SENSITIVITY ANALYSIS OF TOTAL PHOSPHORUS IN A WETLAND BIOGEOCHEMICAL MODEL

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Background

The Everglades is a subtropical oligotrophic wetland that historically received phosphorus (P) inputs through atmospheric deposition (Davis et al., 1994; Noe et al., 2001). Numerous factors over the past century, including urban and agricultural development, have degraded this ecosystem such that only 50% of the Everglades' extent remains today (Chimney and Goforth, 2001; Entry, 2014). P enrichment from agricultural runoff has led to changes in its ecosystem structure and function including water quality issues, fish kills, changes in food webs, and shifts in vegetation composition (Davis et al., 1994; Mitsch et al., 2015; Smith et al., 2009). This led to the establishment of the Comprehensive Everglades Restoration Plan (CERP), and the construction of six stormwater treatment areas (STAs) to reduce the concentration of P from waters entering the Everglades Water Conservation Areas (USACE and SFWMD, 2000). Over the past 20 years, these STAs have removed ~75% of total Phosphorus (TP) inflow loads (Mitsch et al., 2015; Pietro, 2012). While these STAs have brought TP concentrations close to the 50ppb goal from the Everglades Forever Act, efforts continue to enhance treatment efficiency to further reduce TP concentrations (to 13ppb) in these constructed wetlands.

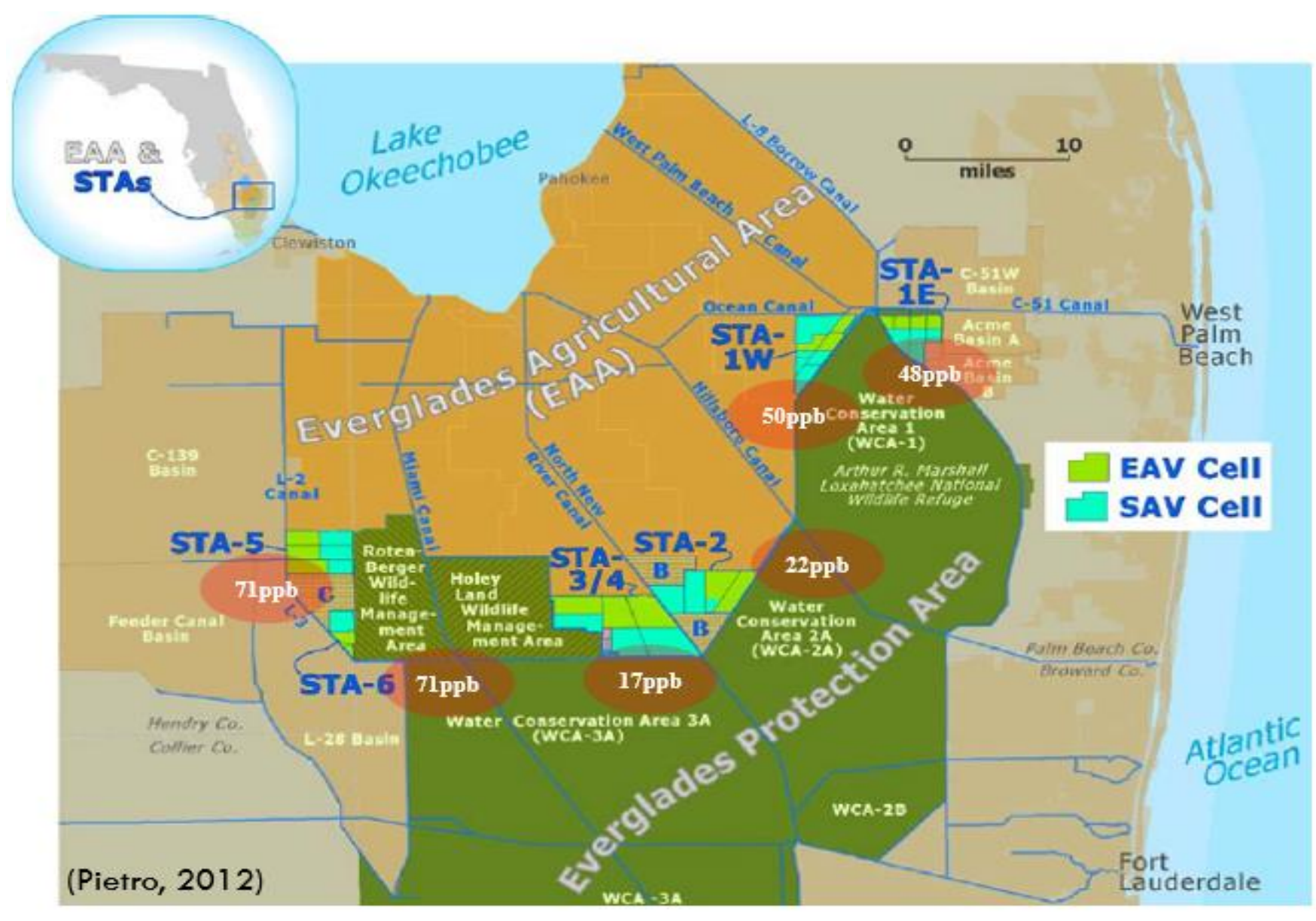


Fig. 1 Location of the six stormwater treatment areas (STAs) in the Everglades Protection Area. The concentrations within the red circles are the geometric mean total phosphorus (TP) outflows for each STA from 1996-2012 (Pietro, 2012). Emergent aquatic vegetation (EAV) and submergent aquatic vegetation (SAV) cells are identified in each of the STAs.

Purpose

Wetland Biogeochemical models are tools that help to understand nutrient cycling in these STAs. With these models, monitoring station data collected at different spatial and temporal scales could be linked. This could help identify or prioritize future data needs in order to evaluate and predict the STAs' performance with respect to nutrient removal. *Here, we set out to identify what processes are influencing the predicted total P (TP) concentration at the outflow of an STA in a model.*

Objectives:

Conduct a global sensitivity analysis (GSA) on a TP wetland biogeochemical model similar to Paudel and Jawitz (2012) to identify:

I. which model parameters contribute the most to TP variance output (direct effects)
II. when considering direct effects and interactions which input parameter contributes the most to TP variance output
III. if these results change with a 10-fold decrease in annual loads or a higher base release of P from pre-STA soil

Global Sensitivity Analysis (GSA)

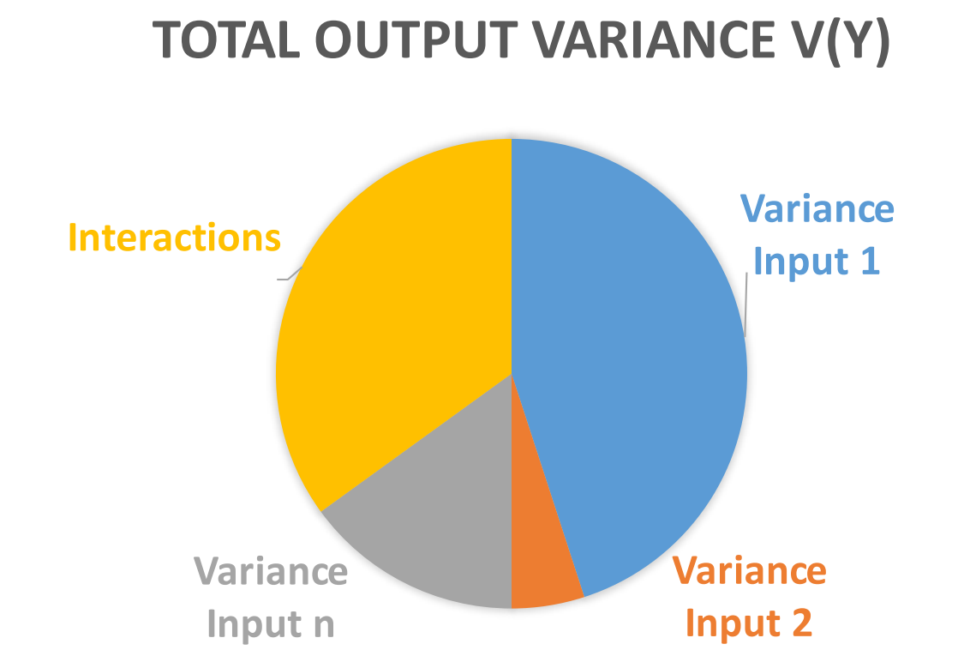
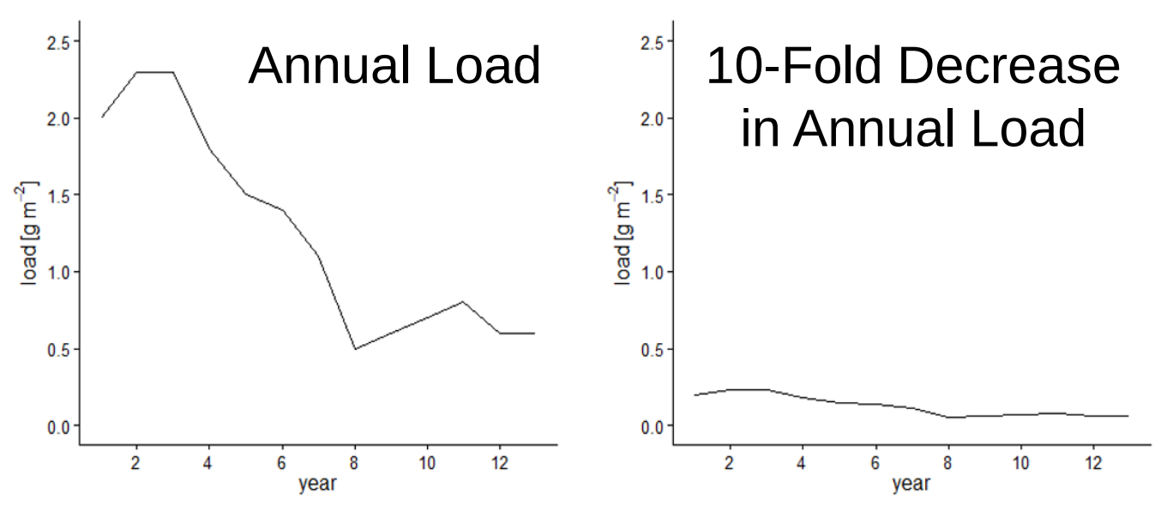


Fig 3. Total variance V(Y) of an output is equal to the sum of the variance contribution of each model input and the contribution of interactions between model inputs to the total variance.



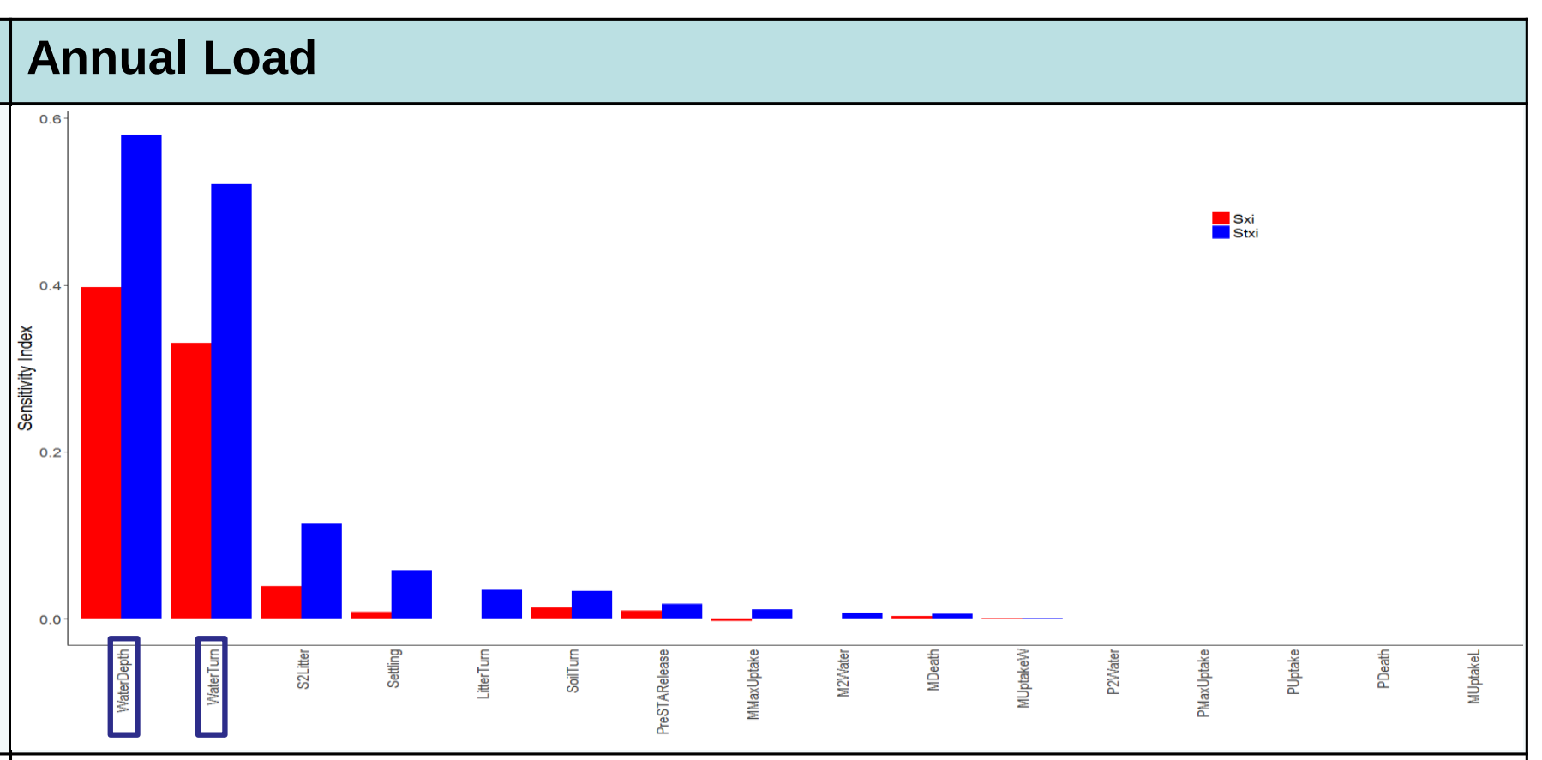
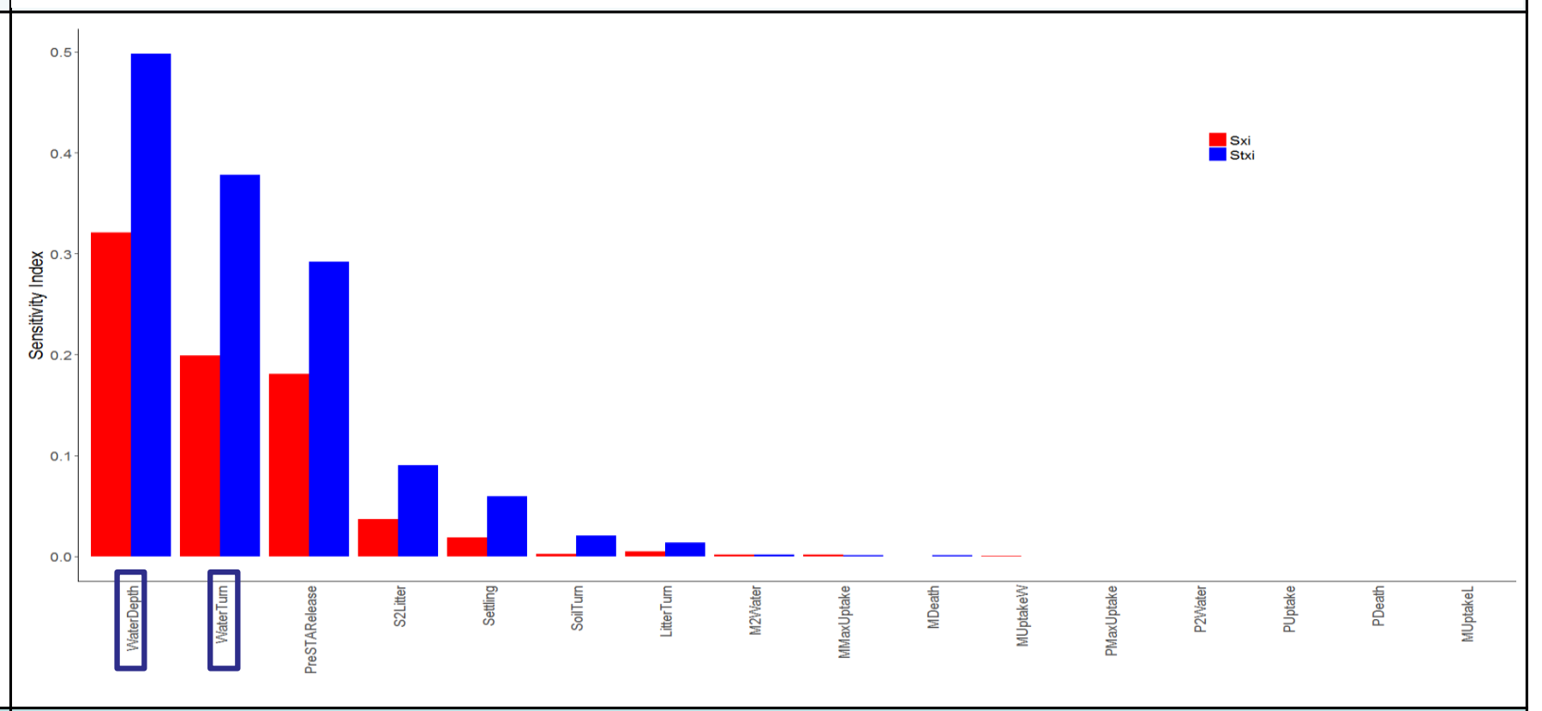
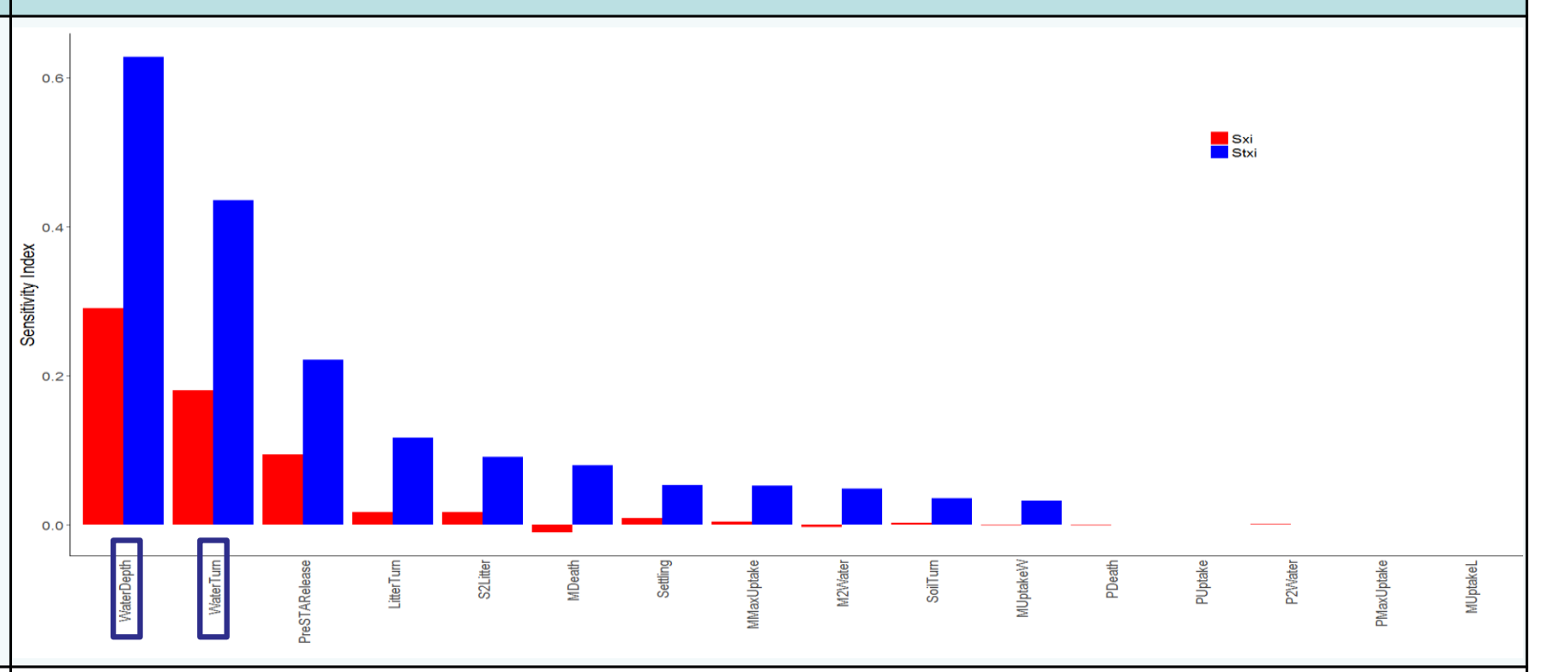
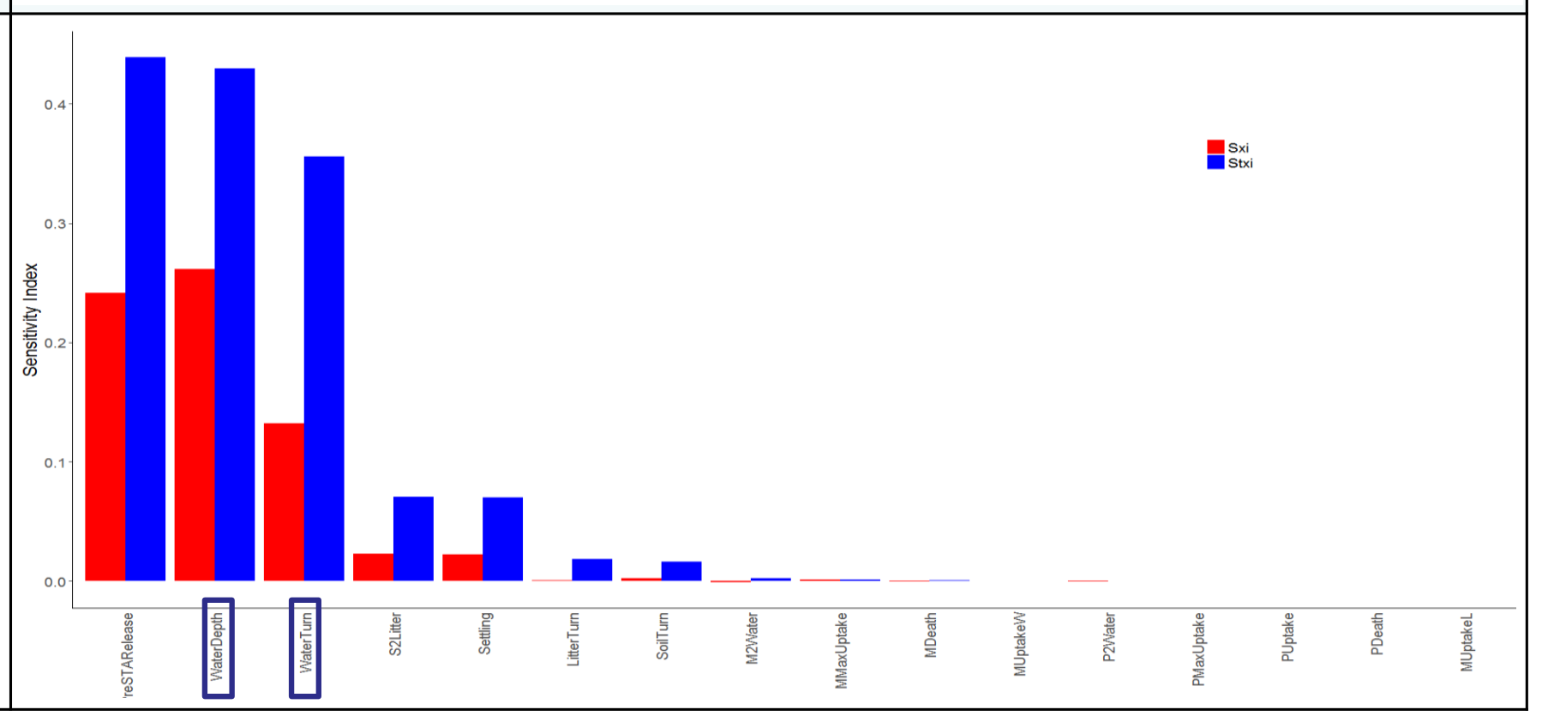
Eq. 1 $$S_{xi} = \frac{V_{x_i}\left(E_{\mathbf{X}_{\sim i}}(Y \mid X_i)\right)}{V(Y)}$$

Eq. 2 $$S_{txi} = \frac{E_{\mathbf{X}_{\sim i}}\left(V_{x_i}(Y \mid \mathbf{X}_{\sim i})\right)}{V(Y)}$$

- S_{xi} is the reduction in expected variance if a input parameter is fixed and the rest vary (factor of 3 in our case)
- S_{txi} is the expected variance remaining if a parameter varies while the rest of the parameters are fixed (Saltelli et al. 2010; Wainwright et al. 2014).
- Analysis was repeated for 10-fold decrease in base release of P in pre-STA soil (3.3e-4 g P/m²/day and 4.0e-3 g P/m²/day)
- Analysis was repeated for ten fold decrease in prescribed annual load.

GSA Results

1. **There is a strong sensitivity with water dynamic parameters: water depth and hydrologic residence time (i.e. average flow velocity)**
2. **This is true regardless of a ten-fold change in annual loads and base release of P from soil.**

	Annual Load
Base release of P from pre-STA soil of 3.3e-4 g P/m²/day	
Base release of P from pre-STA soil of 4.0e-3 g P/m²/day	
	Ten-Fold Decrease in Annual Load
Base release of P from pre-STA soil of 3.3e-4 g P/m²/day	
Base release of P from pre-STA soil of 4.0e-3 g P/m²/day	

Conclusions

- Base release of P in pre-STA soil is also a sensitive parameter, alluding to the importance of legacy phosphorus
- The parameter variations (factor of 3 for each of the parameters) created a significant variability in outlet TP concentration (between 5.3 and 423 µg L^{-1}, 95 % confidence interval).

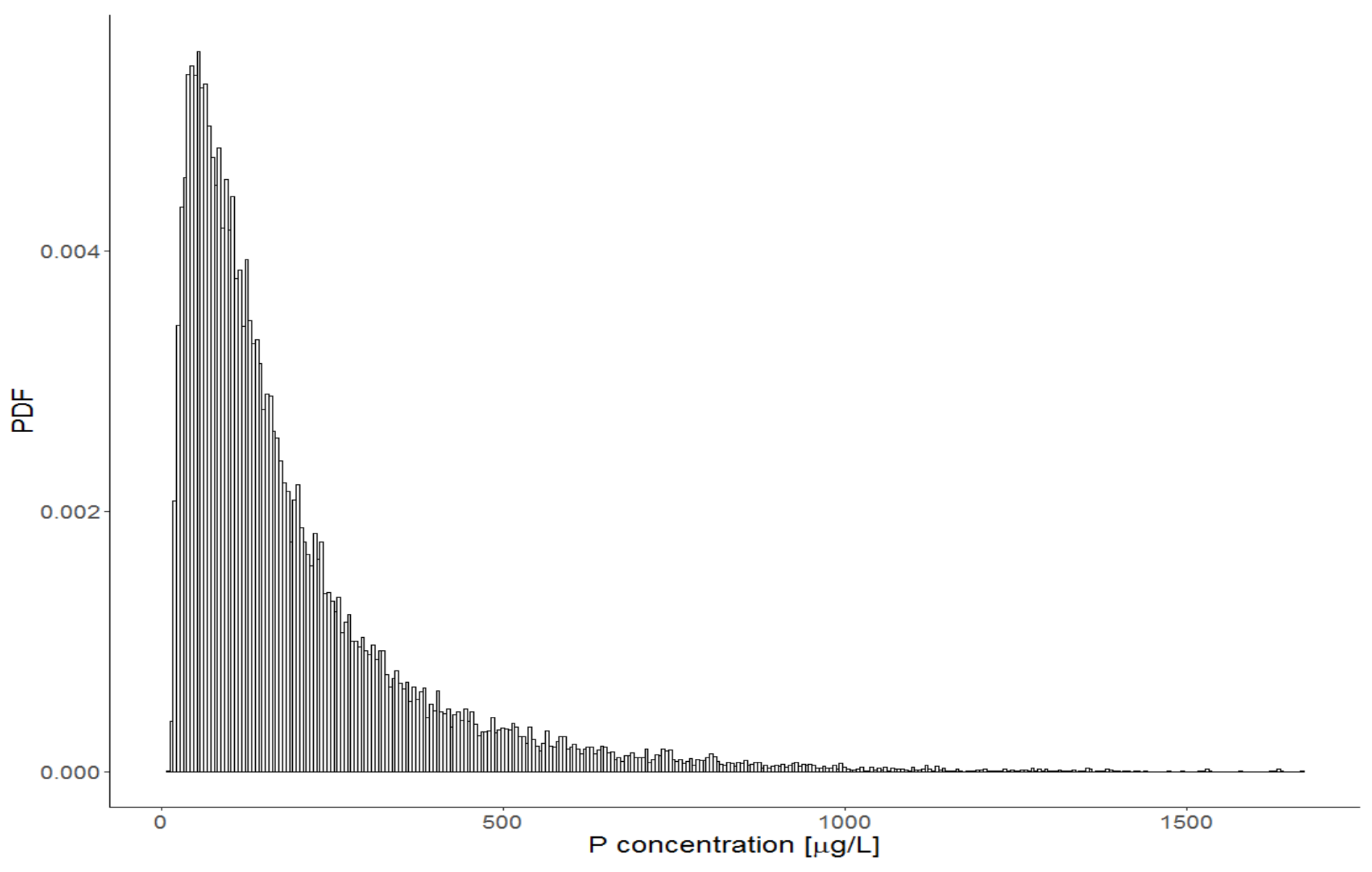


Fig 4. Probability distribution function (PDF) for outlet TP from GSA with base release of P from pre-STA soil of 3.3e-4 g P/m²/day and prescribed annual load.

- If water dynamic parameters (water depth and flow velocity) can be constrained (fixed) about 40-70% of variance in TP could be reduced.
  - S_{txi} tells us that if we constrained (fixed) values for other parameters and not water dynamic parameters, a large expected variance for TP would still exist.
- Our preliminary work that integrates over a long time of wetland operations suggests that contact time of P with reactive surfaces and the combined internal and external load are key factors for P removal.
- Here we treated water column depth and hydrologic residence time as independent variables, but they are likely correlated.

Assuming Steady State Conditions:

$$Residence\ Time = \frac{Reservoir\ Volume}{Inflow\ Rate\ or\ Outflow\ Rate}$$

$$= \frac{Surface\ Area \times Water\ Column\ Depth}{Inflow\ Rate\ or\ Outflow\ Rate}$$

Future Work

1. Water dynamic parameters display a strong sensitivity. These parameters set the potential contact time between water and P removal surfaces and dilute P sources. Thus, hydrologic residence time along the flow path is critical information needed to improve model.
2. Estimate internal loading in our model, particularly in emergent macrophytes.
   - Emergent macrophytes' network of roots and rhizomes readily uptake phosphorus and nitrogen. They have great potential for storage of these nutrients (Reddy et al. 1999).
   - Emergent macrophytes contribute to internal loading thru biomass turnover. 1) Uptake P through roots 2) Translocate root P to shoots and leaves 3) Senescence leading to leaching of P from shoots and leaves to the water column (Reddy et al. 1999).

TP Wetland Biogeochemical Model

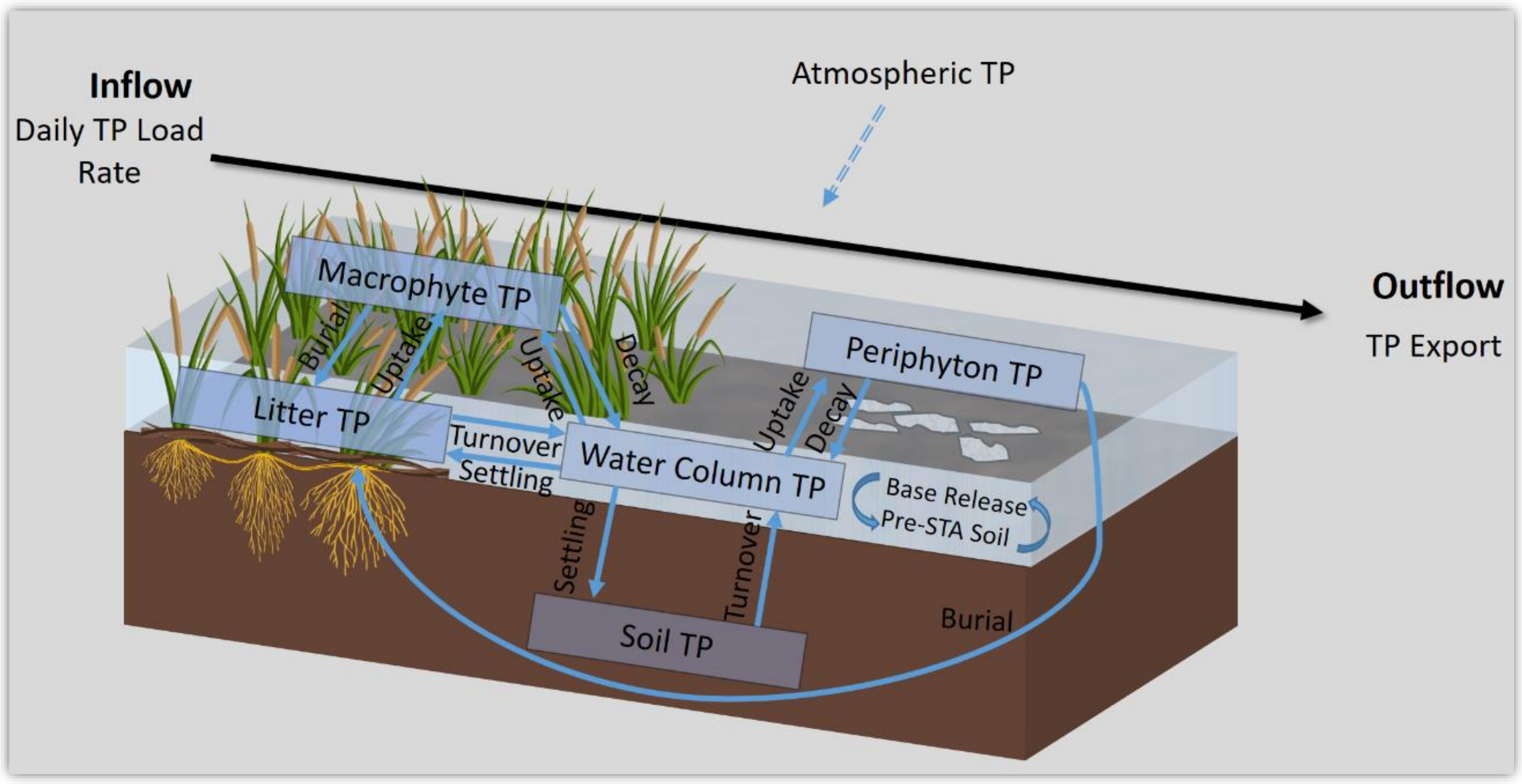


Fig 2. Conceptual diagram of components (Water Column, Soil, Litter, Macrophyte, Periphyton) and processes in our model. We expanded the Paudel and Jawitz (2012) model to include:

- a 1-D spatial flow path
- an internal source of TP originating from pre-STA soils
- maximum TP uptake capacity in periphyton and macrophytes (factors other than P will be limiting productivity)
- a litter pool

The model was run for 13 years with outflow TP concentration as the output variable.

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