A Modeling Approach to Evaluate Horizontal and Vertical Distances for Nitrogen Attenuation from Onsite Sewage Treatment and Disposal Systems (OSTDS)

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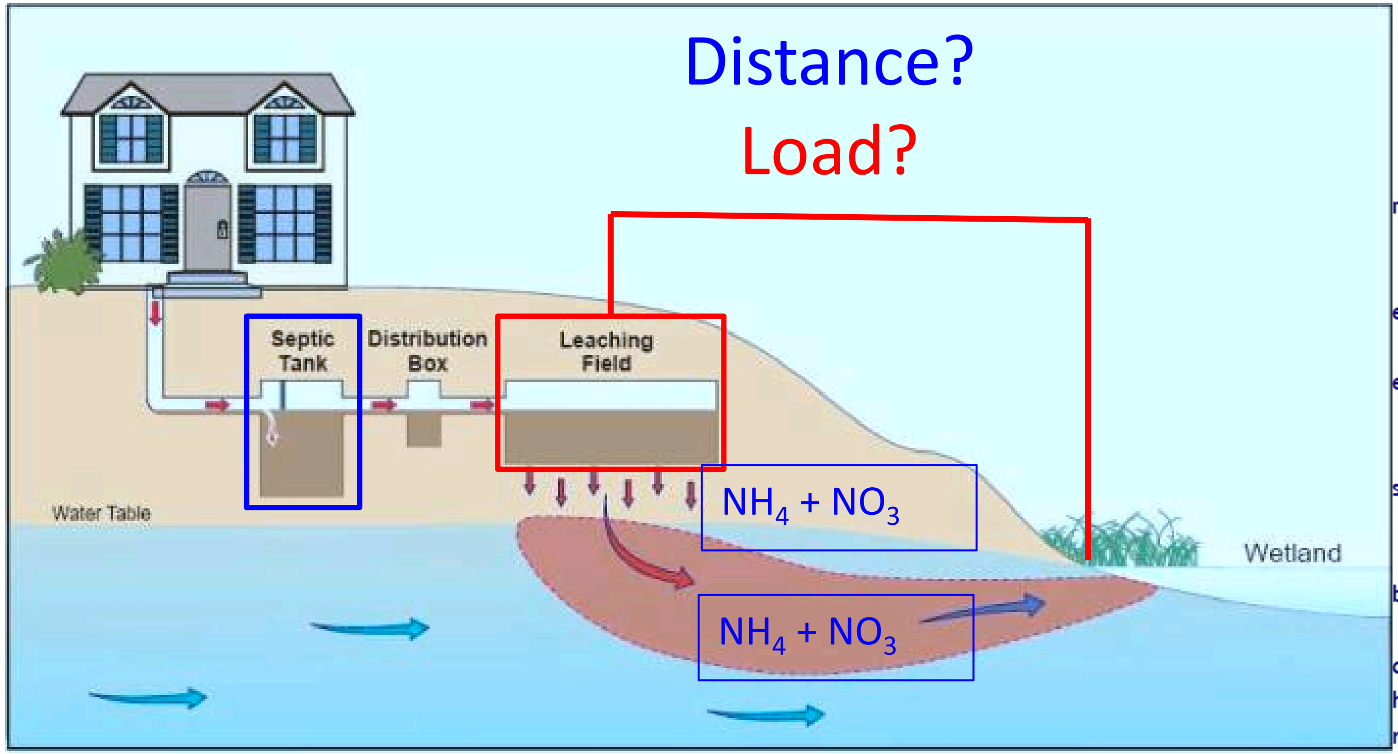
OSTDS Setback Distance



The 2024 Florida Statutes

(f) Onsite sewage treatment and disposal systems that are permitted before June 21, 2022, may not be placed closer than:

1. Seventy-five feet from a private potable well.
2. Two hundred feet from a public potable well serving a residential or nonresidential establishment having a total sewage flow of greater than 2,000 gallons per day.
3. One hundred feet from a public potable well serving a residential or nonresidential establishment having a total sewage flow of less than or equal to 2,000 gallons per day.
4. Fifty feet from any nonpotable well.
5. Ten feet from any storm sewer pipe, to the maximum extent possible, but in no instance shall the setback be less than 5 feet.
6. Seventy-five feet from the mean high-water line of a tidally influenced surface water body.
7. Seventy-five feet from the mean annual flood line of a permanent nontidal surface water body.
8. Fifteen feet from the design high-water line of retention areas, detention areas, or swales designed to contain standing or flowing water for less than 72 hours after a rainfall or the design high-water level of normally dry drainage ditches or normally dry individual lot stormwater retention areas.

Questions:

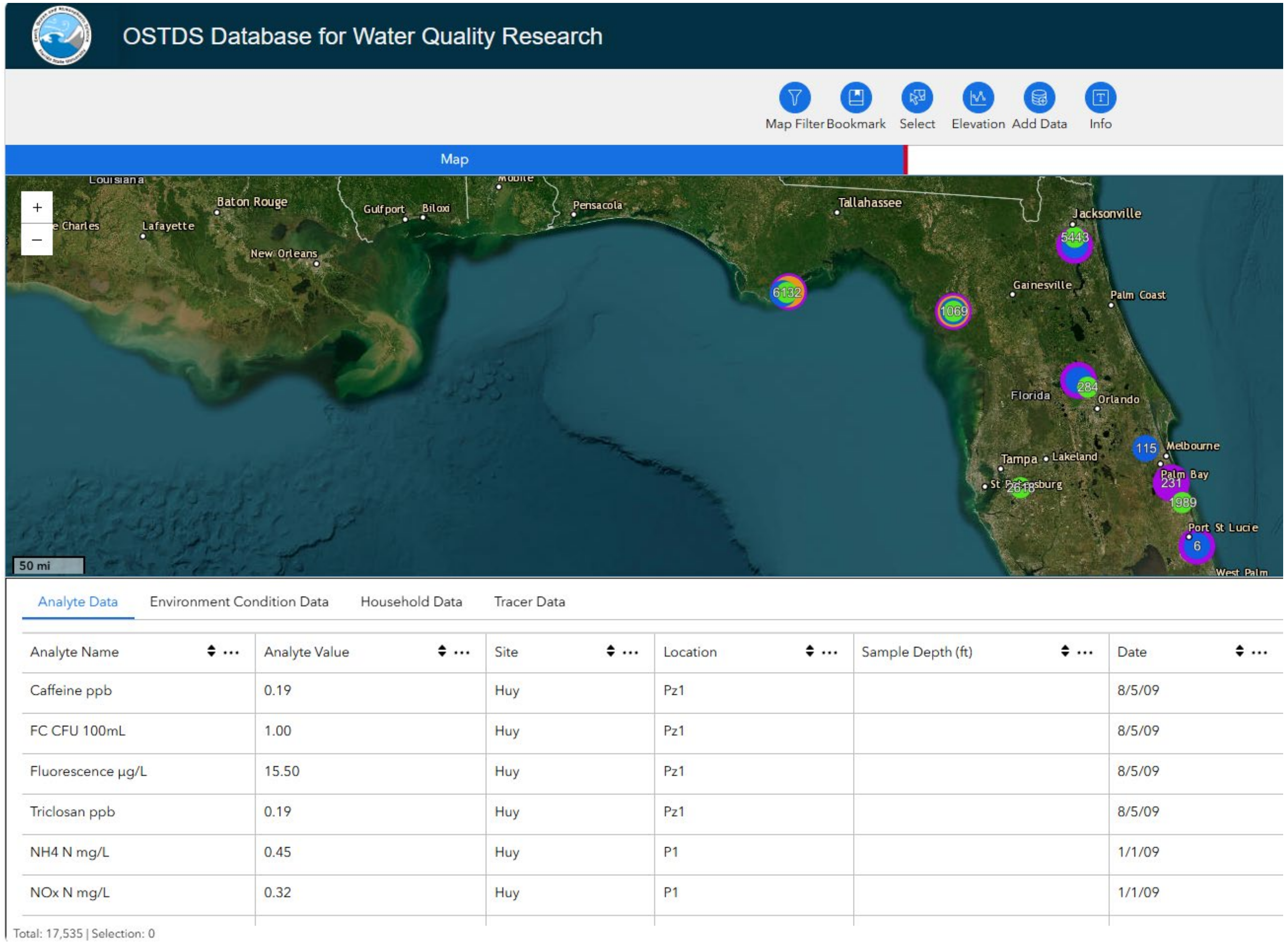
(1) Is the 75-foot horizontal setback distance adequate for nitrogen attenuation?

(2) Is there a need for a vertical setback distance?

An Online Database for Previous Field Studies

Field data are available to support a modeling study.

Online database: [OSTDS Database for Water Quality Research]

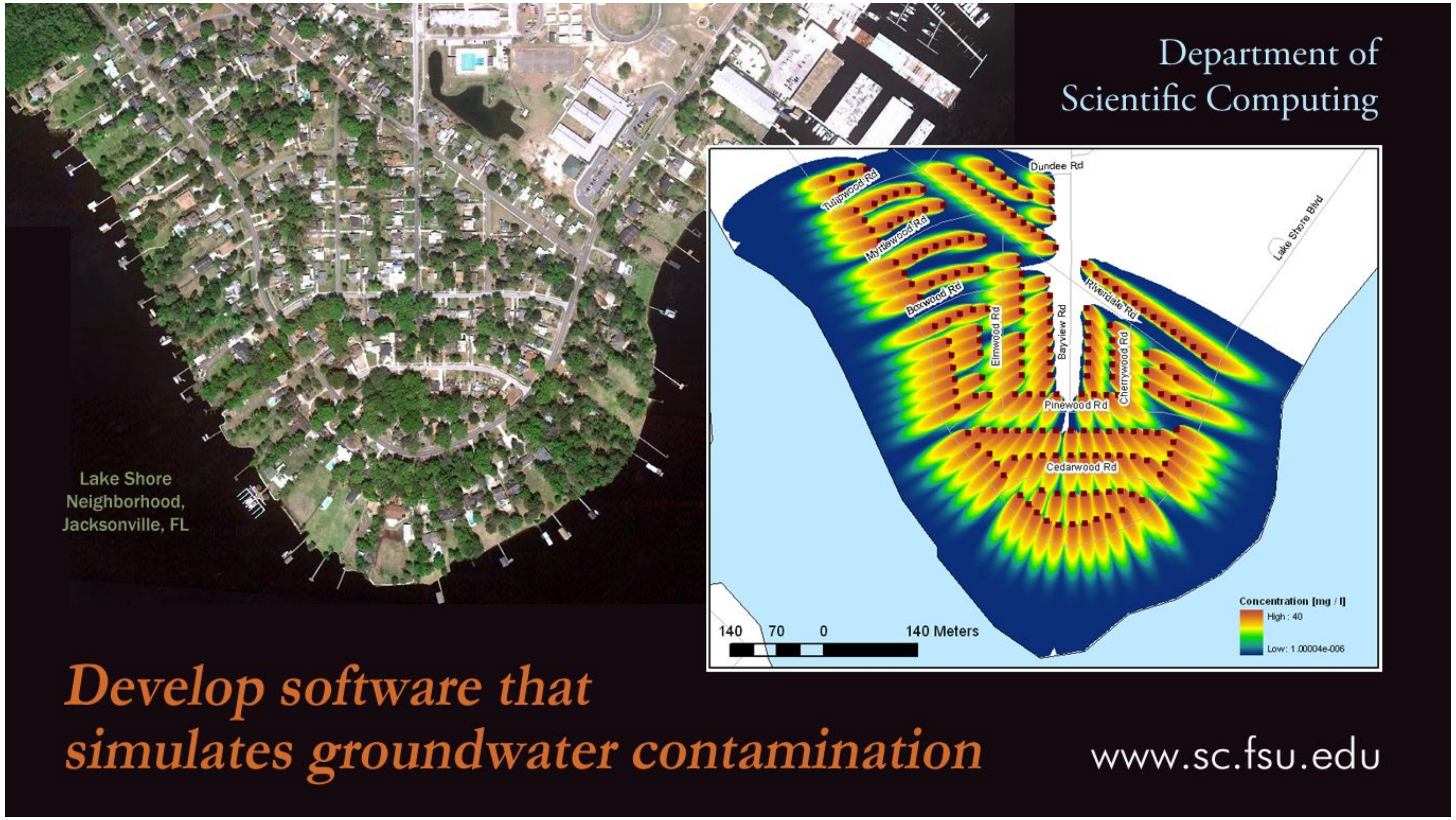


Analyte Name	Analyte Value	Site	Location	Sample Depth (ft)	Date
Caffeine ppb	0.19	Huy	Pz1		8/5/09
FC CFU 100mL	1.00	Huy	Pz1		8/5/09
Fluorescence µg/L	15.50	Huy	Pz1		8/5/09
Triclosan ppb	0.19	Huy	Pz1		8/5/09
NH4 N mg/L	0.45	Huy	P1		1/1/09
NOx N mg/L	0.32	Huy	P1		1/1/09

DEP-Funded Modeling Tool: ArcNLET
ArcGIS-based Nutrient Load Estimation Toolbox

Simulates NH_4 and NO_3 concentrations and loads

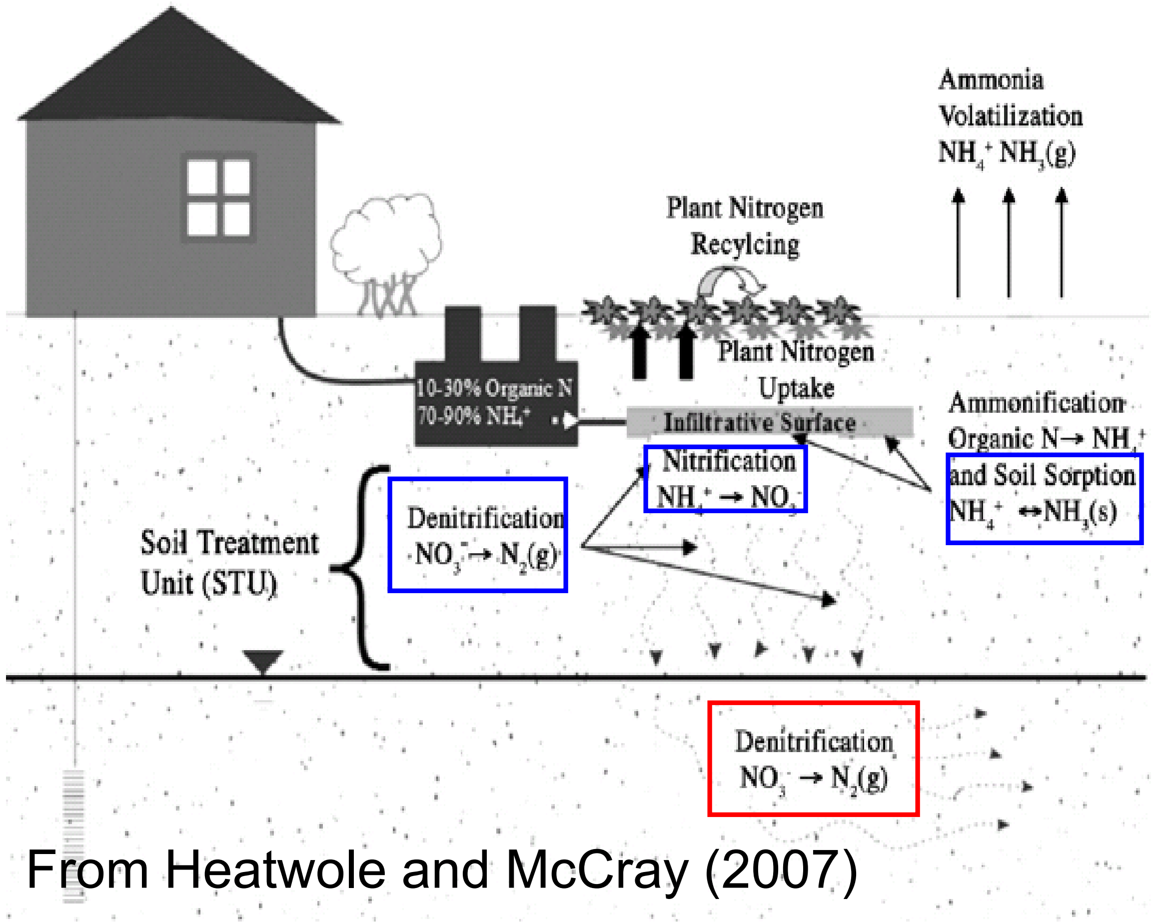
in vadose zone and surficial aquifer from **multiple OSTDS**



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

ArcNLET Nitrogen Modeling

- A simplified (but not over-simplified) model.
- Consider key hydrogeologic processes of flow and nitrogen fate and transport in vadose zone and groundwater.
- Handles spatial variability of OSTDS locations, water bodies, hydraulic conductivity, and porosity.



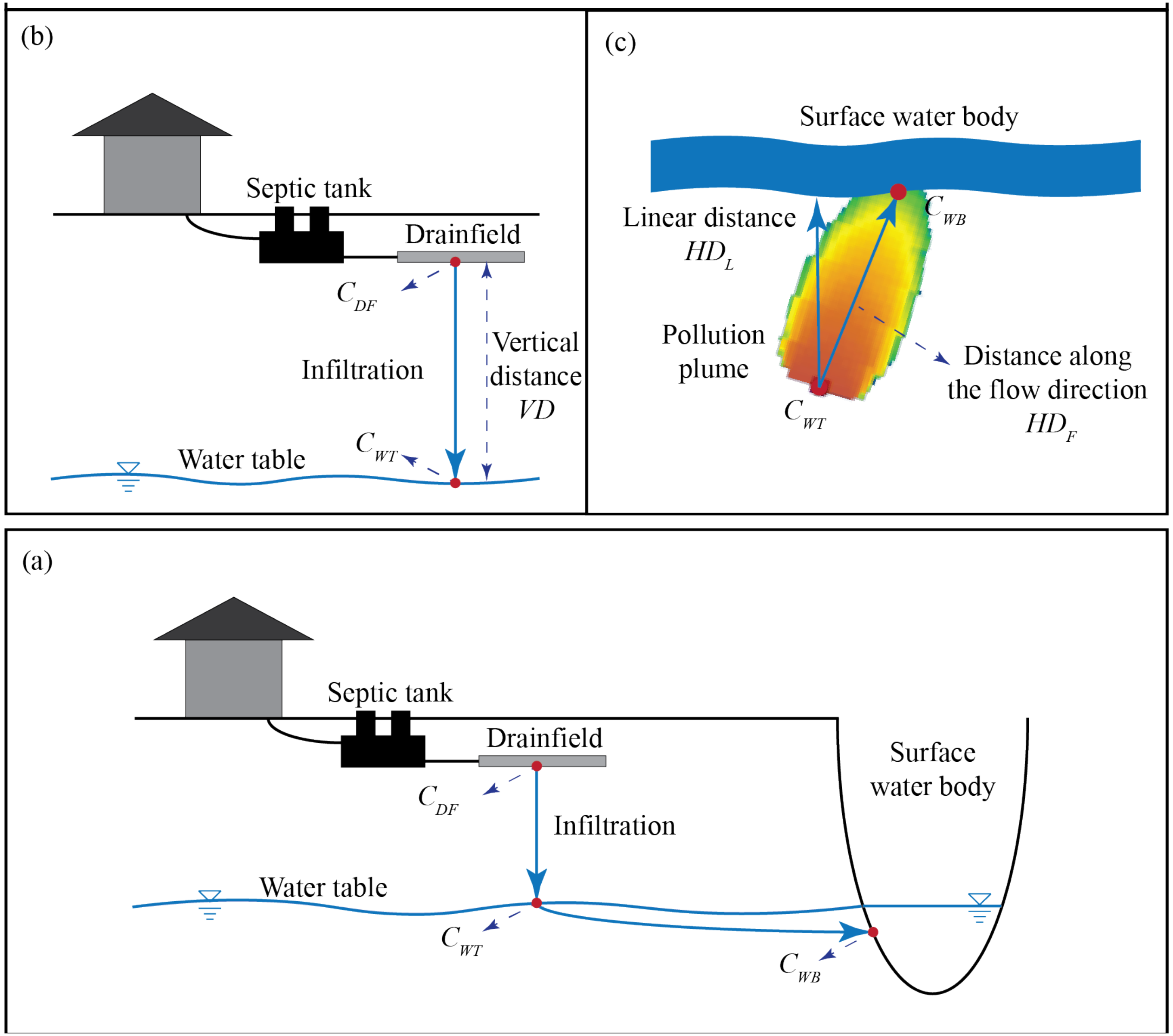
From Heatwole and McCray (2007)

Vadose Zone Processes:
- Unsaturated flow
- Ammonium and nitrate transport with sorption, nitrification, and denitrification

Groundwater Processes:
- Groundwater flow
- Ammonium and nitrate transport with sorption, nitrification, and denitrification

Surface Processes:
- Overland flow
- Ammonium and nitrate transport and mass transfer with soil nitrogen

Three Nitrogen Attenuation Rates



Vertical Attenuation Rate

from drainfield to water table

$$AR_v = \left(C_{DF} - C_{WT}\right) / C_{DF}$$

Horizontal Attenuation Rate

from water table to waterbody

$$AR_H = \left(C_{WT} - C_{WB}\right) / C_{WT}$$

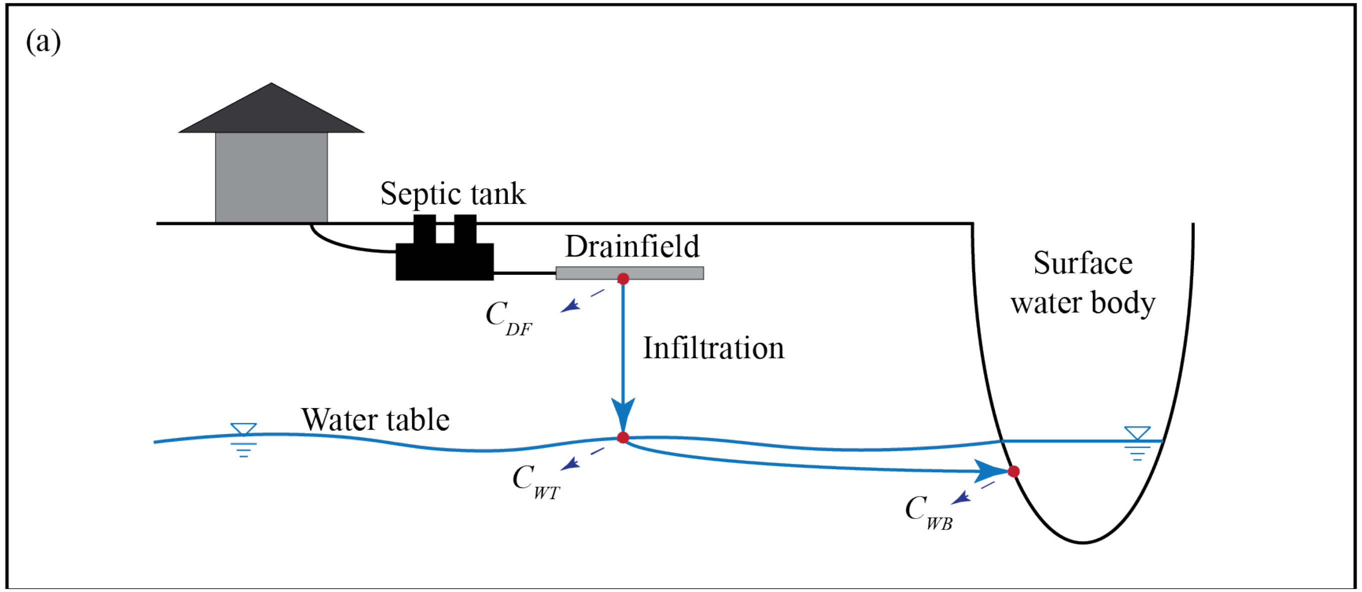
Total Attenuation Rate

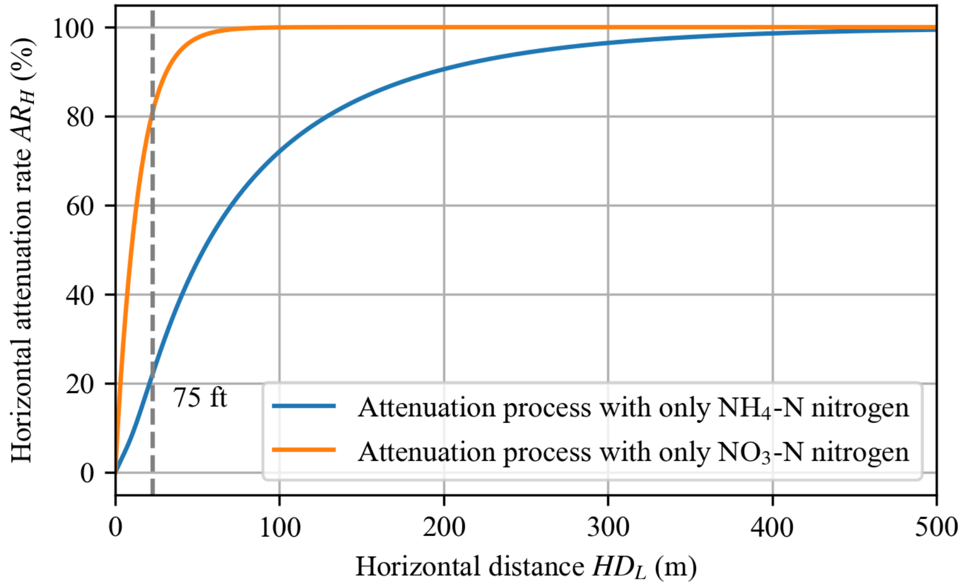
from drainfield to waterbody

$$AR_T = \left(C_{DF} - C_{WB}\right) / C_{DF}$$

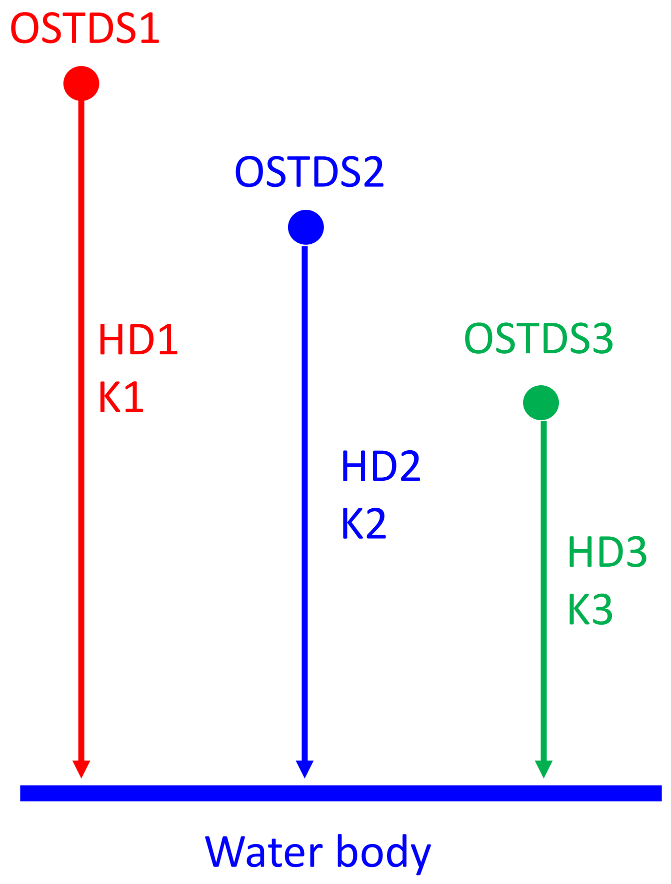
$$AR_T = 1 - (1 - AR_H) \times (1 - AR_V)$$

Nitrogen Attenuation in a Nutshell



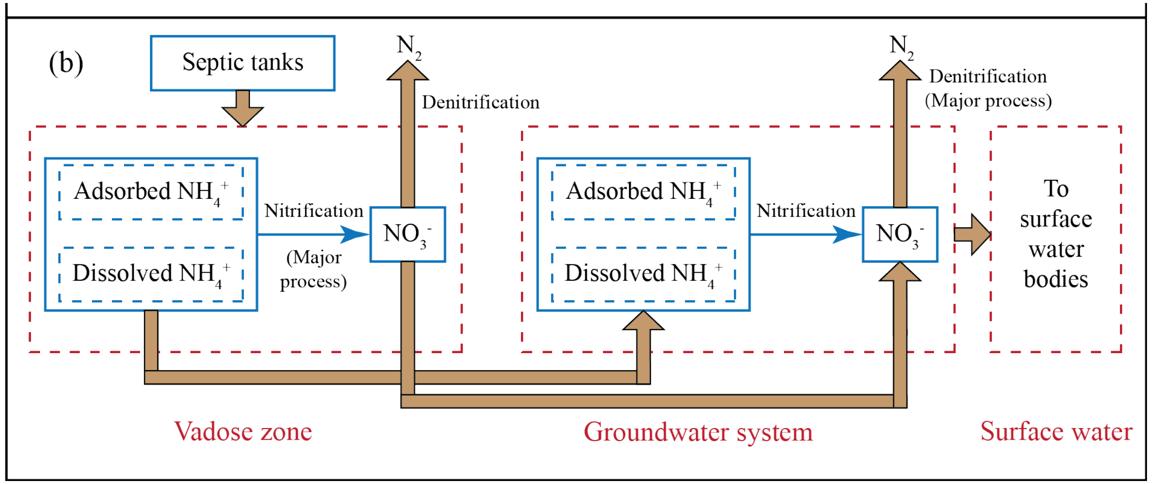


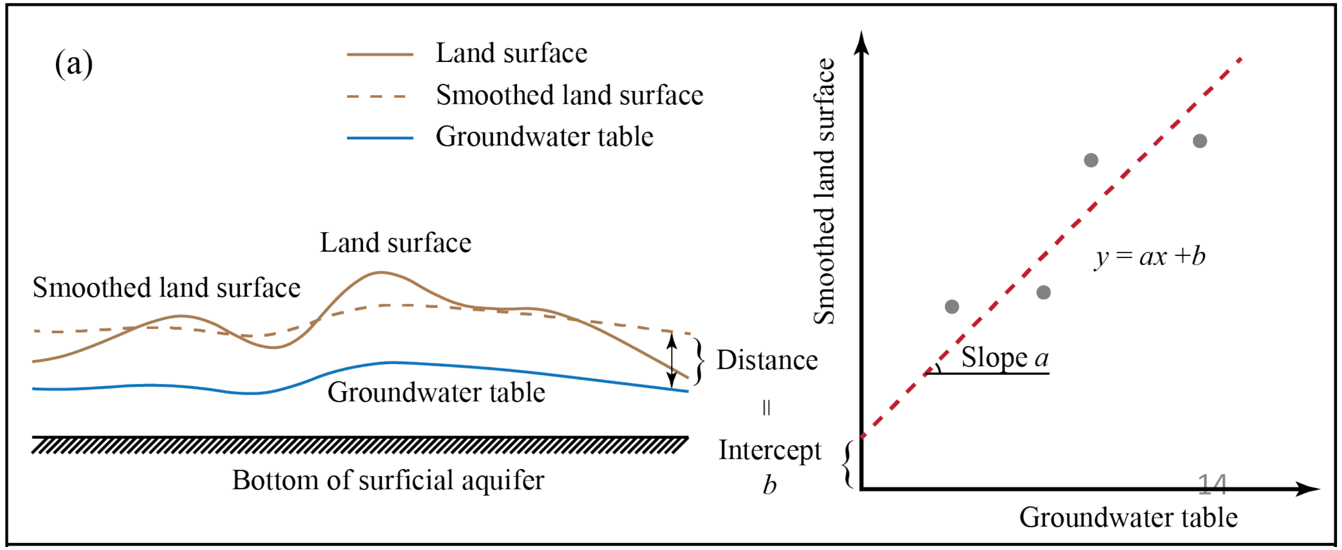
- Ideal Case: Ammonium is **nitrified** into nitrate in the vadose zone, and nitrate is **denitrified** into nitrogen gas in the surficial aquifer.
- Worse Case: Ammonium is NOT nitrified into nitrate in the vadose zone, and ammonium CANNOT be nitrified or denitrified in the surficial aquifer.
- Between the idea and worst cases: vertical and horizontal setback distances need to be carefully determined.



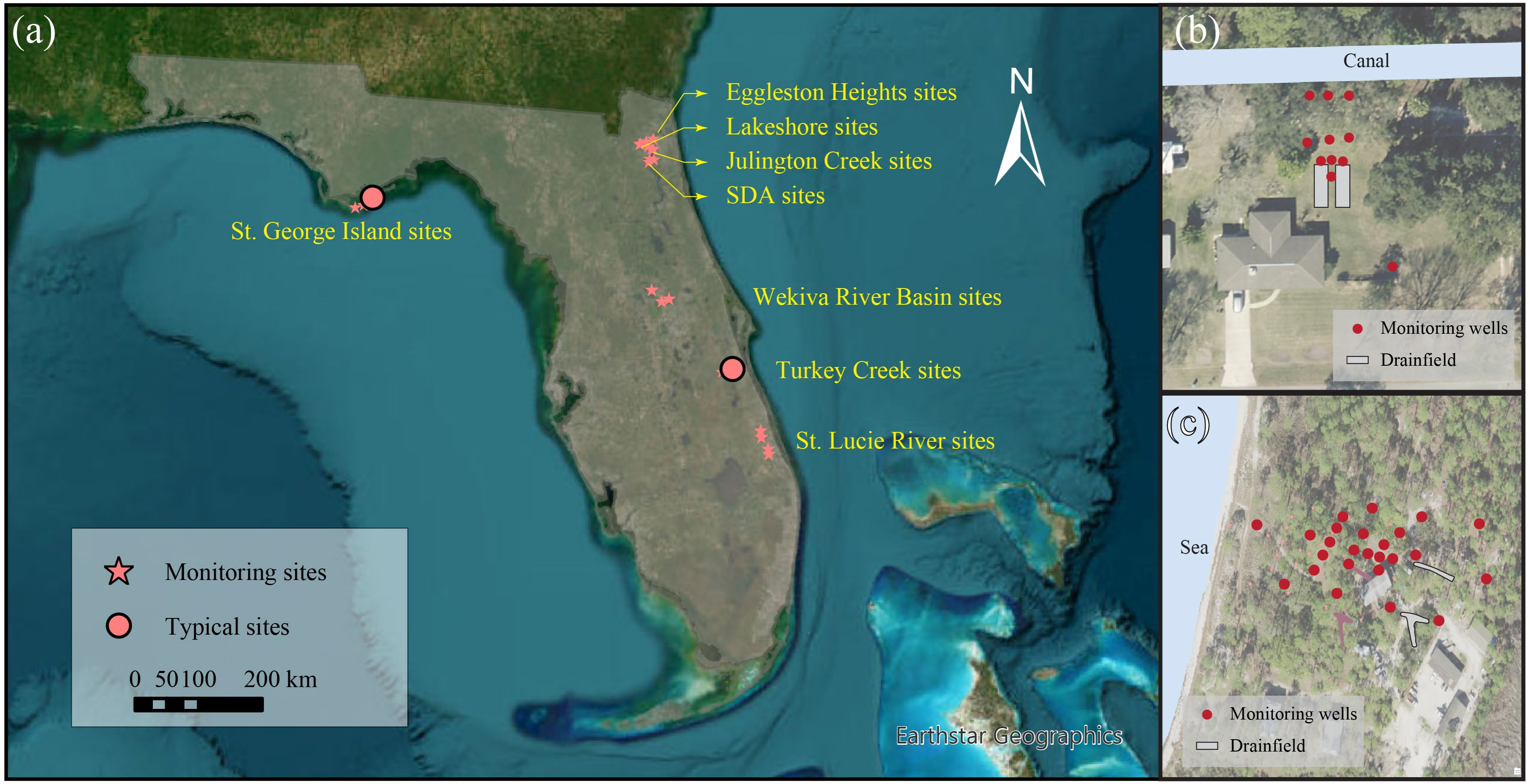
Modeling Procedure

- Select a study area with field measurement of head and nitrogen concentrations.
- **Develop and calibrate** an ArcNLET model.
- Simulate multiple (thousands) OSTDS to evaluate the relations between the attenuation rates and distances (including setback distance).
- Develop **empirical equations** to estimate attenuation rates using distances and hydraulic conductivity.
- Evaluate the empirical relations for multiple study areas.



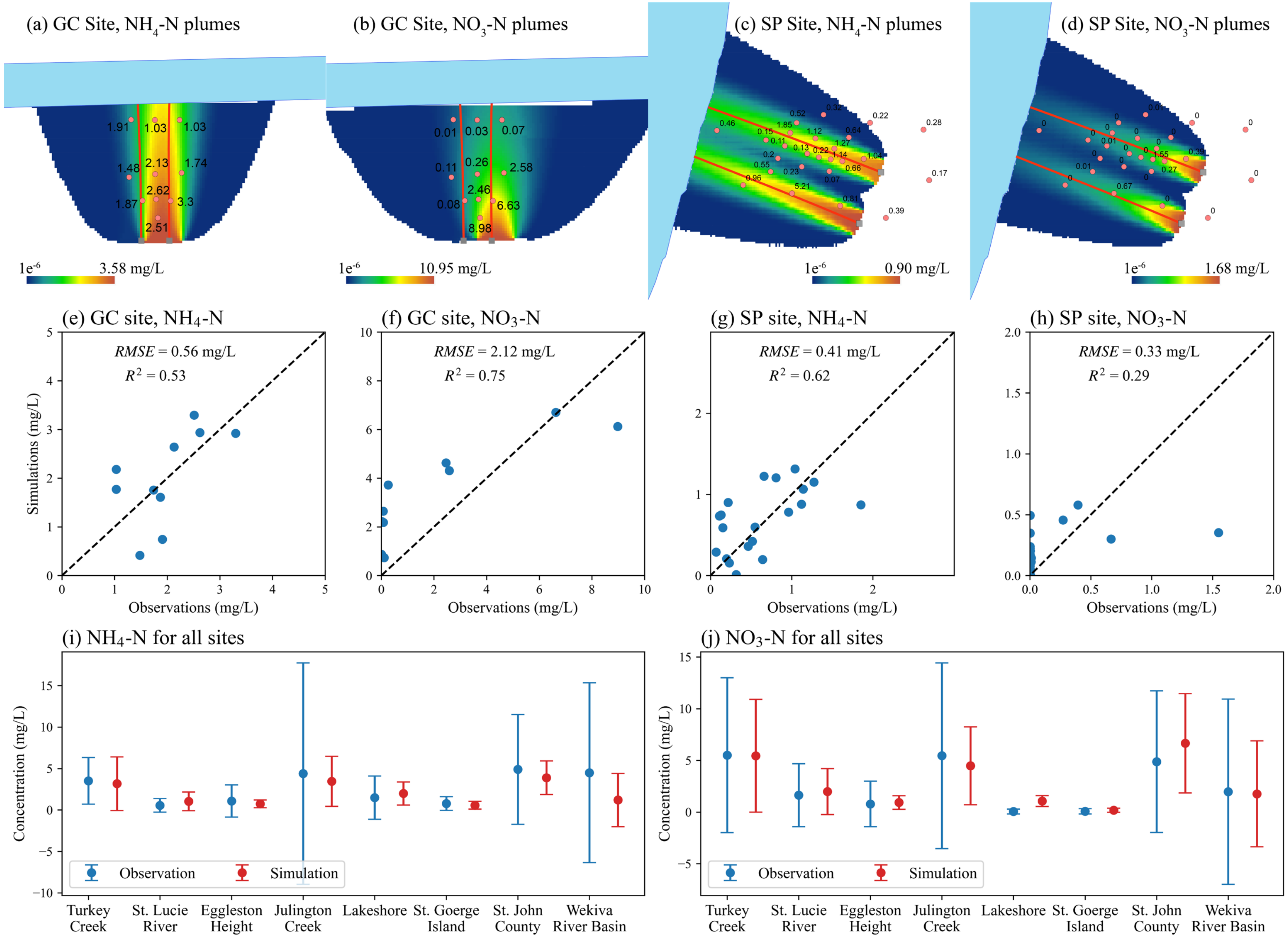


- Eight study areas (26,510 OSTDS) across the state
- Each study area has multiple sites with monitoring wells for hydraulic heads and nitrogen concentrations.
- Two typical study areas:
  - ✓ Turkey Creek (6,095 OSTDS): Sufficient nitrification and denitrification occurring
  - ✓ St. George Island (1,800 OSTDS): limited nitrification and denitrification occurring



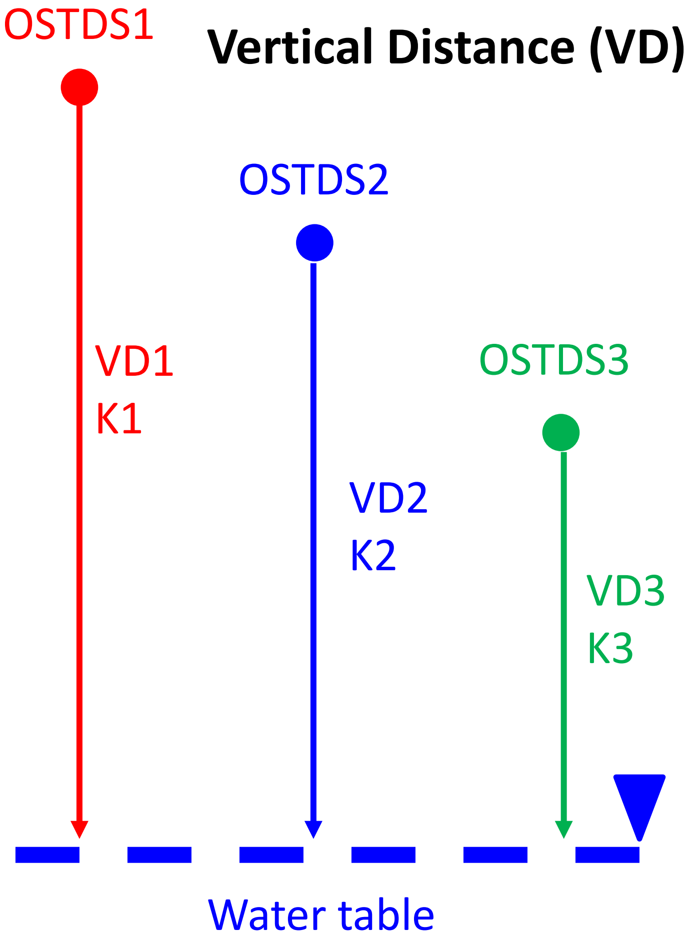
Mao et al. (Journal of Hydrology, 2024; Discover: Water, under review)

Model Calibration Results

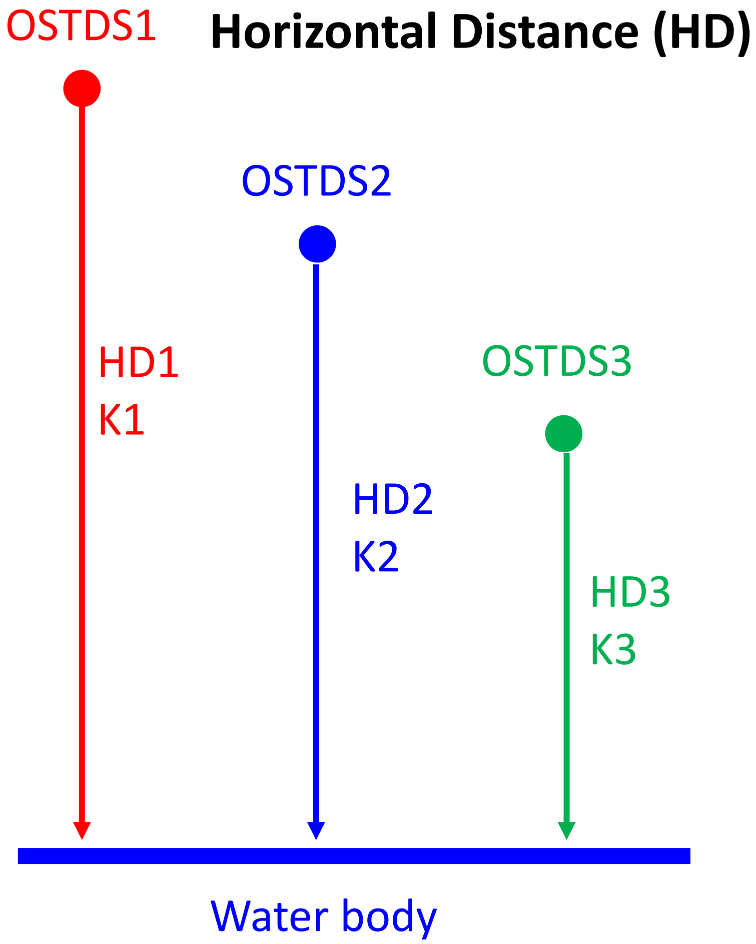


- Calibrated ArcNLET models produce acceptable simulations.
- The calibrated models can be used for studying nitrogen attenuation.

Simulation with Thousands of OSTDS



Each study area have 2 – 4 study sites with monitoring data, but each study area has 3,000 – 6,000 OSTDS.



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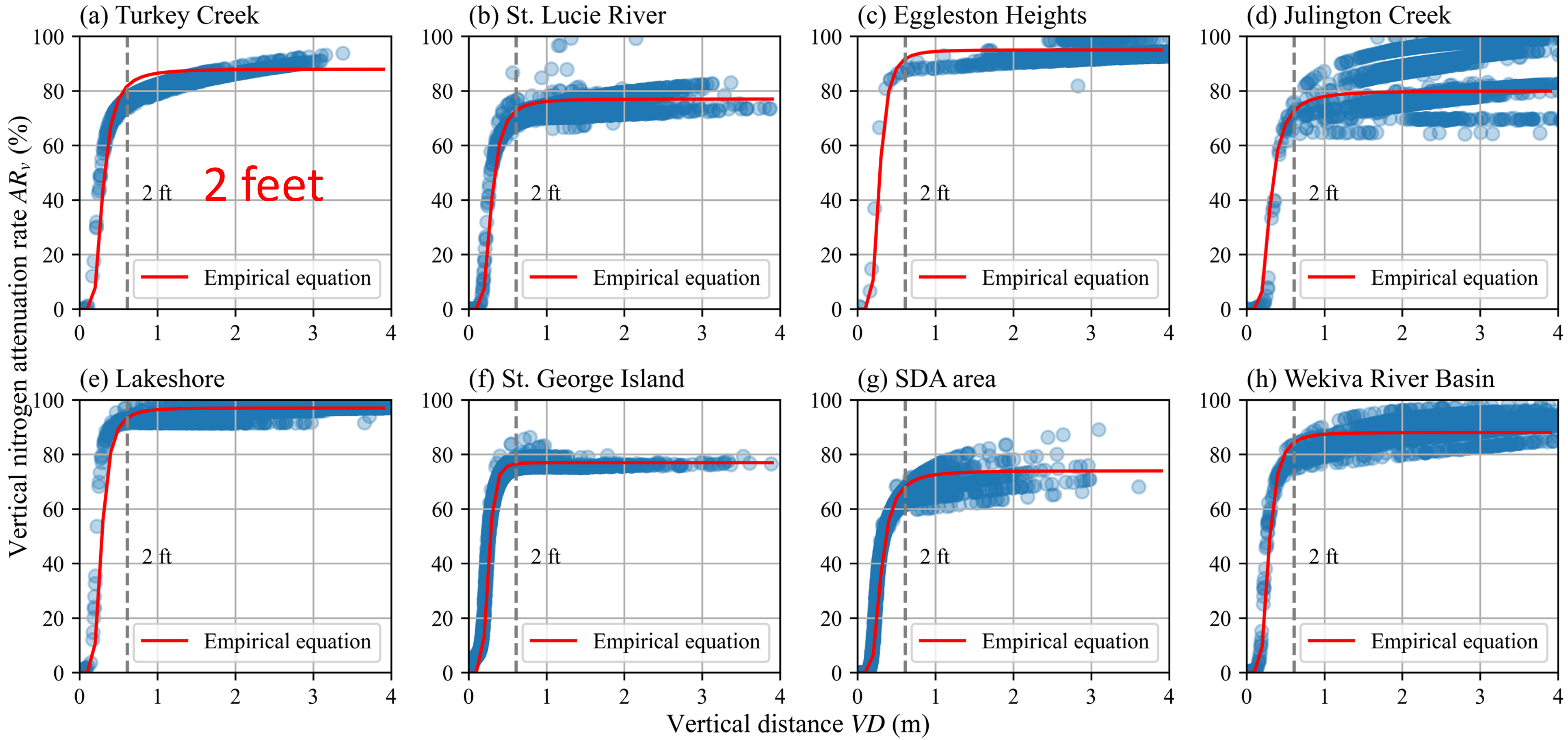
Vertical attenuation rate

Empirical Equation

$$AR_v = AF_v \times \left(1 - \frac{1}{(1 + 20000VD^7)^{0.03 \times K_S + 0.2}}\right) \times 100\%$$



- NH_4 needs to be nitrified into NO_3 during the vertical distance (VD) above water table, so that NO_3 can be denitrified into N_2 during the horizontal distance (HD) in aquifer.
- Vertical setback distance is as important as horizontal distance in governing overall nitrogen attenuation.

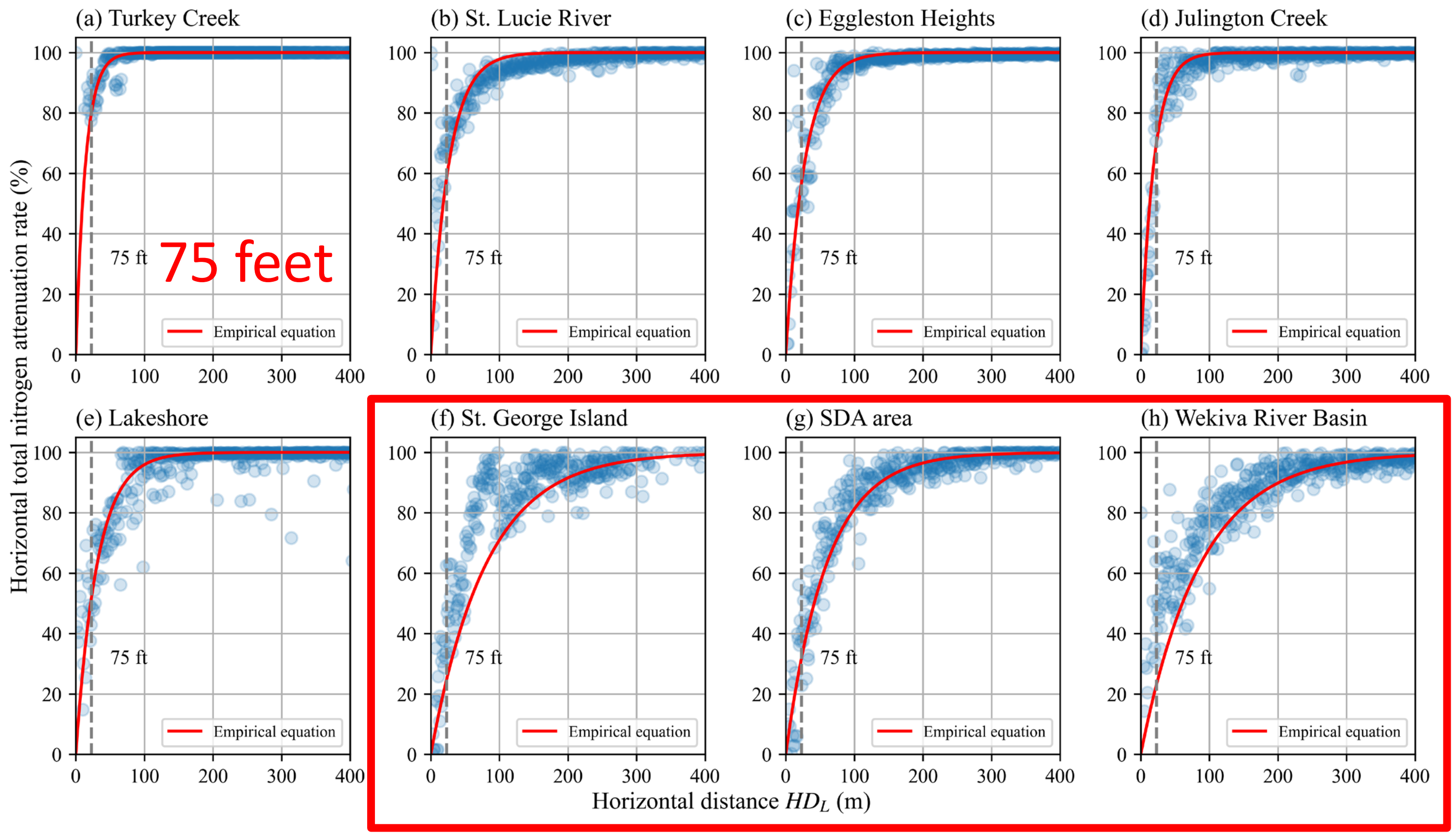
Horizontal attenuation rate

Empirical Equation

$$AR_H = AF_H \times (1 - e^{\frac{-3.28084 \times HD_L}{f \times K_s + 20}}) \times 100\%$$

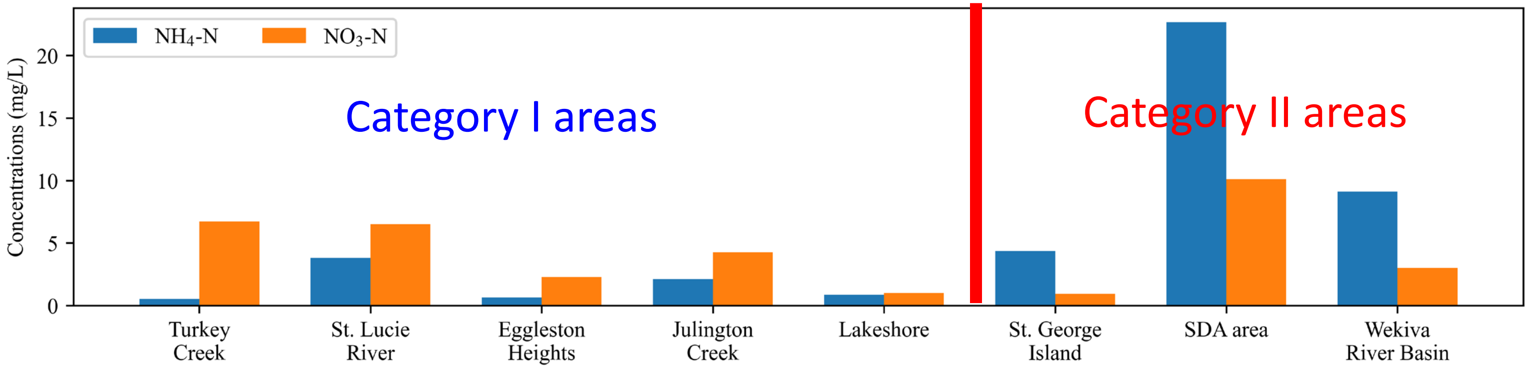
Category I areas

NO_3 dominates groundwater inputs



Category II areas

NH_4 constitutes a substantial fraction of nitrogen entering aquifer.



When a large amount of NH_4 enters water table, it will take a long distance to reduce NH_4 concentration through adsorption, nitrification, and denitrification.

Vertical attenuation rate $AR_v = AF_v \times \left(1 - \frac{1}{(1+20000VD^7)^{0.03\times K_S+0.2}}\right) \times 100\%$ for the vertical distance of 2 feet

Horizontal attenuation rate $AR_H = AF_H \times (1 - e^{\frac{-3.28084\times HD_L}{f\times K_s+20}}) \times 100\%$ for the horizontal distance 75 feet

Total attenuation rate $AR_T = 1 - (1 - AR_H) \times (1 - AR_V)$ corresponding total attenuation rate

Study Area	AR_V	AR_H (DIN)	AR_T (DIN)	AR_H (NO_3-N)	AR_T (NO_3-N)	AR_H (NH_4-N)	AR_T (NH_4-N)
	Category I Areas						
Turkey Creek Area	82%	80%	96%	84%	97%	53%	92%
St. Lucie River area	73%	58%	89%	76%	84%	41%	93%
Eggleston Heights area	92%	57%	96%	70%	95%	34%	97%
Julington Creek area	73%	70%	92%	83%	87%	51%	95%
Lakeshore area	93%	52%	97%	71%	96%	35%	98%
	Category II Areas						
St. George Island area	77%	25%	82%	28%	81%	21%	83%
Soap and Detergent Association (SDA) area	68%	32%	78%	39%	78%	29%	81%
Wekiva River Basin area	84%	23%	88%	29%	88%	21%	89%

It would be interesting to

(1) Select an area with high OSTDS nitrogen loading,
(2) Investigate vertical distance between drainfields and water table, and
(3) Measure concentrations of ammonium and nitrate at water table.

In Category II areas, nitrogen attenuation is small in the horizontal setback distance.

Conclusions and Future Study

- The current vertical and horizontal setback distances are supported by the numerical study, especially in the areas where ammonium nitrification is complete.
- The vertical setback distance appears to be more important than the horizontal setback distance.
- The empirical equations make it possible to determine optimum setback distances for different areas.
- The empirical equations also make it possible to estimate nitrogen load for large areas without ArcNLET modeling.
- More studies are needed for coastal areas with stronger hydrodynamics.