# Improving and testing in-stream phosphorus cycling in SWAT+

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**Abstract**

Hydrologic and water quality models are often used to understand and simulate non-point source nutrient inputs to receiving waterbodies afflicted by eutrophication. The most widely used hydrologic-water quality model for estimating non-point source nutrient loads from agricultural uplands is the Soil and Water Assessment Tool (SWAT). SWAT uses the QUAL-2E 1-dimensional steady-state model to simulate in-stream processes that govern the transport of nutrients through channels and rivers. However, the instream-solute transport routine within SWAT is limited in predicting phosphorus cycling and algal dynamics. In this study, we improve the in-stream module of SWAT+, a restructured version of SWAT. We apply the modified SWAT+ to the Western Lake Erie Basin to examine how improved representation of the in-stream module influences nutrient dynamics from the edge-of-field through streams and to the watershed outlet. Our source code modifications focus on improving the representation of phosphorus exchange between the stream bed and the water column. This phosphorus exchange is governed by the equilibrium phosphorus concentration (EPC), which determines whether the stream bed is a phosphorus source or sink, and a phosphorus transformation coefficient which determines the rate of P exchange. These improvements to the in-stream routine within SWAT+ will aid decision-makers in understanding the time lags and management levers needed to achieve water quality targets for large basins.

# Improving and testing in-stream phosphorus cycling in SWAT

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## INTRODUCTION

1. Phosphorus (P) is one of the key elements fueling Harmful Algae Blooms (HABs) worldwide, and specifically in the Western Basin of Lake Erie (WBLE).
2. Reducing P loading to surface waters is often complicated when the nutrient source is diffuse, as is generally the case in agriculturally-dominated watersheds such as those draining to western Lake Erie.
3. Further, the sediments lining a network of ditches, streams, and rivers can attenuate or exacerbate transport of soluble P (SP) downstream.
4. The Equilibrium Phosphorus Concentration (EPC) is one method of predicting whether in-stream sediments will serve as a P source (i.e., sediment releases P when EPC > SP) or sink (i.e., sediment sorbs P when EPC < SP).

## KEY OBJECTIVES

1. The overarching objective is to implement the EPC algorithm proposed in White et al. (2014) in the most widely used watershed-scale model, Soil and Water Assessment Tool (SWAT), and eventually SWAT+, to understand in-stream P source and sink dynamics in the Maumee River Watershed draining to the WBLE.
2. The objective of this poster is to understand the behavior of P absorption coefficients in determining absorption and desorption of SP over time in two reaches of the watershed.

## METHODS

### Study Site:

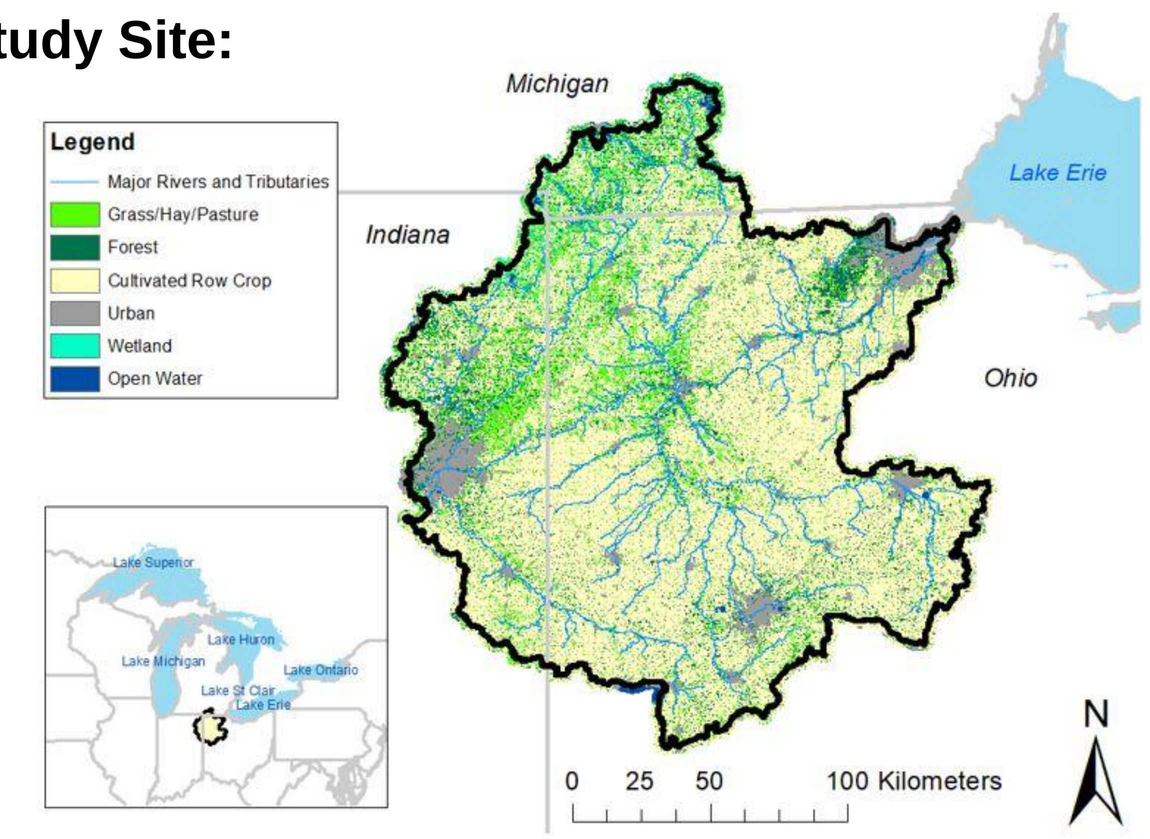


**Figure 1.** The Western Lake Erie Basin (WLEB) delineated to create rivers and streams of various sizes using SWAT 2012 Rev 635 (Adapted from Apostel et al. (2021)).

## Equilibrium Phosphorus Concentration (EPC):

EPC includes the contribution for solution cations and sediment composition which is not well tested in SWAT. Once incorporated, tested, and modified, the EPC algorithm will help to simulate the net sorption and desorption from benthic sediments.

EPC is calculated using equation 1:

$$EPC = \frac{\sum_{t=1}^{-DI} SP_t^* \left(1 + \frac{t}{DI}\right)}{\sum_{t=1}^{-DI} \left(1 + \frac{t}{DI}\right)} \qquad \text{Equation 1}$$

where,

- EPC = Equilibrium Phosphorus Concentration, mg/l
- SP = Soluble Phosphorus, mg/l
- DI is Period of Influence, days
- t is the day

In a condition, where:

$EPC\ is\ either\ smaller\ or\ larger\ than\ SP_{in}$

$$SP_{out} = EPC + \left(SP_{in} - EPC\right)e^{(-Kout\ or\ -Kin)\ TT} \qquad \text{Equation 2}$$

where,

- $SP_{in}$ is the amount of SP coming into the channel and $SP_{out}$ is the amount of SP leaving the channel
- K_in and K_out are SP transformation coefficients
- TT is travel time in minutes and calculated as:

$$TT = L\ \left(S^{0.375} Q^{0.25} n^{-0.75}\right)^{-1} \qquad \text{Equation 3}$$

where,

- L is the channel length (km)
- S is the mean river slope
- Q is the discharge ($m^3$/min)
- n is Manning's roughness coefficient ($m^{1/3}$ $min^{-1}$)

### Study Variables

**(a) Choice of River Channel**

| Channel Property | Unit | Small Channel | Long Channel |
|---|---|---|---|
| Main Channel Width | m | 72.24 | 18.71 |
| Main Channel Depth | m | 1.9 | 0.77 |
| Main Channel Slope | m | 0.00135 | 0.0007 |
| Main Channel Length | m | 162 | 26872 |
| Channel Width to Depth Ratio | No Units | 37.9 | 24.2 |

**(b) Different values of absorption (K_in) and desorption (K_out) coefficients with various days of influence (DI) to understand EPC variations**

| | | |
|---|---|---|
| K_in and K_out | sorption and desorption coefficients | 0.1,0.3,0.5,0.7,1 |
| DI | Period of Influence, days | 2,5,10,100,500 |

## RESULTS

### (a) Period of Influence (DI)

1. *Varying the Period of influence (DI) indicated that at low values (2-10 days) EPC tracks with daily SP, while at higher values (100-500 days) EPC becomes fairly steady over time.*

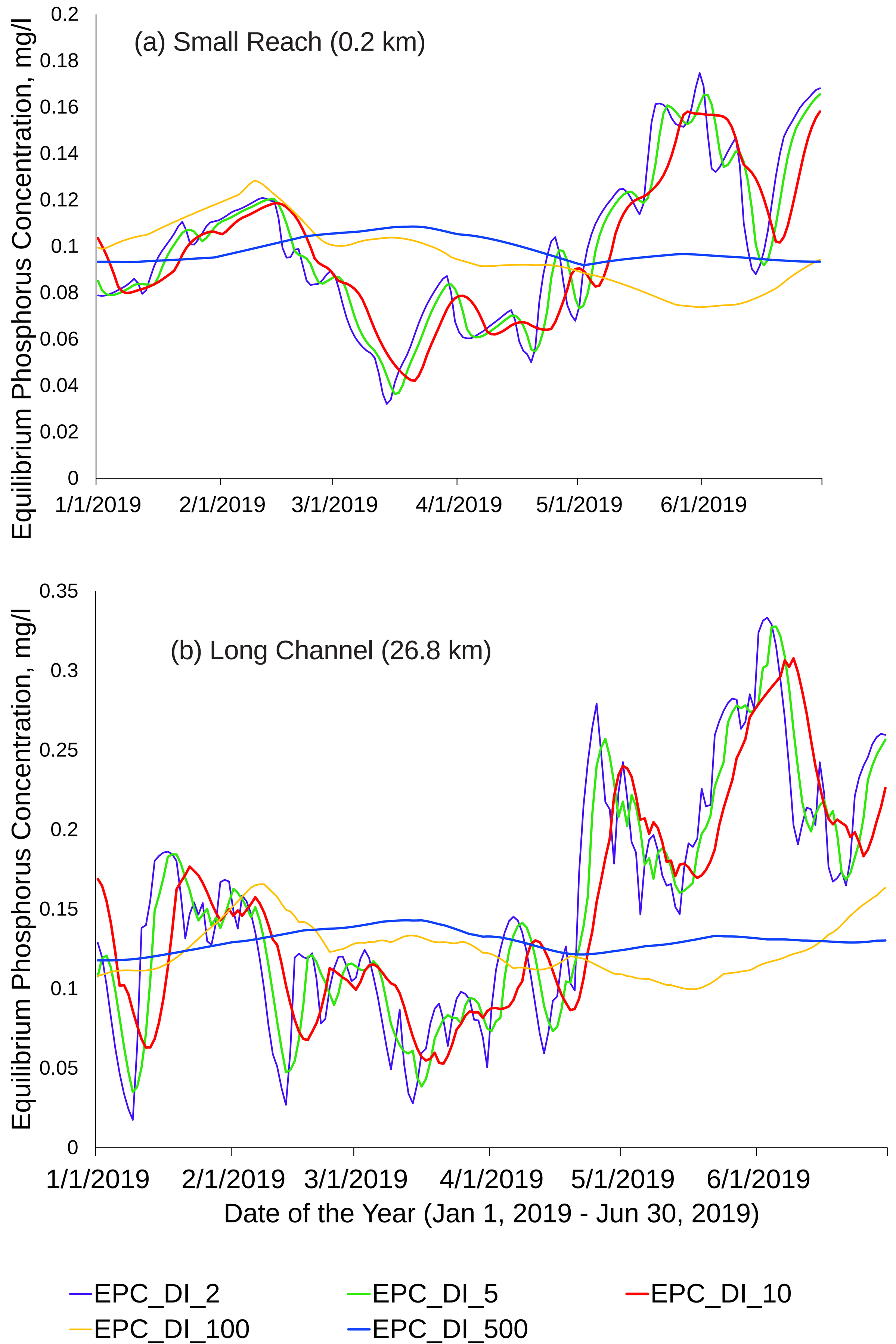


**Figure 2.** Variations of Period of Influence (DI) and their effect on EPC.

### (b) Soluble Phosphorus (SP) transformation coefficients (K_in and K_out)

We compared SWAT's current in-stream module, which lacks transformation coefficients, with the EPC. With DI set at 10 days, and varying K_in and K_out (Figure 3), and found:

1. Higher SP transformation coefficient values (> 0.7) showed a considerable discrepancy in SP concentration simulation by SWAT in its current state and EPC algorithm.
2. The SP transformation coefficients compounded with DI values are important to assess the impact the SP concentration simulations by either SWAT or EPC.

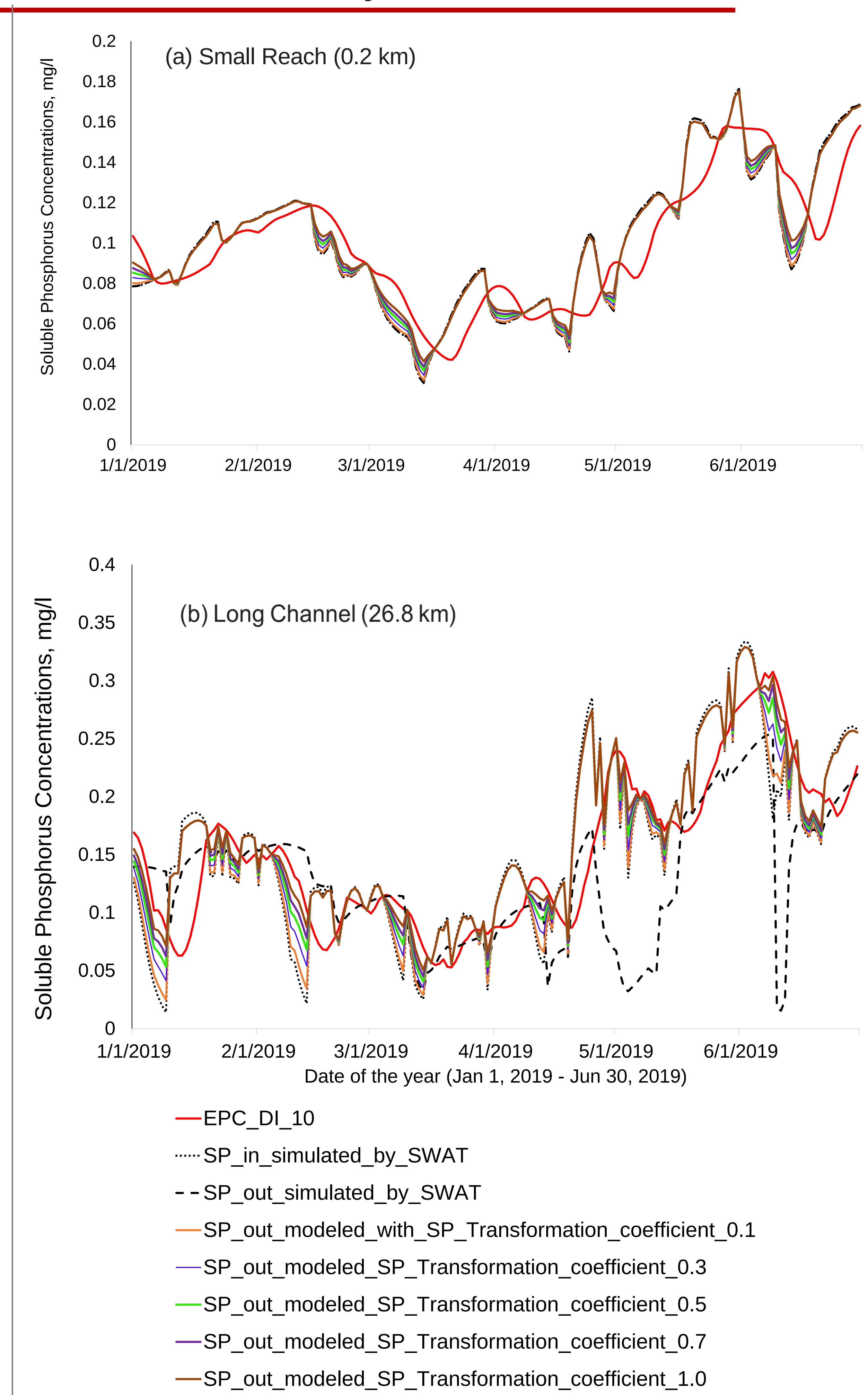


**Figure 3.** Simulated SP concentrations (mg/l) from January 1, 2019 – June 30, 2019, calculated using different values of sorption and desorption coefficients (K_in and K_out).

## FINDINGS

1. The EPC concept has the potential to alter simulation of river P cycling considerably in SWAT.
2. Lab and field data at varying spatial and temporal scales could be used to estimate the values of SP transformation coefficients (K_in and K_out) and Period of Influence (DI).

## FUTURE WORK

Incorporate EPC algorithm in SWAT and eventually with SWAT+ in-stream modules and assess the impact of different management practices on sorption and desorption of P within streams in the Maumee River Basin.

## REFERENCES

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