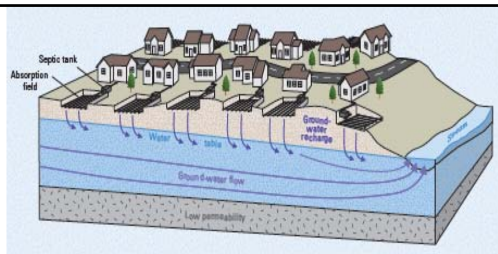

Picture from USGS Scientific Investigations Report 2008–5220

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

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Project Team Members

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

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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)

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Project Overview

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Project Overview: Tasks and Timetable

Duration: 10/1/2009 – 9/30/2011

Year	Year 1				Year 2			
Quarter	1	2	3	4	1	2	3	4
Task 1: Develop a simplified conceptual model of nitrate fate and transport in shallow groundwater aquifer (completed)	×							
Task 2: Incorporate lab measurements and field observations into model implementation and calibration	×	×		×		×		
Task 3: Develop ArcGIS plug-in package for groundwater flow modeling (completed)	×	×						
Task 4: Develop ArcGIS-based package for nitrate fate and transport model (completed)			×	×				
Task 5: Develop ArcGIS-based package for environmental management					×	×		
Task 6: Apply the developed tool to a selected site to facilitate DEP nitrate estimation and management			×	×	×	×		
Task 7: Final project report, software documentation and training							×	×

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Project Background, Motivations, and Objectives

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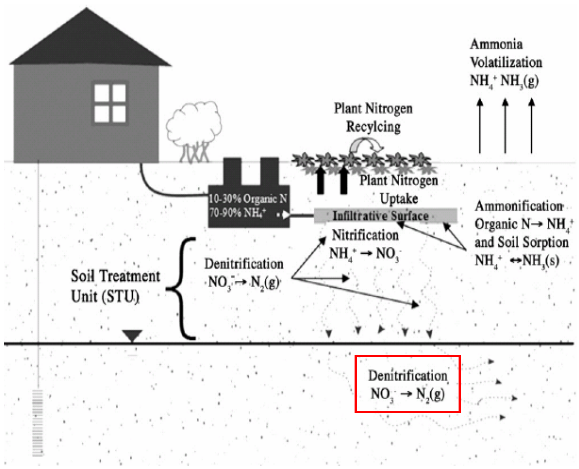
Schematic of an Onsite Wastewater Treatment System (OWTS) and Subsurface Nitrogen Transformation and Removal Processes



From Heatwole and McCray (2007)

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 ground water. (FDEP, 2006)

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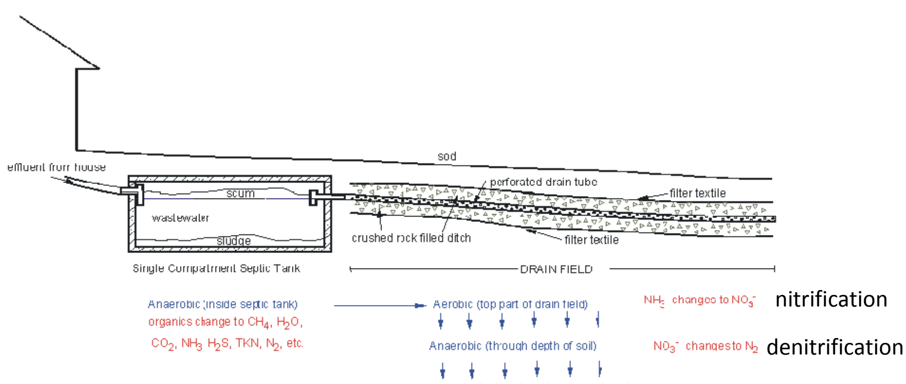
Classic Septic System: anaerobic processes in the tank, aerobic processes in drain field, partial anaerobic in sub-drainfield soil; remaining nitrate leaches to ground water



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

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(Figure from Paul Lee, 2004)

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).

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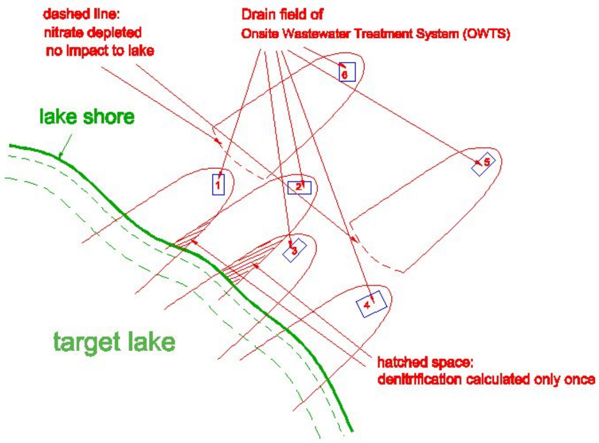
Effect of Spatial Locations of Septic Systems

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



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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

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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

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Simplified Groundwater Flow and Nitrate Fate and Transport Models

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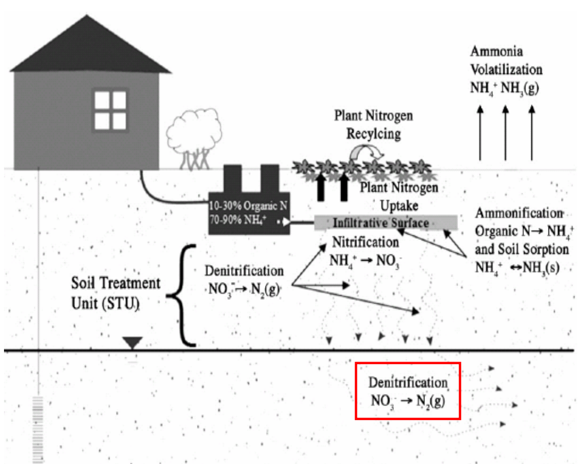
Schematic of an Onsite Wastewater Treatment System (OWTS) and Subsurface Nitrogen Transformation and Removal Processes



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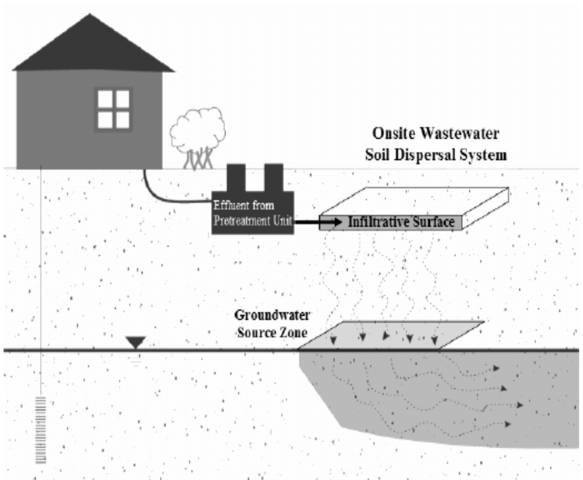
Nitrate Fate and Transport in Groundwater



Due to nitrification in the vadose zone, OSW can generate NO_3-N concentration at the water table from 25 to 80 mg N/L in most situations (McCray et al., 2005).

From Heatwole and McCray (2006)

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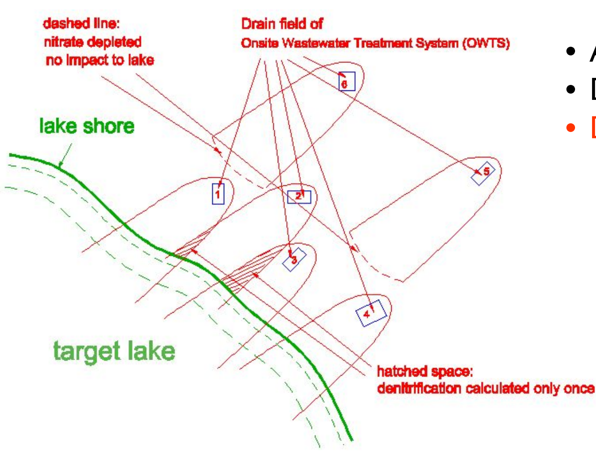
Conceptual Model

Take into account of nitrate contribution from working septic tanks.



- Advection
- Dispersion
- Denitrification

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Denitrification

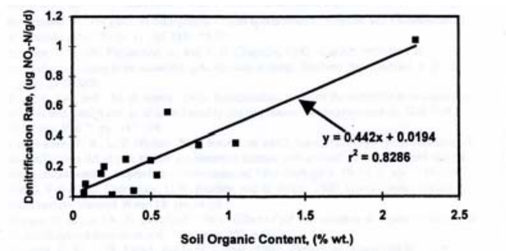
Denitrification refers to the biological reduction of nitrate to nitrogen gas.

$$NO_3^- + \text{Organic carbon} \rightarrow NO_2^- + \text{Organic carbon} \rightarrow N_2 + CO_2 + H_2O$$

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

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).

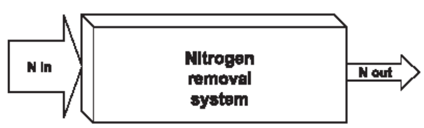
A fairly broad range of heterotrophic anaerobic bacteria are involved in the process, requiring an organic carbon source for energy as follows



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} ($M/T/L^3$): denitrification rate

V_g (L^3): volume of groundwater solution, estimated from groundwater flow and reactive transport modeling

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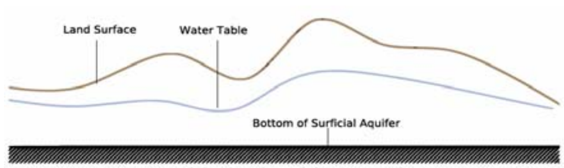
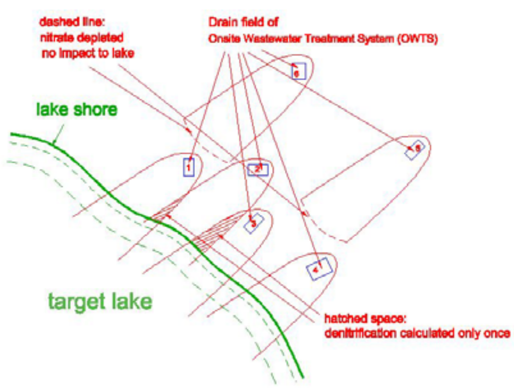
Groundwater Flow Modeling

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



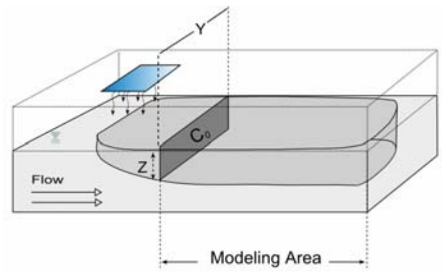
Outputs of Groundwater Flow Modeling



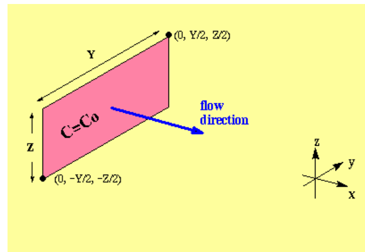
- Flow paths from each septic tank to surface water bodies
- Flow velocity along the flow paths. Heterogeneity of hydraulic conductivity and porosity is considered.
- Travel time from septic tanks to surface water bodies

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

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

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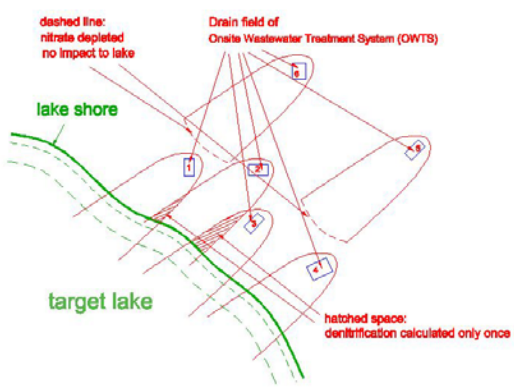
Outputs of Nitrate Transport Modeling and Calculation of Nitrate Load

- 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



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

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

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Research Team

- Fernando Rios

  Development of model and the GIS-based software
- Raoul Fernandes

  Development of statistical methods of estimating denitrification rate
- Liying Wang

  Field application and model calibration

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Software Development and Demonstration

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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.

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Development of the ArcGIS Extension

- Modules
  - Groundwater Flow
  - Transport
  - Denitrification

- Details of model/software verification and validation are referred to the draft manual.

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Future Research

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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

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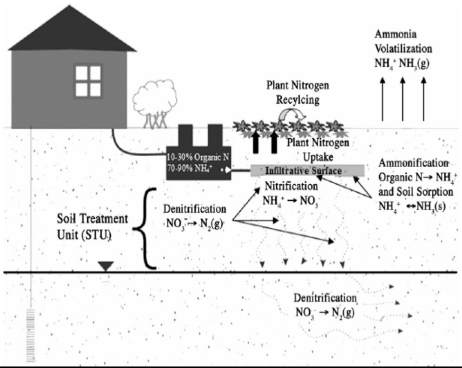
Prospective Research

- 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.



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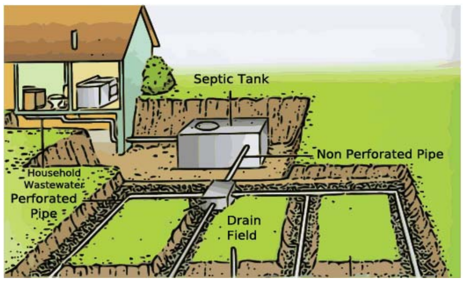
Questions?



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