into smaller subcells to better control the operating depths along the entire length of the flow-way.

Project Characteristics

The project consists of a series of perimeter impoundment levees, canals, flow control structures, and pump stations. The new inflow canal, distribution, collection/spreader canals, and discharge canal were excavated to distribute water into and internally across (west to east flow direction) the STA. The canals were excavated below existing grades and provided fill for the aboveground levee containment system. The STA discharges are conveyed via the discharge canal and are ultimately directed into either the RWMA or water conservation area (WCA) 3A as shown in Figure 3.

The Compartment C buildout project included the construction of two pump stations:

- *Inflow Pump Station G-508 (1,600 cfs)*. Located at the northwest corner of cell 5-3A (just east of the G-406 control structure); pumps water from the L-2/L-3, Deer Fence, and S and M canals to the new inflow canal. G-508 also includes two 25-cu-ft-per-second (cfs) seepage pumps.
- *Hydration Pump Station G-509 (100 cfs)*. Located on the west levee of the discharge canal between cells 5-4B and 5-5B; provides supplemental water originating from the discharge canal to the STA, except for cells 5-1B and 5-2B, which already receive supplemental water from the existing G-507 and G-350B hydration pump stations.

Twenty water control structures were also constructed for flow control of treatment

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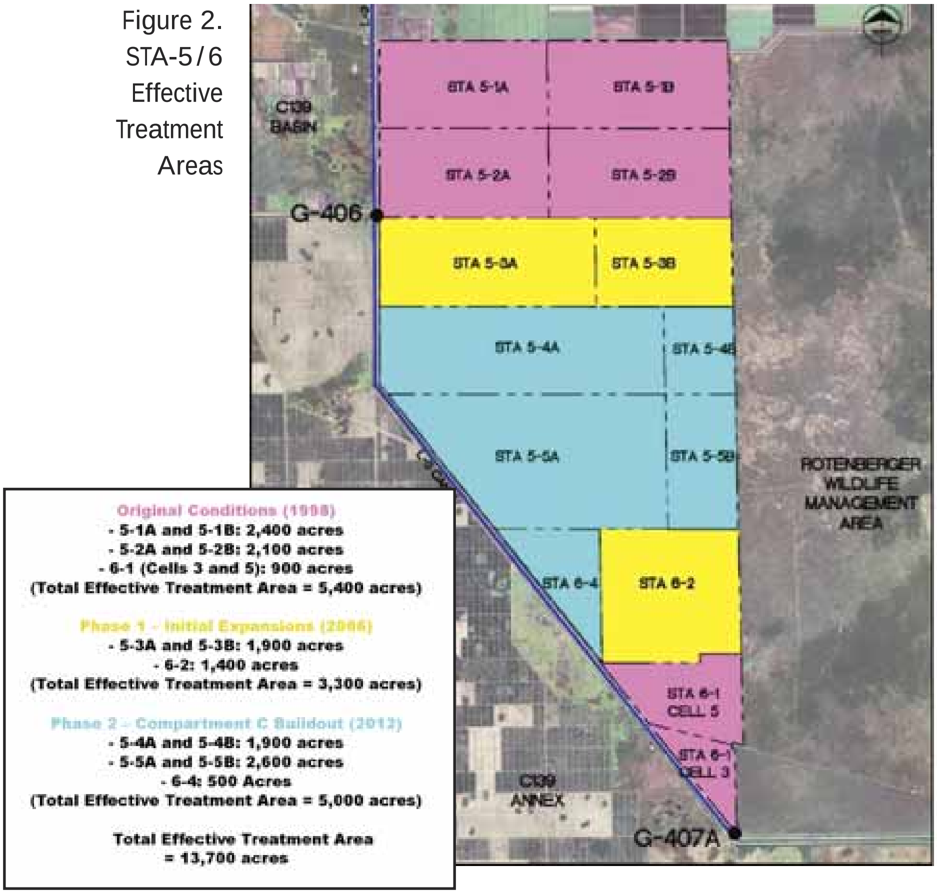
Figure 2. STA-5/6 Effective Treatment Areas



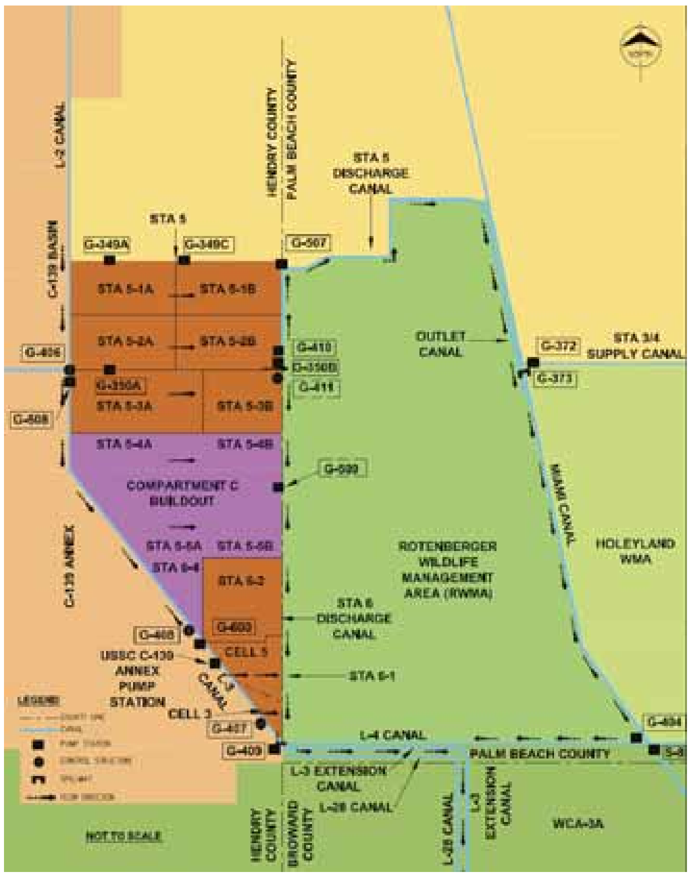


Figure 3. Pump Stations at Compartment C

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water passing through the STA. These structures are reinforced concrete box culverts including four different types: inflow, intermediate, discharge, and diversion.

Twenty concrete overflow weir structures and four 36-in. reinforced concrete pipe (RCP) culvert structures were installed at the west and east intermediate flow control berms to allow connectivity between the EAV subcells. Five 36-in. RCP culvert hydration structures were also included to provide supplemental water deliveries to cells 5-2B, 5-3B, 6-2, and 6-1 (cells 3 and 5).

Hydraulic Design

Inflows for the STA-5/6 system include rainfall into the Compartment C watershed as well as the following flow contributions:

- Agricultural stormwater runoff from the C-139 basin
- Supplemental water necessary to prevent dry-out of the STAs during drought conditions

The hydrographs for 3-day duration storms for the C-139 basin are shown in Figure 4. The storms included the 5-, 10-, 25-year, and standard project flood (SPF) events. For this project, the SPF event is defined as the discharge produced by a rainfall equivalent to 1.25 times the 100-year, 3-day storm event. The 5-year, 3-day storm event was used as the design condition for the system.

The rainfall depths for the modeled storms are shown in Table 1. The incremental distribution of rainfall during the 3-day storm conforms with guidance provided in the SFWMD's Environmental Resource Permitting Manual, Vol. 4 (SFWMD, 2004).

Under the SPF storm inflow condition, the STA-5/6 system may not be able to hydraulically accommodate the total inflow and maintain the existing level of service to the C-139 basin. For storms greater than the 25-year, 3-day storm event (25-year recurrence interval), some untreated flow may be diverted to WCA-3A. The completion of the Compartment C buildout should greatly reduce the diversion of untreated water to WCA-3A, as compared to existing conditions.

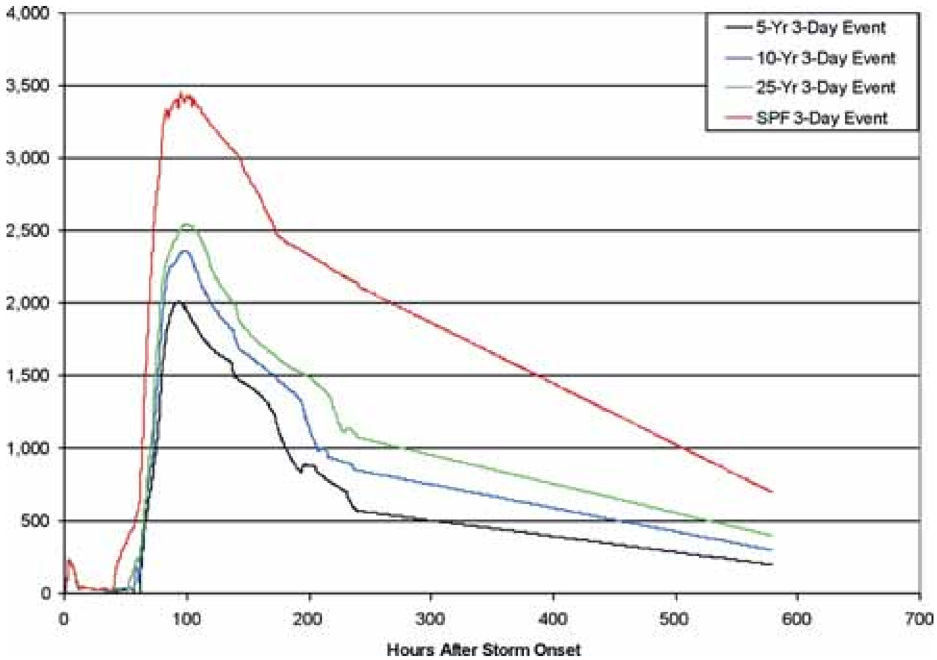

Figure 4. C-139 Basin Hydrographs

Table 1. Modeled Storm Rainfall Depths

Modeled Storm Event	Total Rainfall Depth (in.)
5-year, 3-day	6.1
10-year, 3-day	7.0
25-year, 3-day	8.0
SPF, 3-day	12.5

Hydraulic and Hydrologic Modeling

Hydraulic and hydrologic models of the STA-5/6 system were developed by URS for this study. Hydrologic models of each flow-way and WCA-3A were developed to include the effect of direct rainfall within the project area. The primary hydrologic inputs for the hydraulic modeling were from the C-139 basin. The proposed canals, STAs, and hydraulic structures for the project were designed using several hydraulic analysis methods, including:

- HEC-HMS (USACE, 2005). Calculated hydrologic inputs to STA flow-ways and WCA-3A due to direct rainfall.
- HEC-RAS (USACE, 2005). Assessed the flood elevations and flows within the STA-5/6 system, evaluated the level of service for the C-139 basin for each project phase and the system or operational refinements required to maintain the level of service, determined water surface profiles and predicted flooding effects for the project, and evaluated the proposed canals and dam-break effects.
- FESWMS (Froehlich, 1989). Evaluated the two-dimensional flow through the flow-ways. The configuration of spreader and collector canals and level spreaders was also refined with this model.
- Spreadsheet-Based Hydraulic Modeling. Evaluated the gated control structures proposed for the project. Standard orifice flow and culvert headloss equations were used in the spreadsheet.
- Dynamic Model for Stormwater Treatment Areas Version 2 (DMSTA2), (Walker and Kadlec, 2007). Evaluated the phosphorous removal capability of the recommended Compartment C buildout project configuration. The inflow data sets used in the Everglades Agricultural Area Regional Feasibility Study (EAARFS) were used in this modeling to allow direct comparison with the DMSTA2 modeling performed for the EAARFS (ADA, 2005).
- Spreadsheet-Based Wind Setup and Wave Generation Modeling. Assessed wind setup and wave generation for the SAV cells.
- ACES (Veritech, 2006). Assessed wave runup and minimum embankment height requirements for the flow-ways. The ACES software is a component of the CEDAS software system.

The Compartment C buildout project will accommodate both gravity and pumped inflows. Cells 5-1A, 5-1B, 5-2A, and 5-2B will continue to rely mostly on gravity inflows consistent with existing operations. Pumped flow to STA-5/6 will also be possible via the G-508 inflow pump station. Additionally, 48-in. RCP culverts will connect cell 5-3A to cell 5-2A and 36-in. RCP culverts will connect cell 5-2A to cell 5-1A.

Discharges from cells 5-1B and 5-2B will continue to be conveyed north via the former STA-5 discharge canal to either the RWMA or the Miami Canal. The total average discharge rate for the former STA-5 discharge canal is limited to approximately 1,000 cfs due to capacity limitations at the S-8 pump station. All other flow-ways in the STA-5/6 system will be conveyed to the south via modified STA-6 discharge canal towards WCA-3A; see Figure 3.

Inflow Pump Station G-508 will discharge to the inflow canal and is rated for discharge capacity of approximately 1,600 cfs.

The maximum flows accepted for each of the flow-ways from the canals are listed in Table 2. The table also lists the preferred distribution of flow percentages to the flow-ways. The total STA-5/6 system maximum flow (3,162 cfs) is equivalent to the peak inflow predicted for the SPF event in the Compartment C watershed study (ADA, 2007). To produce evenly distributed hydraulic loadings to all flow-ways, the flow was generally based on the relative area of each flow-way. The hydraulic modeling was adjusted to properly distribute the inflows to the flow-ways and included the direct rainfall within each flow-way. These additional inflows were added directly into each cell.

Total Phosphorus Removal Modeling

Water quality modeling of the STA-5/6 system was conducted using DMSTA2 to assess the level of phosphorus removal from the influent water and the resulting phosphorus concentrations of the effluent water. The DMSTA2 is a conceptual tool developed to predict TP removal in STAs (Walker and Kadlec, 2007). It incorporates knowledge gained from the historical operation of existing full-scale STAs, as well as research studies in biological treatment processes focused on TP removal.

The STA configuration and estimates of effective treatment area within the flow-ways were used to create the system models. Five configuration alternatives for the complete STA-5/6 system were initially identified for preliminary evaluation. Three of the alternatives were identified for additional evaluation.

The modeling performed to assess the three potential STA-5/6 operational alternatives included the following:

- Gravity inflow with a discharge pump station
- Gravity inflow with a discharge pump station, with storage in an off-line reservoir
- Pumped inflow

The calibrated flow-way vegetation datasets contained within DMSTA2 were used to predict the TP removal for the alternatives. The inflow data sets used within DMSTA2 to evaluate the alternatives was identical to that used for the EAARFS. That study assumed the phosphorus concentrations from the C-139 basin would be reduced by 10 percent due to the implementation of best management practices (BMPs). Documentation referenced from the DMSTA2 model was obtained online at the DMSTA2 website (*Ref. 7, http://wwwalker.net/dmsta/index.htm*). The period of record used in the water quality modeling was May 1, 1996, through April 30, 2005.

The average annual inflow volume and inflow TP load for the STA-5/6 system assumed for the DMSTA2 modeling is as follows:

- Average Annual Inflow: 213,700 acre-ft per year
- Average Annual Inflow TP Load : 49.2 metric tons per year

This DMSTA analysis of different configu-

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rations for the complete STA-5/6 system indicated that the alternative including an inflow pump station had the greatest TP removal. The modeling also assessed the impact of varying the proportion of EAV and SAV cells for cells 5-4B and 5-5B. Reducing the size of the SAV cells was recommended to reduce water demands for STA-5/6 system operation.

Based on the simulation period of 10 years, the STA-5/6 system with the G-508 inflow pump station alternative was initially estimated to produce the phosphorus effluent quality shown in Table 3. The results presented are the lower and upper confident limits (CL) which represent the 10 percent and 90 percent confidence limits calculated by the DMSTA2 model. To provide an evaluation of the system sensitivity, the inflow data set was adjusted to include 10 percent increases in flow, concentration, or both. These sensitivity scenarios are also included in Table 3.

The former STA-5 flow-ways (5-1, 5-2, and 5-3) had not performed as predicted considering that the SAV cells provide additional effluent quality improvement and use the effluent quality averaging techniques that had also been used in the long-term plan and the EAARFS.

Both the EAV and EAV/SAV averages were calculated (Table 4). Some DMSTA2 analyses forecasted long-term average annual phosphorus concentrations below the minimum of the calibration data sets for SAV (15 ppb). However, those forecasts were reported as 15 ppb.

The DMSTA2 water quality modeling for the Compartment C buildout project indicates that one or more of the cells were outside of the current model calibration range. The primary source of warnings presented by the DMSTA2 involved low flows and water depths. Another related warning message indicated that the water depths in the cells were less than 10 cm, indicating the potential for vegetation dry-out. The warnings indicate that providing adequate supplemental water deliveries to the STA-5/6 system will need to be a priority to maintain treatment system performance.

Table 2. Buildout Flow Distributions Goals

Flow-way	Flow Percentage	Maximum Flow (cfs)
STA 5-1	17.1	540
STA 5-2	17.1	540
STA 5-3	15.5	489
STA 5-4	15.5	489
STA 5-5	17.8	564
STA 6-2	11.8	375
STA 6-1 cell 5	3.9	124
STA 6-1 cell 3	1.3	41
Totals	**100**	**3,162**

Table 3. Predicted Effluent Quality Sensitivity Analysis

Scenario	Outflow Load (kg/yr)		Concentrations, parts per billion (ppb) Flow-Weighted Mean	
	Lower CL	Upper CL	Lower CL	Upper CL
STA-5/6 (Base Case)	5,614	3,010	23.8	12.8
STA-5/6 + 10 percent Flow Increase	7,007	3,688	26.9	14.2
STA-5/6 + 10 percent Conc. Increase	6,117	3,170	25.9	13.4
STA-5/6 + 10 percent Flow and Conc. Increase	7,663	3,908	29.5	15.0

Table 4. Predicted Phosphorus Effluent Quality

Scenario	Outflow Load (kg/yr)		Concentrations (ppb) Flow-Weighted Mean	
	Lower CL	Upper CL	Lower CL	Upper CL
STA-5/6 (all EAV)	6,240	3,600	32.2	18.6
STA-5/6 (EAV/SAV Averaging)	4,820	2,970	24.9	15.3

Conclusions

The DMSTA2 analysis of different configurations for the complete STA-5/6 system indicated that the alternative using an inflow pump station resulted in the greatest TP removal capacity. The DMSTA2 analysis also concluded that reducing the size of the SAV cells reduced water demands for the STA-5/6 system.

The results of the base case scenario indicate that the average phosphorus load reduction of the STA-5/6 system is predicted to be about 90 percent. The sensitivity results presented in Table 3 show that the system performance may be degraded if flows or loads increase from those of the data set period of record, with flows having a greater effect.

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