Phosphorus Dynamics Modeling of Emergent and Submerged Aquatic Vegetation-based Treatment Wetlands in South Florida

Joong-Hyuk Min[1] and William R. Wise[2]

[1]Soil and Water Science Department, University of Florida, Gainesville, FL, USA
[2]Department of Environmental Engineering Sciences, University of Florida, Gainesville, FL, USA

UF UNIVERSITY of FLORIDA
The Foundation for The Gator Nation

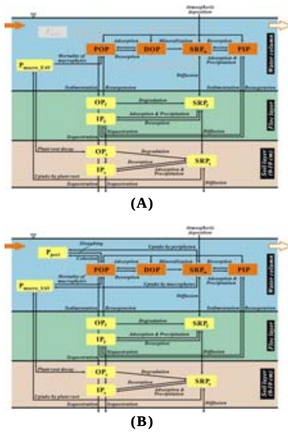
Introduction

The primary goal of Stormwater Treatment Areas (STAs) in South Florida is to remove phosphorus flowing into the Everglades. For optimizing the design and long-term management of constructed wetlands, input-output mass balance or first-order kinetic modeling approaches have been used successfully. However, these applications are limited to predict performance of the treatment wetlands under varied conditions such as altered hydroperiod and vegetation type/density, because these models are not based on transient flow dynamics. In addition, due to the internal complexity of treatment wetlands and the lack of data on each ecosystem compartment, systematical phosphorus dynamics modeling efforts, coupled with hydrodynamics and transport models, have been rarely reported on these large-scaled, subtropical constructed wetlands.

Objectives

- To construct a two-dimensional (2-D), spatially distributed phosphorus dynamics model for emergent (EAV) and submerged aquatic vegetation (SAV)-based treatment wetlands in South Florida.
- To calibrate and validate the model, linked with a flow dynamics and transport model, against data on water column phosphorus species (SRP, DOP, and PP) collected from the northern flow-way of STA 5.
- To determine the significant processes regulating water column phosphorus concentration through sensitivity test of the estimated key model parameters.

Schematization of Phosphorus Dynamics



(A)

(B)

Fig. 1. Diagrams of P dynamics in large-scaled, subtropical constructed wetlands: (A) EAV- and (B) SAV-based treatment systems.

Model scope

- P dynamics in floc layer was assumed to play a critical role in regulating the level of P species in water column.
- Phytoplankton P was not considered because it was sparse in water samples collected from the northern Everglades (McCormick et al., 1998).
- Benthic periphyton was not considered because the biomass was low in open water areas of eutrophic sites and undetectable in cattail stands in the northern Everglades (McCormick et al., 1998).
- Deep soil layer was not considered.
- Ratio between input PIP and POP concentration was assumed to be 0.3:0.7, which originated from the average ratios between IP and OP in floc and upper soil layers of STA 1W and WCA 1A (Pant and Reddy, 2001; Constanje et al., 2006; White et al., 2006).
- For most of the transformation processes, first-order kinetics formulation was used; for the growth rate of macrophytes and periphyton, Michaelis-Menten kinetics was incorporated.
- The model consists of 12 state variables, 34 processes, 56 constants, and 3 forcing functions. Of the state variables, only 4 in water column are mobile (orange colored state variables in Fig. 1).

Study Area

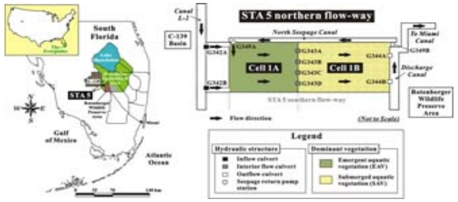
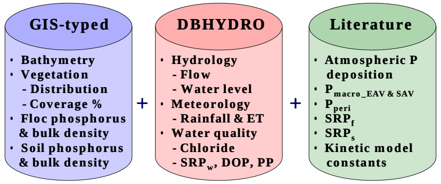


Fig. 2. Location map of STA 5 northern flow-way and the schematic showing the flow, hydraulic structures, and vegetation.

Model Setup

- Modeling framework: DHI ECO Lab (WQ/ecological module).
  - Linked with a depth-averaged, spatially distributed hydrodynamics-transport model (MIKE 21), which was pre-calibrated and validated with contemporary water level and chloride concentration profiles at the study area (not presented here).
- Simulation period: May 1, 03 to Dec. 31, 04 (1.67 yrs).
- Simulation condition: 100 by 100 m rectangular grid cells (# 969) with time step of 10 min.
- Numerical integration scheme: Euler method.
- P data: weekly or biweekly grab samples (DBHYDRO).



GIS-typed
- Bathymetry
- Vegetation
  - Distribution
  - Coverage %
- Floc phosphorus & bulk density
- Soil phosphorus & bulk density

\+

DBHYDRO
- Hydrology
  - Flow
  - Water level
- Meteorology
  - Rainfall & ET
- Water quality
  - Chloride
  - SRP_w, DOP, PP

\+

Literature
- Atmospheric P deposition
- $P_{macro\_EAV \& SAV}$
- P_{peri}
- SRP_f
- SRP_s
- Kinetic model constants

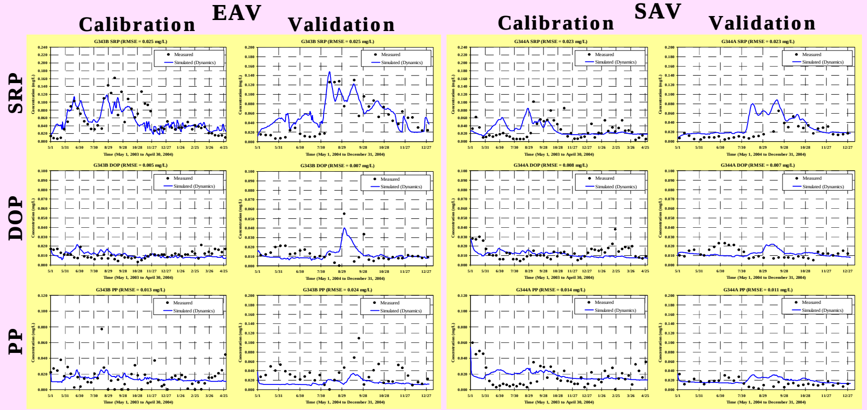
Fig. 3. Data used in the model.

Table 1. Differences of P dynamics model between EAV and SAV systems.

	EAV system	SAV system	Source
State variable			
Periphyton	Not considered	0.021 g/m³	McCormick et al. (1998)
Macrophyte	0.580 g/m³	0.173 g/m³	White et al. (2006)
Average floc TP	958.5 mg/kg	675.8 mg/kg	Pietro et al. (2006)
Average soil TP	466.1 mg/kg	510.2 mg/kg	Pietro et al. (2006)
Processes			
SRP_w uptake by macrophyte in water column	Not considered	Dominant	
SRP_s uptake by macrophyte root in soil layer	Dominant	Minimal	
Macrophyte root decay	Considered	Considered	
SRP_w uptake by periphyton in water column	Not considered	Considered	
P_{peri} decay (periphyton sloughing)	Not considered	Considered	
P_{peri} form (periphyton cohesion)	Not considered	Considered	
Ca-P coprecipitation via periphyton	Not considered	Considered	
Constants used in phosphorus dynamics model			
k_decay3 ($P_{peri} \rightarrow$ POP)	0	0.1	Calibration
k_decay4 ($P_{macro} \rightarrow$ POP)	0.01	0.02	Calibration
k_decay6 ($P_{macro} \rightarrow OP_s$)	0.002	0.004	Calibration
k_form2 ($SRP_w \rightarrow$ PIP)	0.02	0.12	Calibration
k_form3 (POP $\rightarrow P_{peri}$)	0	0.05	Calibration
k_{g}*_macro* (Macrophyte max. growth rate)	0	0.06	Calibration
k_{g}*_peri* (Periphyton max. growth rate)	0	0.15	Calibration
k_{s}*_macro* (Macrophyte uptake half satur. const.)	0	0.1	Calibration
k_{s}*_peri* (Periphyton uptake half satur. Const.)	0	0.05	Calibration
frac_root (Root fraction of macrophyte)	0.667	0.05	Davis (1984)/White et al. (2006)
Average floc bulk density	0.05 kg/L	0.11 kg/L	Pietro et al. (2006)
Average soil bulk density	0.69 kg/L	0.40 kg/L	Pietro et al. (2006)
f_seq1 (Sequestration flux of IP_f into IP_s)	0.0008 g/m²/d	0.0001 g/m²/d	Calibration
f_seq2 (Sequestration flux of OP_f into OP_s)	0.0008 g/m²/d	0.0001 g/m²/d	Calibration
f_seq3 (Sequestration flux of IP_s into deep soil)	0.0044 g/m²/d	0.0025 g/m²/d	Turner et al. (2006)
f_seq4 (Sequestration flux of OP_s into deep soil)	0.0015 g/m²/d	0.0003 g/m²/d	Turner et al. (2006)

Results

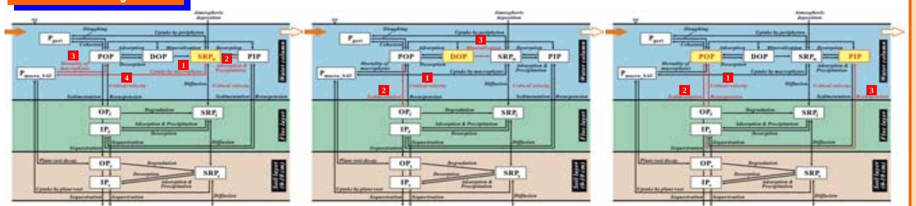
Phosphorus dynamics simulation



(A) (B)

Fig. 4. Model calibration and validation results on phosphorus concentration profiles at the outlet monitoring point of EAV- and SAV-based treatment cells: (A) G343B and (B) G344A.

Sensitivity test



(A) (B) (C)

Fig. 5. Sensitivity test results of water column phosphorus on the kinetic model constants: (A) SRP_w, (B) DOP, and (C) PP.

Discussion and Further Study

- Key model constants, not extensively studied in STA-typed wetlands, were obtained and the spatio-temporal variation of water column P level observed in the field was predicted reasonably well.
- Sensitivity test shows that the model constants related to sedimentation/resuspension processes, including critical velocity (5 cm/s), are most sensitive for water column P species in the flow-way.
- To develop more robust phosphorus dynamics model, in-depth studies on phosphorus cycling and extensive data collecting efforts are imperative for the following topics:
  - Uncertainty of the model parameters on spatio-temporal variations of mass transfer mechanisms between water column and floc layer makes it difficult to predict physical processes in phosphorus retention, particularly PP behavior.
  - To fully simulate the dynamics at the entire ecosystem level, not just focused on the behavior of water column phosphorus, it is necessary to collect time series field/lab data on the various P compartments, such as floc/soil and vegetation (EAV, SAV, and periphyton), at several locations in a treatment cell.