Modeling Spatio-Temporal Phosphorus Cycling in a South Florida Treatment Wetland

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Introduction

Phosphorus (P) enrichment in agricultural runoff comparing to historic inputs has adverse impacts on the ecosystem of the Florida Everglades. As part of the restoration strategies, South Florida Water Management District (SFWMD) has built and operated large treatment wetlands called Stormwater Treatment Areas (STAs) to reduce the P concentration in runoff before it enters the Everglades. It is necessary to gain an understanding of the P removal mechanisms and their interactions to operate and optimize the long-term P removal performance in the STAs. To facilitate optimization of P removal in these STAs, we have developed a mathematical model that can describe the transport and cycling of P within the wetland system. In this study, an integrated modeling framework has been constructed coupling hydrologic and biogeochemical models for marsh wetland systems to examine model performance in predicting total P removal in Cell 4 of Stormwater Treatment Area 1West (STA 1W).

Study Site Description

STA 1W is located in central Palm Beach County, along the northwestern boundary of Water Conservation Area 1 (WCA-1) and on the eastern boundary of the Everglades Agricultural Area (EAA). The STAs are used as buffers to reduce concentrations of nutrients such as P from EAA runoff before entering the adjacent WCA-1 and the Everglades. Most of the year, STA 1W is flooded and the dominant mechanism for flow and transport is overland flow. STA 1W is divided in four different cells by levees. Cell 4, a wetland dominated by submerged aquatic vegetation (SAV), is 147 hectares and receives water from Cell 2 (Figure 1).

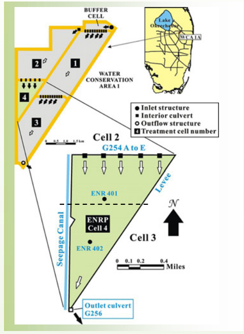


Figure 1. Location map

Submerged aquatic vegetation

Simulation Methodology

This study builds on the Regional Simulation Model – Water Quality (RSM-WQ) to simulate the transport and transformation of total P in Cell 4 of STA1W. Hydrology is provided through the linkage with the South Florida Regional Simulation Model (SFRSM). The RSM-WQ is the linked-library model that is run with Hydrologic Simulation Engine (HSE) of SFRSM. HSE is capable of simulating two-dimensional flow in unstructured triangular mesh (Lal et al., 2005) in response to the variety of forcing functions. The RSM-WQ solves the advection-dispersion-reaction equation using a time-split Godunov mixed finite element method (James and Jawitz, 2007). It is divided in two components: (1) transport of mobile materials (both reactive and non reactive) in variable-depth flow, and (2) flexible biogeochemistry module that allows the model user to incorporate wide range of user selectable mechanisms, define state variables and process equations.

A simple P model is used here to simulate P cycling that describes the exchange between total P in water column and total P in the soil. All the process parameters are lumped into a single uptake (k_{st}) and release (k_{rs}) parameter.

$$\frac{dC_{sw}^{P}}{dt} = -k_{st}C_{sw}^{P} + \frac{k_{rs}}{d}S_p$$

$$\frac{dS_p}{dt} = k_{st}dC_{sw}^{P} + k_{rs}S_p$$

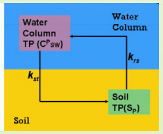


Figure 2. Simple P model

Model Setup

The land surface elevation was obtained from the topographic survey data using inverse-distance weighting interpolation scheme and assigned a unique value for each element. The hydro-meteorological data such as flows, water levels, precipitation, potential evapotranspiration (ET) and P concentration data used in the model were collected by SFWMD and are available on the online environmental database, DBHYDRO (http://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu). Northern and eastern boundaries of the model domain were assigned as no flow boundary conditions for both overland and groundwater flow. A source boundary condition was assigned to inflows and a wall prescribed head boundary condition was specified at outlet culvert structure which discharges water from Cell 4. Seepage out from the model domain was estimated by using cell general head boundary condition across the western levee. In all, finite element mesh contains 298 elements and 179 nodes.

Elevation and Vegetation Maps

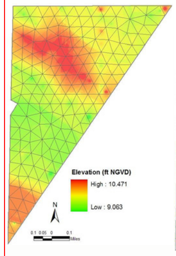


Figure 3. Surface elevation (ft NGVD)

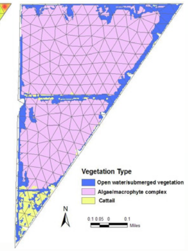


Figure 4. Vegetation type

Hydrodynamic Calibration

Hydrodynamic calibration was performed to match the non-reactive tracer study conducted in December 1999 to January 2000 by Dierberg et al., 2005. This calibration was performed in two steps in order to match the temporal tracer breakthrough curve at outlet boundary: (1) sensitive hydrodynamic model parameters such as empirical constants of effective roughness coefficient and ET vegetation crop coefficient were determined as a function of land-use, and (2) horizontal and transverse dispersivity were adjusted to match tracer distribution. The simulated outflow was further compared with historic outflow data from 1995 to 2000 (Figure 8).

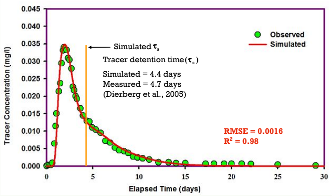


Figure 5. Simulated and observed tracer response curve

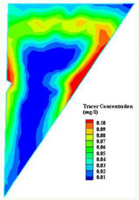


Figure 6. Snapshot of the tracer simulation after 27 hours of injection

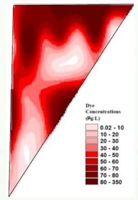


Figure 7. Observed tracer concentration for the 27 hours elapsed time

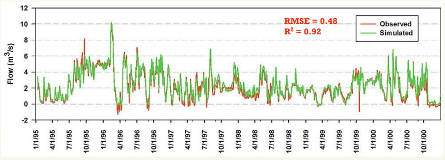


Figure 8. Comparison of simulated and measured flow rate at outflow culvert

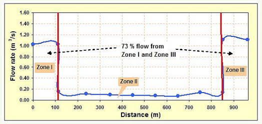


Figure 9. Computed flow rate across the transect (Figure 1)

Preferential flow paths are easily identified (Figure 6) along the levee, that is the evident of short-circuiting and attributable to the relict ditches and borrow canals (Dierberg et al., 2005). Simulated flow rate across the transect shows that the seventy percent or more of the inflow of water to the Cell 4 passes through the zones adjacent to levees (Figure 9).

Transport Simulation

Transport component of the RSM-WQ is validated by comparing historic data of chloride concentrations from 1995 to 1999, obtained from DBHYDRO at two monitoring stations (ENR401 and ENR 402). Calibrated model parameters obtained from the hydrodynamic simulation were used to simulate chloride concentration.

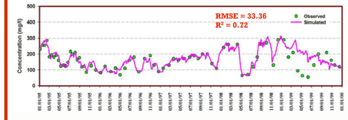


Figure 10. Simulated and observed chloride concentration in water column at ENR 401

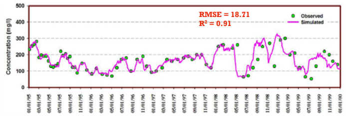


Figure 11. Simulated and observed chloride concentration in water column at ENR 402

Phosphorus Simulation

- Historical total P concentration from 1995 to 2000 were used to simulate transport and uptake of total P within Cell 4
- The initial soil total P content of 8.3 g/m^2 was used based on the study of soils within STA 1W (Reddy and Graetz, 1991) prior to construction
- Spatially distributed uptake and release parameters were assigned to account short-circuiting flow zones, and these parameters were calibrated to total P outflow data for 1995 to 1997 and validated for 1998 to 2000

Results

Parameter values of k_{st} = 1.88 x 10^{-6} s^{-1} (1.62 x 10^{-1} day^{-1}) for short-circuiting flow zones and 2.47 x 10^{-6} s^{-1} (2.13 x 10^{-1} day^{-1}) for SAV and cattail zones and k_{rs} = 2.28 x 10^{-9} s^{-1} (1.97 x 10^{-4} day^{-1}) were chosen to match the first three years (1995 – 1997) of outflow data (Figure 12). To ensure the model's robustness the validation was performed to the data set of subsequent three years (Figure 13).

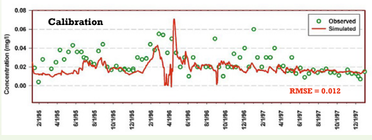


Figure 12. Simulated and observed total P in water column (1995-1997)

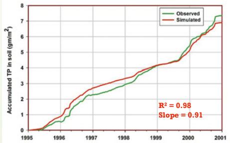


Figure 14. Cumulative observed and simulated accumulated total P in soil

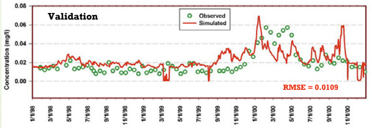
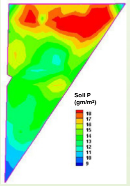


Figure 13. Simulated and observed total P in water column (1998-2000)

Figure 15. Soil P at the end of simulation period (31 December 2000)



Conclusion and Future Works

Since the simple P modeling framework developed in this study is capable of simulating chloride and P levels, both spatially and temporally and the generally good agreement found in these comparisons between observed and computed results, RSM-WQ may provide a valuable predictive tool for P dynamics in marsh-wetland system. Future works will be focused on evaluating the model's predictive performance with additional level of complexities of P transport and cycling processes. Using this calibrated model as a basis, simulation will be undertaken to evaluate different management scenarios that will provide a valuable management tool, primarily to operate STAs and maximize P removal under different hydrologic and P loading conditions.

References

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