Picture from USGS Scientific Investigations Report 2008–5220

A Brief Summary of ArcNLET and Associated Tools for Estimation of Nitrate Load from Septic Systems to Surface Water Bodies

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January 26th, 2012

Presentation at the City of Jacksonville

Last presentation to the City was December 9th, 2010

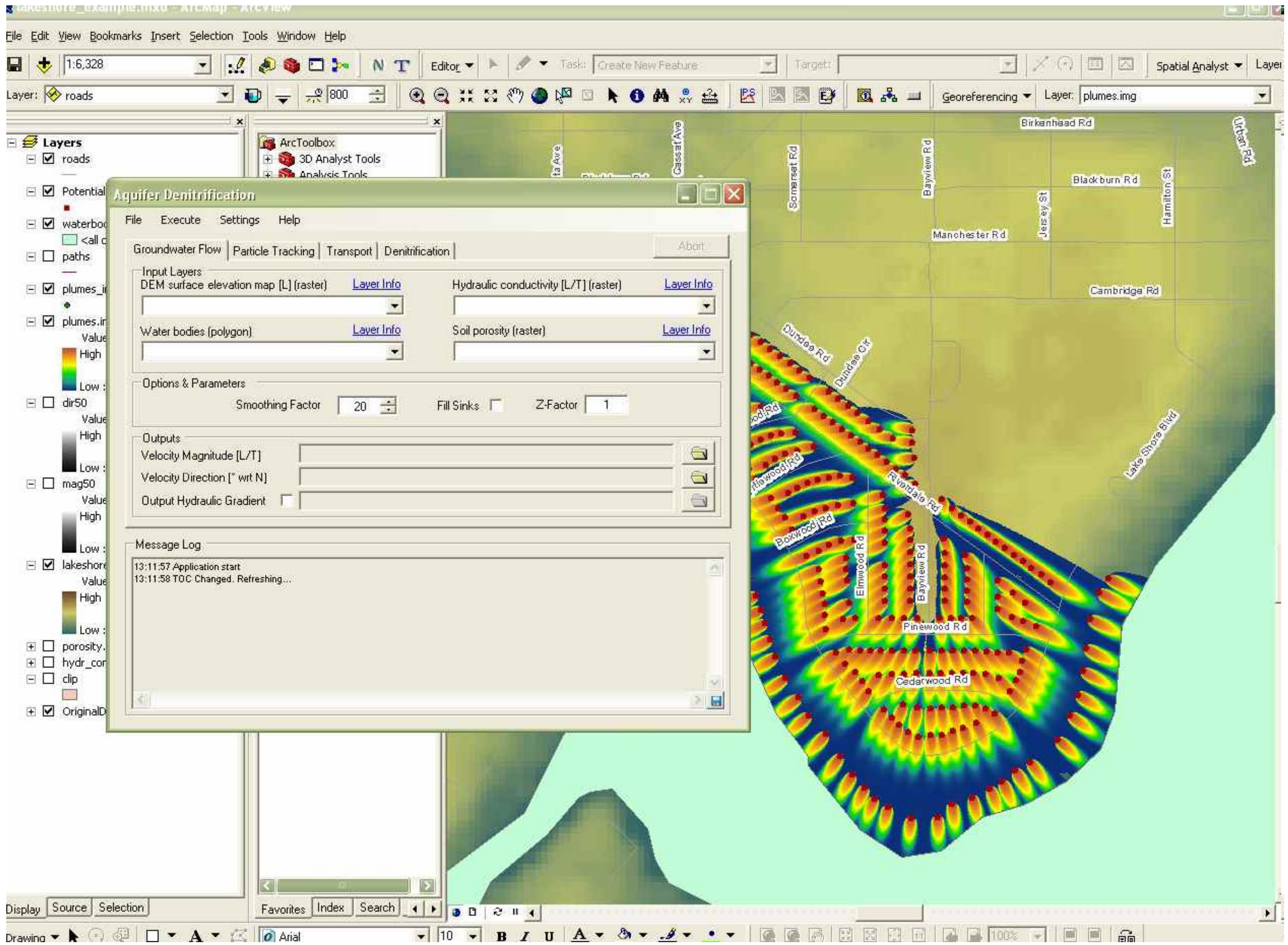
Outlines

- Development of ArcNLET and its applications at Julington Creek and Eggleston Height neighborhoods
- New understanding gained last year
- New tools (developed and under development) associated with ArcNLET to facilitate nitrate load estimation
- Suggestion and comments

What is ArcNLET?

ArcGIS-based Nitrate Load Estimation Toolkit

- A simplified conceptual model of groundwater flow and solute transport
- Implementation as an ArcGIS extension
- Calculation of nitrate plume and nitrate load



Compatible with ArcGIS 9.3 and 10

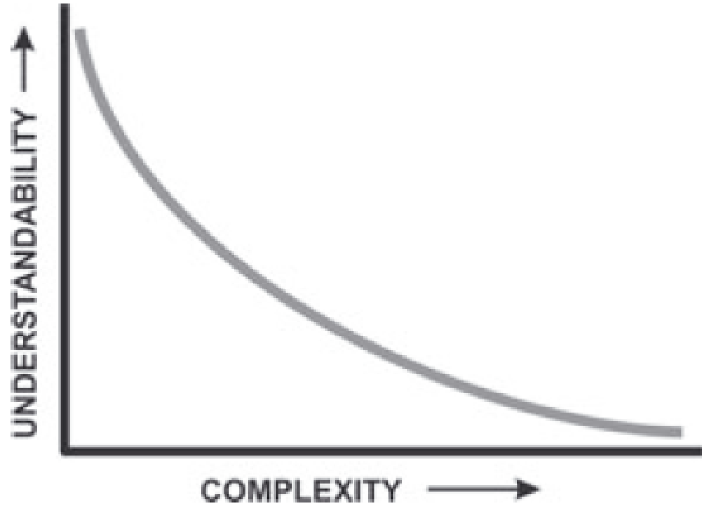
ArcNLET Development History

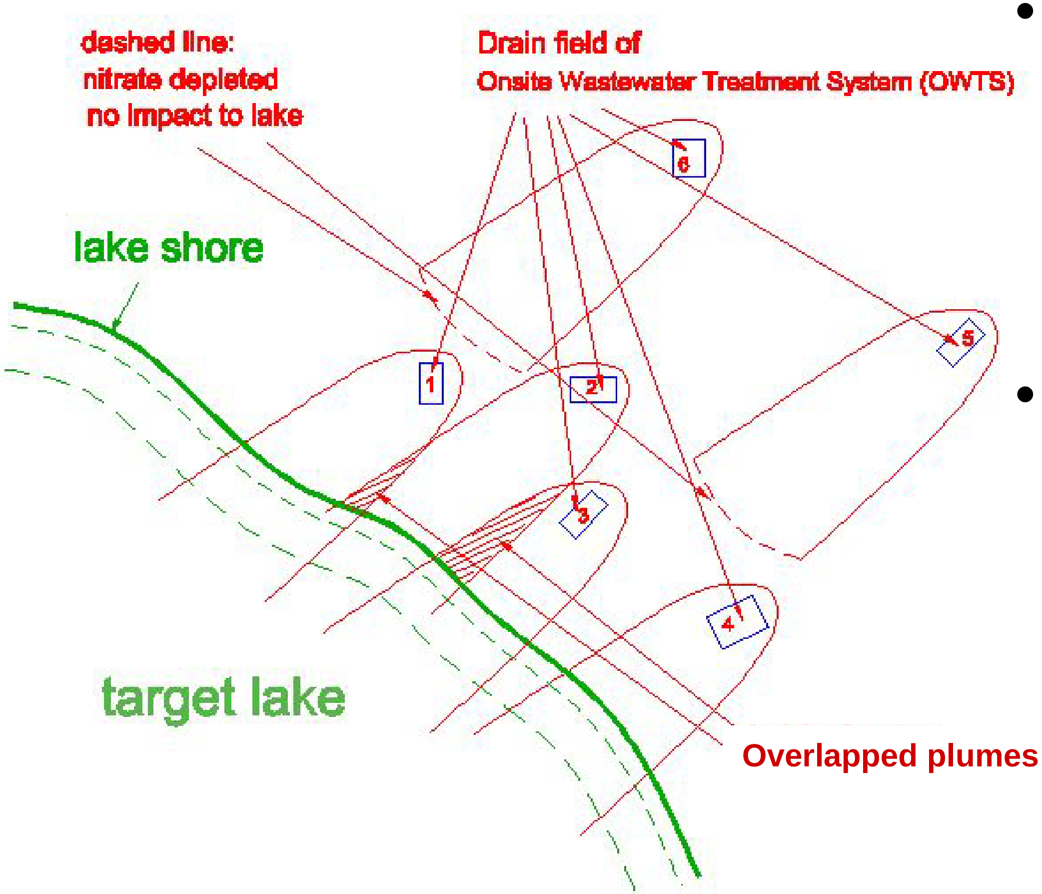
- It was developed during January 2009 – July 2011.
- The first workshop was offered in July 2011.
- Software is available for free download at FSU website http://people.sc.fsu.edu/~mye/ArcNLET/.
- The project was reported on Florida State News as a FSU front page story, and listed as one of the twelve FSU 2011 research highlights.
- We were invited to contribute an article to ESRI Hydro Blog.
- Education and scholarly activities: The project supported two master students and produced two journal articles, one conference proceeding, and a number of conference presentations.

Why Do We Develop ArcNLET?

- There is no suitable tool for estimation of nitrate load to meet TMDL requirements and perform LSJR Nitrogen BMAP. Existing tools are either too simple or too complex.
- Develop a simplified model that consider key hydrogeologic processes of groundwater flow and nitrate fate and transport.
- Implement the model by developing a user-friendly ArcGIS extension to
  - 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
- Use the software to facilitate DEP environmental management and regulation.
- Disseminate the software and conduct technical transfer to DEP staff and other interested parties.

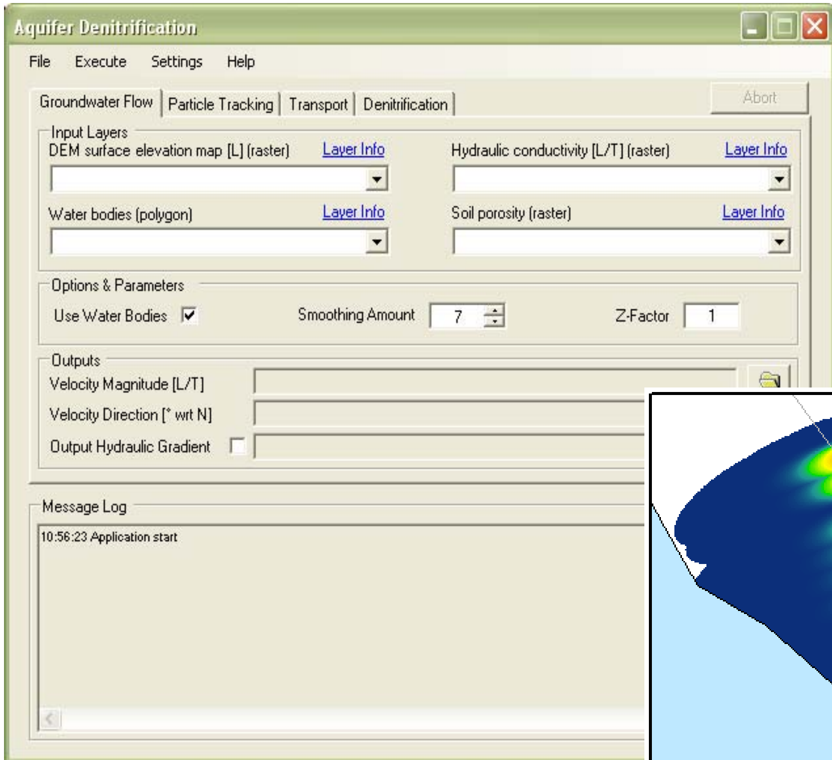
Simplified Conceptual Model to consider key hydrogeologic processes involved in nitrate transport:



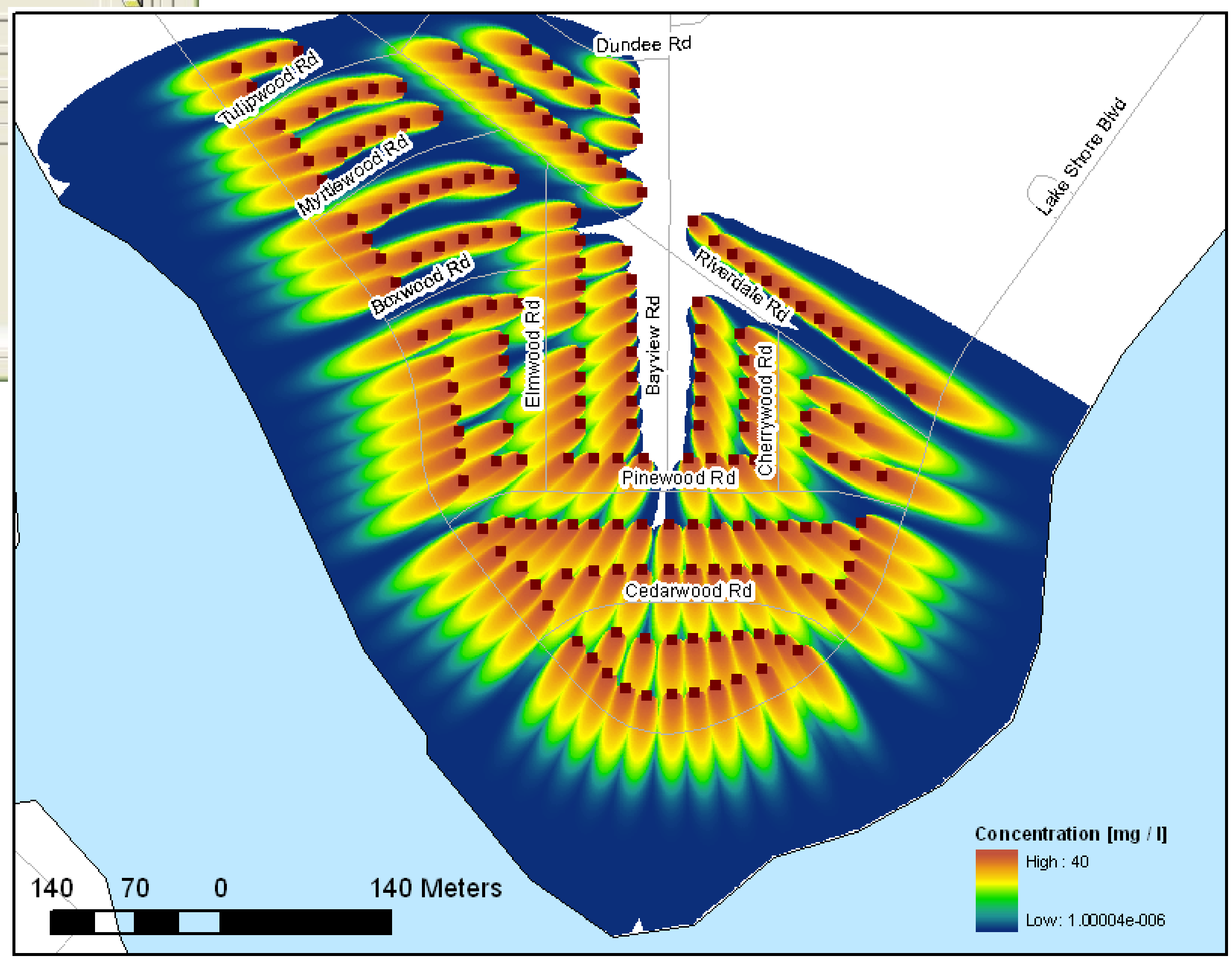


- ***Groundwater flow model*** to estimate
  - flow path
  - flow velocity
  - travel time
- ***Nitrate transport model*** to consider
  - Advection
  - Dispersion
  - Denitrification
- ***.oad estimation model*** to estimate nitrate load

Example Graphic User Interface



Example simulated nitrate plumes



Requirements on Potential Users

- The GUI make it easier for some with little experience in analyzing groundwater transport problems to apply a solute-transport model to a field problem.
- **Use of ArcNLET requires**
  - Basic knowledge of hydrogeology such as concepts of groundwater flow and solute transport
  - Intermediate level of ArcGIS skills for preparing input files and visualizing software output files
- The model (simple or complex) is not an end in itself, but a tool by which to organize one's thinking and engineering judgment.
- **Interpretation and improvement of ArcNLET results require**
  - Fundamental understanding of groundwater flow and solute transport
  - Familiarity with site-specific information such as geology and hydrogeology
- It may be useful to test and tune the model for several representative sites before using the model for general purposes.

What Challenges Do We Face?

- **Keith Beven (2001): The Dalton Lecture**
  How far can we go in distributed hydrological modeling?

  "The principles are general and we have at least a qualitative understanding of their implications, but the difficulty comes in the fact that we are required to apply hydrological models in particular catchments, all with their own unique characteristics."
- **Warren Wood (2000), Editorial of Ground Water** (one of the most widely read groundwater journal)
  It's the heterogeneity!

  "If all aquifer systems were homogeneous, then hydrogeologic problems would be reduced to handbook applications, and there would be no ground water hydrologists as we know them."

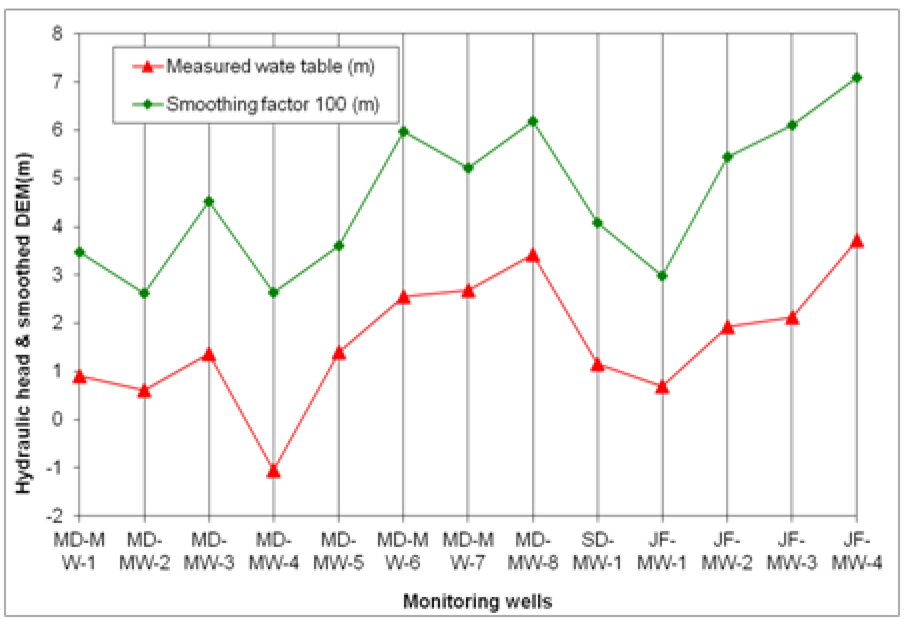
  "It is my guess that … it will be many years before we can effectively deal with heterogeneity on societally important scales."

  Leonard Konikow (2011, Ground Water): "the secret to successful solute-transport modeling may simply be to lower your expectations."

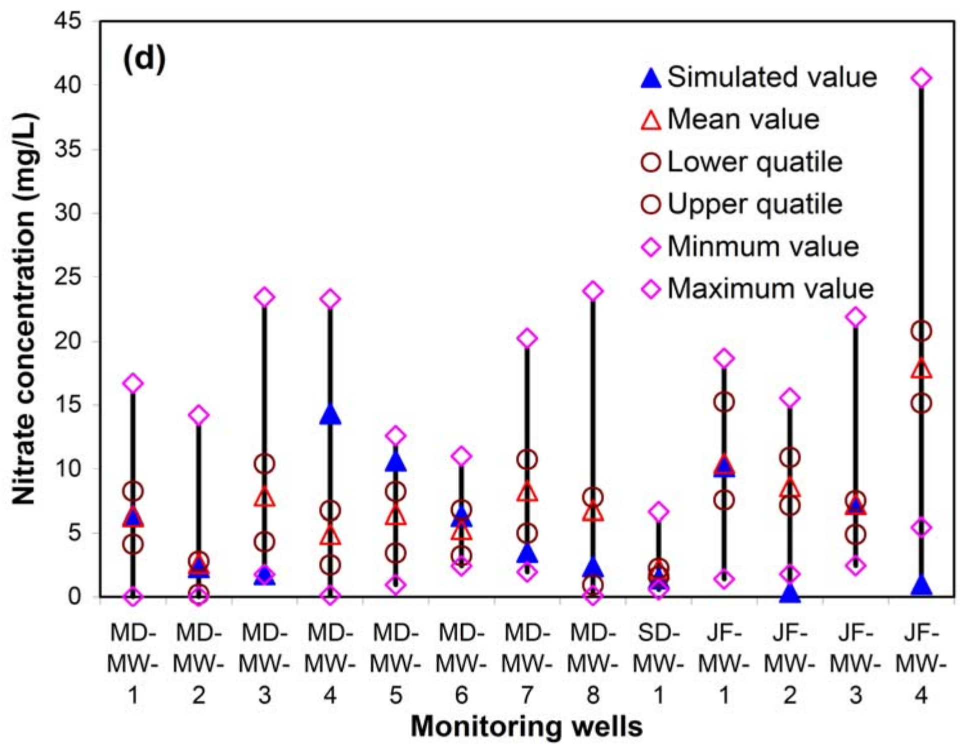
What Do We Find?

- Default parameters obtained from literature
- Site-specific observations and manual model calibration for Julington Creek neighborhood, Jacksonville

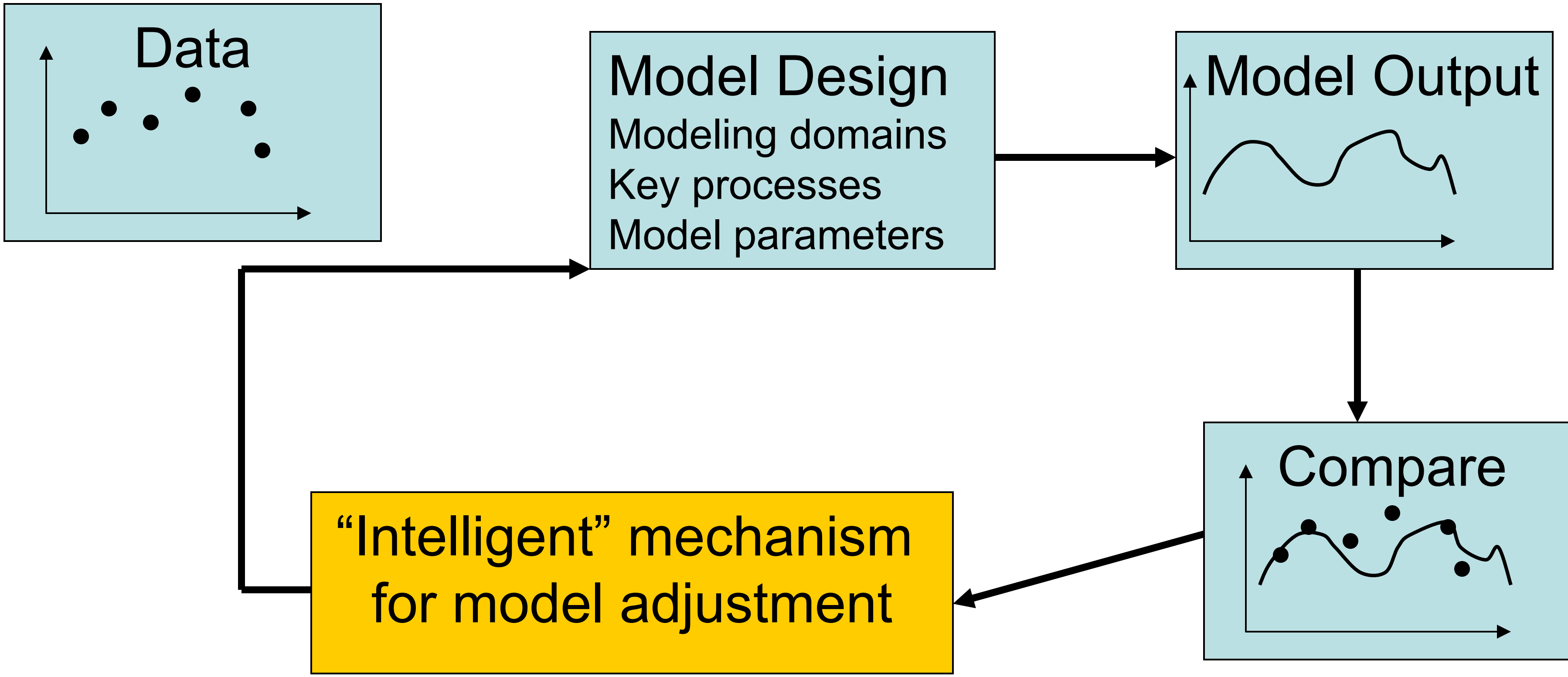
Hydraulic Head



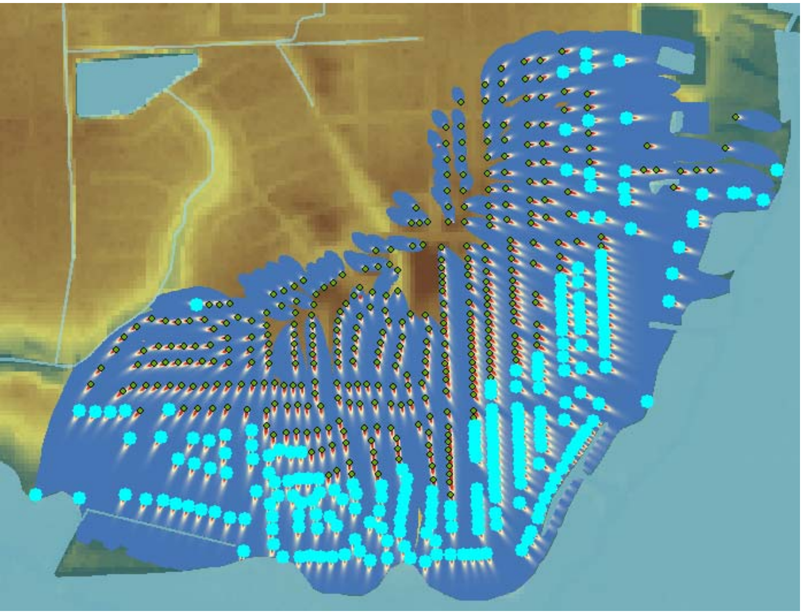
Nitrate Concentration

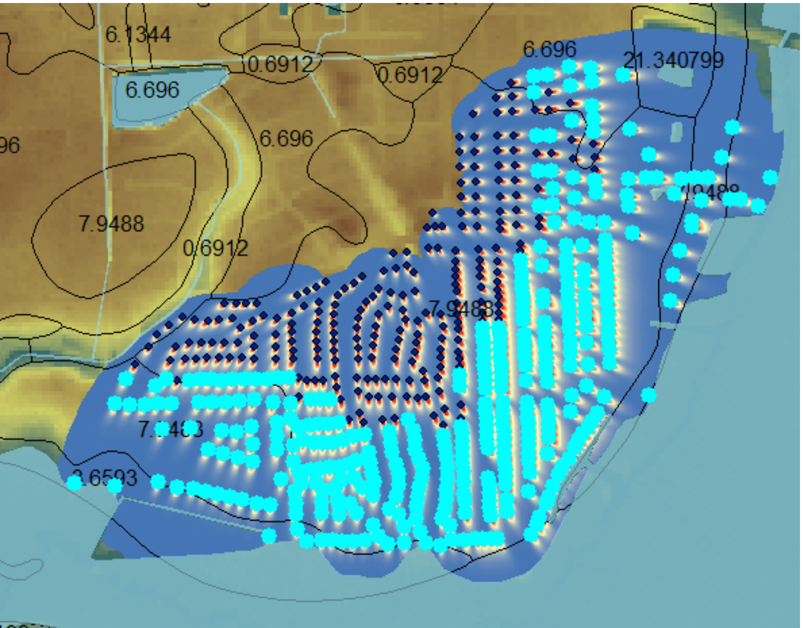


Manual Model Calibration: Trial and Error



What Do We Find?





Default parameter values (91g/d):

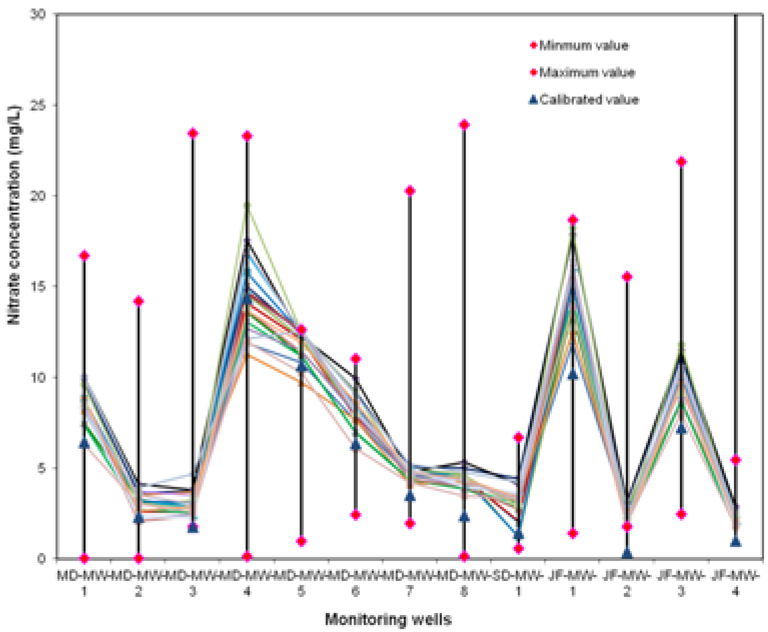
- hy_con: 2.113m/d ← Too small
- Porosity: 0.25
- α_L: 2.113m
- α_T: 0.234m
- C_0: 40mg/L
- k_{den}: 0.008/d
- smthF: 50 ← Too small
- number of plumes reaching river: 228

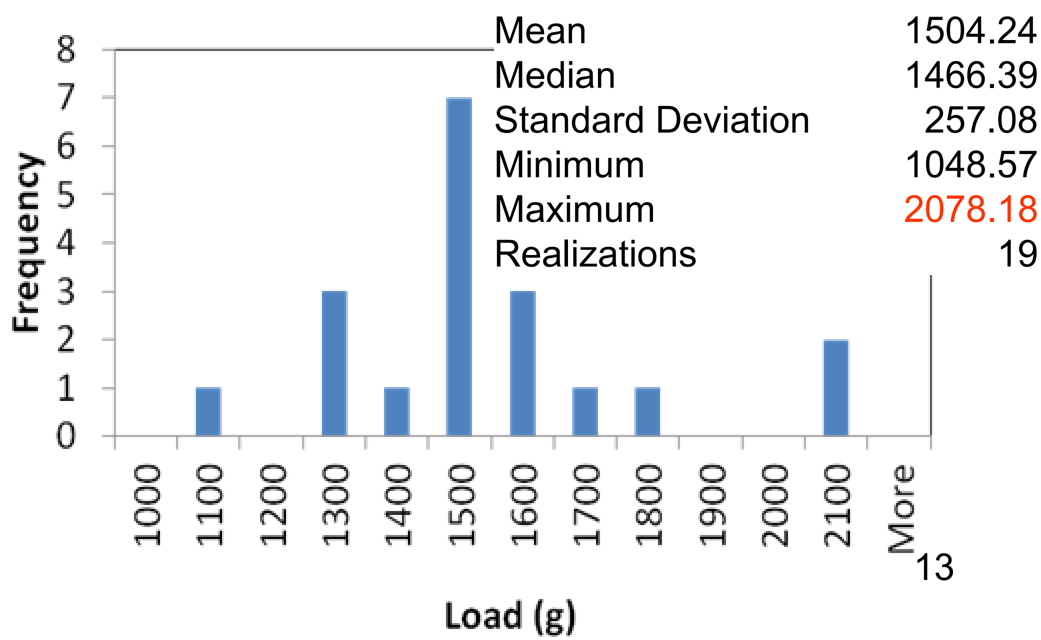
Calibrated parameter values (1023g/d):

- hy_con: see the map
- Porosity: soil data
- α_L: 10m
- α_T: 1.0m
- C_0: 100mg/L ← Adjusted to match observed plumes
- k_{den}: 0.012/d
- smthF: 100
- number of plumes reaching river: 354

Does God Play Dice?

- Different sets of model parameters give similar results of model calibration. Computer can do a better job of calibration.
- The calibrated parameter set is one of the realizations (***E pluribus unum***).
- Parametric Uncertainty:
  "However, we should accept that there may be many different model structures and parameter sets that will be acceptable in simulating the available data." (Keith Beven, 2001, Dalton Lecture)





Why Are Model Parameters Uncertain?

Poetry of Donald H. Rumsfeld:

Feb. 12, 2002

Department of Defense news briefing

The Unknown
As we know,
There are *known knowns*.
There are things we know we know.
We also know
There are known unknowns.
That is to say
We know there are some things
We do not know.
But there are also *unknown unknowns*,
The ones we don't know
We don't know.

Phase I Report: Wekiva River Basin Nitrate Sourcing Study (MACTEC, 2006)

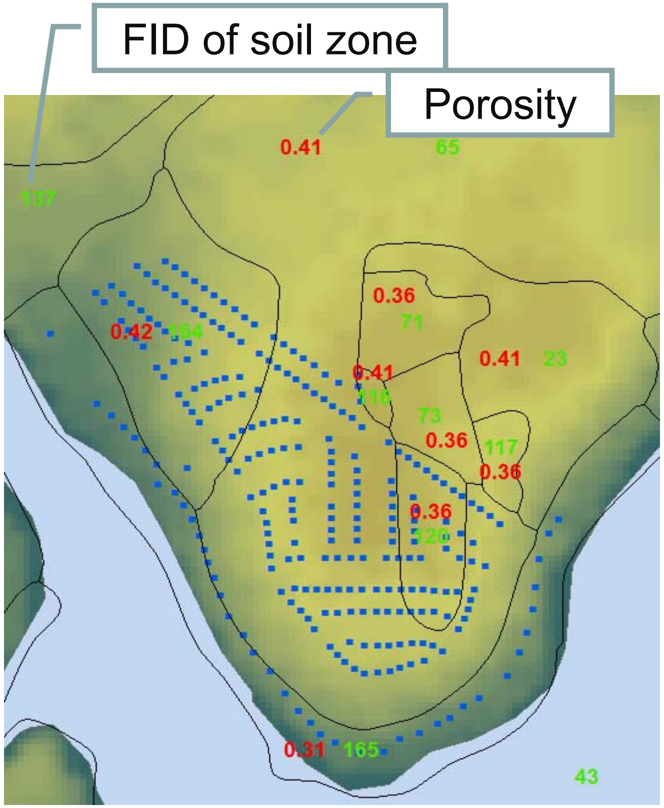
"All inputs used in estimation of inputs and loadings are uncertain to some extent."

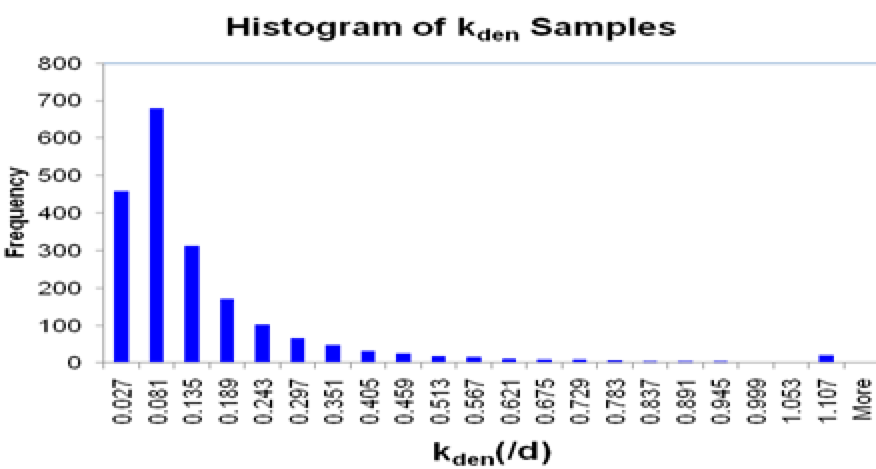
"Significant uncertainties have been identified throughout this report."

How to Address and Reduce Parametric Uncertainty?

- Select random parameters whose values are largely unknown.
- Determine the ranges and probability distributions of the parameters.
- Conduct sensitivity analysis to identify the parameters that are most influential to the load estimate.
- Calibrate the model against field observations to *reduce parametric uncertainty*.
- Conduct Monte Carlo simulation to quantify uncertainty in nitrate load estimation.
- **An example for the Lakeshore neighborhood, where observations are not available.**

Random Parameter and Their Distributions



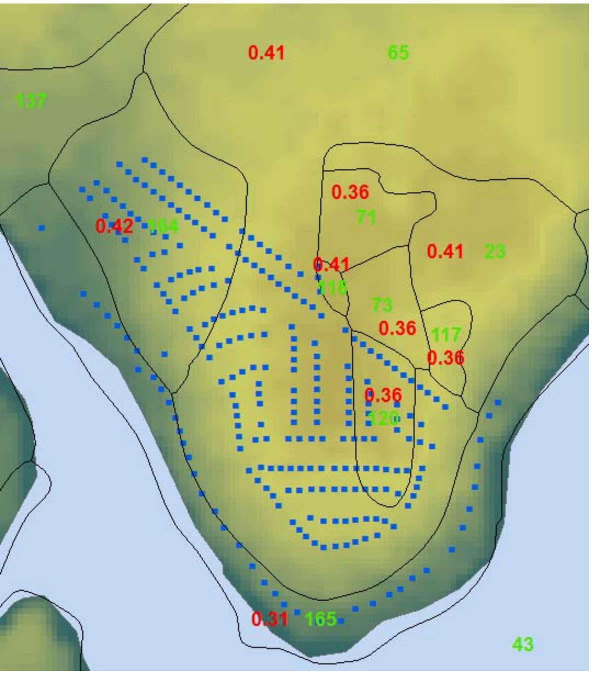


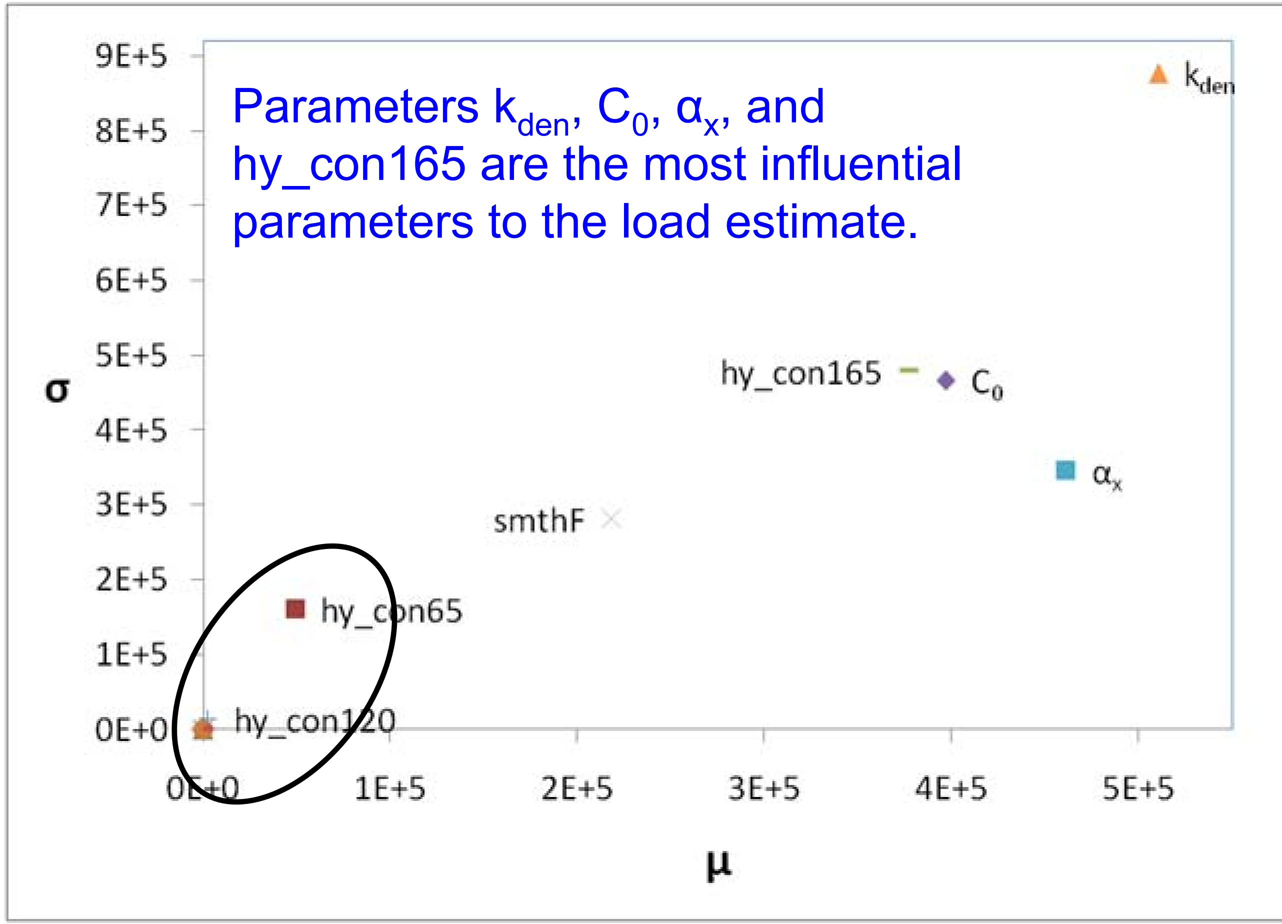
Maximum, minimum and representative values of hydraulic conductivity is derived from soil data

Parameter	Distribution	Max	Representative	Min
hy_con23	TRIANGULAR	3.6593	7.9488	12.1976
hy_con65	TRIANGULAR	3.6593	7.9488	12.1976
hy_con71	TRIANGULAR	0.122	0.6705	1.2198
hy_con73	TRIANGULAR	0.122	0.6705	1.2198
hy_con116	TRIANGULAR	3.6593	7.9488	12.1976
hy_con117	TRIANGULAR	0.122	0.6705	1.2198
hy_con120	TRIANGULAR	1.2198	6.696	12.1976
hy_con164	TRIANGULAR	0.122	0.6912	1.2198
hy_con165	TRIANGULAR	12.1824	21.3408	30.4992
C_0	NORMAL	25		80
α_x	NORMAL	0.21		21.34
k_{den}	LOGNORMAL	0.004		1.08
smthF	UNIFORM	20		80

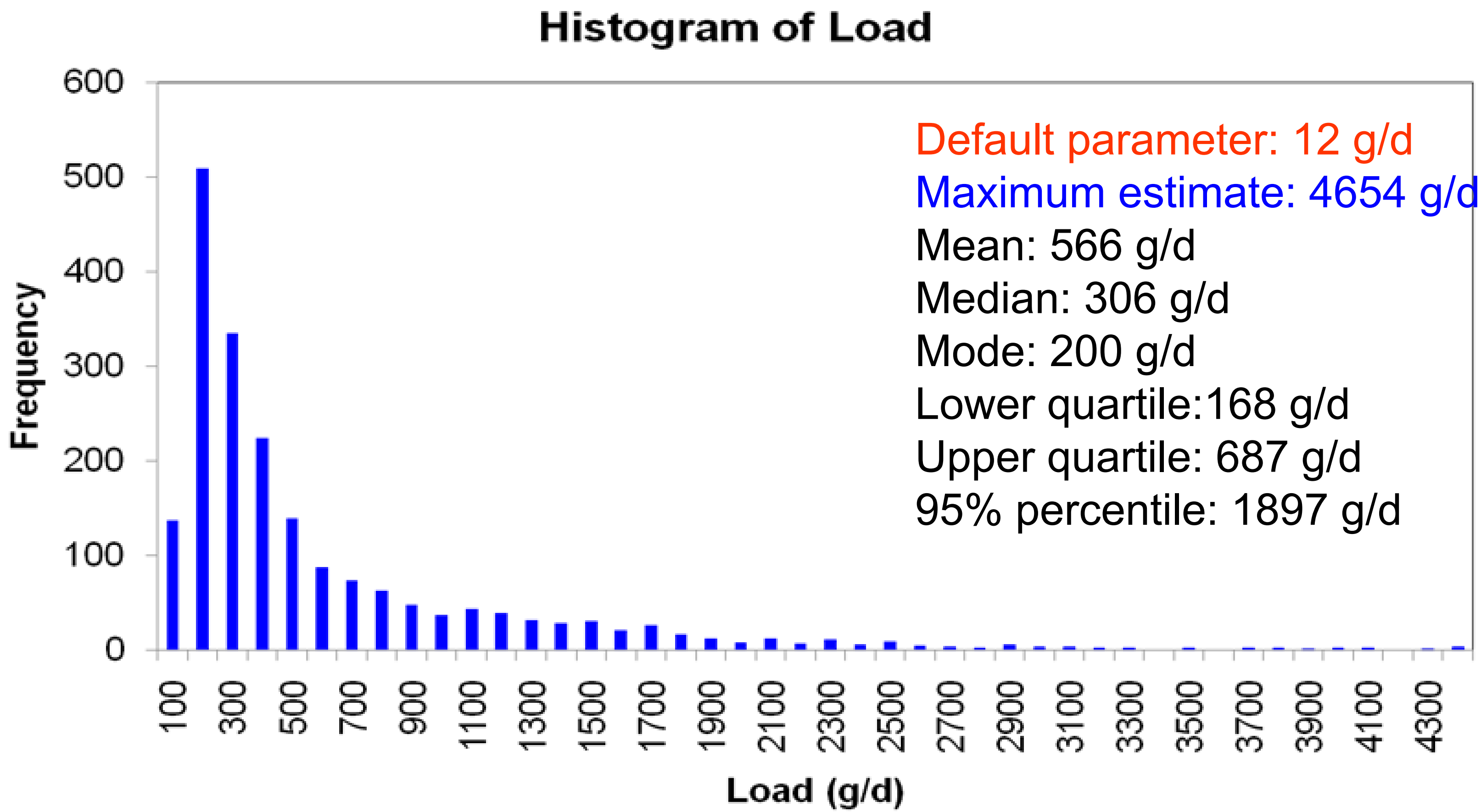
Distributions of LHS Samples

Identify Influential Model Parameters





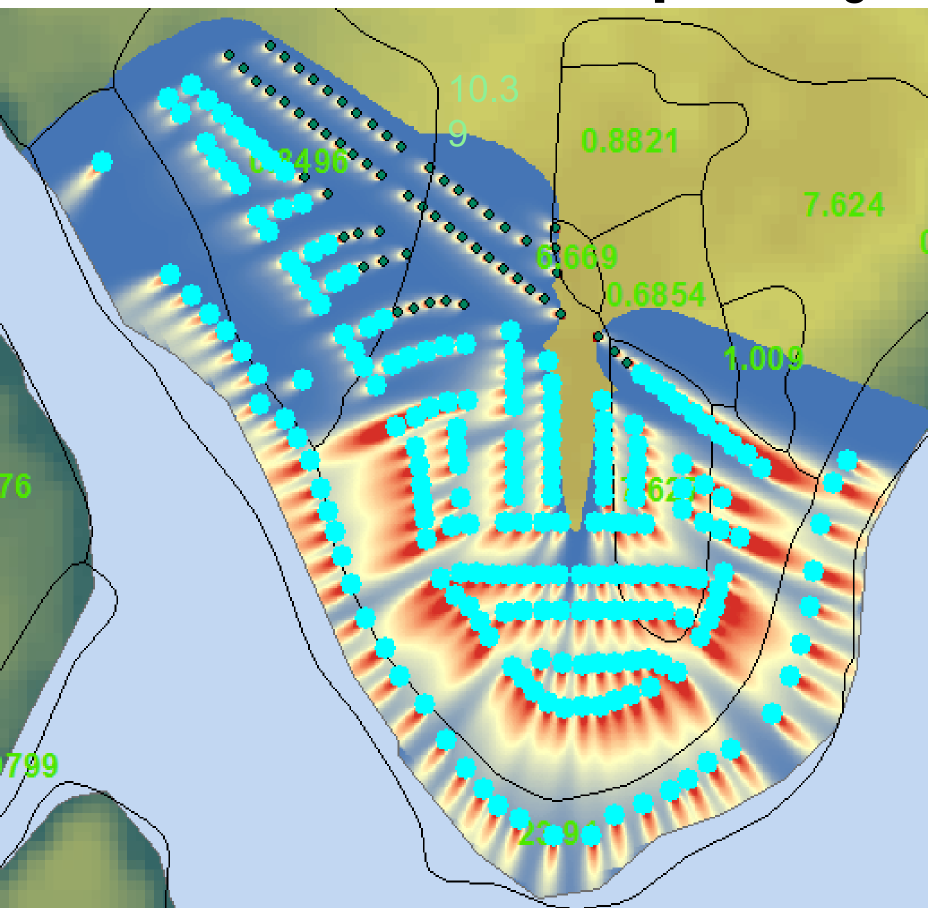
Uncertainty Analysis



The load estimation has large uncertainty, and the uncertainty may be even larger if there are ditches within the neighborhood.

Similarity With CDM Method

- Green zone at right is the 300-meter buffer zone based on the NHD.
- The number of failed septic tanks in the buffer zone and used for the load calculation is 223.
- The total amount of nitrate load is 223 x [11.2 g/d x 2.51 x 0.8] = 5015 g/d. Denitrification is not considered.



Parameter values of the largest load estimate:

- hy_con: see the map (hy_con169: 23.9 m/d)
- Porosity: soil data
- α_x: 9.351m
- α_y: 0.935m
- C_0: 54.76mg/L
- k_{den}: 0.004/d ← Smallest value from literature
- smthF: 24

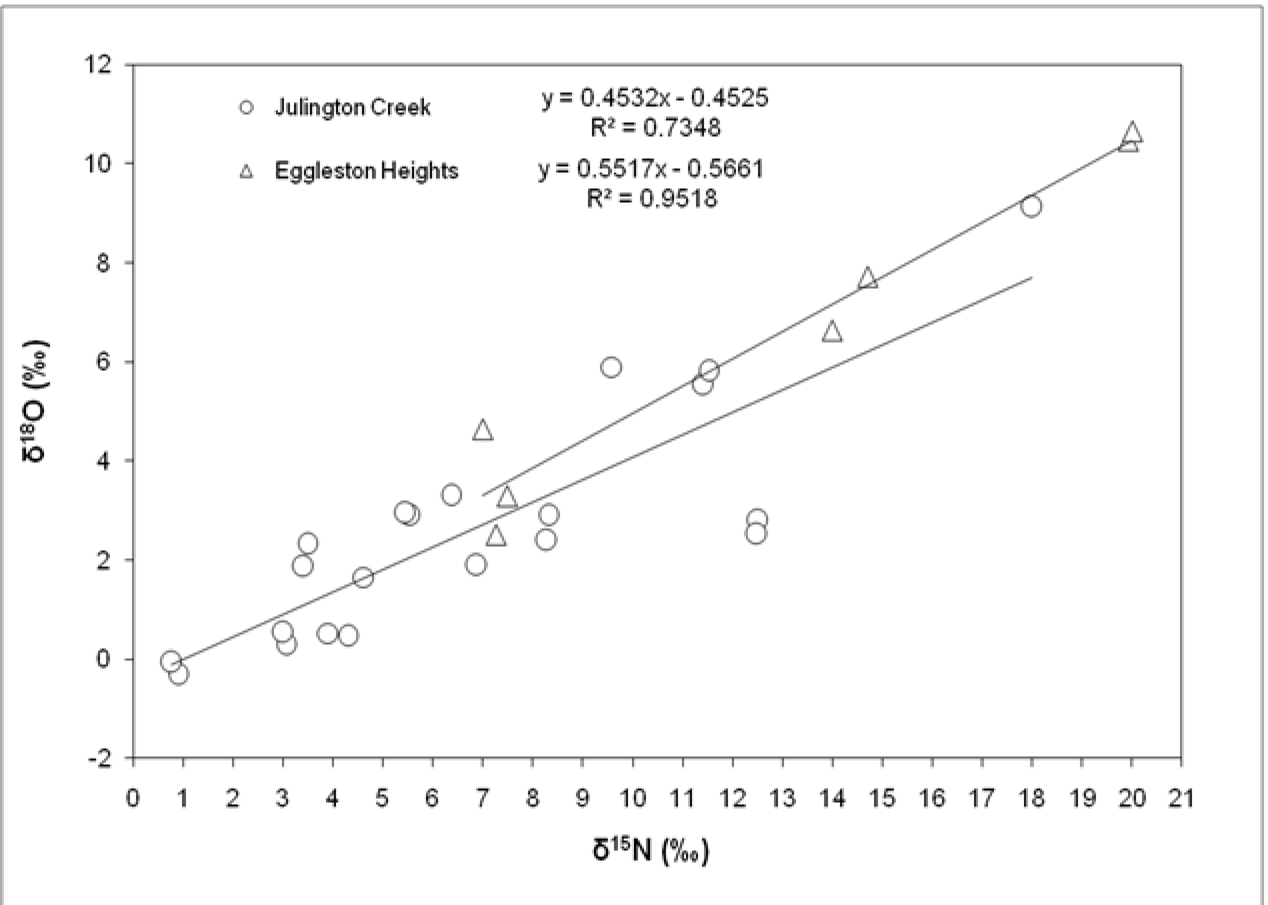
Estimated load:

4654 g/d from 205 out of 265 plumes that reach the river

Isotope Signature of Denitrification

Indication of denitrification occurrence (Chen and Mcquarrie , 2005) :

- Linear relationship
- Slope close to 0.51

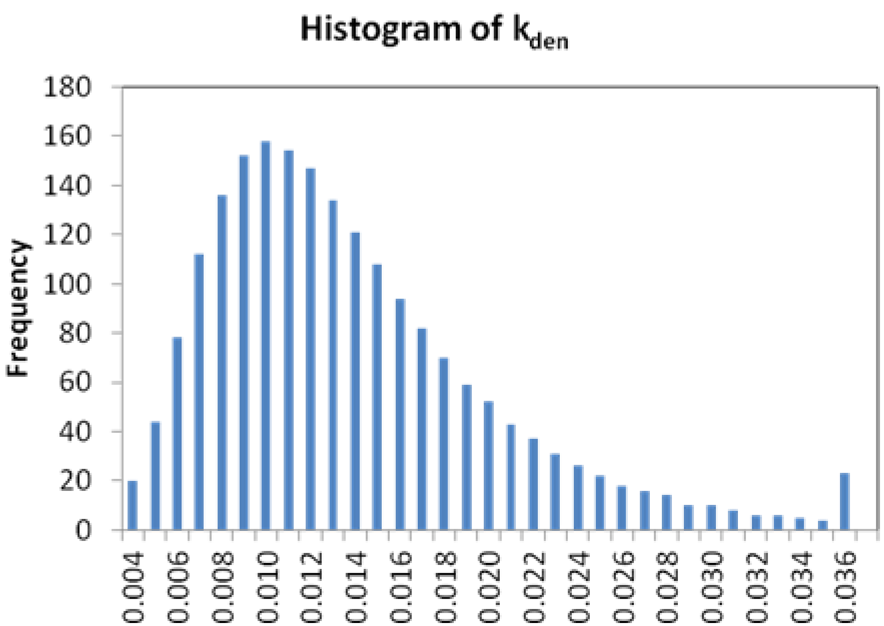


$\delta^{18}O$ vs. $\delta^{15}N$ at Julington Creek and Eggleston Heights (Sep & Oct, 2010).

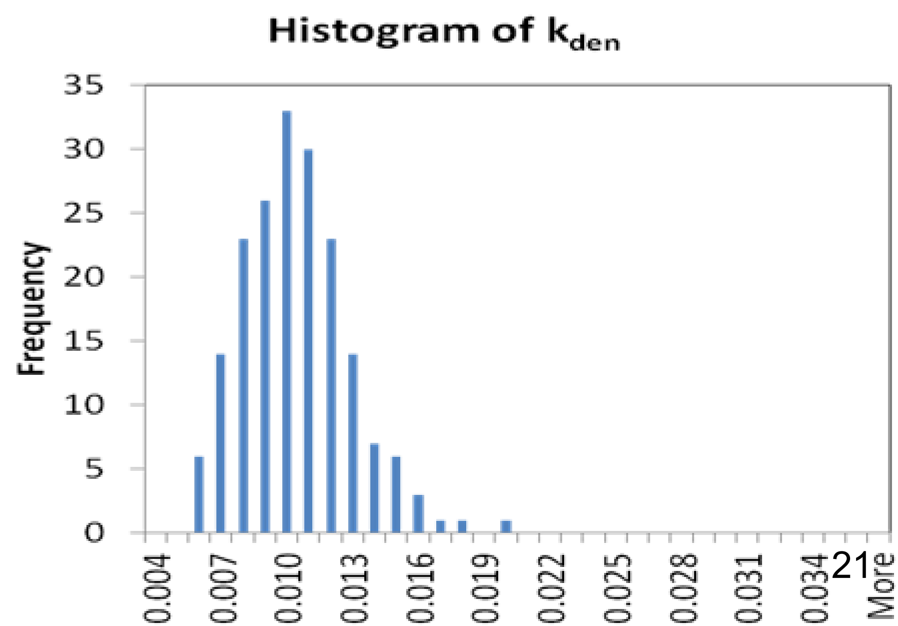
How Much Parametric Uncertainty Can Be Reduced by Field Observations?

- The parametric uncertainty can be reduced dramatically by incorporating the field observations into model calibration.
- Take the first-order decay coefficient as an example.

Minimum	0.004
Maximum	0.036

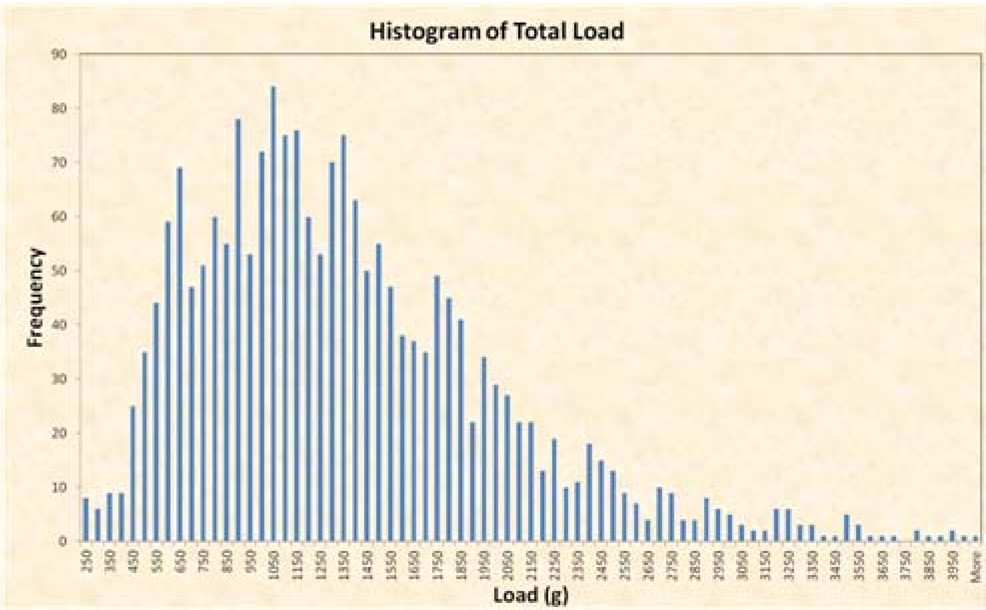


Minimum	0.005
Maximum	0.019



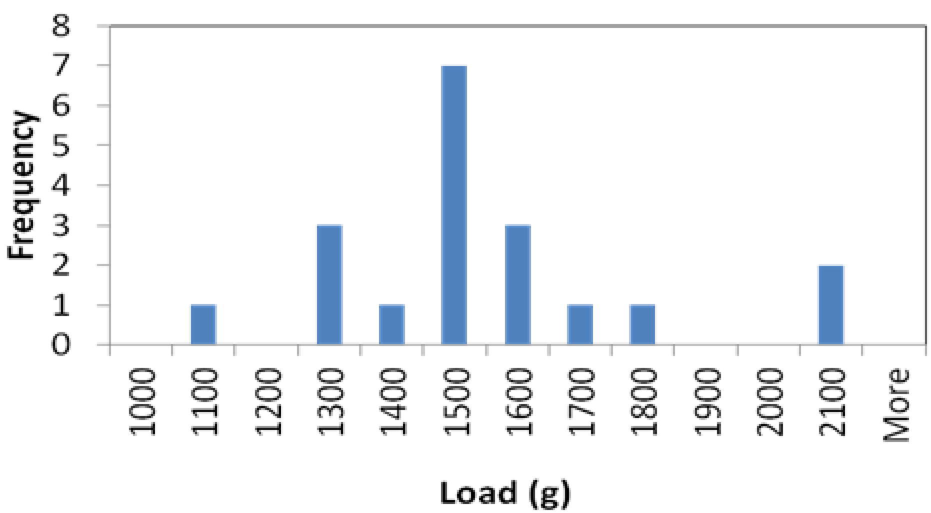
Reduction of Load Estimation Uncertainty

Load estimates before incorporating field observations.



CDM estimate is 7624/8292 g/d

Mean	1334.48
Median	1225.43
Standard Deviation	652.61
Minimum	177.62
Maximum	5655.87
Realizations	2000
95th percentile	2581.89
5th percentile	513.28



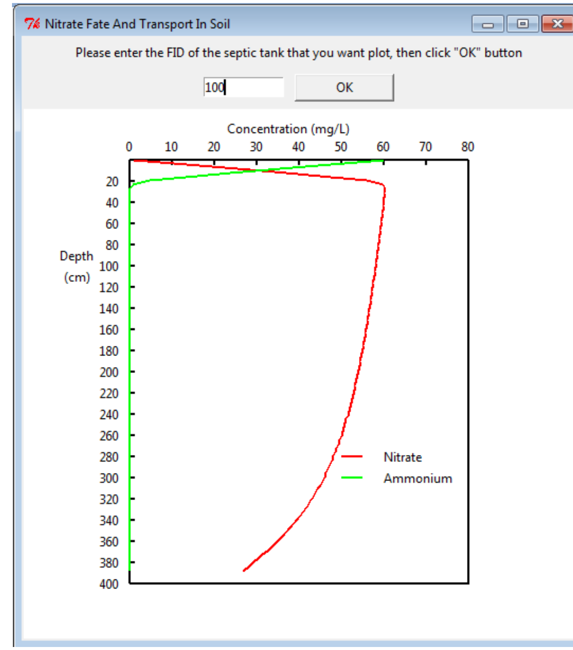
Mean	1504.24
Median	1466.39
Standard Deviation	257.08
Minimum	1048.57
Maximum	2078.18
Realizations	19

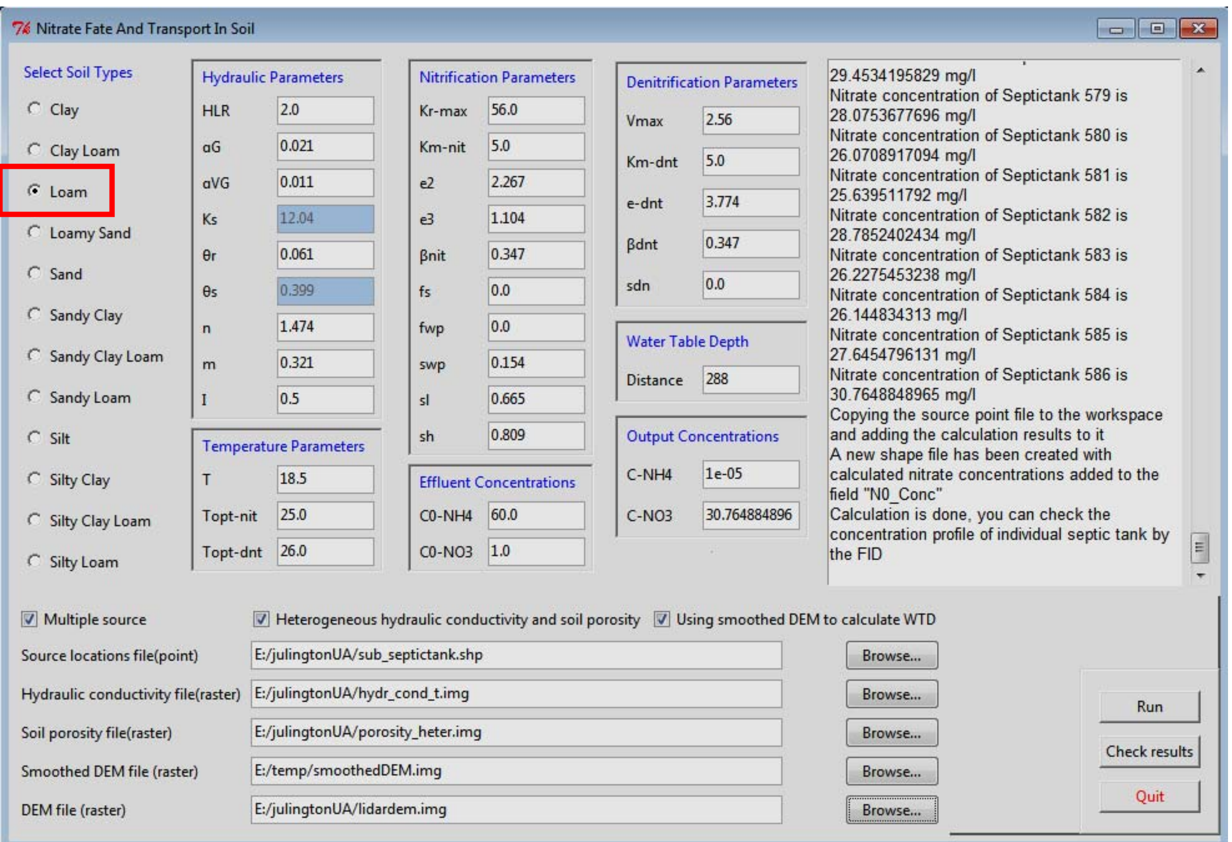
What Have Been Developed After ArcNLET?

- Python codes of sensitivity analysis to identify the most influential model parameters to load estimation.
- Python code of uncertainty analysis and automated model calibration.
- GUIs are not available, but can be developed in several weeks.
- Python code of simulating nitrate fate and transport modeling in unsaturated soil. We are at the last stage of verification and validating. GUI is available.

Illustration for loamy soil

- Share data files of ArcNLET such as raster files of DEM, hydraulic conductivity and porosity.
- Model parameters for various soil types.
- Estimate nitrate load to groundwater for multiple septic tanks.





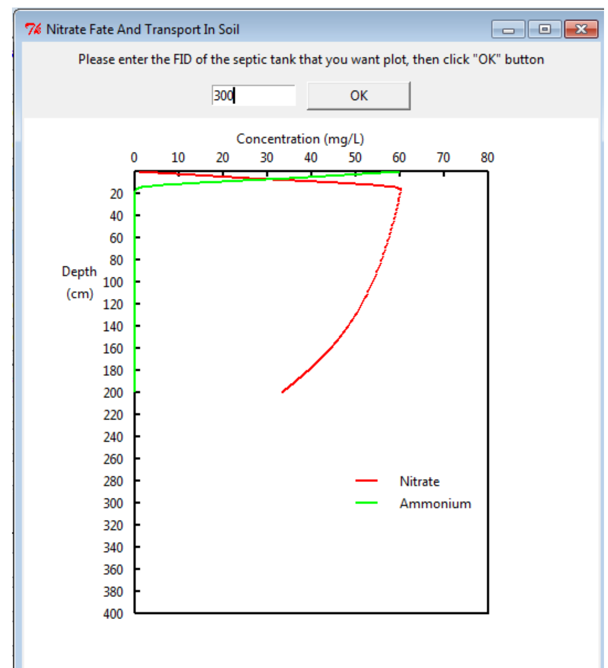
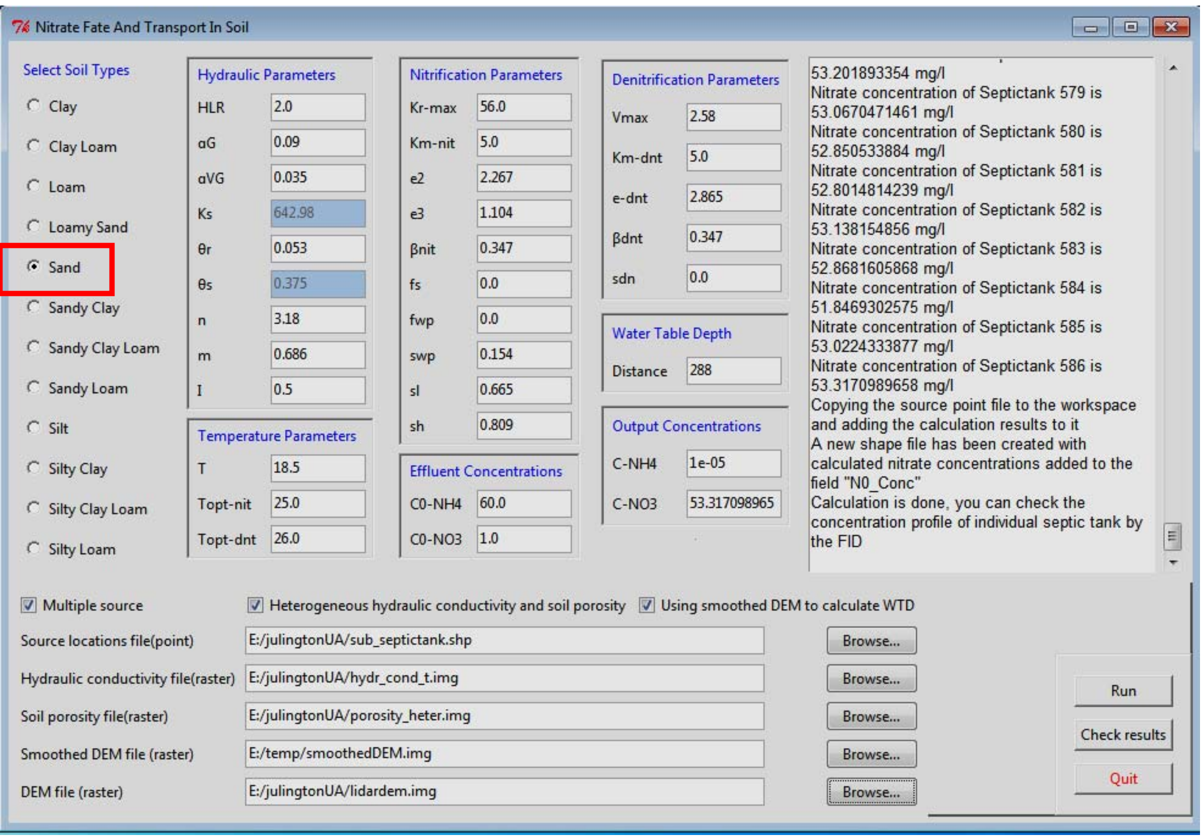
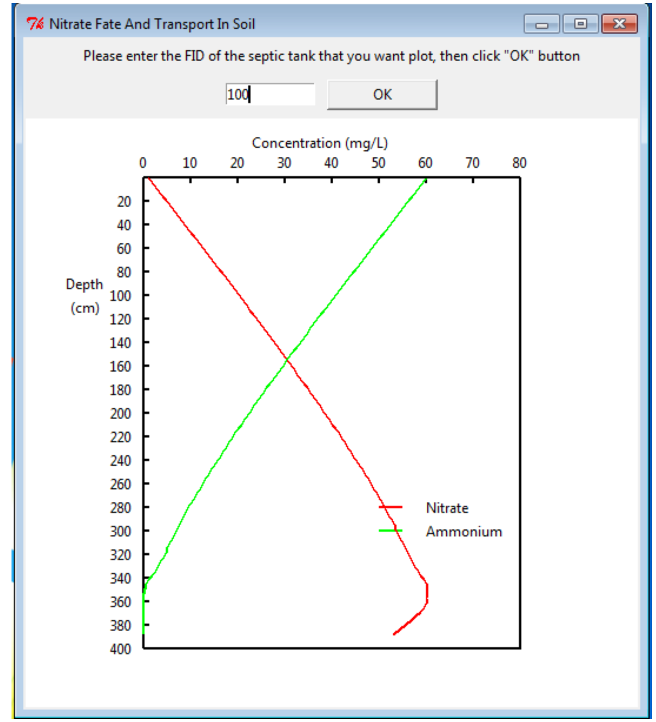
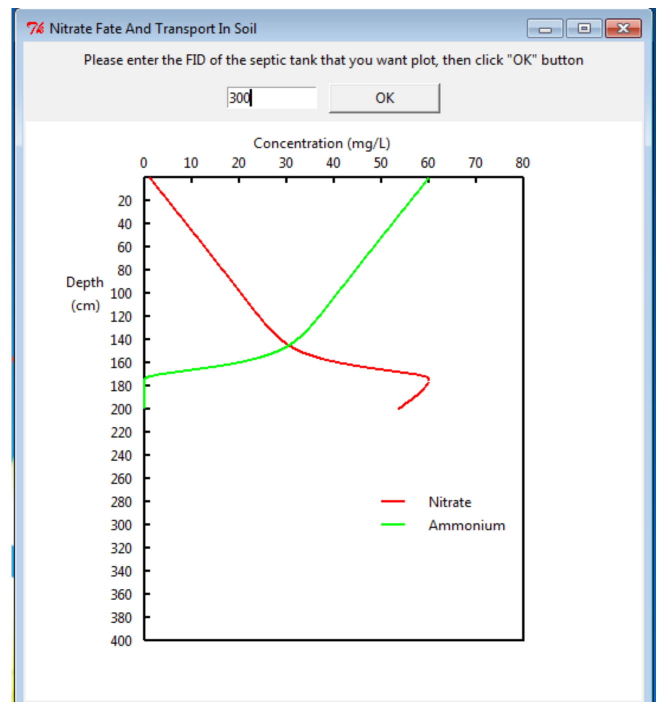


Illustration for sandy soil

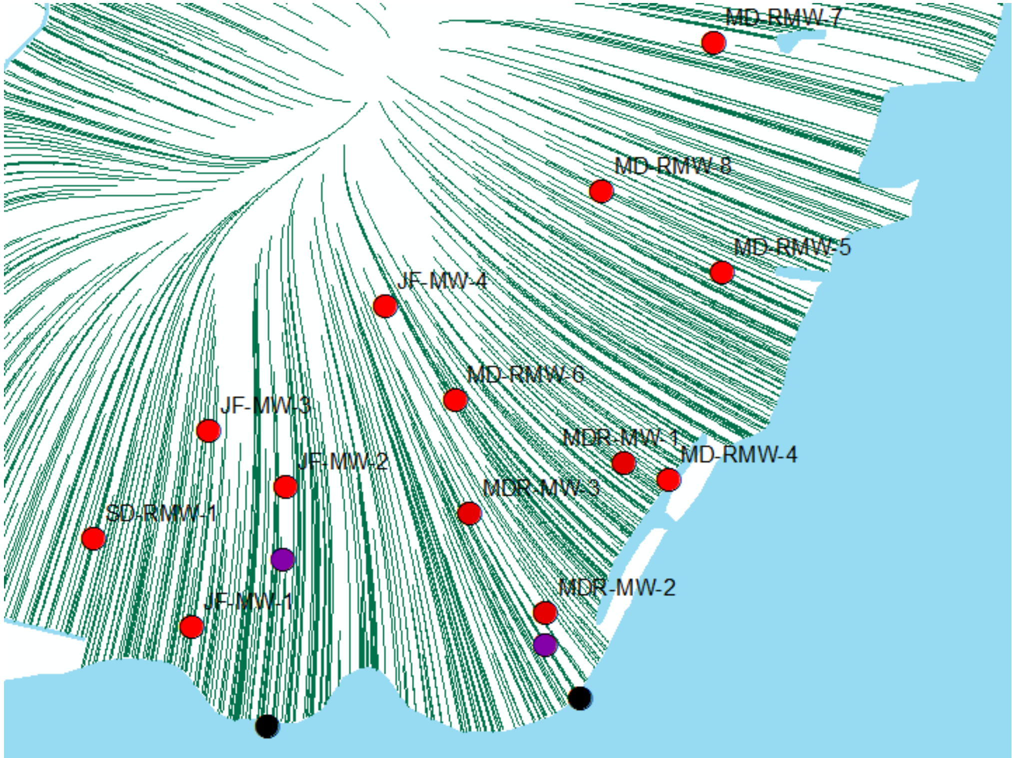






What are Being Developed?

- Python code of data-worth analysis for design of monitoring network and field investigation. It is based on the OPR-PPR method of U.S. Geological Survey.



Potential locations of new monitoring wells

General Ideas for Moving Forward

- Select several representative sites measured by, for example, values of organic carbon (OC) and groundwater velocity
- Conduct field investigation to measure, for example, OC, pH, water content, nitrate concentration, and seepage velocity.
- Calibrate the model against field observations and conduct sensitivity and uncertainty analysis to obtain
  – Representative parameter values and distributions: use them for similar sites to simulate nitrate load, if resources are available
  – Representative load values and distributions: use them for similar sites directly, if resources are unavailable

Questions, Suggestions, and Comments?