



# Introduction of ArcNLET-Py

## Phosphorus modelling

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9/30/2024

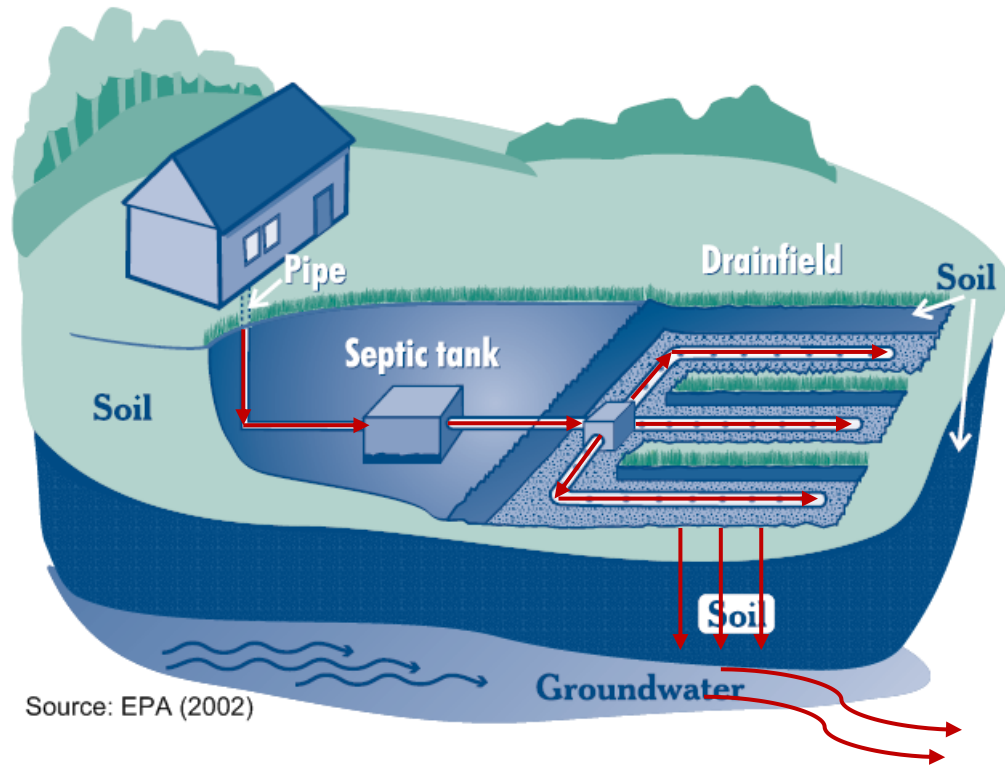
# CONTENTS

- 1 Brief Introduction of ArcNLET-Py
- 2 Conceptual Model of Phosphorus
- 3 Case Study



# I. Brief Introduction of ArcNLET-Py

# 1.1 Background



- OSTDS (Onsite Sewage Treatment and Disposal Systems) are currently used by more than 20% of the U.S. population (US EPA, 2024a).
- Sewage from OSTDS is recognized as a significant source of nitrogen and phosphorus in groundwater (US EPA, 2024b).

ArcNLET was developed to estimate both nitrogen and phosphorus loads from OSTDS to groundwater and, subsequently, to surface waterbodies.

# 1.2 ArcNLET introduction

- ArcNLET, an ArcGIS-based Nutrient Load Estimation Toolbox.
- The development of ArcNLET has lasted for more than 10 years, led by Dr. Ye, Dr. Rios, Dr. Wang, Dr. Zhu, and others.
- Since last year, we have significantly redeveloped the toolbox, creating a new version called ArcNLET-Py. This version is rewritten in Python and integrated with ArcGIS Pro.



## 1.3 ArcNLET-Py resources

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- Source code on GitHub and online User's manual:

<https://github.com/ArcNLET-Py/ArcNLET-Py>

- Training videos on YouTube:

<https://www.youtube.com/@mingye9168/videos>

- FSU Website:

<https://atmos.eoas.fsu.edu/~mye/ArcNLET/>

# 1.4 Overview

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- Section 2 Conceptual Model of Phosphorus

Conceptual model and mathematical models used to develop OSTDS phosphorus functionality in ArcNLET-Py.

- Section 3 Case Study

The Lakeshore example was used to demonstrate the application of the phosphorus function.

For users who are new to ArcNLET-Py, it is recommended to watch the introductory video and follow the tutorial to become familiar with the toolbox and its features before proceeding.

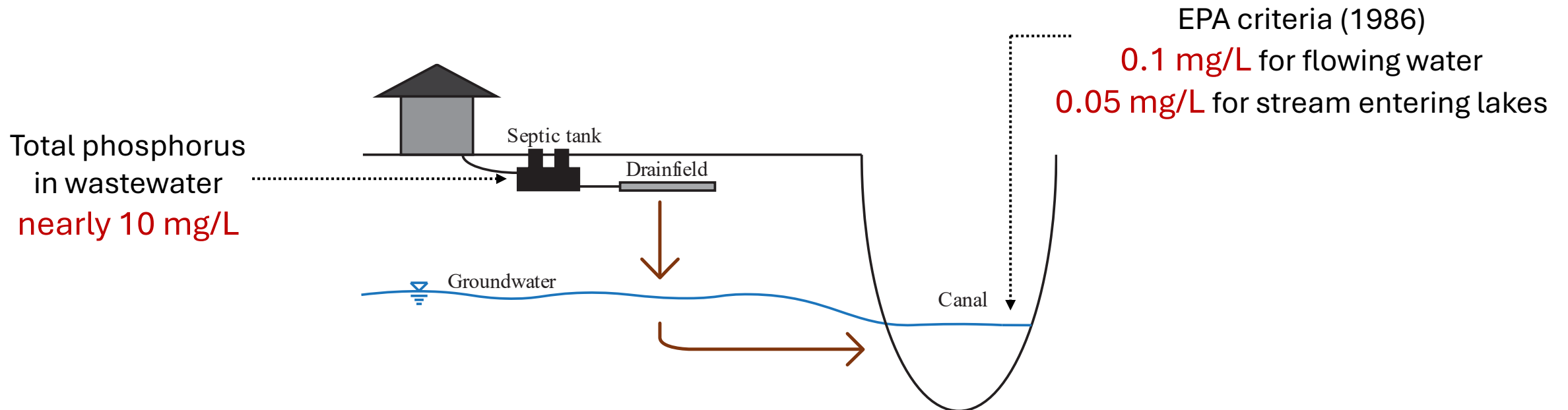


## 2. Conceptual Model of Phosphorus



## 2.1 Background

- Phosphorus loss from septic tanks can impact water quality at much lower concentrations compared to nitrogen.
- Phosphorus in wastewater comes from human waste, detergents, food waste, etc.

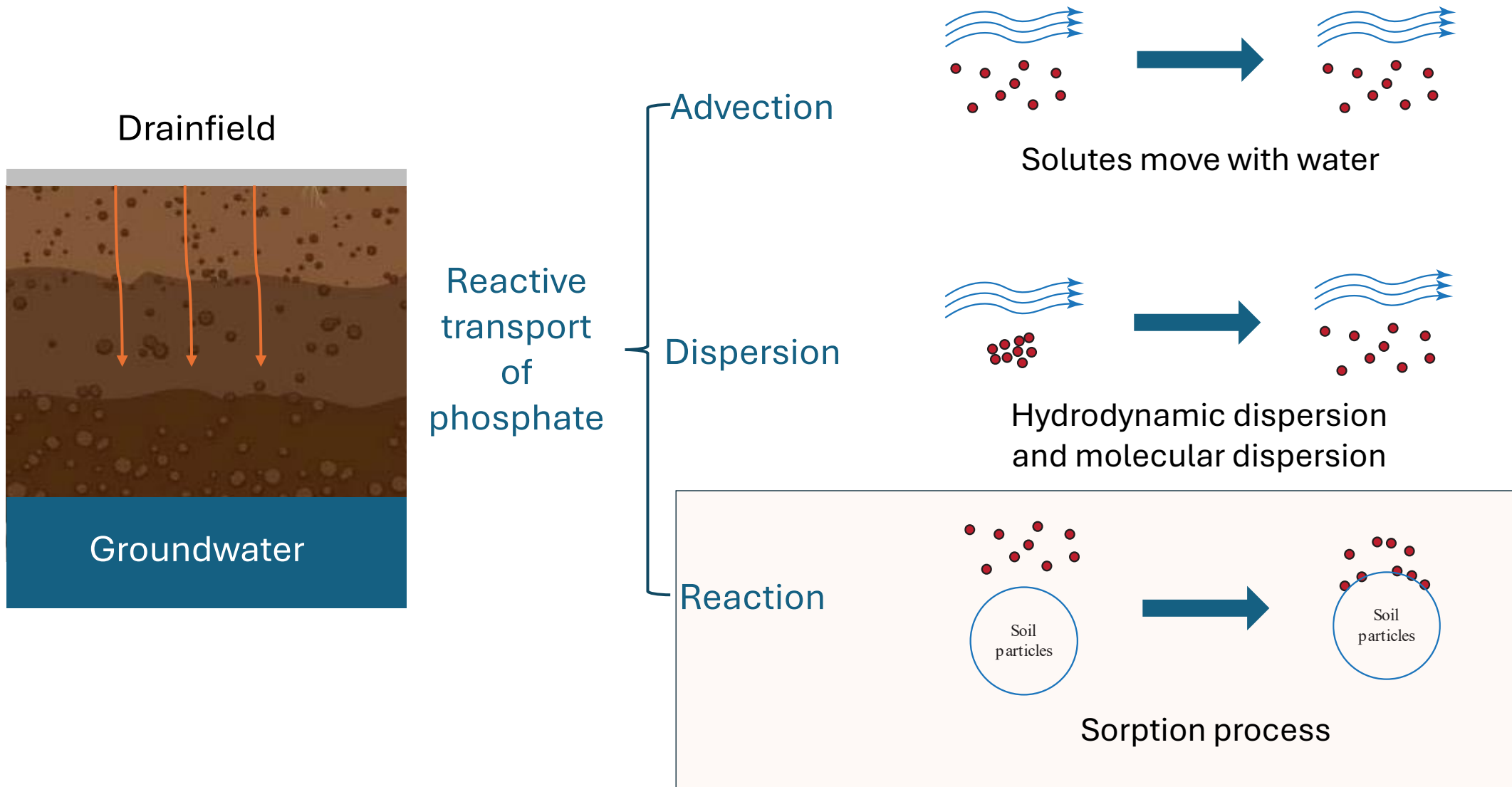


## 2.2 Phosphorus concentration in wastewater

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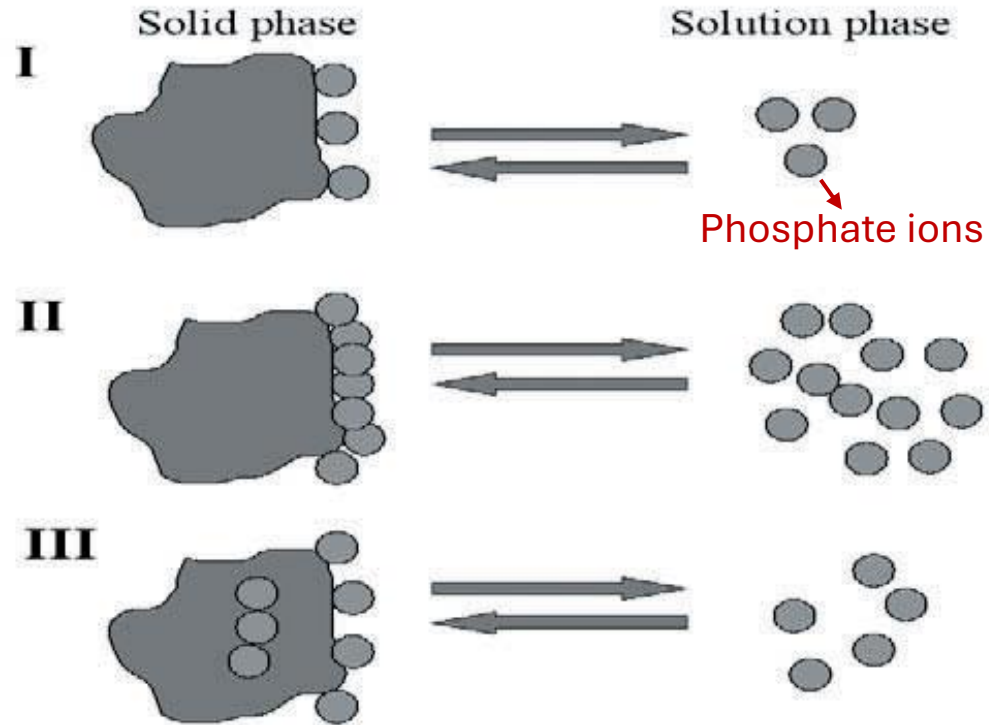
- Total phosphorus concentrations in septic tank wastewater range from 0.2 to 32 mg-P/L (Robertson et al., 2019; Lowe et al., 2009; McCray et al., 2005), with an average around 9-10 mg-P/L.
- In septic tank wastewater, about 85% of the phosphorus is in the form of inorganic phosphorus, while the remaining 15% is organic phosphorus (Lusk et al., 2017; McCray et al., 2005; Tchobanoglous and Schroeder, 1985). Additionally, most organic phosphorus is mineralized into inorganic phosphorus in the soil (Lusk et al., 2017).
- Therefore, we assume total phosphorus concentrations in septic tank wastewater are roughly equal to inorganic phosphorus (Orthophosphate) if data is absent.

## 2.3 Phosphate reactive transport



## 2.4 Phosphate sorption

### Phosphate Sorption



Two-step process

Quick, reversible process

Slow, irreversible processes

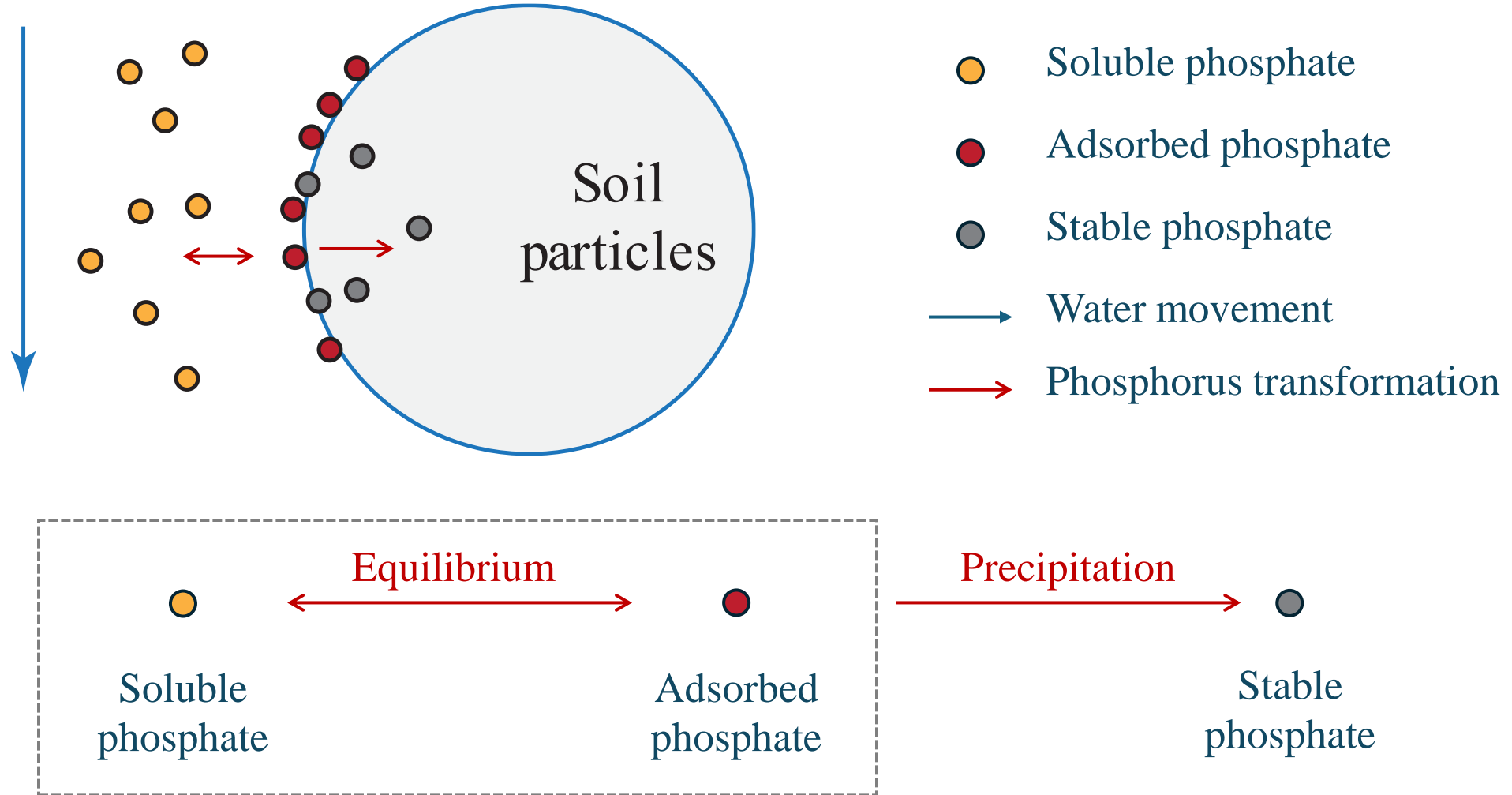
Sims, J.T., Sharpley, A.N., 2005. Phosphorus: agriculture and the environment. American Society of Agronomy.

## 2.4 Phosphate sorption

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- Phosphate sorption is a complex process, including a combination of several processes, and it can be influenced by factors such as soil texture, soil organic matter, pH, mineralogy, temperature, and degree of soil P saturation.
- Generally, phosphate sorption is divided into a fast reversible process, and a range of slower, irreversible processes (This division is somewhat arbitrary).
- These slower processes are more complex and have been described by various authors using terms such as “precipitation”, “deposition”, “slow adsorption”, “the slow reaction”, “fixation”, or “solid-state diffusion” (McGechan and Lewis, 2002).

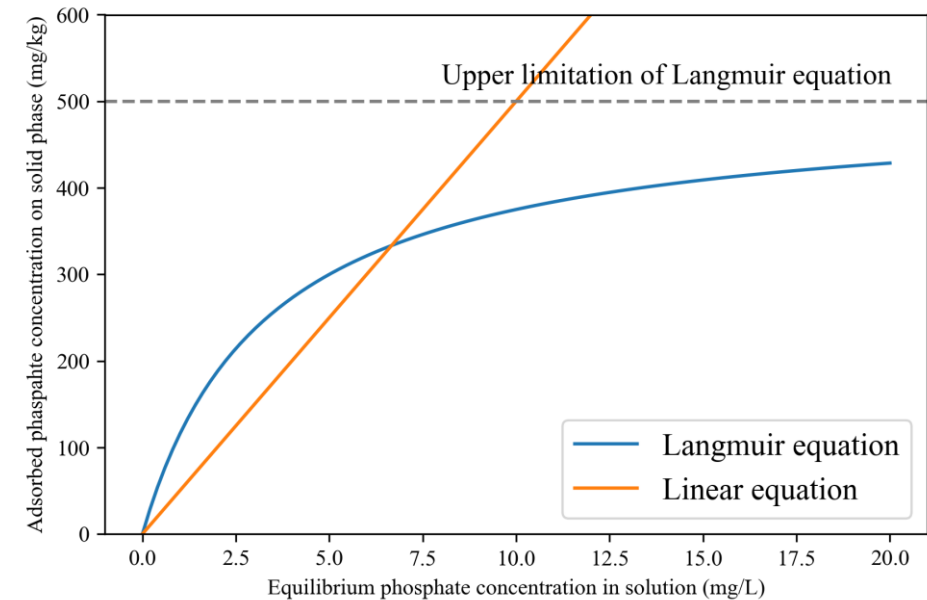
## 2.5 Phosphorus conceptual model



## 2.5 Phosphorus conceptual model



- Soluble P and adsorbed P are in equilibrium, indicating a fast and reversible process.
- Both the Langmuir equation and the linear equation are used to describe this process.
- The linear equation is recommended when phosphate concentration varies from less than 1 mg/L to less than 10 mg/L (McCray et al., 2005).
- The Langmuir equation is recommended for larger phosphate concentrations (Lusk et al., 2017).
- Precipitation is calculated by first-order reaction rate.



## 2.4 Governing Equations Vadose zone

➤ Linear sorption

➤ Langmuir sorption

| Dispersion                                |   | Precipitation process   |
|---|---|---|
| $0 = D \frac{\partial^2 C}{\partial z^2}$ | $-\frac{q}{\theta} \frac{\partial C}{\partial x}$ | $-R_{precip} \left( 1 + \frac{\rho k}{\theta} \right) C$                        |
| $0 = D \frac{\partial^2 C}{\partial z^2}$ | $-\frac{q}{\theta} \frac{\partial C}{\partial x}$ | $-R_{precip} \left( 1 + \frac{\rho}{\theta} \frac{KQ_{\max}}{1 + KC} \right) C$ |
|   | Advection   | Equilibrium adsorption  |

The finite different method is used to solve the equation.



## 2.5 Governing Equations Groundwater

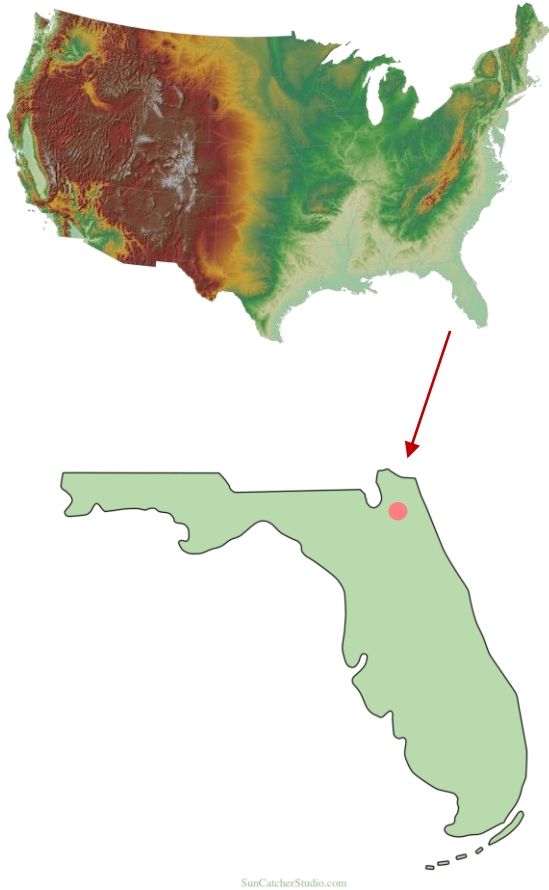
$$0 = \overbrace{D_x \frac{\partial^2 C}{\partial x^2} + D_y \frac{\partial^2 C}{\partial y^2}}^{\text{Dispersion}} - \underbrace{v \frac{\partial C}{\partial x}}_{\text{advection}} - \overbrace{R_{precip}}^{\text{Precipitation process}} \underbrace{\left(1 + \frac{\rho k}{\theta}\right) C}_{\text{Equilibrium adsorption}}$$

Linear sorption is recommended for groundwater transport because phosphorus concentrations in groundwater are likely to be considerable < 10 mg/L (McCray et al., 2005).



## 3. Case Study

# 3.1 Study area



265 septic tanks

## 3.2 Data preparation

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- Study area – shapefile with one polygon
- DEM – raster
- Location of septic tanks – multi-point shapefile
- Waterbodies – shapefile

This case extends a previous example by incorporating the phosphorus calculation component.



The objective is to show the procedures for using ArcNLET-Py to estimate the loading of nitrogen (ammonium and nitrate) and phosphorus from OSTDS to surface waterbodies.

## 3.3 Procedure 1, preprocessing module

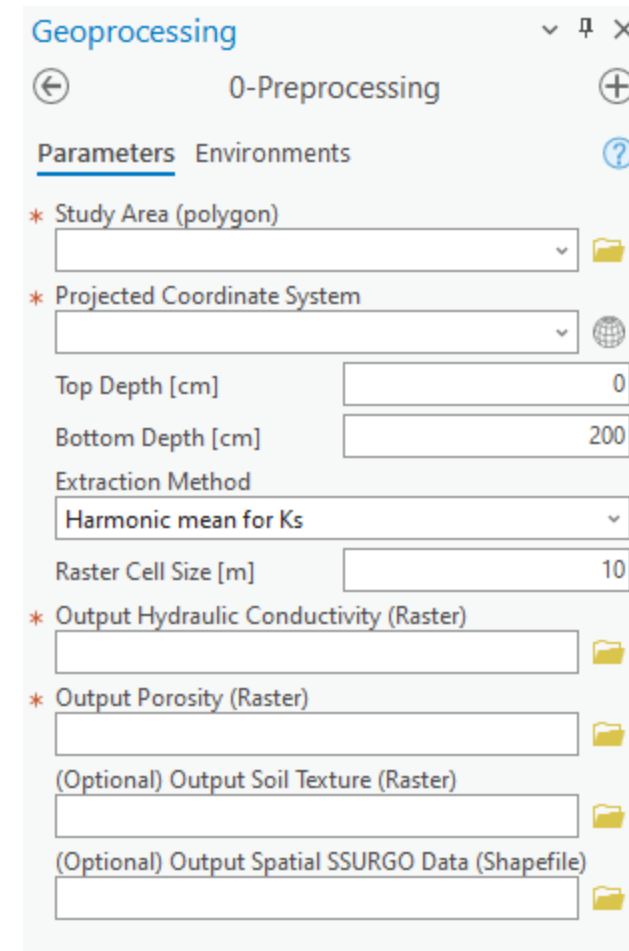
**Objective:** Extract data from the online SSURGO database for subsequent calculations.

### ➤ Inputs

- Study area

### ➤ Outputs

- Hydraulic conductivity
- Porosity
- Soil types



The screenshot shows the 'Geoprocessing' window with the '0-Preprocessing' tool selected. The 'Parameters' tab is active, displaying the following settings:

- Study Area (polygon):** A dropdown menu with a folder icon to the right.
- Projected Coordinate System:** A dropdown menu with a globe icon to the right.
- Top Depth [cm]:** A text input field containing the value '0'.
- Bottom Depth [cm]:** A text input field containing the value '200'.
- Extraction Method:** A dropdown menu with 'Harmonic mean for Ks' selected.
- Raster Cell Size [m]:** A text input field containing the value '10'.
- Output Hydraulic Conductivity (Raster):** A text input field with a folder icon to the right.
- Output Porosity (Raster):** A text input field with a folder icon to the right.
- (Optional) Output Soil Texture (Raster):** A text input field with a folder icon to the right.
- (Optional) Output Spatial SSURGO Data (Shapefile):** A text input field with a folder icon to the right.

## 3.4 Procedure 2, groundwater flow module

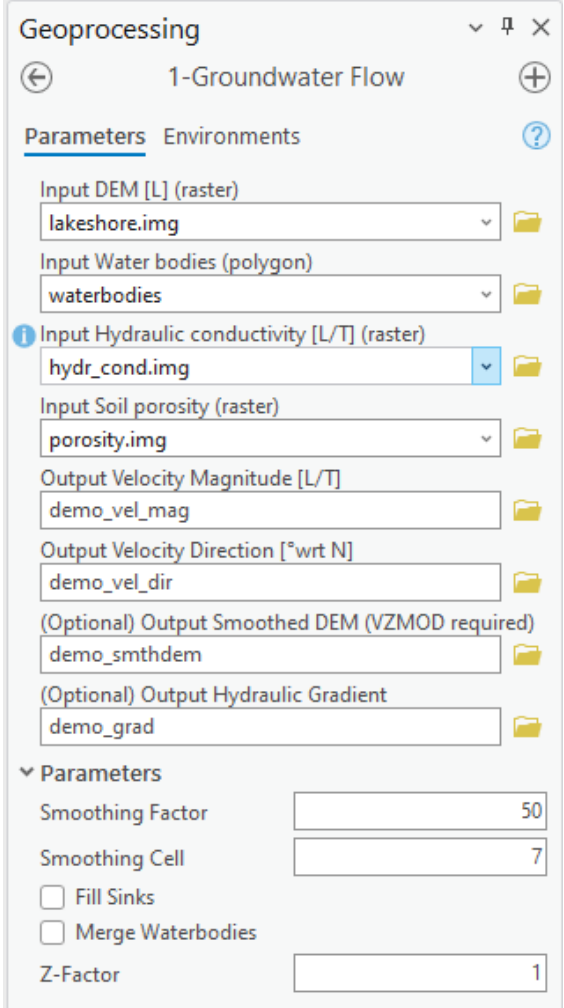
**Objective:** calculate groundwater velocity and velocity direction based on DEM and soil data.

### ➤ Inputs

- DEM
- Waterbodies
- Hydraulic Conductivity
- Porosity

### ➤ Outputs

- Velocity Magnitude
- Velocity Direction
- Hydraulic Gradient
- Smoothed DEM



The screenshot shows the 'Geoprocessing' window with the tool '1-Groundwater Flow' selected. The 'Parameters' tab is active, displaying the following inputs and outputs:

- Input DEM [L] (raster):** lakeshore.img
- Input Water bodies (polygon):** waterbodies
- Input Hydraulic conductivity [L/T] (raster):** hydr\_cond.img
- Input Soil porosity (raster):** porosity.img
- Output Velocity Magnitude [L/T]:** demo\_vel\_mag
- Output Velocity Direction [°wrt N]:** demo\_vel\_dir
- (Optional) Output Smoothed DEM (VZMOD required):** demo\_smthdem
- (Optional) Output Hydraulic Gradient:** demo\_grad

Below the parameters, the 'Parameters' section is expanded, showing the following settings:

- Smoothing Factor:** 50
- Smoothing Cell:** 7
- ☐ Fill Sinks
- ☐ Merge Waterbodies
- Z-Factor:** 1

## 3.5 Procedure 3, particle tracking module

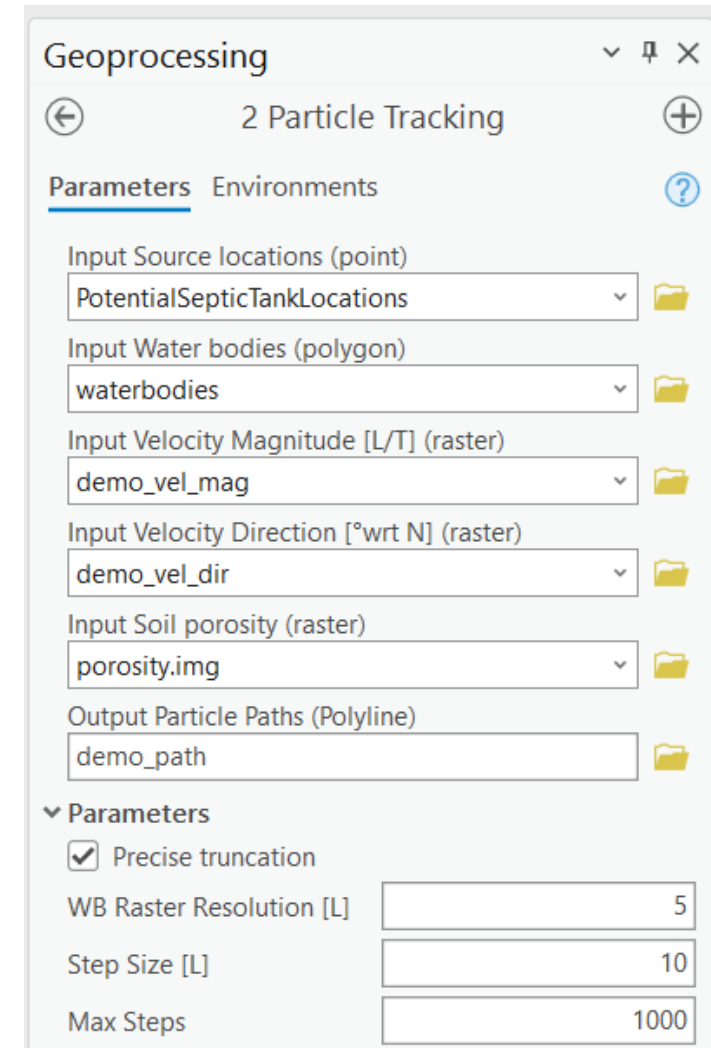
**Objective:** simulate water particle movement from sources (septic tanks) to surface waterbodies.

### ➤ Inputs

- Velocity Magnitude and Direction
- Locations of septic tanks
- Waterbodies
- Porosity

### ➤ Outputs

- Particle paths



The screenshot shows the '2 Particle Tracking' tool in a Geoprocessing environment. The interface includes a 'Parameters' tab and an 'Environments' tab. The 'Parameters' section lists several input fields with dropdown menus and folder icons for selection:

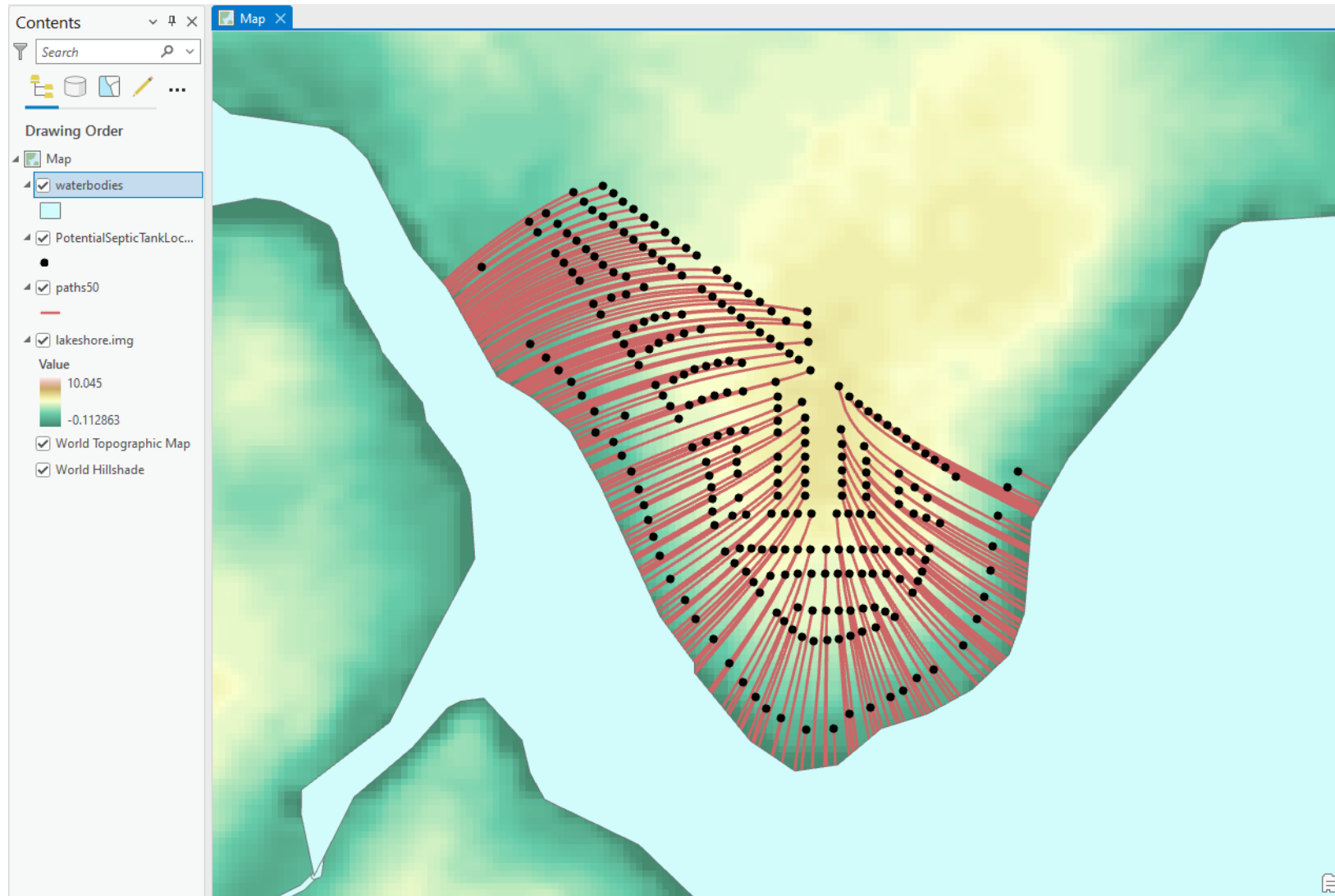
- Input Source locations (point): PotentialSepticTankLocations
- Input Water bodies (polygon): waterbodies
- Input Velocity Magnitude [L/T] (raster): demo\_vel\_mag
- Input Velocity Direction [°wrt N] (raster): demo\_vel\_dir
- Input Soil porosity (raster): porosity.img
- Output Particle Paths (Polyline): demo\_path

Below the input fields, there is a 'Parameters' section with a checked box for 'Precise truncation' and three numerical input fields:

- WB Raster Resolution [L]: 5
- Step Size [L]: 10
- Max Steps: 1000



## 3.5 Procedure 3, particle tracking module





## 3.6 Procedure 4, VZMOD

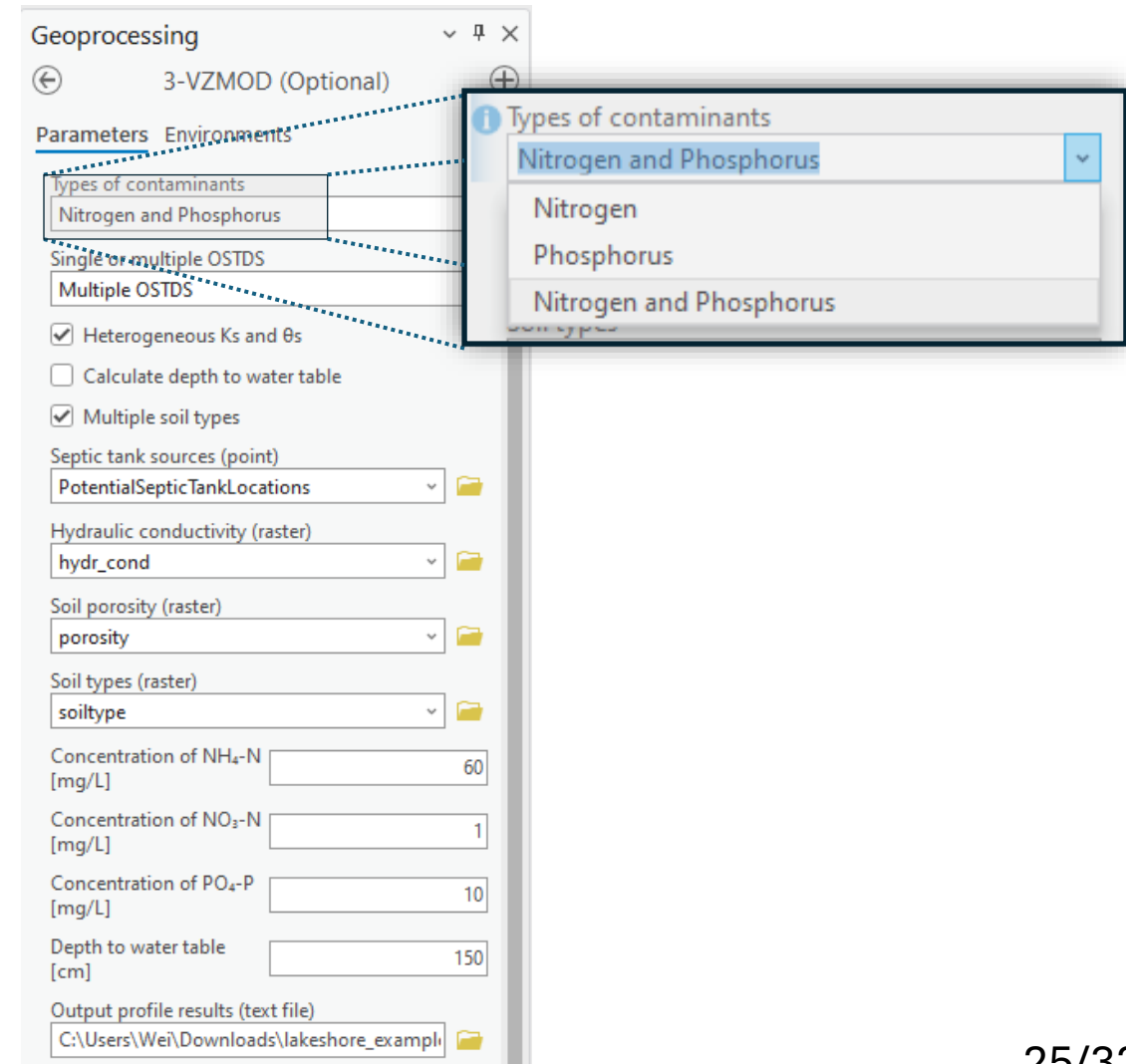
**Objective:** Model nitrogen and phosphorus reactive transport in the vadose zone.

### ➤ Inputs

- Regional scale hydraulic parameters
- Initial concentration values
- Depth from drainfield to water table
- Reactive transport parameters

### ➤ Outputs

- Nitrogen and phosphate concentrations entering groundwater



Geoprocessing 3-VZMOD (Optional)

Parameters Environments

Types of contaminants  
Nitrogen and Phosphorus

Single or multiple OSTDS  
Multiple OSTDS

☒ Heterogeneous Ks and  $\theta_s$

☐ Calculate depth to water table

☒ Multiple soil types

Septic tank sources (point)  
PotentialSepticTankLocations

Hydraulic conductivity (raster)  
hydr\_cond

Soil porosity (raster)  
porosity

Soil types (raster)  
soiltype

Concentration of  $\text{NH}_4\text{-N}$  [mg/L]  
60

Concentration of  $\text{NO}_3\text{-N}$  [mg/L]  
1

Concentration of  $\text{PO}_4\text{-P}$  [mg/L]  
10

Depth to water table [cm]  
150

Output profile results (text file)  
C:\Users\Wei\Downloads\lakeshore\_examp...

## 3.6 Procedure 4, VZMOD

### ➤ Linear sorption

$$0 = D \frac{\partial^2 C}{\partial z^2} - \frac{q}{\theta} \frac{\partial C}{\partial x} - R_{precip} \left( 1 + \frac{\rho k}{\theta} \right) C$$

Precipitation rate

Linear distribution coefficient

▼ Phosphorus Parameters

Rprecip [mg/kg 1/day]

Sorption isotherm  
Linear ▼

Linear distribution coefficient [L/kg]

### ➤ Langmuir sorption

$$0 = D \frac{\partial^2 C}{\partial z^2} - \frac{q}{\theta} \frac{\partial C}{\partial x} - R_{precip} \left( 1 + \frac{\rho}{\theta} \frac{K Q_{max}}{1 + K C} \right) C$$

Precipitation rate

Langmuir coefficient

Maximum sorption capacity

▼ Phosphorus Parameters

Rprecip [mg/kg 1/day]

Sorption isotherm  
Langmuir ▼

Langmuir coefficient [L/mg]

Maximum sorption capacity [mg P / kg]

# 3.7 Procedure 5, transport module

**Objective:** simulate nitrate, ammonium, and phosphate plumes in groundwater.

## ➤ Inputs

- Septic tank location and concentration values entering groundwater
- Particle paths and waterbodies
- Reactive transport parameters

## ➤ Outputs

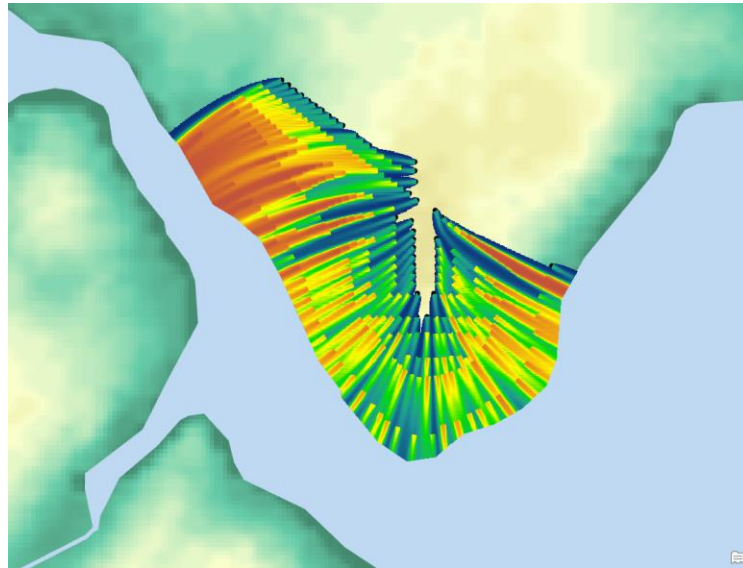
- Nitrate, ammonium, and phosphate plumes

The screenshot displays the 'Geoprocessing' window for the '4-Transport' tool. The 'Parameters' tab is active, showing the following settings:

- Types of contaminants:** Nitrogen and Phosphorus
- Consideration of NH<sub>4</sub>:** ☒
- Input Source locations (point):** PotentialSepticTankLocations
- Input Water bodies (polygon):** waterbodies
- Input Particle Paths (polyline):** paths50
- Output Plumes of NO<sub>3</sub> (raster):** no3plumes
- Output Plumes of NH<sub>4</sub> (raster):** nh4plumes
- Output Plumes of P (raster):** po4plumes
- Solution Options:**
  - Solution type:** DomenicoRobbinsSSDecay2D
  - Plume warping control point spacing [Cells]:** 48
  - Plume warping method:** Spline
  - Threshold Concentration [mg/l]:** 0.000001

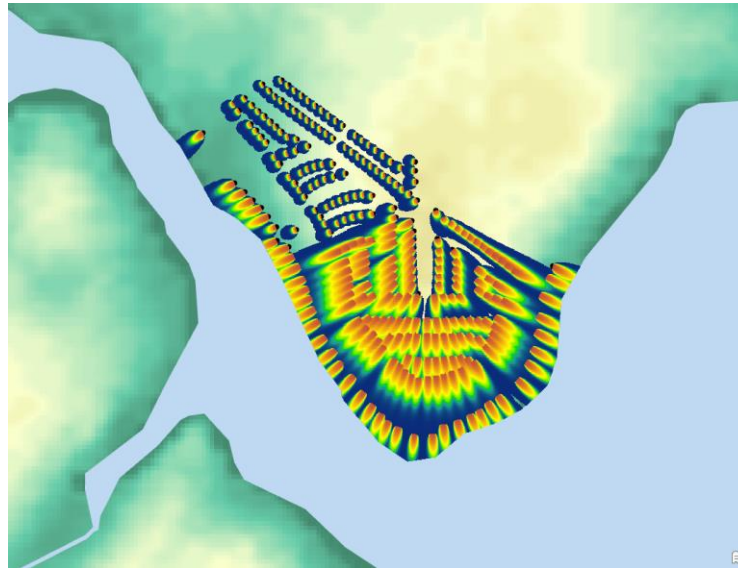
## 3.7 Procedure 5, transport module

➤  $\text{NH}_4\text{-N}$  plumes



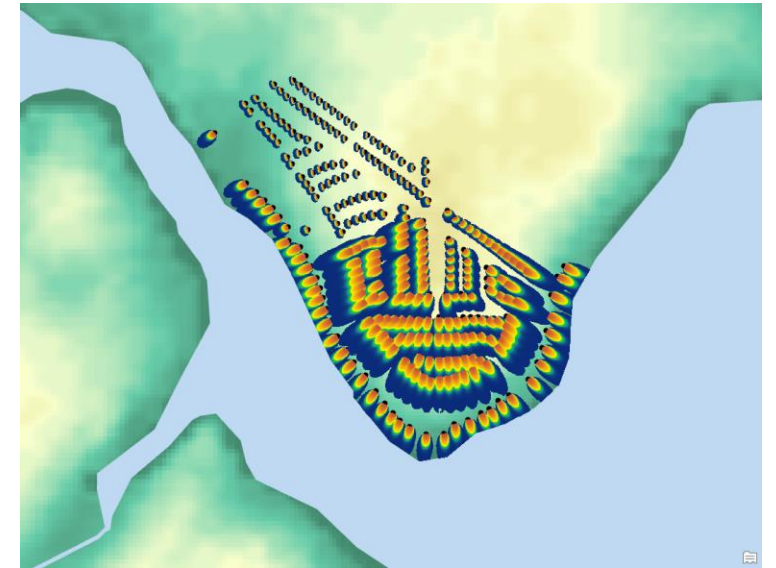
Low High  
1e-6 0.0007 mg/L

➤  $\text{NO}_3\text{-N}$  plumes



Low High  
1e-6 57.0 mg/L

➤  $\text{PO}_4\text{-P}$  plumes



Low High  
1e-6 2.6 mg/L

## 3.8 Procedure 6, load estimation module

**Objective:** estimate nitrate, ammonium, and phosphate loading to surface waterbodies.

### ➤ Inputs

- Plume information shapefile of  $\text{NH}_4\text{-N}$
- Plume information shapefile of  $\text{NO}_3\text{-N}$
- Plume information shapefile of  $\text{PO}_4\text{-P}$

### ➤ Outputs

- Loading results, CSV files

The screenshot shows the 'Geoprocessing' window for the '5-Load Estimation' tool. The 'Parameters' tab is active. The 'Types of contaminants' dropdown is set to 'Nitrogen and Phosphorus'. The 'Consideration of  $\text{NH}_4$ ' checkbox is checked. The 'Risk Factor' is set to 1. The 'Input Plumes  $\text{NO}_3$  info (Point)' dropdown is set to 'no3plumes\_info'. The 'Input Plumes  $\text{NH}_4$  info (Point)' dropdown is set to 'nh4plumes\_info'. The 'Input Plumes P info (Point)' dropdown is set to 'po4plumes\_info'. The 'Output Results for  $\text{NO}_3$ ' dropdown is set to 'C:\Users\Wei\Downloads\lakeshore\_example\2'. The 'Output Results for  $\text{NH}_4$ ' dropdown is set to 'C:\Users\Wei\Downloads\lakeshore\_example\2'. The 'Output Results for P' dropdown is set to 'C:\Users\Wei\Downloads\lakeshore\_example\2'.

# 3.8 Procedure 6, load estimation module

## Loading estimation results

|                                      | NH <sub>4</sub> -N | NO <sub>3</sub> -N | PO <sub>4</sub> -P |
|--------------------------------------|--------------------|--------------------|--------------------|
| Loading to groundwater (g/d)         | 0.059              | 19,409.1           | 450.5              |
| Removed in groundwater (g/d)         | 0                  | 18,632.7           | 422.6              |
| Loading to surface waterbodies (g/d) | 0.059              | 776.4              | 27.9               |

# Reference

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# Thank you!