



Picture from USGS Scientific Investigations Report 2008-5220

Developing a **GIS-Based Software** for Estimating **Nitrate** Fate and Transport in Surficial Aquifers: from **Septic Systems** to **Surface Water Bodies**

November 5th, 2010

Presentation at the Department of Health

Project Team Members

- **Contract Manager:**
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- **Principal Investigators:**
 - Ming Ye (FSU) (mye@fsu.edu)
 - Paul Lee (FDEP) (paul.lee@dep.state.fl.us)
- **Graduate Students:**
 - Fernando Rios (FSU)
 - Raoul Fernandes (FSU)
- **Post-doc:**
 - Liying Wang (FSU)
- **No-Cost Collaborators:**
 - Hal David (USGS)
 - Tingting Zhao, Amy Chan-Hilton, Joel Kostka (FSU)

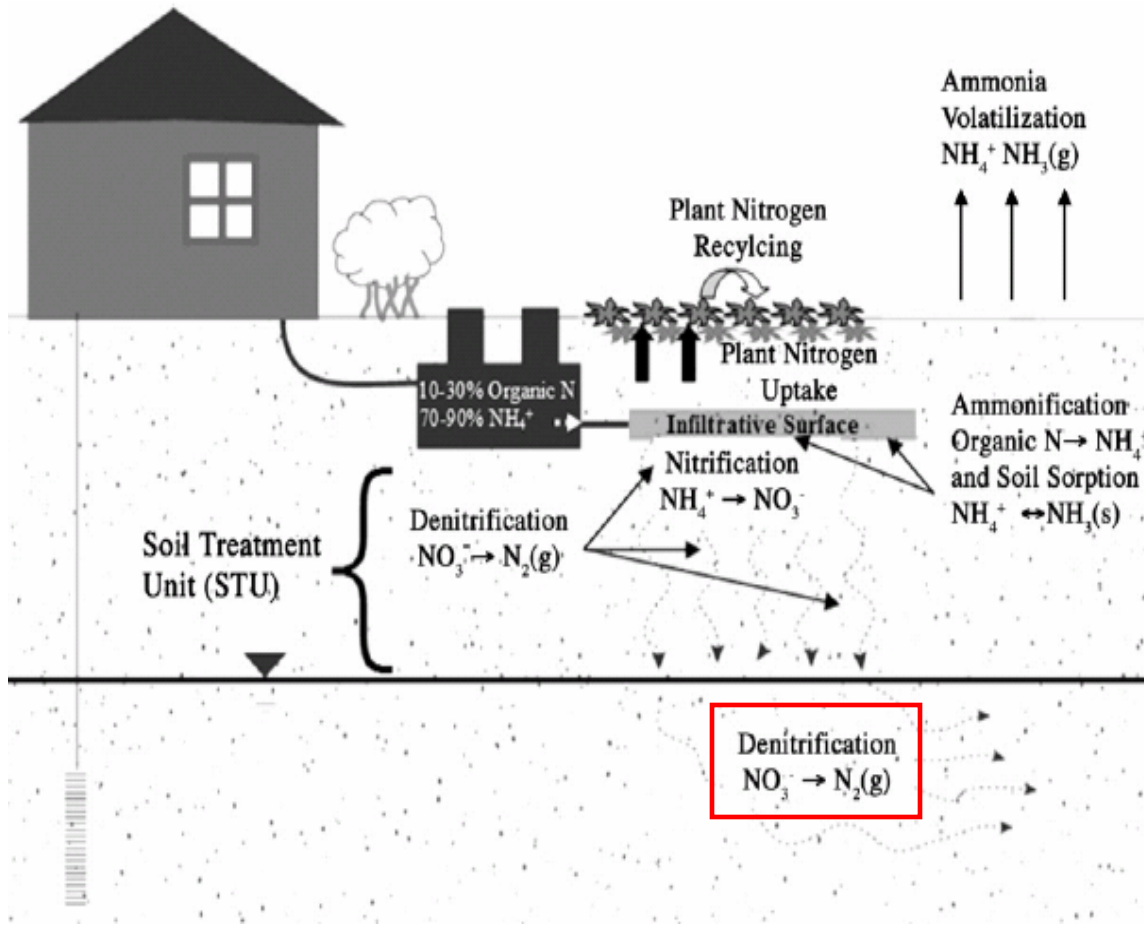
Presentation Outlines

- Project overview (Hicks)
- Project background, motivations, and objectives (Lee)
- Development of groundwater flow and nitrate fate and transport models (Ye)
- Development of GIS-based software and demonstration (Rios)
- Future research (Ye)

Project Overview

Project Background, Motivations, and Objectives

Schematic of an Onsite Wastewater Treatment System (OWTS) and Subsurface Nitrogen Transformation and Removal Processes

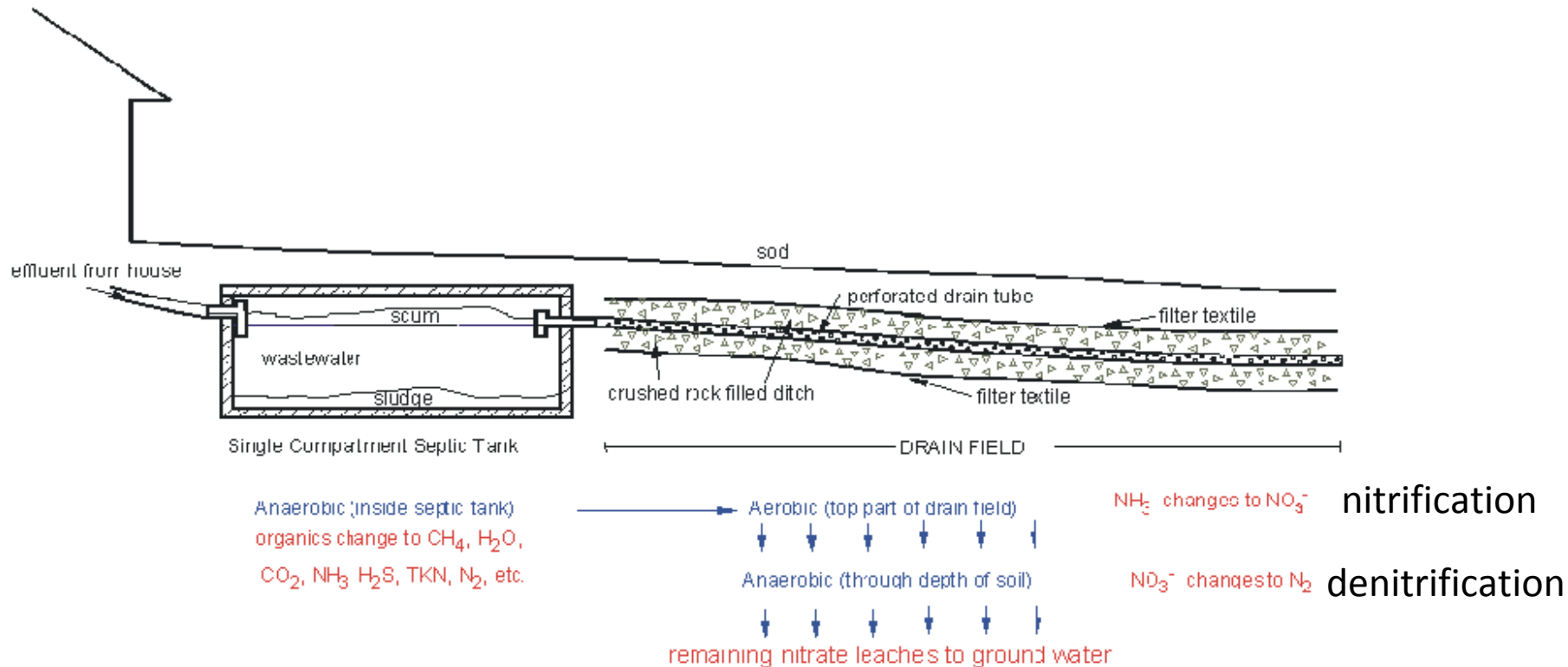


Approximately one-third of the population of Florida utilizes an OWTS for wastewater treatment. (Ursin and Roeder, 2008, FDOH)

Denitrification rates are much smaller than nitrification rates.

Ninety percent of the water used for drinking comes from the groundwater. (FDEP, 2006)

Classic Septic System: anaerobic processes in the tank, aerobic processes in drain field, partial anaerobic in sub-drainfield soil; remaining nitrate leaches to ground water



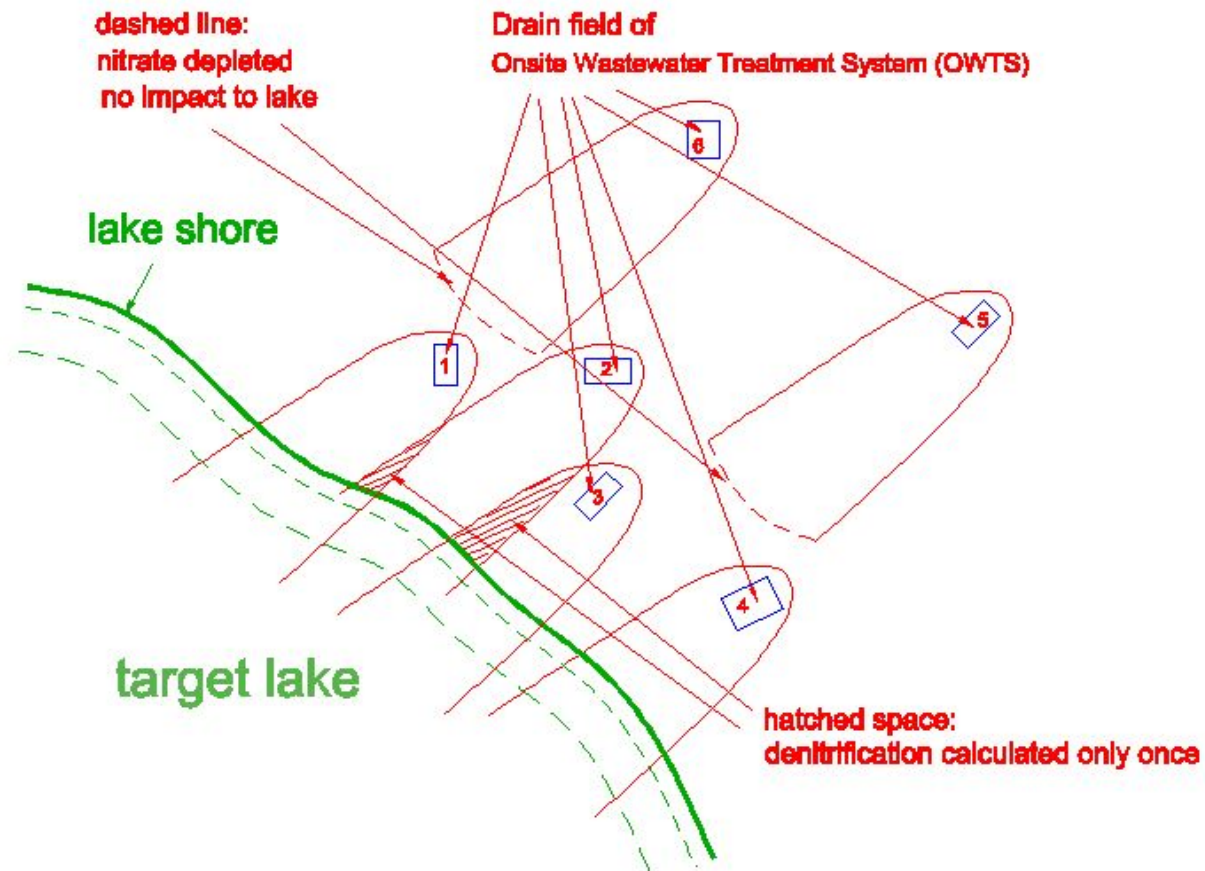
Denitrification rates are much smaller than nitrification rates in natural soils.

Motivations

- Traditional estimate of nitrate loading (e.g., in TMDL) may **ignore**
 - **Nitrate from normally working septic systems**
 - Denitrification process occurring between drainfield and surface water body
 - Effect of spatial locations of septic systems on nitrate load
- **Consequence**
 - Over- or under-estimation of the nitrate load
- **Sophisticated numerical models** have been developed to study fate and transport of nitrate from septic system, but they may not be applicable for certain types of estimation (e.g., in TMDL).

Effect of **Spatial Locations** of Septic Systems

Negative or zero N_t indicates no nitrate load from the septic system to the surface water body.



Project Goal

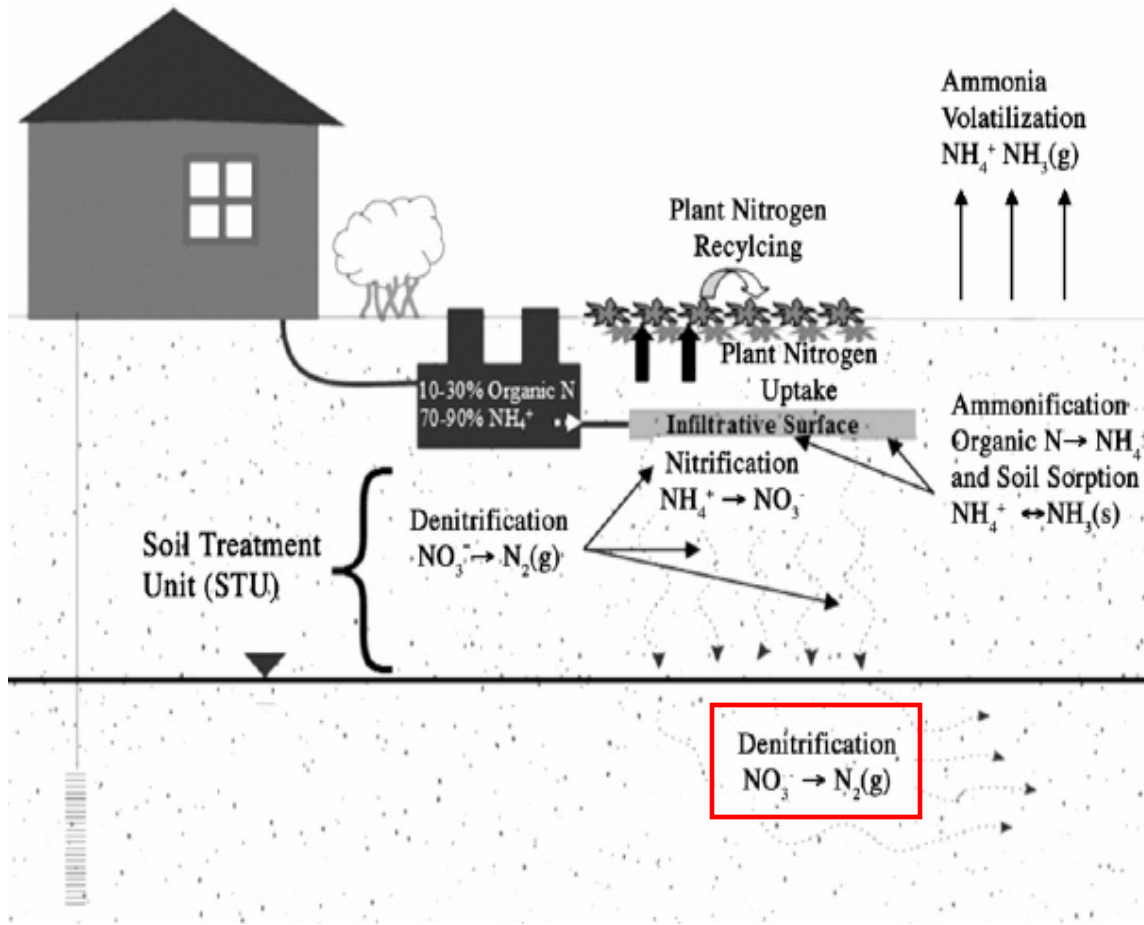
- Goal:** To develop a simplified model and software to support the TMDL.
- It should be **scientifically defensible** under scrutiny.
 - It should be **user-friendly and GIS-based** to incorporate location information for both septic tank cluster and surface water receiving the nitrate load.
 - It should be **available in public domain**, to be used by all parties, including the challengers and for comparison reasons

Project Objectives

- Develop **a simplified model** of groundwater flow and nitrate fate and transport
- Implement the model by developing a **user-friendly ArcGIS extension (ArcGIS-N)**
 - Simulate nitrate fate and transport including the denitrification process
 - Consider either individual or clustered septic tanks
 - Provide a management and planning tool for environmental management and regulation
- Apply this software to nitrate transport modeling at the **Lower St. Johns River basin** to facilitate DEP environmental management and regulation
- Disseminate the software and conduct **technical transfer** to DEP staff and other interested parties

Simplified Groundwater Flow and Nitrate Fate and Transport Models

Schematic of an Onsite Wastewater Treatment System (OWTS) and Subsurface Nitrogen Transformation and Removal Processes

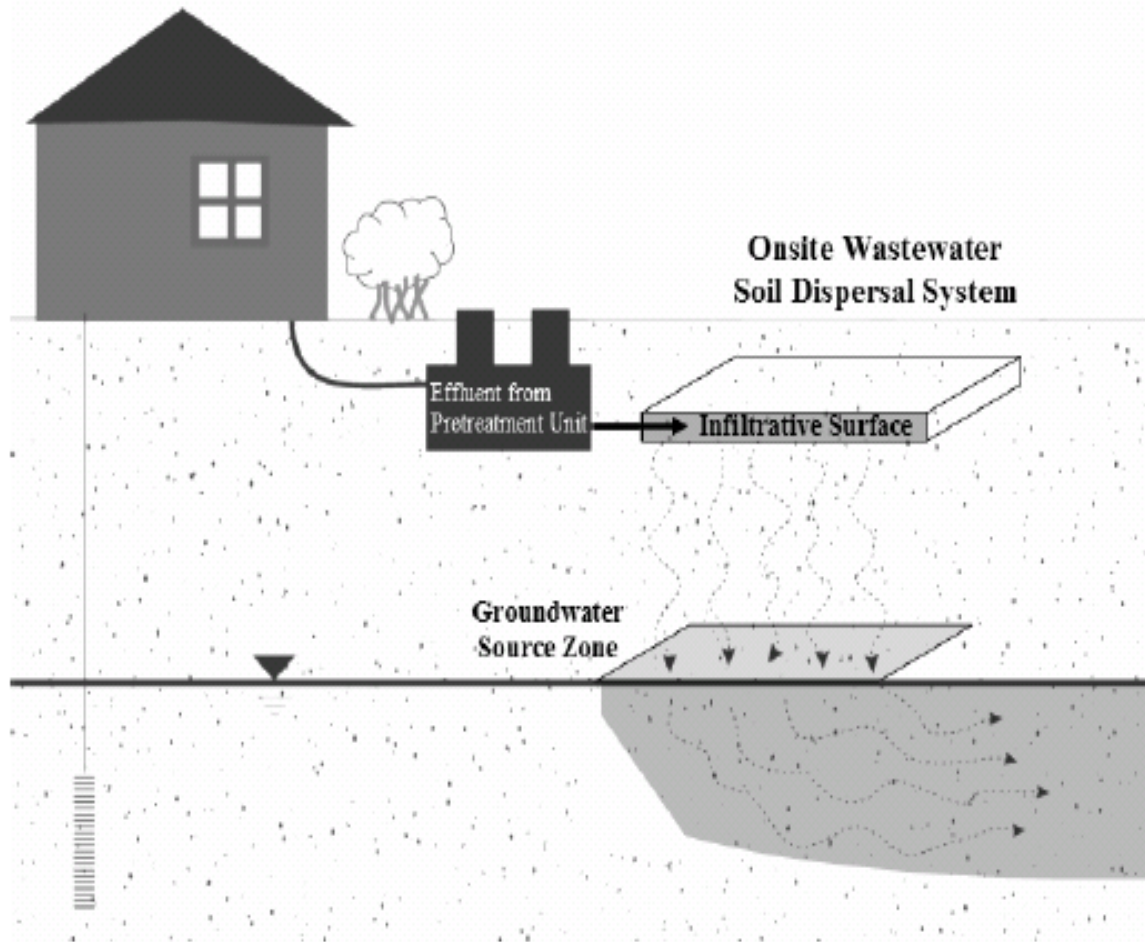


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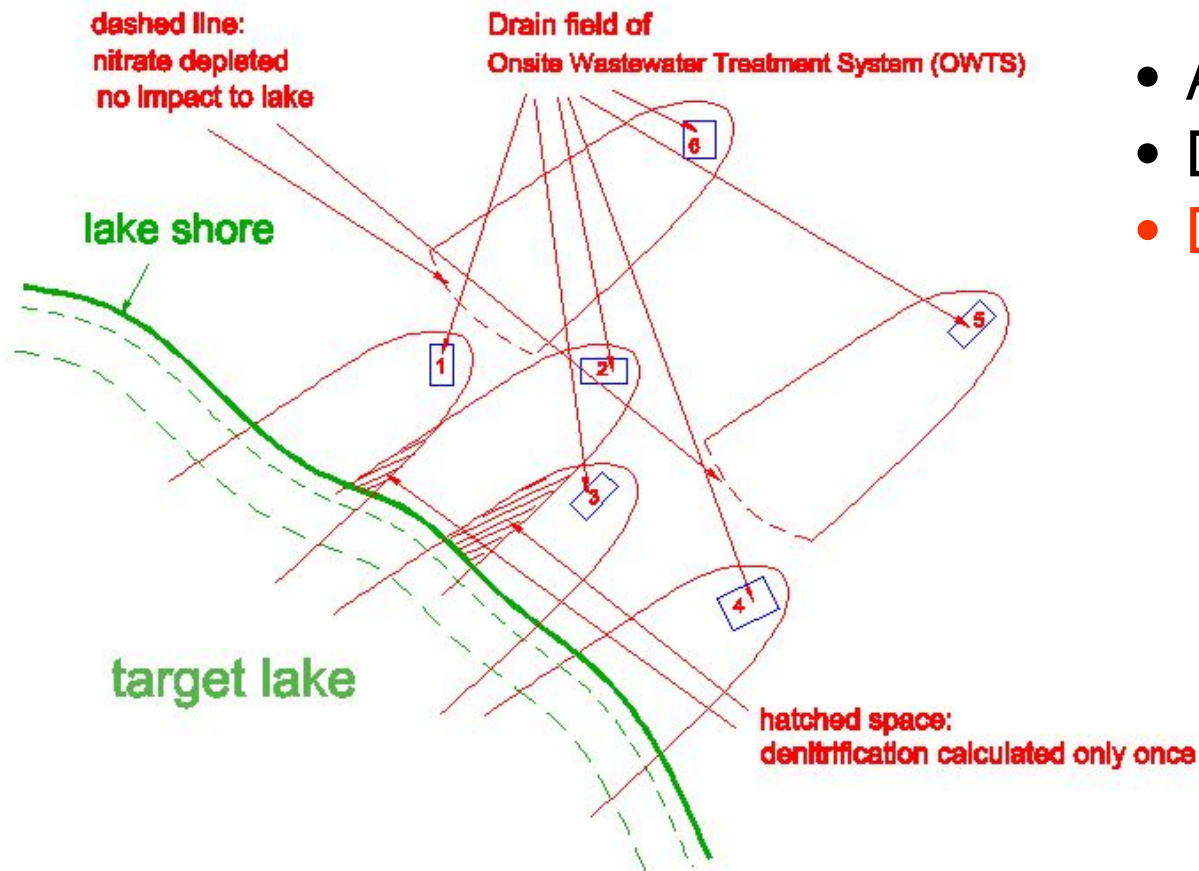
Nitrate Fate and Transport in Groundwater



Due to nitrification in the vadose zone, OSW can generate $\text{NO}_3\text{-N}$ concentration at the water table from **25 to 80** mg N/L in most situations (McCray et al., 2005).

Conceptual Model

Take into account of nitrate contribution from **working septic tanks.**



- Advection
- Dispersion
- Denitrification

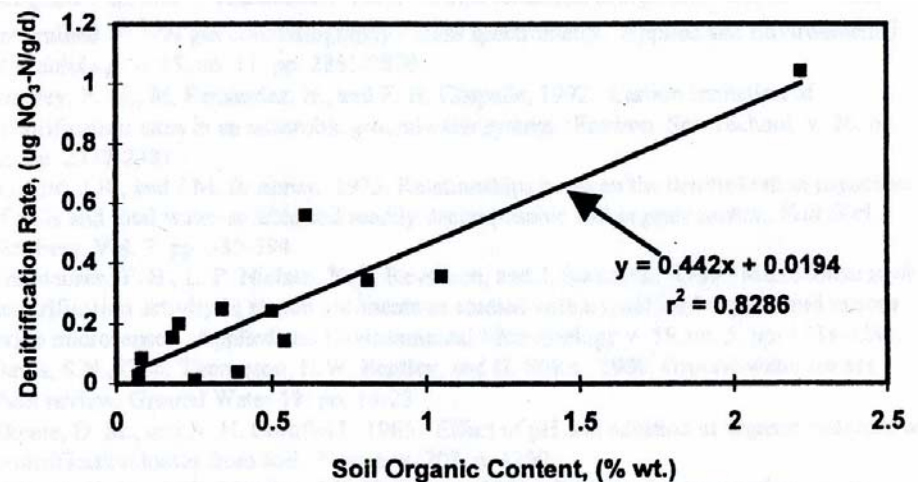
Denitrification

Denitrification refers to the biological reduction of nitrate to nitrogen gas.



Denitrification ... has been identified as **basic factor** contributing to the generally low levels of nitrate found in the **groundwater of the southeastern United States** (Fedkiw, 1991).

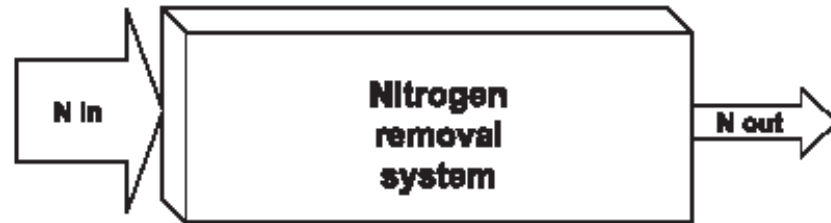
A fairly broad range of heterotrophic **anaerobic bacteria** are involved in the process, requiring an **organic carbon** source for energy as follows



Anderson (1989)

Estimation of Nitrate Load

$$M_l = M_{in} - M_{dn}$$



- M_l (M/T): nitrate load to rivers
- M_{in} (M/T): nitrate from septic tanks to surficial aquifer
- M_{dn} (M/T): nitrate loss due to denitrification

$$M_{dn} = R_{dn} V_g$$

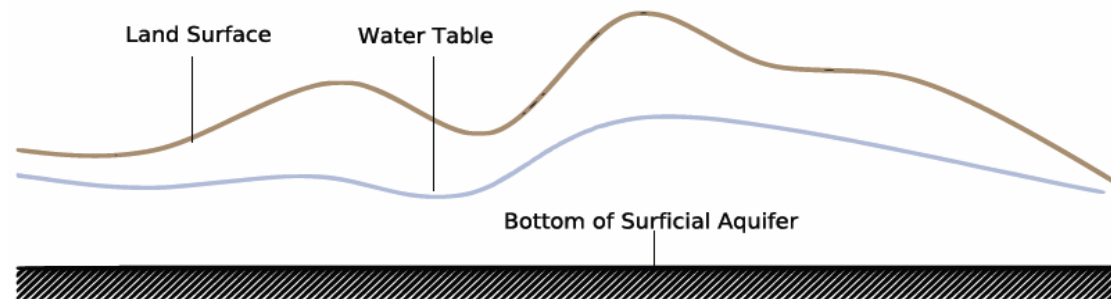
R_{dn} (M/T/L³): denitrification rate

V_g (L³): volume of groundwater solution, estimated from **groundwater flow and reactive transport modeling**

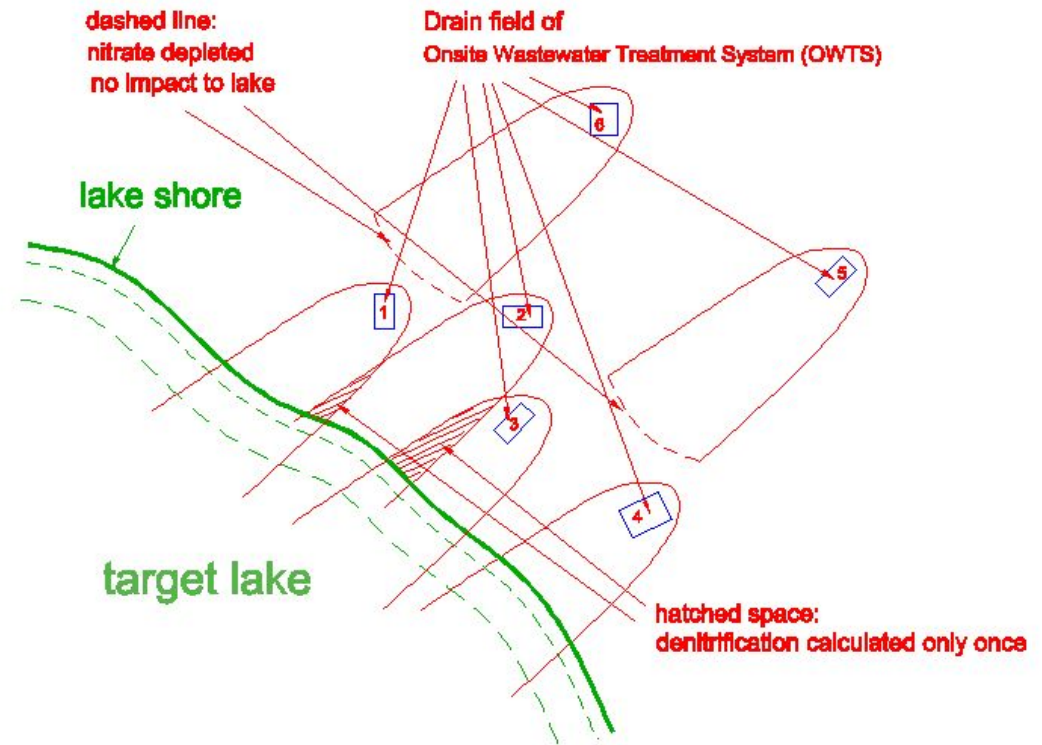
Groundwater Flow Modeling

Assumptions and Approximations:

- Steady-state flow
- Ignore mounding on top of water table
- Use Dupuit assumption to simulate 2-D groundwater flow
- Treat water table as subdued replica of the topography
- Process topographic data and approximate hydraulic gradient using the topographic gradient



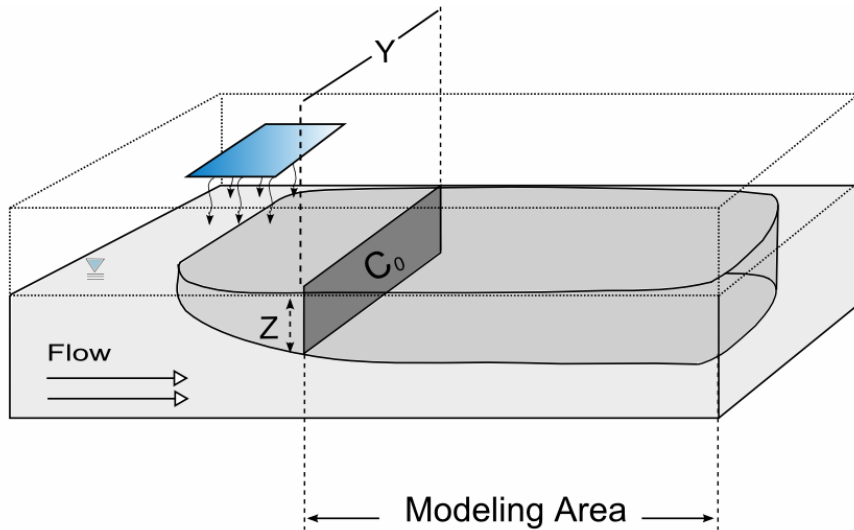
Outputs of Groundwater Flow Modeling



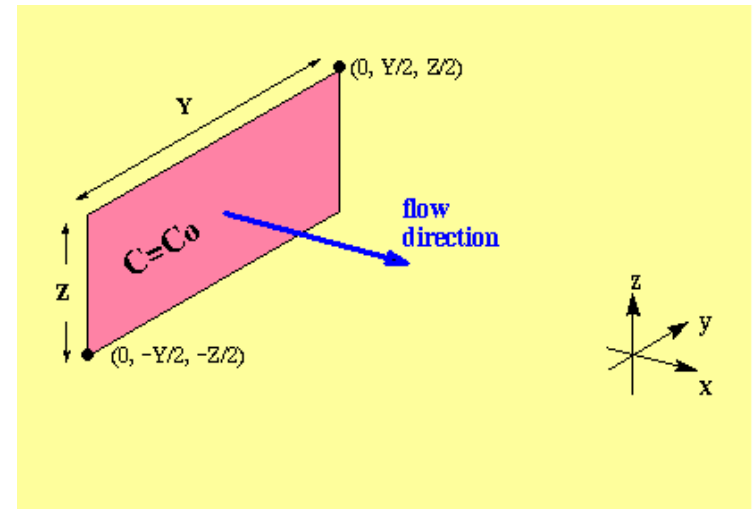
- **Flow paths** from each septic tank to surface water bodies
- **Flow velocity** along the flow paths. Heterogeneity of hydraulic conductivity and porosity is considered.
- **Travel time** from septic tanks to surface water bodies

Nitrate Transport Modeling

EPA BIOCHLOR model



Domenico analytical solution



$$\frac{\partial C}{\partial t} = \alpha_{\ell} v \frac{\partial^2 C}{\partial x^2} + \alpha_{T_h} v \frac{\partial^2 C}{\partial y^2} + \alpha_{T_v} v \frac{\partial^2 C}{\partial z^2} - v \frac{\partial C}{\partial x} - kC$$

Dispersion

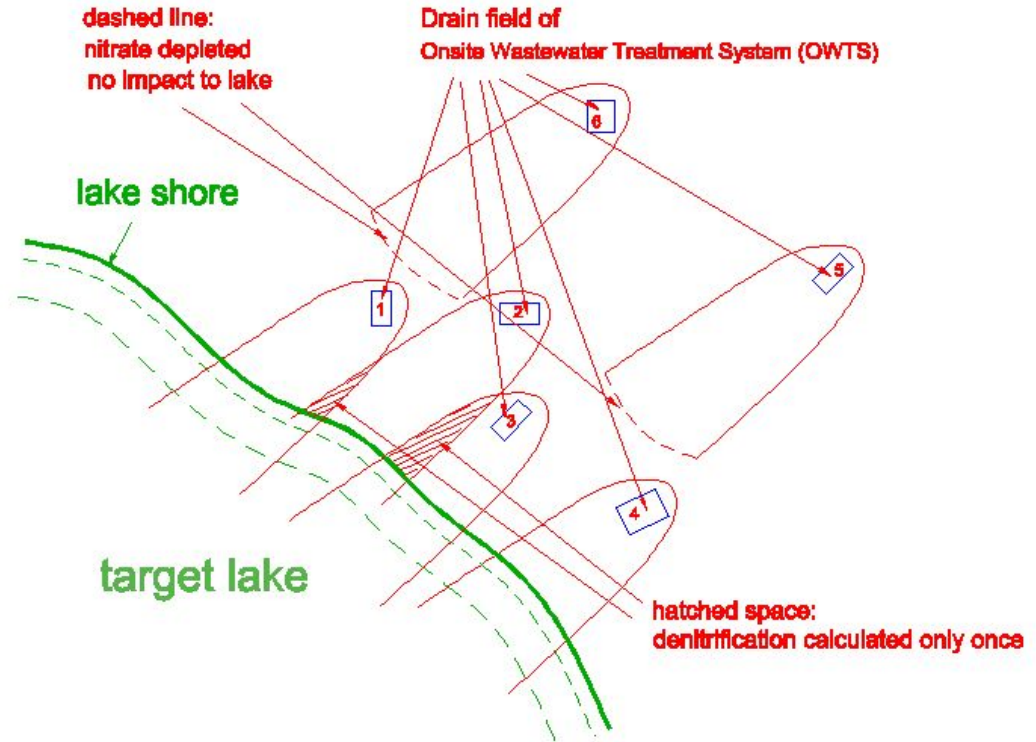
Advection Decay

Denitrification

$$C(x, y, z, t) = \frac{C_0}{8} F_1(x, t) F_2(y, x) F_3(z, x)$$

Outputs of Nitrate Transport Modeling and Calculation of Nitrate Load

- Apply the analytical solution to each septic tank.
- Obtain the nitrate plume of the entire area.
- Calculate mass of inflow and denitrification.
- Calculate load to rivers



$$M_l = M_{in} - M_{dn}$$

$$M_{dn} = R_{dn} V_g$$

Research Team

- **Fernando Rios**

Development of model and the GIS-based software

- **Raoul Fernandes**

Development of statistical methods of estimating denitrification rate

- **Liyang Wang**

Field application and model calibration

Software Development and Demonstration

Development of the ArcGIS Extension

- All the development is within a GIS, including pre-processing, post-processing, and computation.
- We developed a user-friendly interface using Visual Basic.
 - The .NET framework is used to expedite development.
- The software development is for ArcGIS 9.3.
 - The software can be updated with newer version of ArcGIS.
- Final product is a installation file that installs the ArcGIS extension on PC.

Development of the ArcGIS Extension

- Modules
 - Groundwater Flow
 - Transport
 - Denitrification
- Details of model/software verification and validation are referred to the draft manual.

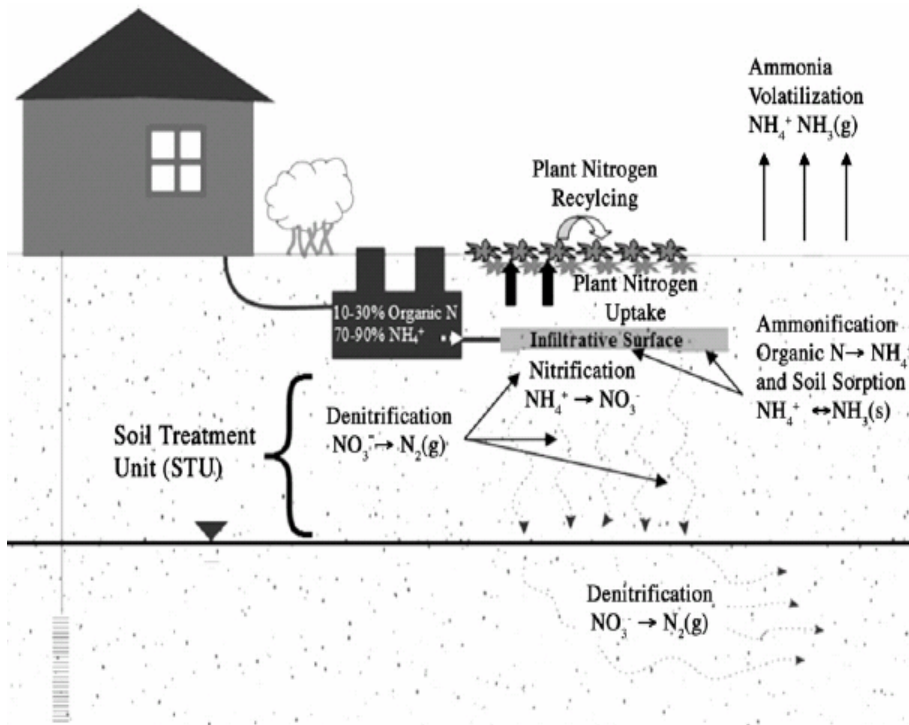
Future Research

Future Work

- Model/software verification and validation
- Field data collection and compilation
 - Parameters (e.g., hydraulic conductivity, effective porosity, dispersivity)
 - Field conditions related to denitrification (e.g., OC and soil texture)
 - Field observations (hydraulic heads, flow rate, and nitrate load and concentrations)
- Model calibration to match model simulations to field observations
- Software dissemination and technical transfer and training

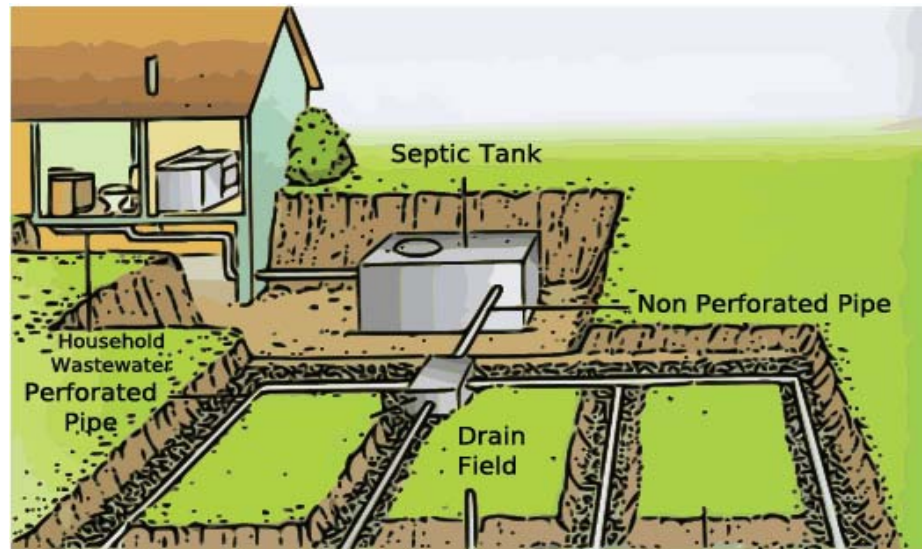
Prospective Research

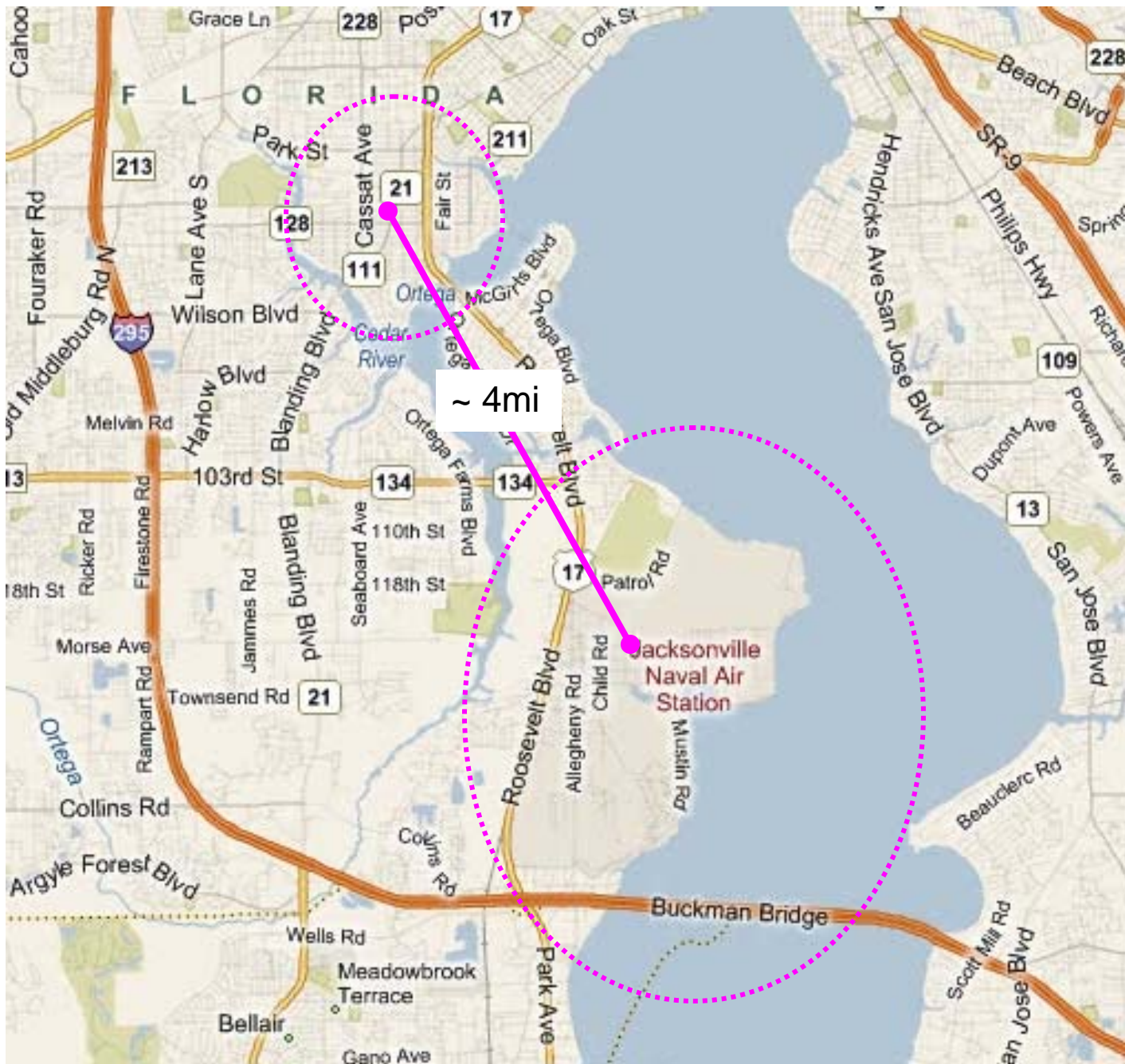
- Continue developing the software to meet other needs of DEP environmental management and regulation.
- Consider nitrification process (e.g., nitrification and plant up-take) in the vadose zone.
- Apply this software to different sites to provide guidelines for environmental management and regulation.



Due to nitrification in the vadose zone, OSW can generate $\text{NO}_3\text{-N}$ concentration at the water table from **25 to 80** mg N/L in most situations. (McCray et al., 2005)

Questions?





Nonlinear Relationship

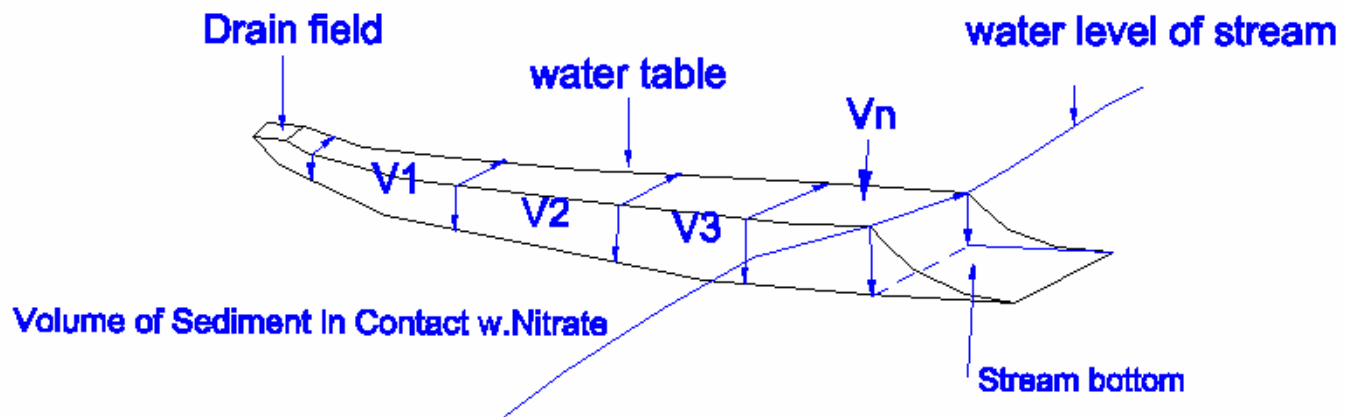
$$M_l = M_{in} - R_{dn} V_g$$

The volume is determined by

- **Advection** of groundwater flow
- **Dispersion** of nitrate transport
- **Denitrification** due to biological processes

All these affect nitrate concentration and nitrate concentration in turn affect denitrification rate.

V_1, V_2, \dots, V_n are volumes of plume in contact with sediment in equal travel time



Modeling Procedure: Data Preparation

- $N_t = N_0 - R_{dn} V_{aq}$
- Input the **topographic map** of the selected site.
- Input the map of **septic tank locations**. The location can be obtained from the county property appraiser's office. If the actual location of the septic tank on each property lot is unknown, the center of the property polygon will be used as the septic system location.
- Delineate **boundary line of target surface water body** (e.g., a lake and/or a stream) based on the topographic map. The boundary line can be of any shape.
- Delineate **parameter zones** of hydraulic conductivity, percent of soil organic carbon, porosity, and dispersion coefficients to incorporate heterogeneity of the aquifer. These hydraulic properties can be obtained from literature and/or field/laboratory experiments.

Modeling Procedure: Estimation

- Determine **hydraulic gradient** along the flowpath from each septic system to the boundary line.
- For each septic system, calculate the **travel time** for each segment based on the Darcy's law. The travel time varies for each segment of each septic system.
- For each septic system, calculate **aquifer volume** within which denitrification would occur using the analytical solution of Domenico and Robbins (1985).
- Calculate **N loss** for each septic tank.
- Calculate **nitrate load** to the target surface water for each septic tank.
- **Sum the load for all the septic tank.**