# Appendix 5C-1: iModel for Restoration Strategies Operational Protocol Development

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## INTRODUCTION

The Everglades Stormwater Treatment Areas (STAs) are constructed wetlands along the northern perimeter of the Everglades. The primary purpose of STAs are to treat stormwater runoff and to use biological processes to reduce total phosphorus (TP) concentrations in the water before it enters the Everglades. As part of the *Restoration Strategies Regional Water Quality Plan* (SFWMD 2012), flow equalization basins (FEBs) have been constructed upstream of the STAs to attenuate peak stormwater flows prior to delivery to the STAs (**Figure 1**). The STAs are required to meet a water quality based effluent limit (WQBEL) that was developed to achieve compliance with the State of Florida's Everglades numeric TP criterion.

Stormwater runoff from the Everglades Agricultural Area (EAA) and other basins, as well as water from Lake Okeechobee, enters the Everglades through a system of FEBs/STAs representing three different flow paths (Eastern, Central, and Western). The hydrology, hydraulics, hydrodynamics, and water quality within the STA systems involve numerous complex processes and limited available data. Model development to simulate these processes and the management of this system remain a challenge. A formal operational protocol of the above system to optimize flow releases into and from the STAs of the Central Flow Path to achieve the WQBEL is the focus of this study.

Water in the Central Flow Path is routed from the S-2, S-3, S-6, S-7, and S-8 drainage basins via the Hillsboro, North New River, and Miami canals into STA-2 and STA-3/4 (a total of eight treatment flow-ways; **Figure 1**). A portion of the stormwater and Lake Okeechobee discharges is directed to the A-1 FEB, with a storage capacity of 60,000 acre-feet (ac-ft), for peak flow attenuation prior to discharge to the STAs for treatment and subsequent discharge into Water Conservation Area (WCA) 2A and WCA-3A. The Central Flow Path FEB/STA system is operated via 23 flow control structures subject to various constraints such as target stages in the treatment cells, and upstream and downstream stage conditions. Modeling will assist the optimization of this complex system.

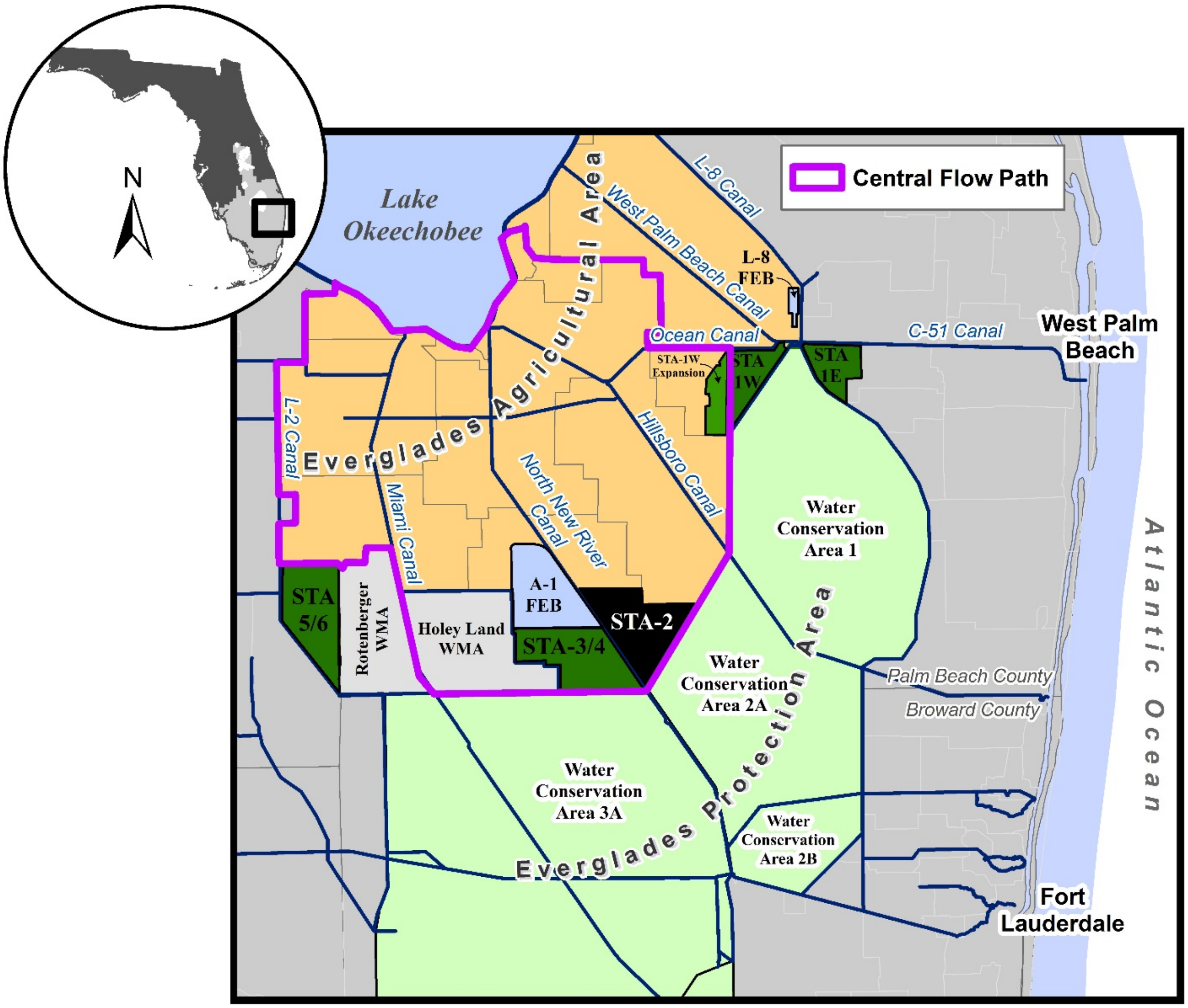



**Figure 1.** Central Flow Path.

# METHODS

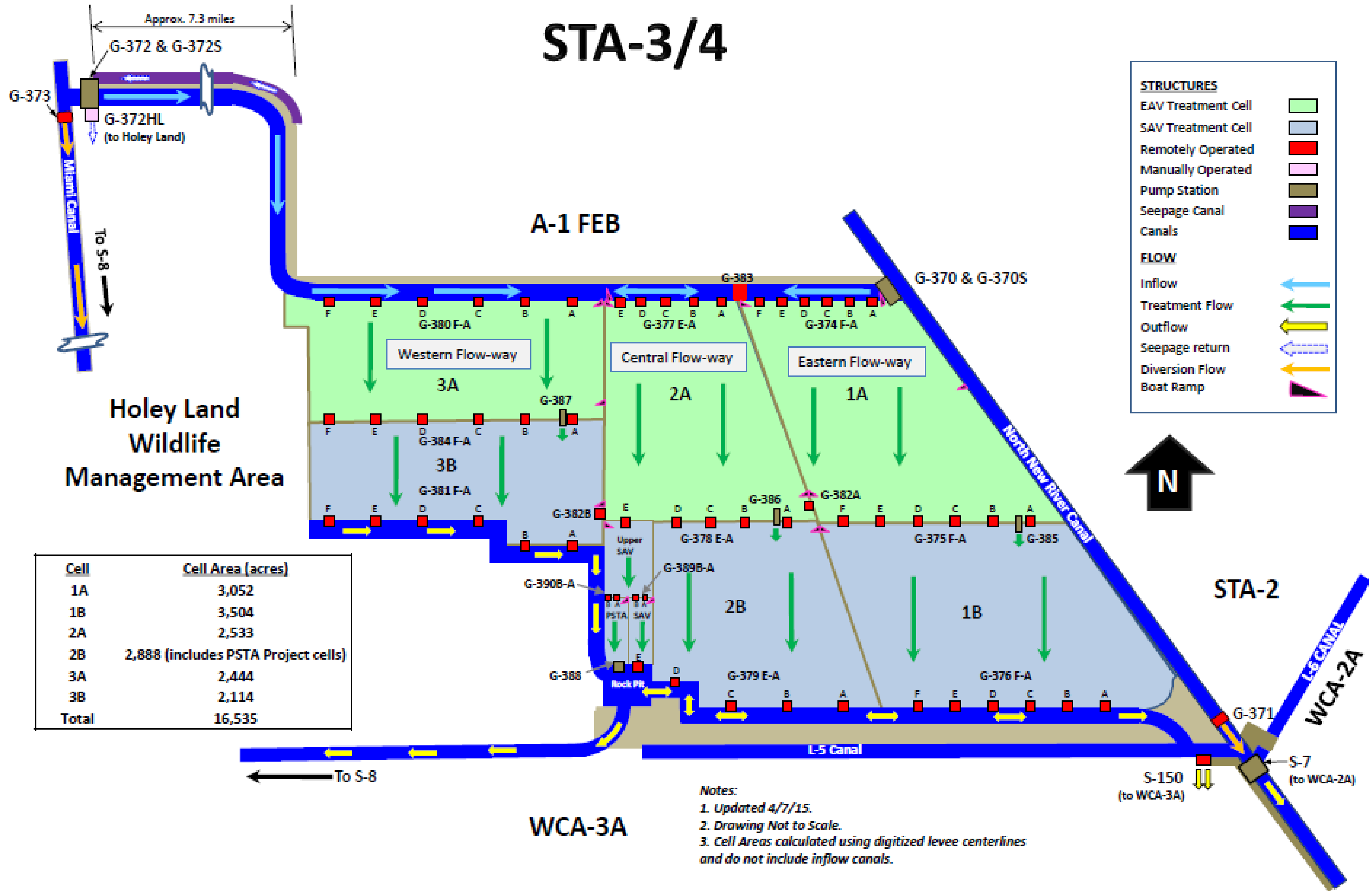
With the projects (new and existing) being operational, the objective of this study is to establish an operational framework for the Central Flow Path. Specifically, this study implements the iModel for formal optimization of the Central Flow Path FEB/STA system to achieve the WQBEL at the upstream ends of WCA-2A and WCA-3A. In this study, we first present the project data followed by a detailed presentation of the iModel implementation for the Restoration Strategies Operation Plan Development (iModel-RSOPD) is provided. Results and challenges are also presented. In the final section of this appendix, we offer our conclusions and recommendations.

## CENTRAL FLOW PATH STA/FEB SYSTEM

The Central Flow Path STA/FEB system consists of the following:

- A-1 FEB (**Figures 1** and **2**)
- STA-3/4 represented by Western, Central, and Eastern flow-ways (**Figure 2**)
- STA-2 represented by Flow-ways 1 through 5 (**Figure 3**)

This system receives stormwater runoff from the EAA and other basins and Lake Okeechobee water via three points: G-372, NNRCDIV, and Qeast, which holistically represent the North New River, Miami, and Hillsboro canals. A portion of the G-372 flows gets routed to the A-1 FEB for storage and flow attenuation. Structures G-370, G-434, and G-337A are used to route the flow to the two STAs.




| Cell | Cell Area (acres) |
|---|---|
| 1A | 3,052 |
| 1B | 3,504 |
| 2A | 2,533 |
| 2B | 2,888 (includes PSTA Project cells) |
| 3A | 2,444 |
| 3B | 2,114 |
| Total | 16,535 |

**Figure 2.** STA-3/4.
(Note: EAV – Emergent Aquatic Vegetation; PSTA – Periphyton-based Stormwater Treatment Area; SAV – Submerged Aquatic Vegetation.)

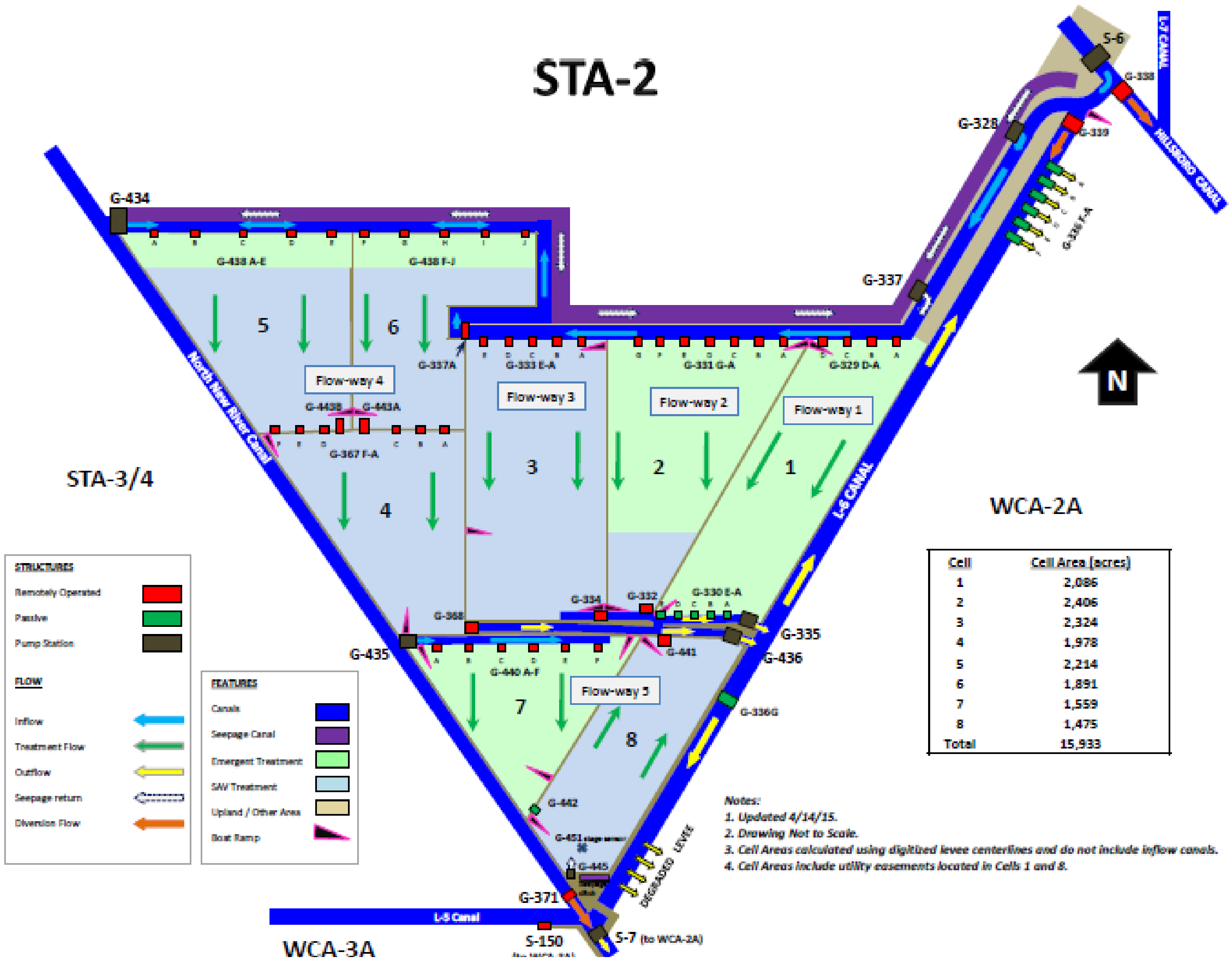



**Figure 3.** STA-2.
(Note: SAV – Submerged Aquatic Vegetation.)

## PROJECT DATA

Hydrologic data[1] were identified and compiled including flow, TP concentration, stage, rainfall, potential evapotranspiration (ETp), and other pertinent data to the Central Flow Path within the EAA. The data included three independent data sets, which all included historical rainfall and ETp. The first data set (January 1, 1965–December 31, 2005) included Regional Simulation Model- (RSM-; SFWMD 2005) simulated flow and stage, and Dynamic Model for Stormwater Treatment Areas- (DMSTA-; Walker and Kadlec 2005) simulated TP concentration. The second set (January 1, 2001–April 30, 2005) and the third set (October 1, 2014–May 31, 2005) included historical flow, stage, and TP concentration. The first data set that was initially used in this project was advantaged by its long period of record, however, DMSTA-simulated TP concentration and RSM-simulated stage and flows used for Hydrologic Model Emulator (HME) development had correlation and upscaling issues. The second data set (historical data) was then considered to be a more defensible product. The third data set (historical data) was used for the dry season application. All data sets are available upon request.

## IMODEL IMPLEMENTATION

The iModel architecture consists of the simulation engine (HME) development and the optimization engine (nonlinear optimization technique). The HME is based on an autoregressive model with exogeneous variables as defined below. The optimization engine is based on a genetic algorithm with a fitness function that minimizes outflow TP concentration to 13 micrograms per liter (µg/L) and stage to specified target values. See Ali (2009) and Ali (2015) for a detailed presentation about these techniques.

## HME DEVELOPMENT

Nine flow-ways were identified for HME development: three flow-ways for STA-3/4, five flow-ways for STA-2, and the A-1 FEB. Each of the nine flow-ways was defined in terms of inflow and outflow points, rain, ETp, inflow TP concentration and outflow TP concentration measurement points, stage locations, number of interior cells, and other modeling considerations. Using this compiled data, the HME and iModel formatted input files were constructed. A set of HMEs were then developed for each flow-way. The methodology developed by Ali (2009) was extended to include TP concentration (weekly flow-weighted mean [FWM]) as another primary variable (in addition to stage). For a given STA, the general formulation of HME is as follows:

$$\{\mathrm{Stg}_{t+1}, \mathrm{C}^{\mathrm{out}}_{t+1}\} = \phi(\mathrm{C}^{\mathrm{out}}_{t}, \mathrm{rain}_{t}, \mathrm{ET}_{t}, \mathrm{C}^{\mathrm{in}}_{t}, \mathrm{Q}^{\mathrm{in}}_{t}, \mathrm{Q}^{\mathrm{out}}_{t}) \tag{1}$$

The auto regressive with exogenous variable formulation (**Figure 4**) is as follows:

$$S - C\,|_{t+1} = \sum_{i=0}^{q-1} \Gamma_i u_{t-i} + \sum_{j=1}^{p} \Phi_j s_{t-j} + \nu + \omega_t \tag{2}$$

- $q,p$ → input and output maximum time delays (model orders)
- $n$, $m$ → number of state and exogenous variables
- $\boldsymbol{u}$ → $mxq$ residual exogenous input (inflow, inflow TP concentration, outflow, rainfall, and ETp) matrix
- ***S-C*** → $p \times n$ residual state variable matrix (stage and FWM outflow concentration)

[1] Data are from the South Florida Water Management District's corporate environmental database, DBHYDRO (http://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu), which was accessed in 2015.

- Γ → *nxm* exogenous coefficient matrix
- Φ → *p x p* state transition matrix
- $\nu$ → bias vector
- ω → random vector with zero mean and a covariance matrix

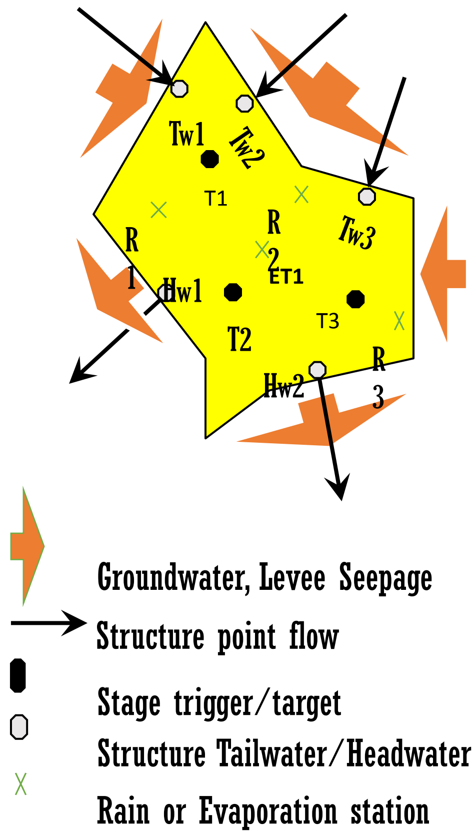



**Figure 4.** Schematic of the HME formulation.

Earlier efforts that considered DMSTA-simulated TP concentration as the basis for HME development did not produce satisfactory results. Subsequent efforts used historical data (January 1, 2001, through September 30, 2012) for HME development (the first development that was based on historical data).

## HME VERIFICATION

The above HME simulates both stage and concentration. To verify HME efficacy, we applied HME to a period of record (October 1, 2012, through July 1, 2015) that was not part of the development. We selected one site in STA-2 and another site in STA-3/4 to present HME performance for both stage and concentration one-step prediction. Results are shown in **Figures 5** and **6**. The figures clearly show reasonable predictions of both stage and TP concertation during the period of record with a relatively small standard estimation error compared to the overall time series variability. Other comparisons at different sites throughout the study area are available.

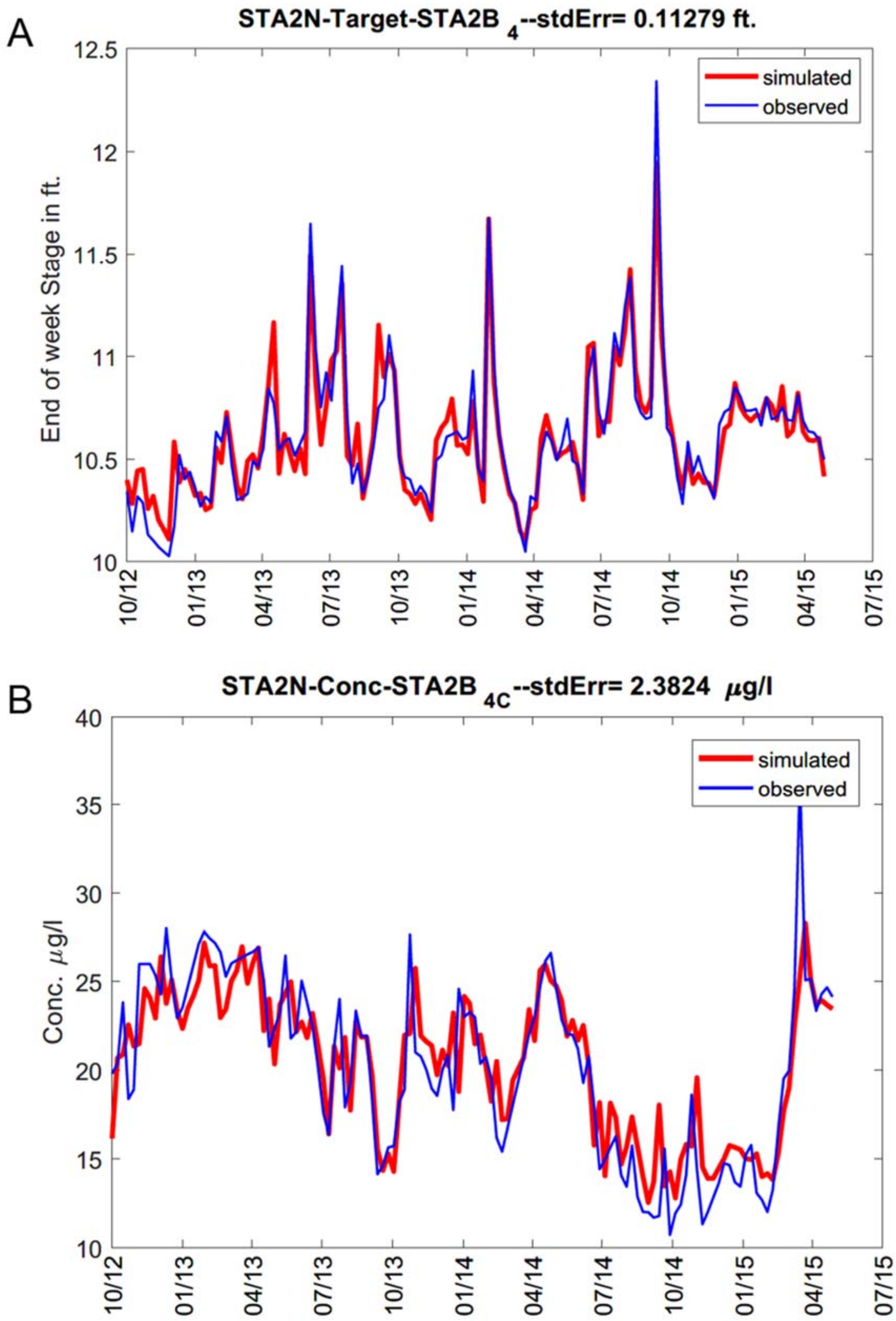



**Figure 5.** Observed and HME-predicted values at STA-2 Flow-way 4 outflow for (A) stage and (B) TP concentration. (Note: Conc. – Concentration, ft. – feet, and stdErr – standard error.)

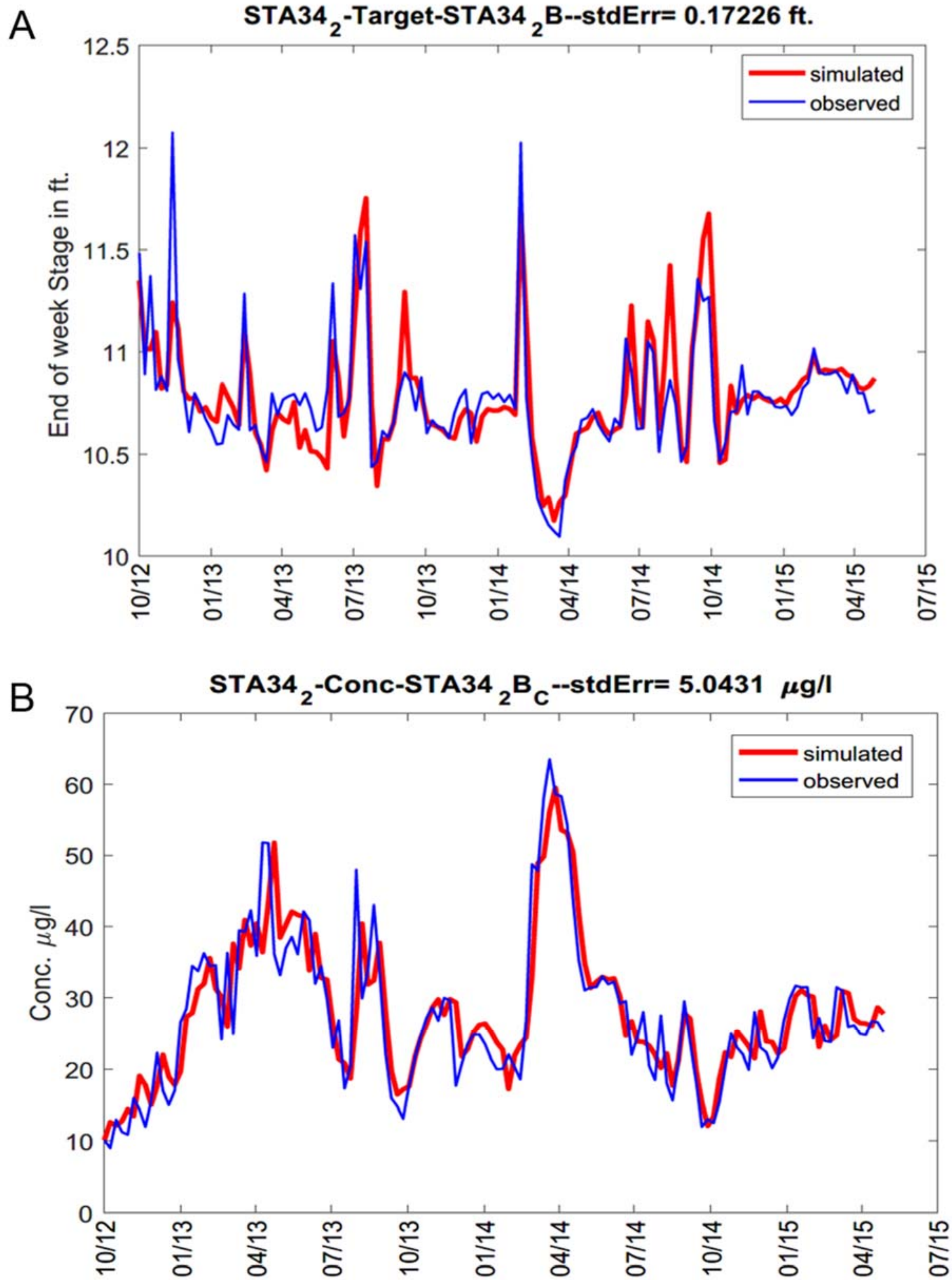



**Figure 6.** Observed and HME-predicted values for STA-3/4 Flow-way 2B outflow for (A) stage and (B) TP concentration. (Note: Conc. – Concentration, ft. – feet, and stdErr – standard error.)

## GENETIC ALGORITHM FITNESS SCORE (OBJECTIVE FUNCTION)

Genetic algorithm is one of the iModel adopted nonlinear optimization techniques that use the HME to develop optimal flow solutions to minimize annual average TP concentration. The goal is to help achieve the WQBEL of 13 µg/L through this flow optimization. If a TP loading rate (PLR) at an inflow or an outflow point represents a gene (or a component), the coding of all genes (all PLRs) into one string represents a chromosome (or PLR vector) that corresponds to a solution. The entire population of chromosomes represents a generation. Chromosome fitness, at time step t, is evaluated through the system's performance as represented by the above referenced HMEs and a user defined target according to the following objective function:

$$f(q) = \left| \begin{array}{l} \sum_{STAs} \left(C_i(q) - 13\right)^2, C_i(q) > 13 \\ 0, C_i(q) \leq 13 \end{array} \right. \quad (3)$$

Where C is the FWM concentration for each STA and 13 is the WQBEL.

## iMODEL CONSTRAINTS

The set of constraints that govern the HME performance in the optimization engine are defined as follows (see **Figure 7**):

1) Structure flow interrelationships (see **Figures 2** and **3**) are as follows:
   - G337A = Qeast - STA2
   - G434 + G337A = STA2N
   - G434 + G370 + STA2S = FEB_out + NNRCDIV
   - G370 + G372 = STA34 + Fbin
   - G335 + G441 + G368 ≤ 3,000 cfs
   - $q_i < \alpha * \Delta H^{\beta}$
2) Inflow concentration run time derivations are defined as follows:
   - $C_{in}$ for STA2 → $C_4 = BC_3$
   - $C_{in}$ for STA2S → $C_2 = \left(BQ_2 * BC_2 + Q_{feb}^{out} * C_{feb}^{out}\right) / \left(BQ_2 + Q_{feb}^{out}\right)$
   - $C_{in}$ for STA2N → $C_3 = \left(Q_{g434} * C_2 + Q_{g337A} * C_4\right) / \left(Q_{g434} + Q_{g337A}\right)$
   - $C_{in}$ for STA34 → $C_1 = \left(BQ_1 * BC_1 + Q_{g370} * C_3\right) / \left(BQ_1 + Q_{g370}\right)$
   - $C_{in}$ for FEB → $C_1$

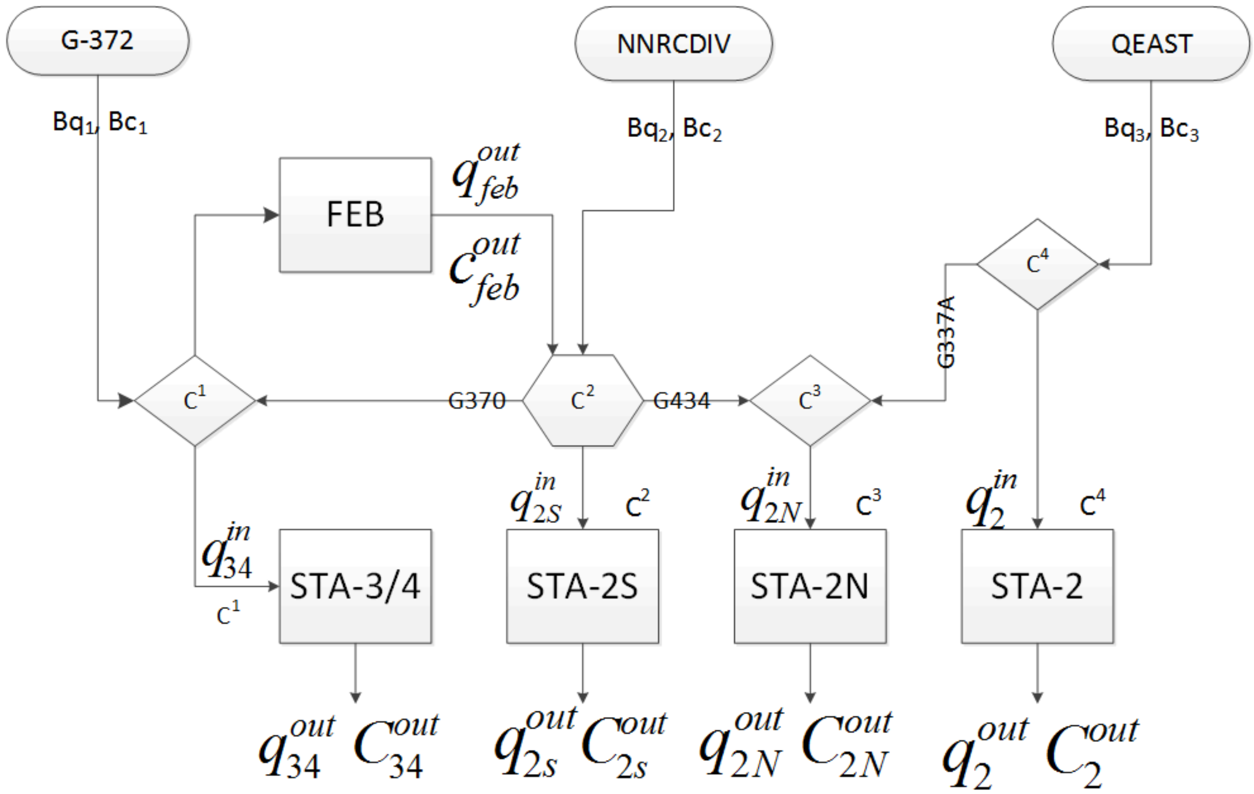



**Figure 7.** Flow routing schematic for the Central Flow Path.

## iMODEL APPLICATION

The iModel was applied to the above described system for the duration of the 2014–2015 dry season (October 1, 2014–May 31, 2015). The iModel output is a minimized FWM TP concentration for STA-2 and STA-3/4. Four runs were considered:

1. TP inflows from Lake Okeechobee and EAA runoff **without** utilizing FEB
2. TP inflows from Lake Okeechobee and EAA runoff **with** utilizing FEB
3. TP inflows from EAA runoff only **without** utilizing FEB
4. TP inflows from EAA runoff only **with** utilizing FEB

In each run, flow releases were optimized to achieve an outflow TP concentration below 13 µg/L and to meet a stage target for each cell. A key measure of the success of this optimization was to obtain a reasonably balanced water budget. All model inflow and outflow values were very similar to observed (data not shown). Any differences were attributed to other budget components plus budget error due to the imperfection of HME prediction.

# RESULTS

The iModel achieved average outflow concentrations were less than observed by between 2 and 30 percent (**Table 1**). For the scenario consisting of total inflow from Lake Okeechobee and EAA runoff under the existing conditions (without FEB), the concentration improvement for STA-2 was very small (0.3 µg/L) while the improvement was significant for STA-3/4 (3.9 µg/L). If the FEB is in place and the same amount of inflow is treated, a performance improvement of almost 2 µg/L was achieved for STA-2 with no improvement for STA-3/4 because the achieved concentration was already below 13 µg/L. When the amount of inflow was limited to EAA runoff less than 1 µg/L concentration reductions were achieved for STA-2 and STA-3/4, respectively, for the existing conditions (without FEB). This could be attributed to better water quality for the EAA runoff compared to the Lake Okeechobee water (i.e. the inflow concentrations used in this study). If the FEB is in place, and the flow is limited to EAA runoff only, the STA-2 achieved outflow concentration was reduced by 3 µg/L while STA-3/4 achieved outflow concentration was almost unchanged.

**Table 1.** Observed FWM TP concentrations (µg/L) for the STAs (October 1, 2014–May 31, 2015) and optimized iModel TP concentrations for four simulations.

| Category | | STA-2 | STA-3/4 |
|---|---|---|---|
| Observed Values | | 14 | 15 |
| iModel Achieved Concentration | Lake Okeechobee & EAA Run-off without FEB | 14 | 11 |
| | Lake Okeechobee & EAA Run-off with FEB | 12 | 11 |
| | EAA Runoff without FEB | 13 | 10 |
| | EAA Runoff with FEB | 10 | 10 |

Weekly achieved TP concentrations from iModel results vary between 7 and 16 µg/L for STA-2 (**Figure 8**) and 6 to 12 µg/L for STA-3/4 (**Figure 9**). There is a consistent improvement in achieved TP concentration for STA-2 when the FEB is included (**Figure 8**). The improvement is not clear for STA-3/4 since the achieved outflow concentrations already are below 13 µg/L (**Figure 9**). The reason is the iModel sacrifices more improvement of “already compliant” STA-3/4 to improve the performance of STA-2.

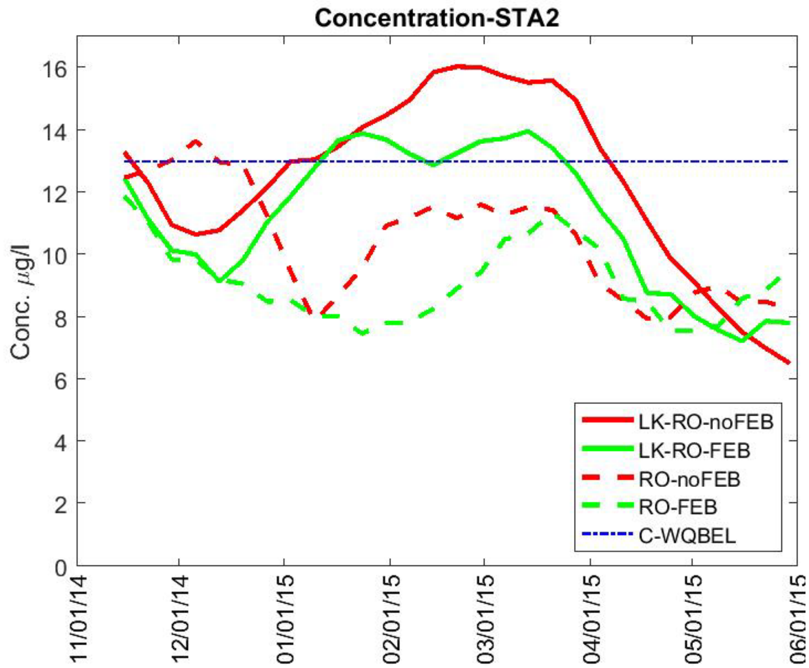



**Figure 8.** Weekly achieved FWM TP concentration for STA-2.
(Note: C-WQBEL – WQBEL criterion; Conc. – Concentration; LK-RO-FEB – Lake Okeechobee and EAA runoff with FEB; LK-RO-noFEB – Lake Okeechobee and EAA runoff without FEB; RO-FEB – EAA runoff with FEB; and RO-noFEB – EAA runoff without FEB.)

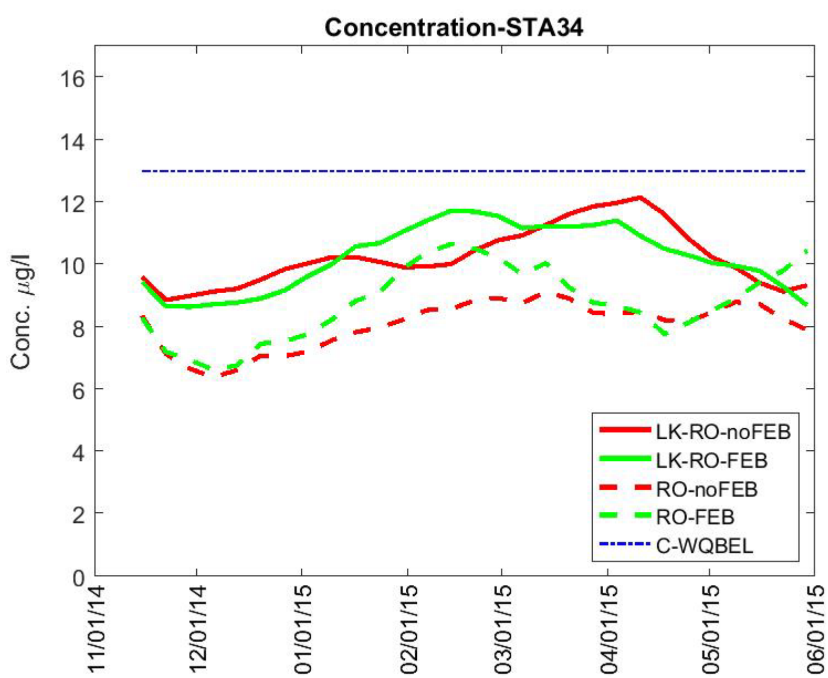



**Figure 9.** Weekly achieved FWM TP concentration for STA-3/4.
(Note: C-WQBEL – WQBEL criterion; Conc. – Concentration; LK-RO-FEB – Lake Okeechobee and EAA runoff with FEB; LK-RO-noFEB – Lake Okeechobee and EAA runoff without FEB; RO-FEB – EAA runoff with FEB; and RO-noFEB – EAA runoff without FEB.)

# CONCLUSIONS AND RECOMMENDATIONS

This study presented the first formal optimization scheme of the STA systems. The iModel-RSOPD was implemented to optimize the flow releases along the Central Flow Path of the FEBs and STAs to meet the WQBEL. Development of HMEs based on DMSTA-simulated concentration and RSM-simulated flows and stages did not produce satisfactory results primarily due to the difference between the two models and the upscaling/downscaling requirements. For the first time, historical data have been used for HME development. Results show a good performance for stage prediction and promising performance for concentration that requires further understanding. The iModel results showed the efficacy of the simulation-optimization tool in managing an FEB/STA system and providing measurable and consistent improvement in the outflow TP concentration as an FEB is introduced to the system.

iModel-RSOPD development faced many challenges due to the high uncertainty associated with TP concentration resulting from many sources. Concentration data measurement frequencies and methods of acquisition required additional layers of processing to be ready for usage. The complexity of the settling uptake process coupled with weak correlation between TP inflow loading rate and TP outflow loading rate significantly increased modeling uncertainties. The use of the RSM/DMSTA-simulated data for HME development was problematic due to the difference in how hydrology was handled in both models, resulting in high budget HME residuals for concurrent prediction of both stage and TP concentration. RSM/DMSTA simulated data were replaced with historical data making the iModel-RSOPD the first iModel version ever developed based solely on historical data. The shortcoming of using historical data was the assumption of a static system over the entire period of record. Budget residuals have been recognized and incorporated in the HMEs as another predictor. The new HME (based on historical data and with budget residuals being predicted) showed prediction improvement, but the goodness of fit for TP concentration prediction remained low compared to that of stage prediction. While the HME shows performance superiority in recursive prediction of stage, it fails to control error propagation for recursive TP concentration prediction.

Given the progress made in this project, the end user may use the iModel-RSOPD for weekly evaluation of flow releases at the inflow and outflow points. Input requirements are stage at the beginning of the week, weekly PLR, weekly hydraulic loading rate (HLR), rainfall, and ETp. The iModel-RSOPD outputs optimal flow releases and the associated stage and the achieved outflow concentration towards achieving the WQBEL at the downstream end of the Central Flow Path. These flow releases can then be adjusted by water managers with input from other stakeholders for other practical considerations.

While the iModel results are promising, this implementation exercise reveals needs for improvement on many fronts if the tool is to be useful for operational optimization to achieve the WQBEL. Water quality data that is being collected and analyzed as part of other Restoration Strategies Science Plan Studies, in particular the Evaluation of Phosphorus Sources, Forms, Flux, and Transformation Processes in the STAs, also known as the P Flux Study, (Appendix 5C-3 of this report) can be used to improve the prediction capabilities of the iModel.

Longer-term modeling plans need to expand on water quality research and modeling activities and to explore additional variables, such as calcium, nitrogen, dissolved organic carbon, chlorophyll, and iron that can improve TP concentration predictability. Also, more accurate models shall consider the temporally varying characteristics of the treatment cells.

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