Designing STAs to Achieve Treatment and Restoration Objectives

Briefing information prepared for

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Questions and Answers

The Academy has submitted a list of the questions on the subject STA design to achieve low TP concentrations as a resource for preparing its next report. This report supplements answers to these questions provided by Kadlec (2011x) and provides additional ideas on integrating treatment and hydrologic restoration. One of the key questions with respect to treatment is:

"1. Do we know what conditions are required for each STA to produce output that would meet the quality based effluent limit of 10 ppb TP or less?"

The treatment goal is to achieve a long-term (40-year) geometric mean TP concentration of 10 ppb in the STA discharge (not an annual maximum of 10 ppb). There are sufficient resources (data, research, modeling tools, design experience, operating experience, and land) available now to support design and adaptive implementation of a control program to achieve compliance with the treatment goal on schedules that consider other restoration priorities and economic constraints. Achieving low TP concentrations requires treatment cells with sufficiently low P loading rate, inflow P concentration, size, pulse control, and substrate (Kadlec, 2011x). The specific design parameters for each STA depend on the mean and variance of the inflow volumes, P loads and water depths, topography, hydraulic features, and P cycling dynamics of the partially "engineered" wetland treatment communities.

The evolution of mass-balance models for designing STAs to achieve treatment goals over the past 20 years is been described (Walker & Kadlec, 2011; Kadlec 2011x). The abundant data from experimental, test, and full-scale cells has been translated into an engineering design model (DMSTA, Dynamic Model for Stormwater Treatment Areas) and applied to develop alternatives for achieving the treatment goal for each STA (USEPA, 2010; Walker, 2010), as described below. One of the alternatives provides significant hydrologic benefits along the way (improved stage in the Refuge, delivery of an additional 170 kac-ft/yr to the central flow path), as well as urban water supply and flood control benefits. This demonstrates that water quality and hydrologic restoration is not an "either/or" situation, even though funding constraints and priorities may determine the implementation schedules.

The current design model (DMSTA2, Walker & Kadlec, 2005) and its precursor (DMSTA, Walker & Kadlec, 2000) include calibrations for several community types that have been calibrated and tested over a range of approximately 6 – 1200 ppb: (1) EMG = Emergent (peat); (2) SAV = Submergent (deeper cells on farmland peat); (3) PSTA = Periphyton (shallower cells on shellrock/limerock); (4) PEW = Pre-Existing Wetland (mixed communities built on natural soils as opposed to farmland); (5) NEWS = Non-Emergent Wetland System (SAV / PSTA hybrid designed to reflect transition from submerged vegetation to periphyton communities that evolve along P gradients extending from ~100 to 6 ppb); (6) RES (periphyton communities in deeper lakes and reservoirs). We considered including one labeled WGT ("Whatever Grows There"). The District and others have demonstrated, however, that vegetation communities can be engineered to improve performance relative to the naturally evolving communities by implementing such measures as compartmentalization, water depth control, selective herbicide applications, and substrate preparation. The partitioning of datasets used to calibrate DMSTA for each community type was based on those design and operational features, as opposed to the actual vegetation that developed in each cell.

Performance is ultimately constrained by treatment area size and the available information indicates that the existing STAs are simply not large enough to achieve treatment objectives, even if the STA optimization and vegetation management efforts are highly successful. Operating experience has demonstrated that performance of the existing STAs is also limited by canal conveyance capacities (Ocean, C51, etc), which have made it difficult to operate the STAs within the design limits for inflow volumes and P loads for STAs designed to achieve 50 ppb discharge concentrations, particularly in the eastern basin.

Supporting Information

I prepared a report for the USEPA describing preliminary design alternatives for achieving treatment goals for each STA using the best available data, model calibrations, and design assumptions developed primarily in discussions between state and federal technical staff (Walker, 2010). Narrative descriptions of the alternatives are contained in court testimony (Walker, 2011ab). Additional information has been extracted from the DMSTA website (http://www.wwwalker.net/dmsta) and other reports prepared for federal agencies (http://www.wwwalker.net/doi) and provided to the committee.

Substantial court testimony regarding the design of P control measures has been presented by expert witnesses from the state, federal, tribal, and environmental groups in recent hearings associated with the State/Federal Consent Decree. As far as I know, all of that information is publicly available as a resource for the Academy in preparing its next report. While some of the concepts and controversies are reflected in written testimonies, others are embedded in transcripts and hundreds of exhibits. It is difficult to piece together all of the information and track all of the threads. If the process envisioned by the USEPA moves forward, additional refinements to the data and modeling will be integrated into more detailed designs and that information will be available to the Academy in a more concise and comprehensive format for use in preparing its next report.

USEPA Amended Determination

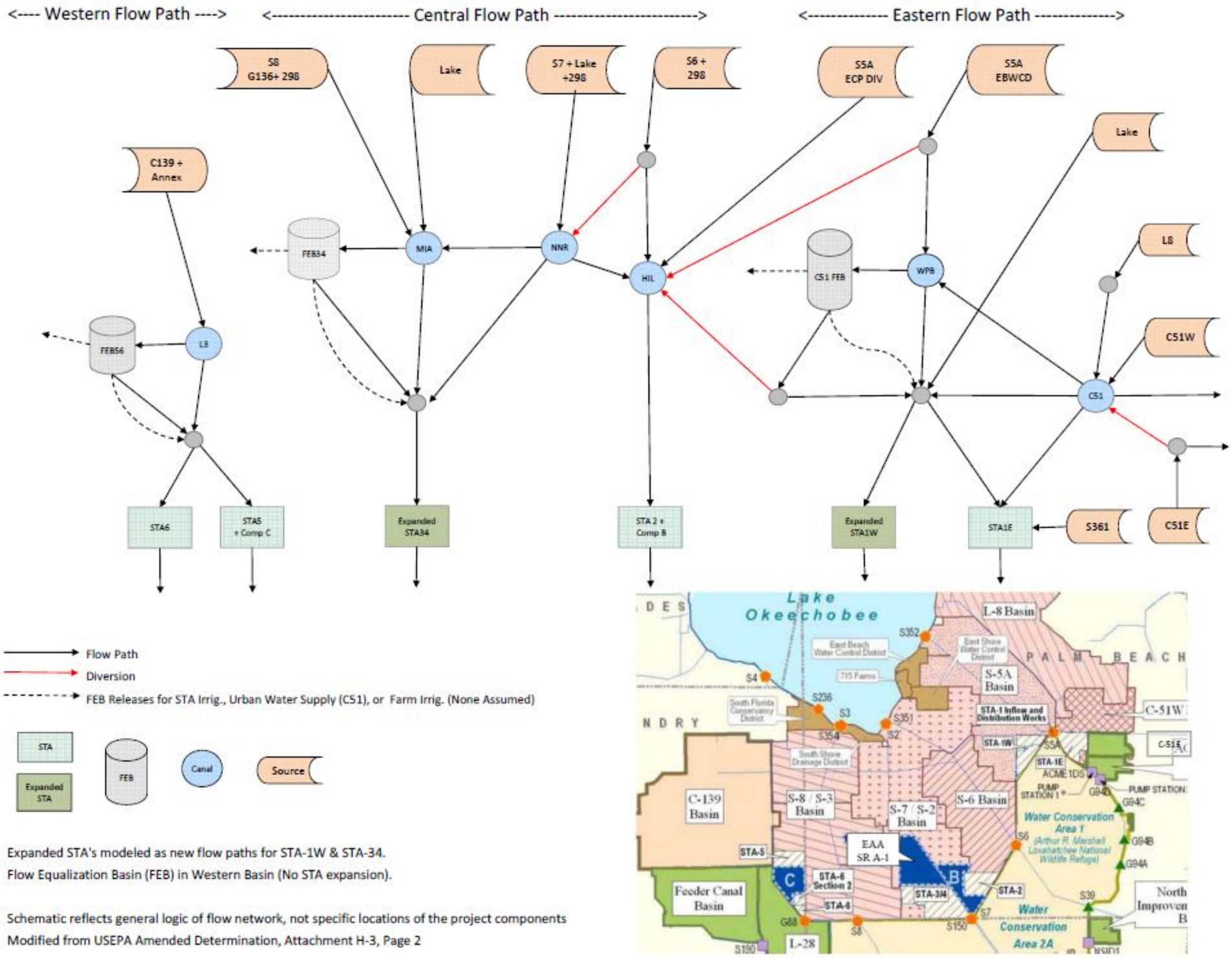
The USEPA derived a water quality based effluent limit for the STAs discharges to achieve compliance with the Everglades phosphorus criterion throughout the marsh (USEPA, 2010; Walker, 2011d). The criterion is expressed as a long-term geometric mean of 10 ppb. Accounting for concentration vs. flow dependence observed in STA discharges, this is statistically equivalent to a long-term flow-weighted mean of approximately 12 ppb. The annual compliance limit (18 ppb) allows for the expected year-to-year variations in the discharge concentrations around the design value. A second provision of is that the geometric mean concentration in the STA discharges not exceed 10 ppb in more than two consecutive years.

The STA design target adopted by the USEPA is expressed as a long-term (40-year) flow-weighted mean of 11.5 ppb. Along with other conservative modeling assumptions, this provides a margin of safety (vs. the 12 ppb performance goal) to hedge against the unavoidable uncertainty in performance forecasts.

An initial array of alternatives was developed using the best available data and modeling tools for predicting future flows (2x2 modeling), STA performance (DMSTA), and design assumptions developed primarily in discussions between state and federal technical staff (Walker, 2010;USEPA, 2010). It was envisioned that subsequent steps would be taken by the State after September 2010 to develop specific plans reflecting a technical consensus of stakeholders and factoring in all of the additional information (research, monitoring, operating experience) developed by the District.

Eight scenarios were developed to represent different configurations for the three Everglades Flow-paths: Western (treated in STA-5, STA-6, and Compartment-C), Central (STA-3/4, STA-2, and Comp-B), and Eastern (STA-1W, STA-1E). There were two baseline scenarios (with and without Compartments B & C) and six scenarios designed to meet the treatment goal for each STA using different combinations of expanded STAs, Flow Equalization Basins (FEBs), flow balancing across STAs, and construction sequences, as illustrated in Figure 1.

Figure 1: Flowchart for USEPA Amended Determination Alternatives



Two out of the six scenarios reflected interim configurations designed to expedite STA-3/4 performance improvements. The four remaining scenarios reflect different ultimate configurations of STAs and FEBs in each basin:

- Because of the relatively high variability in runoff and high seepage rates, a flow-equalization basin (FEB, 7 kac, 12 ft. deep) was considered to be more beneficial than STA expansion as a remedy for the Western Basin. The added feature would fit within the footprint of the C139 Annex recently purchased by SFWMD from the U.S. Sugar Corporation.

- The Central basin alternatives involved expansion of STA-3/4 (14 -22 kac) with and without a FEB (34 kac, 8 ft deep). Treatment objectives for STA-2 and Compartment-B would be accomplished by diverting inflows to the expanded STA-3/4 and/or the FEB. While the designs were not attached to specific parcels, the added features would fit in the footprints of existing publicly owned lands (EAA Compartments A1 and A2).

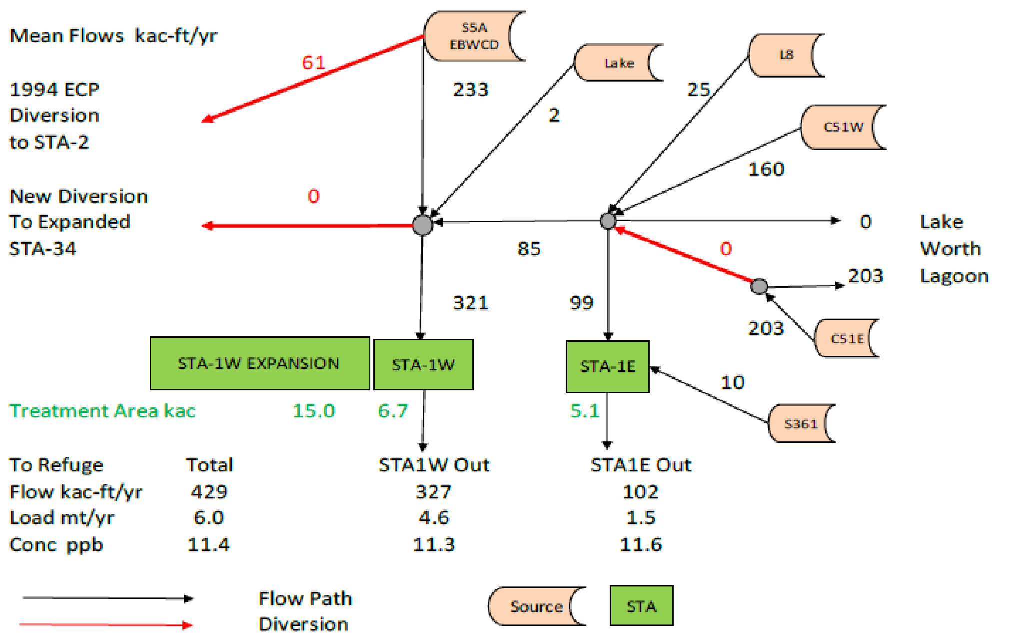
- The Eastern basin (Refuge) alternatives involved expansion of STA-1W (8-15 kac) with and without a FEB (1.7 kac, 44 ft deep). Treatment objectives for the rehabilitated STA-1E would be accomplished by diverting inflows from the C51 West canal to the expanded STA-1W and/or FEB. The STA-1W expansion would range from 8 kac with the FEB to 15 kac without the FEB, as compared with 8.9 kac in the northern S5A basin recently purchased by SFWMD from the U.S. Sugar Corporation.

The total new effective treatment area (FEBs + STAs) varied from 38 to 40 kac beyond the existing 57 kac, including Compartments B and C. The total new project area (including an additional 10% for pump stations, levees, etc.) ranged from 41 to 44 kac.

While the various alternatives were similar with respect to total land requirements, they differed with respect to other factors that would be considered in selecting final alternatives, such as feature locations, flow distribution, canal conveyance and pump capacities, schedule, cost, operational flexibility, and other potential benefits of the FEBs (restoration hydrology, flood control, water supply). While final designs could involve land exchanges to optimize treatment area locations and/or to construct associated canals and pump stations, the preliminary evaluations indicated that project objectives could be accomplished without major new land purchases. The exception is the Refuge basin alternative without an FEB (C51 Rockpit), which would require sufficient additional land in the S5A basin to accommodate approximately 7 kac of effective treatment area, above and beyond the 8.9 kac already purchased by the District.

Flow charts for the Eastern flow-path design alternatives are shown in Figure 2 (STA expansion) and Figure 3 (C51 Rockpit + STA Expansion). The preliminary analysis indicated that including the C51 Rockpit and associated diversion of relatively high-quality runoff from the C51E basin into the Eastern flow path would provide significant benefits with respect to reduced treatment acreage, urban water supply, operational flexibility, improved water quality and hydrology for the Refuge, improved water quality for the Lake Worth Estuary, urban flood control, approximately 177 kac-ft/yr of new inflow to the central Everglades basin, and cost. The Rockpit operating rule (expressed as outflow vs. water level and season) was tweaked to benefit Refuge hydrology (improved stage), stabilize STA water levels, and meet potential urban water supply needs under most drought conditions. While more detailed hydrologic analysis is needed, preliminary calculations indicate that dry-season releases from the Rockpit could be routed through the STAs and Refuge before reaching the urban areas. While attenuated along the way, the same water would provide three benefits (STA irrigation, Refuge stage management, and urban water supply). While seemingly attractive, the project requires more thorough hydrologic assessment, potentially complex agreements with regional water utilities, and consideration in the broader context of hydrologic restoration goals.

Figure 2: Refuge Basin Flowchart for the STA-1W Expansion Alternative

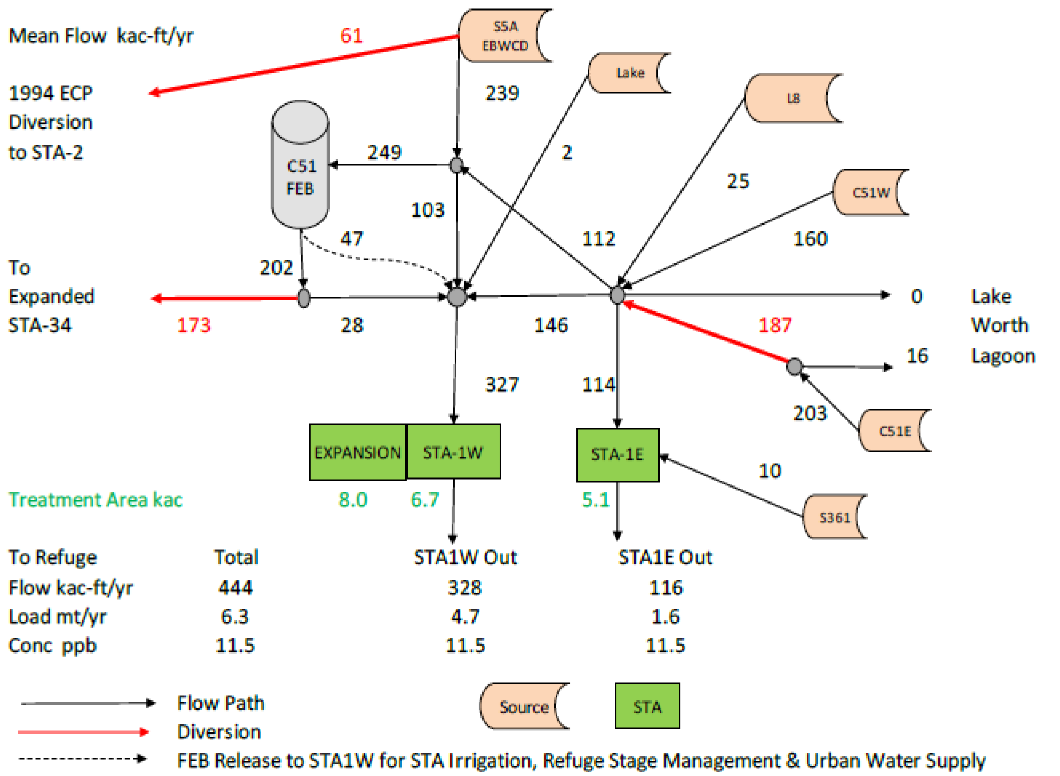


Source	Flow kac	Load mt	Conc pp
S5A to STA2	61.0	16.0	213
S5A Runoff	208.9	47.0	182
EBWCD Runoff	24.2	14.7	492
Lake to S5A	2.3	0.3	103
L8 Runoff	25.0	4.2	135
C51 West	159.7	32.2	163
S361	9.7	0.9	73
C51 East	202.6	23.9	96
Total Sources	693.4	139.2	163
To Refuge Basin	429.7	99.3	187
To Estuary	202.6	23.9	96
To West	61.0	16.0	213

Source	Flow kac	Load mt	Conc pp
C51 to STA1E	99.2	19.5	159
C51 to STA1W	85.5	16.9	160
STA1E Inflow	108.9	20.4	152
STA1E Outflow	102.0	1.5	11.6
STA 1W Inflow	320.8	78.9	199
STA1W Outflow	326.8	4.6	11.3
Refuge Inflow	428.8	6.0	11.4

Derived from USEPA AD-H, Scenario 3.

Figure 3: Refuge Basin Flowchart for the C51 Rockpit / STA-1W Expansion Alternative



Terms	Flow kac	Load mt	Conc ppb	Terms	Flow kac	Load mt	Conc ppb
S5A to STA2	61.0	16.0	213	C51W to STA1E	113.6	17.8	127
S5A Runoff	215.3	48.5	182	C51W to STA1W	146.1	23.0	127
EBWCD Runoff	24.2	14.7	492	C51W to FEB	112.1	17.7	128
Lake to S5A	2.3	0.3	103				
L8 Runoff	25.0	4.2	135	FEB Bypass to S5A	103.0	23.2	182
S361	9.7	0.9	73	FEB Inflow	248.6	57.7	188
C51 West	159.7	32.2	163	FEB Release to STA	47.0	10.5	181
C51E Total	202.6	23.9	96	FEB Outflow	201.7	45.1	181
C51E Div to C51W	187.1	22.1	96	FEB Out to STA1W	28.5	6.3	179
C51E to East	15.6	1.9	96	FEB Out to West	173.2	38.8	181
Total Sources	699.8	140.7	163	STA1E Inflow	123.3	18.7	123
To Refuge Basin	450.1	84.0	151	STA1E Outflow	115.8	1.6	11.5
To West	234.2	54.8	190	STA1W Inflow	326.9	63.2	157
To Estuary	15.6	1.9	96	STA1W Outflow	328.2	4.7	11.5
				Refuge Inflow	444.0	6.3	11.5

Derived from USEPA AD-H, Scenario 7.

Treatment Community Assumptions

For purposes of the initial designs, it was assumed that cells constructed on peat and managed to promote a non-emergent community (SAV and periphyton) can achieve the target concentration without extreme substrate preparation measures, provided that the designs provide sufficiently low inlet P load, pulse control, and appropriate water depths. It was assumed that P releases from the antecedent peat soils will decrease over time as the stored P is depleted and the community builds new soil with stable P residuals. If P loading rates are sufficiently low and spikes are attenuated, secretion of alkaline phosphatase enzymes by the evolved microbial communities would help to assimilate organic phosphorus that is otherwise resistant to treatment in the higher TP concentration ranges, as observed at the lower end of the P gradient in WCA-2A (Richardson & Quian, 2008).

Historically, STA cells operating in the low TP range have apparently reached stable performance in periods ranging from 2 to 5 years, but longer periods may be necessary to achieve TP concentrations below the lower end of observed range for SAV cells in cells that were not designed to achieve the criterion (~15 ppb long-term, 12 ppb annual). The calibration datasets may not be sufficiently long, however, to identify subtle decreasing trends due to continued stabilization. To the extent that data used for DMSTA calibration is influenced by P release from antecedent soils, immature communities, and/or hydraulic inefficiencies, the calibrated uptake rates are likely to under-estimate those that would occur after full stabilization of soils and communities in cells with improved hydraulic designs. Uncertainties related to performance, stabilization time scales, and other factors (e.g. actual vs. assumed inflow volumes and loads) must be considered in an adaptive management framework. In addition to source controls, further enhancements to the STA designs, such as peat scraping, capping, compartmentalization, and/or expansion, may be needed at a future date, depending on actual performance and designed with the benefit of additional knowledge gained in ongoing research, monitoring, and model refinements.

All of the regional plans developed by the District since 2001 have assumed that non-emergent communities on peat can achieve the low TP concentrations and allowed for subsequent measures to hedge against the uncertainties; i.e. adaptive management under the state's Long-Term Plan. While there is evidence that removing or capping the peat to remove the antecedent P source and foster periphyton communities will shorten the time scale and achieve lower TP concentrations, those designs are likely to involve much initial cost and design uncertainties, as compared with the peat-based design. While a PSTA design may achieve the treatment goal sooner by removing the antecedent P source, the higher initial cost and funding constraints may extend the time scale of construction. These fundamental design assumptions and the appropriate model calibrations can be re-considered in the next design step while factoring in more recent information from SAV and PSTA treatment cells and peat characteristics. The ratio of emergent to submergent cell area (vs. the assumed 40/60 split) can also be reconsidered in light of the hydraulic problems than have been experienced in the existing emergent cells.

Benefits of FEBs

The primary functions of FEBs are to improve STA performance by storing and attenuating peak flow during wet periods and by releasing flow during dry periods to help maintain STA water levels and vegetation. FEBs provide operational flexibility for real-time regional water management (e.g. balancing flows across STAs; maintaining STA water levels, and facilitating STA maintenance). These benefits provide an additional margin of safety that is not reflected in the STA simulations. Optimization of the FEB and conveyance parameters in subsequent design studies may improve performance and provide additional operational flexibility.

Because of the deep and highly fluctuating water levels, the P removal performance within the FEBs is very limited. While not included in the preliminary designs, some releases from the FEBs could be recycled back to the farms for irrigation provided that it does not interfere significantly with releases for STA irrigation and urban water supply. Recycling the farm runoff back to the farms through the farms would provide an additional P removal benefit but result in a net decrease in flow delivered to the STAs. Fostering floating vegetation in the FEBs can also be considered to enhance P removal.

While model forecasts for the various alternatives are identical with respect to STA discharge concentrations, designs with FEBs provide more efficient use of the treatment area, as manifested by higher net settling rates back-calculated from DMSTA output and demonstrated by Kadlec (2011xs) using simpler models.

While FEB components are significantly more expensive per unit area than the STAs, they can to some extent be engineered and operated to provide other benefits (restoration, water supply, flood control) without compromising treatment benefits. A full accounting should consider all of the costs and benefits; i.e. the cost of the FEB should not be ascribed exclusively to treatment and could be offset by the other benefits (avoiding flood damage, for example). It could be argued that there is much greater uncertainty (and costs) associated with constructing and operating the deep reservoirs, as compared with the expanded STAs designed to meet the TP criterion.

Model simulations indicate that most of the treatment benefits of the FEBS can be achieved by attenuating runoff pulses that occur on time scales of one to two weeks if the STAs are sufficiently sized. This could provide supplementary flood control benefits and not conflict with hydrologic restoration targets expressed as monthly or wet vs. dry-season distributions.

Based upon my limited understanding of the hydrologic restoration targets, it appears that treatment and restoration goals are generally compatible with respect to spatial and seasonal distribution of inflows. Providing treatment capacity for lake releases during extreme high-flow years in restoration scenarios would be difficult and require purchase of additional lands for storage and treatment.

Modeling Treatment and Restoration Alternatives

The DMSTA template (Figure 1) developed for the USEPA could be refined to facilitate design of FEB/STA networks to provide treatment and restoration benefits. This would require that the restoration goals be expressed in terms of desired seasonal and year-to-year distribution of flows discharged from the STAs into the WCAs. The modeling tool is analogous to the RESOPS spreadsheet developed by the District for use in the River of Grass planning process and could be linked with the 2x2 or a similar hydrologic model operating on a daily time step.

While the scope and complexity would increase significantly, it would also be possible to include an explicit simulation of Lake Okeechobee phosphorus dynamics in the model template using the existing DMSTA calibration or other relatively simple mass balance models that have been developed for use in TMDL planning (Walker, 2000; Pollman and James, 2011). The boundary condition could be extended to the Lake inflows or linked to whatever models exist for the Lake watershed.

Additional restoration and treatment components could be integrated and sequenced depending on restoration priorities and funding constraints. In considering the sequencing of restoration and treatment components, the uncertainty in the goals themselves should be considered. The treatment goals seem to be much more clearly defined than the restoration goals. The progress of planning for restoration has been handcuffed by absence of plans or commitments to treat inflows sufficiently to meet the TP criterion and avoid creating new impacted areas in the remaining Everglades marsh.

Monitoring and Research

Despite economic constraints and controversies that have evolved over the past decade with respect to STA design goals and compliance, the integrity of the STA monitoring program has been maintained and substantial knowledge has been gained in operating the STAs over the years. Good databases exist for refining the models and managing the STAs, as reflected in the South Florida Environmental Reports. Continued expansion of knowledge gained in operation, research, monitoring, and modeling will contribute to achieving long-term goals for water quality and hydrologic restoration.

Short-term plans for refining DMSTA include updating the model calibration data sets, further testing and possible refinement of the existing calibrations, and refinements to allow simulating the effect of topographic variations on performance. The latter is likely to improve the existing simulations during dry periods. Long-term plans include development of calibrations for floating vegetation (FAV), effects of calcium levels on P removal, and a separate version for the nitrogen cycle. The concept of using FAV to enhance P removal in the FEBs and/or STA inflow cells has been discussed.

To assist in real-time operation of the STA's, the district generates weekly reports on STA performance that summarize water and mass balances for each flow path on weekly, monthly, and annual time scales. While DMSTA was developed primarily for use in design, it could also be applied on a real-time basis to assist in operation. Linking the performance report data to the model would provide periodic comparisons of the observed and predicted performance of each cell. By adjusting for hydrologic variations, the model provides a basis for tracking the P removal performance of the vegetation communities relative to design assumptions and interpreting the real-time data to steer management.

References

Kadlec, R.H., 2011x. Reports for CISRERP:
"Models for Treatment Wetland Systems at Low Phosphorus Concentrations: Everglades Protection", "Effect of Pulsing", "Harvest to Remove Phosphorus", "Phosphorus Loading Graph Misconceptions", "Treatment Wetlands Wear Out, Don't They?", "Wetlands in Series and Parallel", "Alternative Technologies".

Pollman, C.D. and R.T. James, "A Simple Model of Internal Loading of Phosphorus in Lake Okeechobee", Lake and Reservoir Management, Vol. 27, No. 1, pp. 6-14, March 2011.

Richardson, C.J. and S.S. Qian, "Long-Term Phosphorus Assimilative Capacity (PAC) in the Everglades", Chapter 23, In Richardson, C.J.,The Everglades Experiments, Lessons for Ecosystem Restoration. Springer, 2008.

U.S. Environmental Protection Agency, Amended Determination, September 2010.

Walker, W.W. and R.H. Kadlec, Dynamic Model for Stormwater Treatment Areas, prepared for U.S. Department of the Interior, Version 1 (2000) http://www.wwwalker.net/dmsta1
Version 2 (2008) http://www.wwwalker.net/dmsta

Walker, W.W., Jr. and Kadlec, R.H., "Modeling Phosphorus Dynamics in Everglades Wetlands and Stormwater Treatment Areas", Critical Reviews in Environmental Science and Technology, Vol. 41, No. 6, pp. 430-446, 2011.

Walker, W.W., "Estimation of a Phosphorus TMDL for Lake Okeechobee", prepared for Florida Department of Environmental Protection & U.S. Department of the Interior, December 2000.

Walker W.W. "Evaluation of Alternatives to Achieve Phosphorus WQBELS in Discharges to the Everglades Protection Area", prepared for U.S. EPA, Attachment H, September 2010.

Walker W.W., "Initial Remedies Report", Testimony, USA vs. SFWMD et al, 2011a.

Walker W.W., "Rebuttal Report", Testimony, USA vs. SFWMD et al., February 2011b.

Walker, W.W., Maximum Annual Discharge Limits to Achieve Compliance with the Consent Decree's Water Quality Requirements - Summary of Exhibits and Issues", TOC Presentation, March 1, 2011c.

Related Reports on Everglades Restoration prepared for U.S. Department of the Interior:
http://www.wwwalker.net/doi