



# Florida Onsite Sewage Nitrogen Reduction Strategies Study

Task D.14

## Development of Aquifer-Complex Soil Model for Multiple Spatial Inputs

**White Paper**

May 2015

442-27-001

**HAZEN AND SAWYER**  
Environmental Engineers & Scientists

In association with:



**AET**  
Applied Environmental Technology

**Otis Environmental  
Consultants, LLC**

# **Florida Onsite Sewage Nitrogen Reduction Strategies Study**

## **TASK D.14 WHITE PAPER**

### **Development of Aquifer-Complex Soil Model for Multiple Spatial Inputs**

#### **Prepared for:**

Florida Department of Health  
Division of Disease Control and Health Protection  
Bureau of Environmental Health  
Onsite Sewage Programs  
4042 Bald Cypress Way Bin #A-08  
Tallahassee, FL 32399-1713

FDOH Contract CORCL

**May 2015**

#### **Prepared by:**

**HAZEN AND SAWYER**  
Environmental Engineers & Scientists

In Association With:





## **Section 1.0**

### **Introduction**

---

As part of Task D for the Florida Onsite Sewage Nitrogen Reduction Strategies (FOS-NRS) Study a combined vadose zone and saturated zone model is being developed (STUMOD-FL-HPS). FOSNRS Task D.14 involves development of a new or revised model to simulate nitrogen concentrations and mass flux from several onsite wastewater treatment systems (OWTS) in a development scale area.

The second step of this task involves calibration/corroboration of the model using existing data from a development scale plume. The final component of the task is final model preparation for delivery and preparation of a white paper describing the Task D.14 efforts, which is the purpose of this document.





## Section 2.0

### Approach

---

In order to ensure protection of groundwater the performance of multiple OWTS in an area (e.g., development) and their impacts would be beneficial. Numerous models exist that have been used to evaluate contaminant transport from OWTS ranging widely in complexity (Conan et al., 2003; Jeong et al., 2011; Kinzelbach et al., 1991; Lee et al., 2006; Rios et al., 2013). Increasing mathematical complexity typically correlates with more flexibility allowing for better mathematical representation of the physical processes that are occurring. However, increasing complexity comes at a cost including limited users, increased input data requirements, and increased cost of using the model. Generally it is advisable to begin with the simplest tools first and then decide if further action is needed or more complex models are required.

Many existing models are not useful as screening-level models because they require too much input or technical expertise to be of practical use to most OWTS professionals. These models require a high level of technical proficiency to correctly use due to the numerical techniques that are used to solve the governing equations and because of the input data requirements. Other models developed as screening-level models either do not explicitly consider OWTS or use analytical solutions that may introduce mathematical error in the results (Aziz et al., 2000; Newell et al., 1996; Srinivasan et al., 2007).

Regardless of the complexity of a mathematical model, all models are to some degree, simplifications of reality. Model performance with respect to observed data is specific to the conditions under which the observed data were collected and should not be taken as the expected performance for all conditions (Beven and Young, 2013). The approach for FOSNRS Task D.14 combined evaluation of existing GIS models to predict aquifer vulnerability from OWTS and incorporation of multiple OWTS inputs into STUMOD-FL-HPS.

The GIS-based nitrogen removal model discussed in Section 2.1 is different from the ArcNLET model recently developed and described by Rios et al., 2013. ArcNLET is intended for the evaluation of subsurface transport and pollution at a downstream water body or well point, while the GIS-based model described here is intended for assessing aquifer vulnerability at the water table for the entire state of Florida. The GIS-based

model considers removal processes in the unsaturated zone, while ArcNLET considers removal processes in the saturated zone.

ArcNLET adopts a two-dimensional, steady-state version of Domenico solution with a vertical plane source which requires a few assumptions and estimations in order to be used to model OWTS. While the HPS solution (used for FOSNRS tool development) does not exist in closed form, it avoids the assumptions used by the Domenico and Robbins (1985) solution, which can introduce error under certain conditions (Srinivasan et al. 2007). A multiple spatial input option will be included in the STUMOD-FL-HPS version and will generate a more accurate loading downstream than the module incorporated to ArcNLET with a more consistent representation of the source plane to reflect OWTS.

The GIS-based model discussed in Section 2.1 would be best compared to VZMOD rather than ArcNLET as both models assess removal in the unsaturated zone. VZMOD is a vadose zone model that simulates transformation of ammonium and nitrate in the vadose zone beneath OWTS (Wang et al, 2012) based on modeling principles adopted from McCray et al., 2010. The GIS-based model is based on the N-Calc model developed at CSM (described in McCray et al 2010). The benefit of the approach described here is evaluation of the maps produced from the GIS model that provides high level screening tools (similar to a nomographs) without required GIS experience. The vulnerability maps are generated with identical equations as in VZMOD extended throughout the state for screening level vulnerability assessment, eliminating the need to run the model for each site.

It is recognized that different approaches/tools are best suited for various users and applications due to the benefits and limitations of the different approaches/tools (McCray et al., 2010). While development of a GIS model is not planned as part of FOSNRS D.14, evaluation of existing GIS models provides insight into the benefits and limitations of such an approach compared to STUMOD-FL. Computational constraints within a simple to use tool such as STUMOD-FL, limits the number of spatial inputs while a GIS approach better handles a higher number of spatial inputs but requires greater user technical expertise. Alternatively, STUMOD-FL accommodates more detailed parameter input improving the ability to calibrate the model and obtain relatively more accurate results. Incorporation of multiple spatial inputs into STUMOD-FL will be limited due to computational time required. All of these approaches/tools (vulnerability maps, GIS models, and STUMOD-FL-HPS with multiple spatial inputs) should be considered by decision makers.

## 2.1 Evaluation of Aquifer Vulnerability from OWTS Based on GIS Models

Spatial variability in OWTS systems and site conditions contribute to groundwater vulnerability to nitrogen contamination. As part of Task D.14, an aquifer vulnerability study using three Geographic Information System (GIS) models has been completed (Cui, 2014). Classification of vulnerability was based on nitrate concentrations reaching the water table, categorized into less vulnerable, vulnerable, and more vulnerable based on Jenks' Natural Breaks algorithm. Natural breaks classification identifies groups with similar values and maximizes the difference between classes (Jenks, 1967).

There are three main aquifer systems in the State of Florida: the Surficial Aquifer System (SAS), the Intermediate Aquifer System (IAS), and the Floridan Aquifer System (FAS). Previous studies have focused on developing vulnerability assessment models to address the susceptibility of Florida's aquifer systems but not specific to OWTS impact to the surficial aquifer system.

The first aquifer vulnerability map developed by Florida's Department of Environmental Protection utilized the DRASTIC model to determine vulnerability based on parameters significant in contaminant transport. The DRASTIC model is based on seven parameters: Depth to aquifer, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone, and hydraulic Conductivity. The parameters define a composite description of major geological and hydrologic factors that affect and control groundwater movement (Aller et al., 1985). The DRASTIC model calculates an aquifer vulnerability index based on a system of rates and weights. Each of the seven parameters is assigned a rate on a scale of 1 to 10 based on their effect on aquifer vulnerability and a weight from 1 to 5 based on their relative importance (Babiker et al., 2005). The rates are assigned based on site characteristics as related to a specific parameter. If for instance, the water table is very deep, a low rate is assigned to depth to water table. On the other hand the weights reflect the relative importance of each parameter regardless of site. Depth to water table may have a higher weight even when the water table is deep. The main advantages of the DRASTIC index model include its applicability to multiple contaminants, easily obtainable or interpolated data, and large number of parameters for good representation and reduced impact of errors (Babiker et al., 2005). However, there are a number of limitations, as described in Arthur et al. (2007) and Babiker et al. (2005), including high sensitivity to certain parameters, but underweighting important parameters such as net recharge and hydraulic conductivity, a subjective ranking system, sharp transitions between data sets and vulnerability maps, generalization of site

features (such as soil types and karst features), and over emphasizing effect of topography.

The DRASTIC model was later succeeded by the Florida Aquifer Vulnerability Assessment (FAVA) to provide a data-driven modeling approach (Arthur et al., 2007). The FAVA completed by the Florida Department of Environmental Protection in 2005 utilizes the Weight of Evidence (WofE) model to make predictions based on spatial data. The modeling utilizes training points or areas of known occurrences to assess prior probability, weights of spatial data, and posterior probability of the results. The training points used in this model are wells with a sampled total dissolved nitrogen concentration greater than the median value of the sampled values. Then, the spatial data is weighed based on which areas of the evidence share a greater association with location of training points, forming the evidential themes. Evidential themes are combined in GIS to produce a response theme. The response themes show the probability that a unit area contains a training point based on the evidence. The probability is delineated to generate a final probability map illustrating aquifer vulnerability (Arthur et al., 2007). The main advantage of the FAVA with the applied WofE model is its updatable format, data driven analysis, empirical calculation, and limited subjectivity. The limitations of this model are data time sensitivity (need for up-to-date data), low resolution (30 m), and intrinsic vulnerability, which do not take into account natural and human sources of contamination or specific contaminants.

Both the DRASTIC and FAVA models are applied broadly to the three main aquifer systems. To address aquifer vulnerability based on the vadose zone processes from OWTS, an alternative and new modeling approach was developed: the GIS-N model, a GIS-based nitrogen fate and transport model. The calculation for contaminant removal in the vadose zone in the GIS-N model is based on the simplified Advection Dispersion Equation (ADE) implemented in similar models (Rao et al., 1985; Geza et al., 2014; McCray et al., 2010). The simplified ADE uses first-order reaction rates for nitrification and denitrification, ignores the effects of dispersion, and assumes steady state conditions. The GIS-N model also considers operational inputs (effluent concentration, effluent loading rates, porosity, and soil depth) in addition to sorption and reaction parameters (nitrification and denitrification) for nutrient transformation (Jury et al., 1987; McCray et al., 2010). The GIS-N model considers two different approaches: single-step and two-step modeling. The single-step model considers a denitrification process assuming all the ammonium is converted to nitrate before land application, while the two-step model uses ammonium as an input and considers nitrification followed by denitrification.

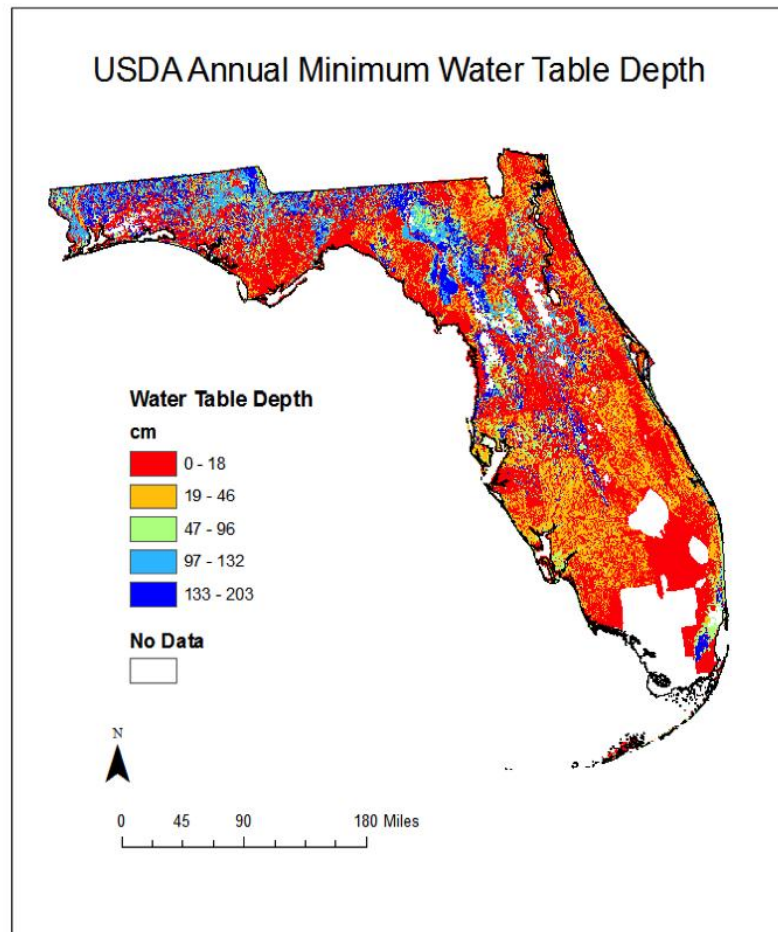
GIS data for the required input data layers were acquired from the Natural Resources Conservation Service (NRCS) soil survey, Florida Department of Environmental Protection, and Florida Geographic Data Library (FGDL). The NRCS provides soil data for the entire State of Florida from the Gridded Soil Survey Geographic (gSSURGO) database in the format of an Environmental Systems Research Institute, Inc. (ESRI) file geodatabase. Attributes used from the NRCS database included: soil organic carbon, soil water content at field capacity, density, soil temperature, and soil texture. Florida land cover data were obtained through the Florida Fish and Wildlife Conservation Commission. Other parameters used in the contaminant removal calculation are from literature and reports. Nitrification, denitrification and sorption rates were obtained from peer reviewed literature.

Locations of OWTS, effluent concentration, and loading rates were obtained from the 2009 Florida Department of Health wastewater inventory database. For parcels with an unknown OWTS treatment method, a logistic regression model was used to estimate the probability of the parcel being on an active OWTS based on parcels with a known wastewater treatment method (EarthSTEPS, LLC and GlobalMind, 2009). The parcels with OWTS identified in the database were used as contaminant input location for spatially variable contaminant input in the existing OWTS application scenario. Of the 2,559,757 parcels with an OWTS in the 2009 inventory, 1,612,305 of those parcels also had corresponding soil data from NRCS for nitrogen fate and transport calculations.

The GIS-N model was applied to four different scenarios: a single-step model with uniform application (single-step uniform input), a two-step model with uniform input (two-step uniform input), a single-step with variable input (single-step variable input), and a two-step model with variable input (two-step variable input).

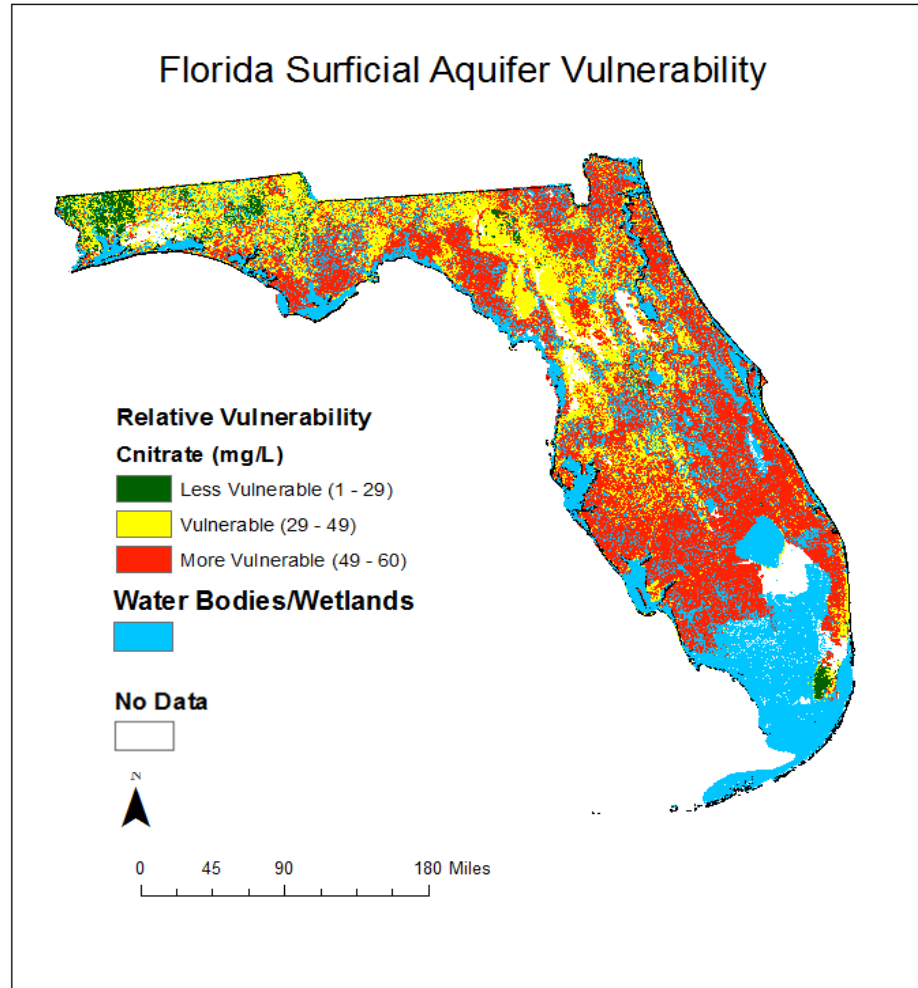
- The single-step uniform input model assumes all the ammonium is nitrified before it is applied to the soil (considers only the denitrification process) representing a scenario where ammonium is nitrified before soil application. The denitrification process is highly sensitive to water table depth. Thus, nitrate concentrations reaching the water table correlated well with the depth to water table (Figure 2.1) as the depth to water table value controlled the travel time and the time available for denitrification. This assessment cannot be applied directly to drinking water in lower aquifer systems, but provides a general understanding of vulnerability. Figure 2.2 illustrates that the most vulnerable areas are along the borders of water bodies and areas in southern Florida and vulnerable areas mostly grouped around central Florida and less vulnerable areas in the sand and gravel aquifer (Figure 2.3).





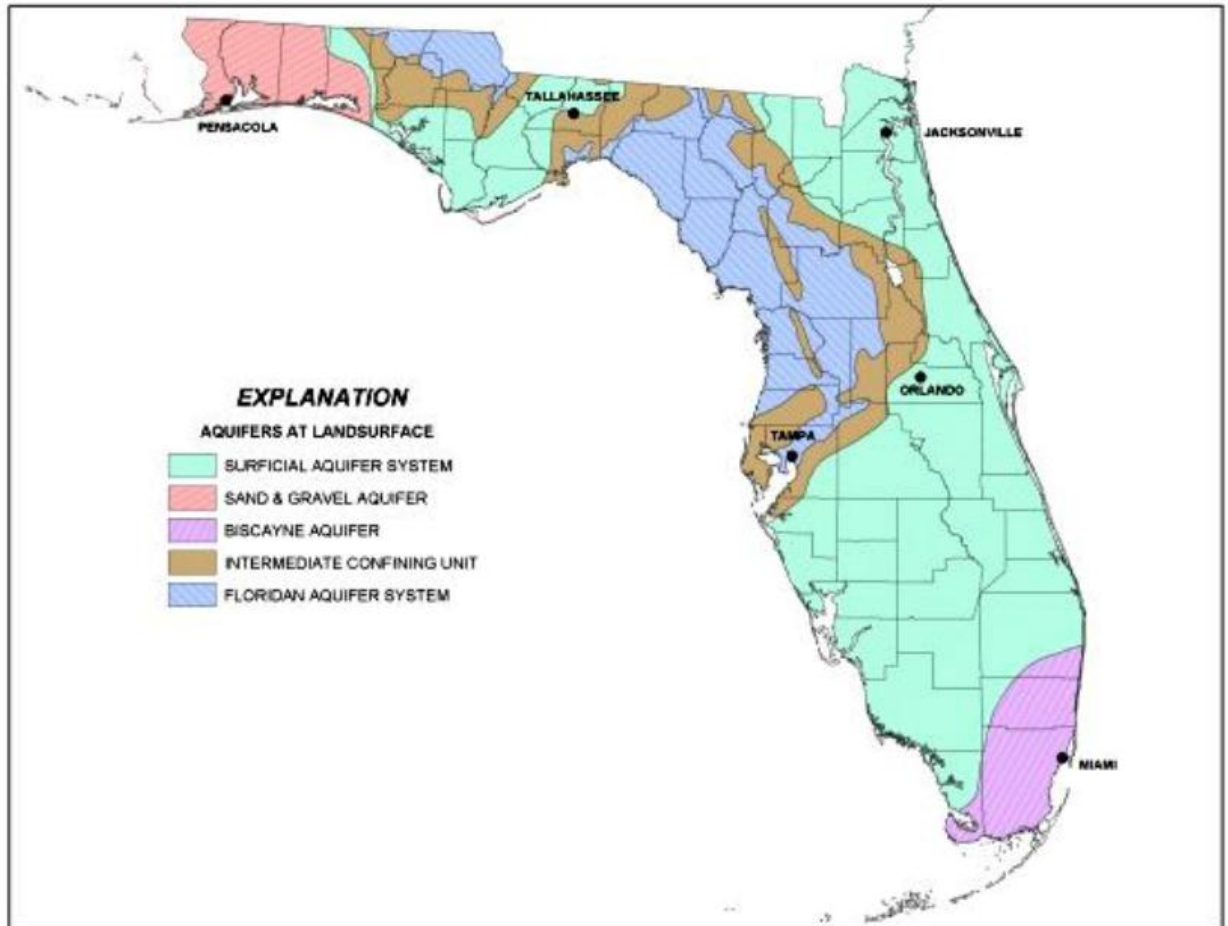
**Figure 2.1**  
**Depth to groundwater table, from 0 cm to 203 cm, for the State of Florida.**

O:\44237-001R005\Wpdocs\Report\Final



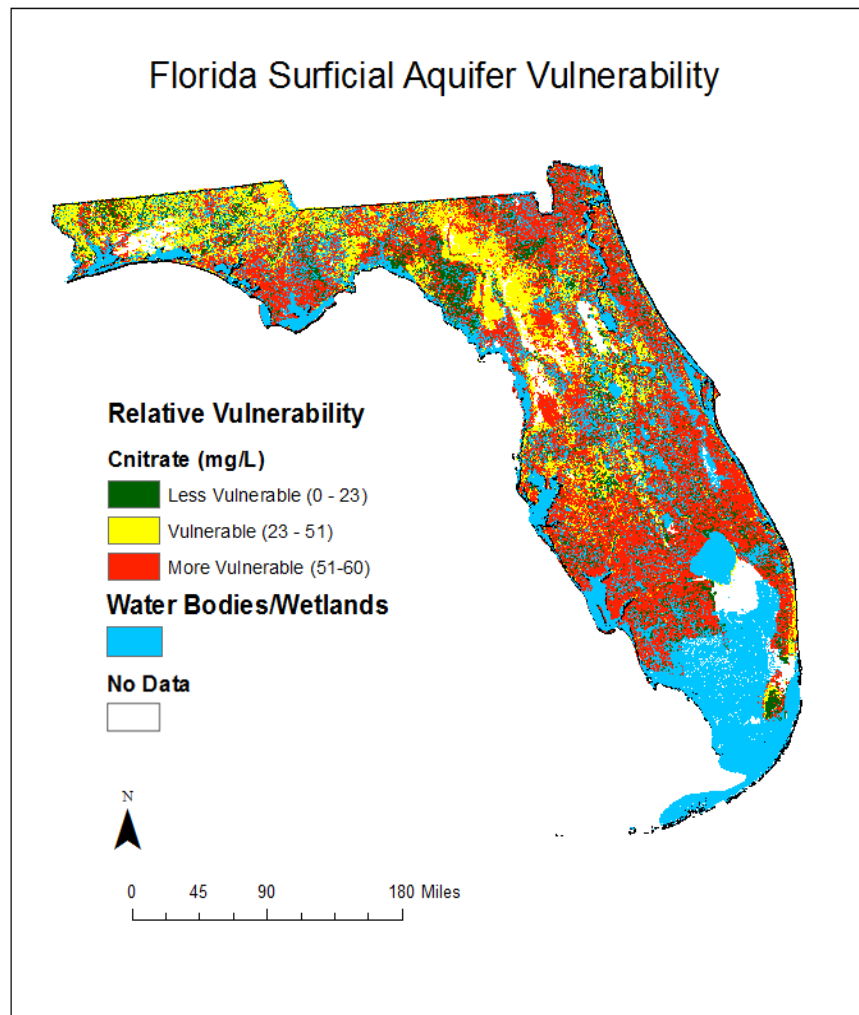
**Figure 2.2**  
**Florida surficial aquifer vulnerability map based on the single-step uniform input nitrogen removal model, showing remaining NO<sub>3</sub>-N concentrations in mg/L.**

O:\44237-001R005\Wpdocs\Report\Final



**Figure 2.3**  
**Florida aquifer systems and their extent**  
 (<http://www.dep.state.fl.us/swapp/aquiferPframe.html>).

- The two-step model assumes ammonium is nitrified first, followed by a denitrification representing a conservative estimate (a higher concentration) of nitrate reaching the water table compared to a single step model. The nitrate output from the first nitrification step is an input to the second denitrification step occurring in the bottom soil layer above the water table and below the nitrification layer where the nitrate is converted to gaseous nitrogen. The two-step model predicts more vulnerable areas in southern Florida and vulnerable areas in northern and central Florida (Figure 2.4).

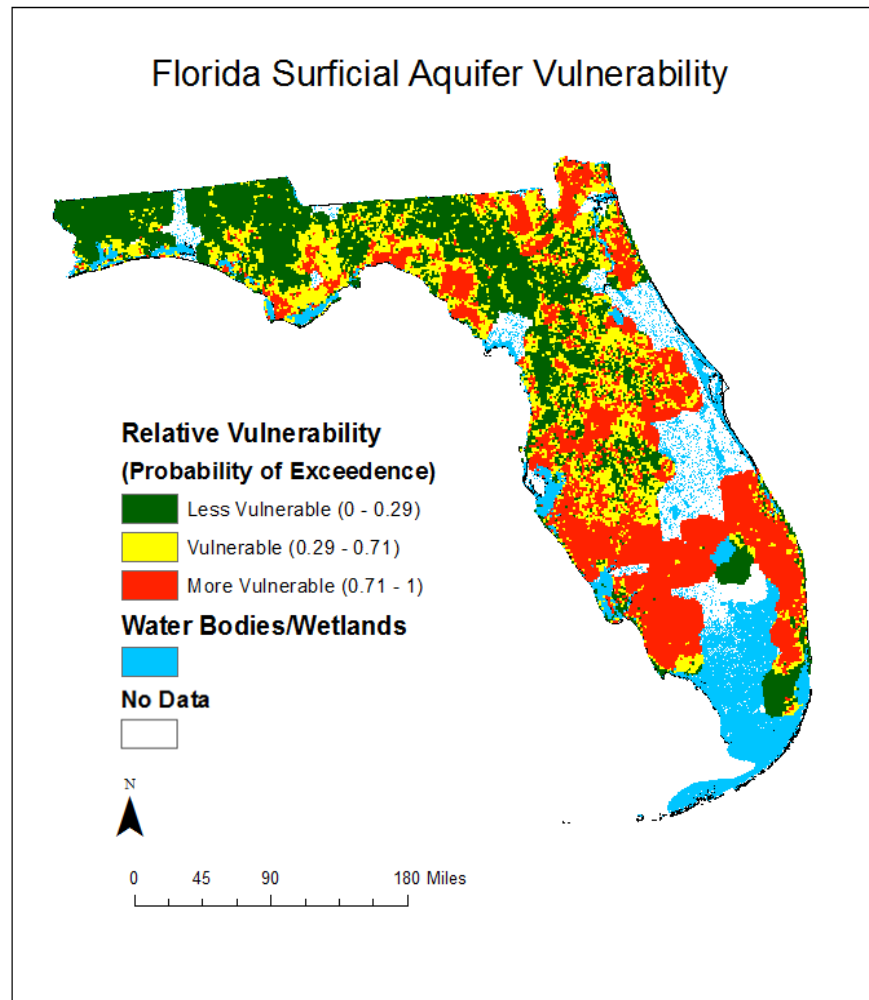


**Figure 2.4**  
**Florida surficial aquifer vulnerability map based on the two-step uniform input nitrogen removal model, showing remaining NO<sub>3</sub>-N concentrations in mg/L.**

- The single-step variable input is similar to the single-step uniform input except the distribution of active OWTS are input as point features. Parameters from the developed map layers are converted to point features for the output calculation. This scenario provides information on areas currently affected by OWTS. The radial extent of the contaminant transport was estimated by kriging over a large range and does not represent actual flow patterns. Thus, vulnerability is low at

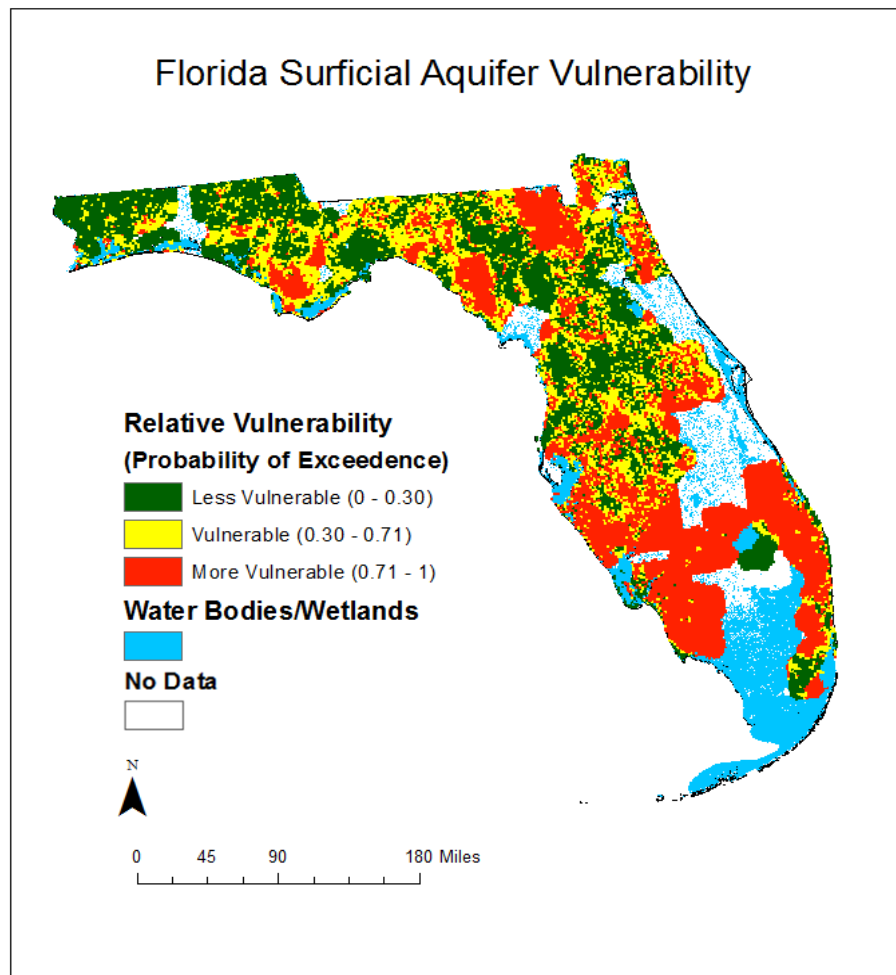


locations further away from OWTS and vulnerability at a point with an OWTS is based on the soil parameters considered in the simplified ADE. The aquifer vulnerability for the single-step variable input approach depicts areas being less vulnerable in northern and central Florida (Figure 2.5). Vulnerable areas border the outer parameter of less vulnerable areas, and more vulnerable areas surround coastal water bodies.



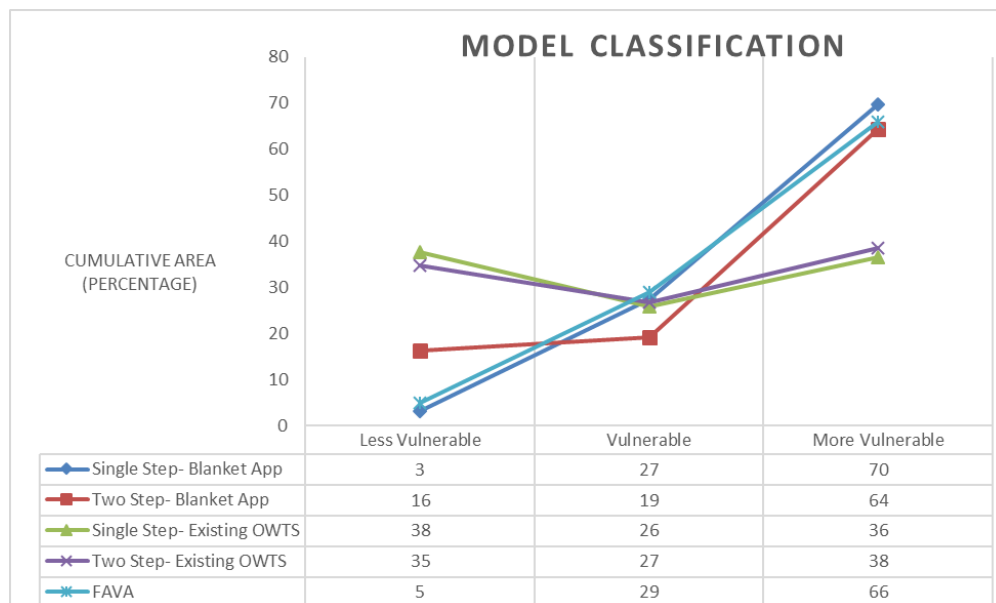
**Figure 2.5**  
**Florida surficial aquifer vulnerability map based on the single-step OWTS nitrogen removal model with vulnerability classification based on the natural break in the predicted probability of exceedance.**

- The two-step variable input model follows the same idea where contaminant input is spatially varied based on existing locations of active OWTS but calculates remaining nitrate concentrations. The aquifer vulnerability for the two-step variable input model also depicts areas being less vulnerable in northern and central Florida, with vulnerable areas bordering the outer parameter of less vulnerable and more vulnerable areas surround costal water bodies (Figure 2.6).



**Figure 2.6**  
**Florida surficial aquifer vulnerability map based on the two-step OWTS nitrogen removal model with vulnerability classification based on the natural break in the predicted probability of exceedance.**

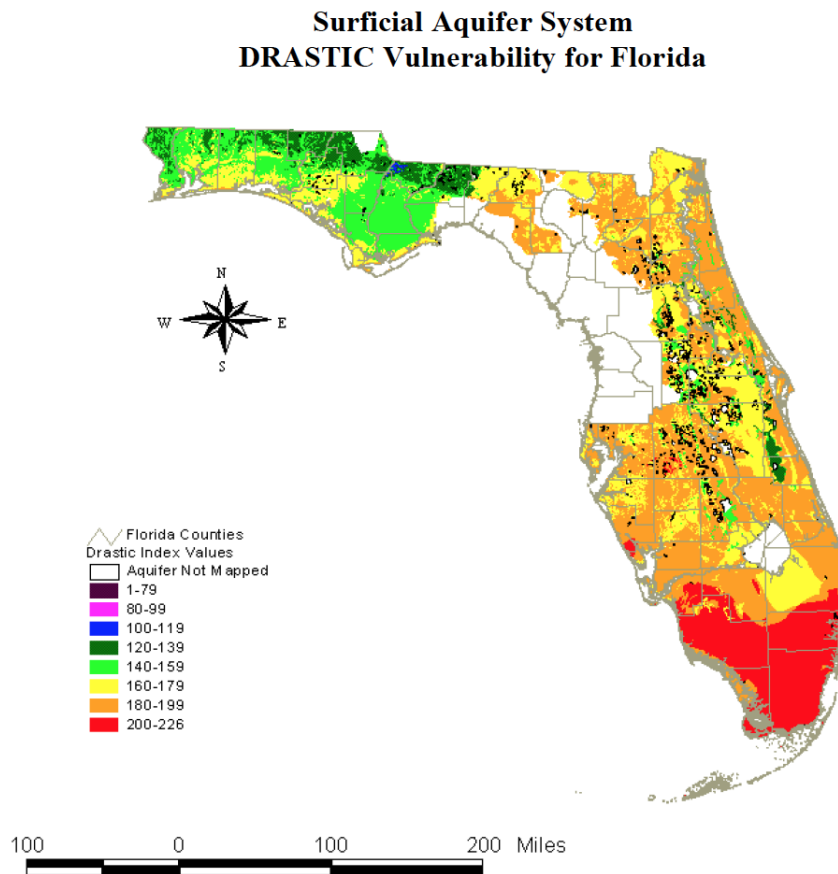
Each of the four nitrogen removal scenarios/approaches has pros and cons. For the uniform input scenarios, the two-step approach predicts a higher overall trend in aquifer vulnerability for the sand and gravel aquifer compared to the single-step approach, but more localized areas of less vulnerable zones within different regions were observed (Figure 2.7). This is due to the relatively small distance for the denitrification process because part of the unsaturated zone has to be used for the nitrification. Nitrifying ammonium before application to soils in areas with shallow depth to water table can help reduce vulnerability.



**Figure 2.7**  
Cumulative area in percentage in each vulnerability classification class for all nitrogen removal models and the FAVA model.

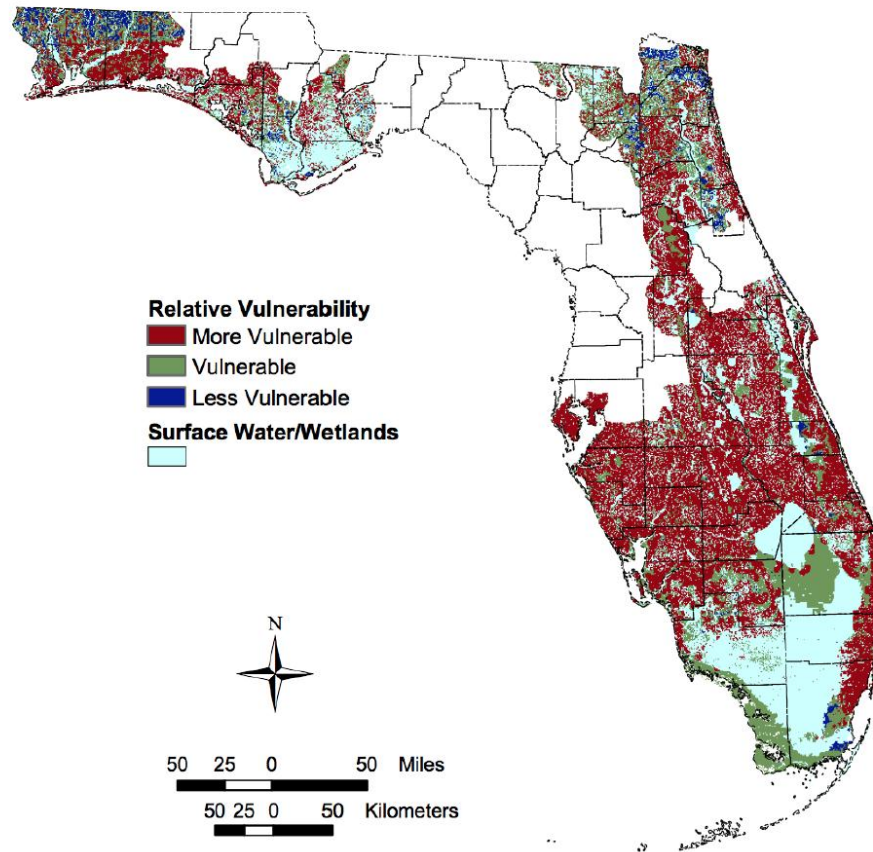
As expected, the results showed that groundwater vulnerability from OWTS is most sensitive to the depth to water table, first-order reaction rates, and parameters controlling the time and amount of conversion. Ultimately, nitrate concentration was highest in areas with shallow water table depth. When compared to the DRASTIC model approach (Figure 2.8), the GIS-N model offers a more detailed approach that considers reaction and sorption of contaminants. Because the more generalized DRASTIC model is based on subjective weights and rates, the GIS-N model produces relatively more accurate vulnerability maps for the surficial aquifer system. The GIS-N model is also more dynamic and applicable to current and future impacts from OWTS than the FAVA model (Figure 2.9). The FAVA model, based on the use of training points from past well data, may not

be applicable to the current concentration distribution because the FAVA model does not allow a general sensitivity map from current measured levels of nitrate concentration from a mixture of anthropogenic and natural sources as the development of the maps was based on past concentration measurements. On the other hand, the GIS-N model allows the user to define the source location and concentration, adjusting the initial input concentration to forecast future vulnerability.



**Figure 2.8**  
**DRASTIC vulnerability map for the surficial aquifer system. A higher DRASTIC index score represents areas with higher vulnerability to contamination (from Aller et al., 1985 and Arthur et al., 2007).**





**Figure 2.9**  
**FAVA response theme for the surficial aquifer system (from Arthur et al., 2007).**

The main advantages of the GIS-N model include: consideration of parameters influencing the fate and transport of nitrogen in the vadose zone, more detailed depiction of the bio-chemical processes and based on the application of the ADE, updatable and flexible in adjusting contaminant input concentration and location, utilizes anthropogenic sources of contamination from OWTS, 10- meter resolution for raster map format, mostly data driven analysis, and indirectly accounts for karst features with the depth to water table layer. However, the limitations of the GIS-N model include: applicable to removal in the vadose zone only and represents the surficial aquifer system only, some NRCS soil parameters (soil temperature, depth to water table, soil moisture) are data time sensitive, the model is sensitive to water table depth and first-order biological reaction rate, and uncertainty in the first- order biological reaction rates.

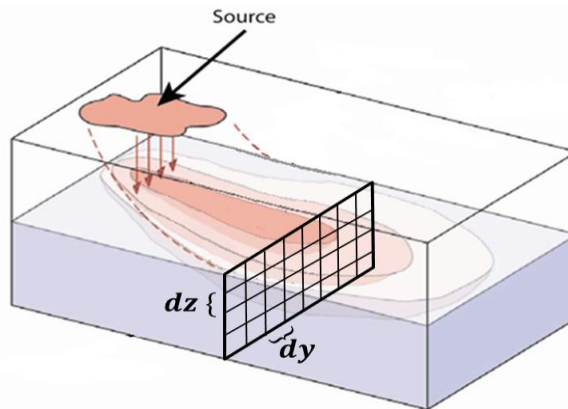
## 2.2 STUMOD-FL-HPS Multiple Spatial Inputs

To date a limited number of models specifically consider OWTS and fewer still are designed with a wide user group in mind. Because STUMOD-FL is a spreadsheet based tool, it will be available to a wide range of users and does not require a GIS platform. Thus, STUMOD-FL-HPS has been modified to include a module to account for multiple spatial inputs.

This module calculates nitrogen mass flux [kg/yr] downstream at a specified distance from multiple sites. In each approach, the mass flux estimate for a plume cross section from a single source is estimated as product of concentration and flow rate with equation 1 below.

$$M \left[ \frac{\text{kg-N}}{\text{yr}} \right] = \sum_{i=1}^n v \cdot c_i(t, x, y, z) \cdot dy \cdot dz \quad (2-1)$$

The mass flux algorithm is constructed using equation (2-1) and calculates mass flux for a cross-section perpendicular to the hydraulic gradient (Figure 2.10). The extent of the plume in the  $\pm y$  and  $z$  direction is determined by calculating the location where the plume concentration is approximately 0.0004 mg/L. These locations mark the maximum extent of the plume. This concentration value was chosen to delineate the extent of the plume after testing several different values including zero concentration. Smaller concentration values require significantly more calculations and can cause the model to fail. While smaller values are preferable for accuracy, larger concentration values increase the speed of the model but reduce the accuracy of the mass flux calculation. The plume delineated for each site using this procedure is discretized into a number of cells. The concentration in equation (2-1) is calculated at the center of each cell and mass flux is calculated as the product of the volumetric flux and the cell concentration. The user must specify the down gradient distance, 'x', where the plume cross section is to end. The total mass loading from a source is then calculated as the sum of mass loading through each cell across the vertical plane at the specified distance from the source.



**Figure 2.10**

**Illustration of how the plume is discretized into M columns and N rows. Mass flux is then calculated for each element.**

The above describes how the mass flux is calculated for a single source while the approach for calculating mass flux from multiple sources is described below. There are two separate modules (Multiple Sites I and II) incorporated into STUMOD-FL-HPS. The mass loading from each site is calculated slightly differently in these modules to get the total mass loading at the down gradient point of interest as described in Sections 2.2.1 and 2.2.2.

### 2.2.1 Multiple Sites I

The mass flux at a point down gradient of the OWS is calculated in two steps. First, the nitrogen mass flux through the vadose zone to the water table is calculated using the vadose zone module, STUMOD-FL. Mass flux from STUMOD-FL is used as boundary input to the saturated zone HPS module. There are two options under the Multiple Sites I option; the unique parameter set option and the lumped parameter set option.

#### Unique Parameter Approach

For the first option or the unique parameter set option, the model calculates the mass flux down gradient of the OWTS for each of the sites individually using unique data inputs for each site (both for the saturated and unsaturated zone). The total mass loading from all sites down gradient of the OWTS is ultimately obtained by adding the mass loading from each of the sites. The percent removed is calculated both at the water table and at a down gradient distance. The number of sites should be specified with larger number of sites requiring longer simulation time.

In this option, users need to specify both saturated and unsaturated zone input parameters for each site. The inputs for individual site include soil type. Users can choose one of the 13 soil type listed for each site using a drop down menu. The parameters related to unsaturated zone are automatically populated with default values when the user chooses a soil type. However the user has the option to replace the default values with site-specific values. The user can also restore the default values by clicking on the 'restore to defaults' button. Some parameters may not be automatically populated when choosing a soil type. These parameters are populated by the user for each site. An example is depth to water table and options for depth to water table.

Key saturated zone inputs include hydraulic gradient, porosity and saturated hydraulic conductivity used to calculate seepage velocity. Porosity and saturated hydraulic conductivity are obtained from the unsaturated zone inputs. Concentration at the water table is obtained from the unsaturated zone output. Another essential input is the distance to the point of interest down gradient of the STU from each of the sites.

The unsaturated zone outputs include fraction of ammonium, nitrate, and total N remaining at the water table and mass flux for each site. The saturated zone output is the mass flux from each site, total mass flux to the site, and fraction of mass removed for each site and for all sites.

### **Lumped Parameter Approach**

Unlike the first option where the mass loading is calculated individually for each site, for the second option or lumped parameter set option, model inputs are averaged together. In this approach, the model is run only one time for a single combined site represented by averaged soil properties to calculate the mass flux at the user specified down gradient distance. This option takes a short time to run and is recommended for initial screening and when the sites are assumed to be very similar and the distance from each site to the down gradient point of interest are similar. If the site properties and distance to the point of interest are not similar, it should be noted that the results from the lumped approach would be very different compared to the unique parameter set option.

Like the unique parameter set option, users need to specify both saturated and unsaturated zone input parameters for each site. However, for this case one lumped parameter set is generated by averaging parameter values from all the sites. Thus, users need to specify the number of sites and inputs for each site.



Again like the unique parameter set option, the unsaturated zone outputs include fraction of ammonium, nitrate and total N remaining at the water table and mass flux. The saturated zone output is the total mass flux at the point of interest/user specified down gradient distance and fraction of mass removed.

### **2.2.2 Multiple Sites II**

This module calculates nitrogen mass flux [kg/yr] downstream at a specified distance from multiple sites just like the 'Multiple Site I' option described In Section 2.2.1. However, it assumes a known mass flux from the vadose zone to the water table for each site and no computations are made for the unsaturated zone. This module is applicable where estimates of mass loading to the water table are available and the user wants to use the saturated zone module only. Multiple site II does not include a vadose zone run, therefore takes a relatively shorter time.

The concentration at the water table is a direct input to the model, unlike the "Multiple Site I" case where it is calculated using STUMOD-FL. The 'Multiple Sites II' approach requires relatively shorter time because only the saturated zone module has to be run. However like the "Multiple Sites I" approach, the number of sites should be specified with larger number of sites requiring longer simulation times.

Again like the "Multiple Sites I" approach, there are two options; the unique parameter set option and the lumped parameter set option. For the first option, the model calculates the mass flux down gradient of the OWTS for each of the sites individually using unique data inputs for each site. For the lumped parameter set option, users input parameters for each site that is then averaged together and represented by a single combined average site. In other words, the total area of the combined sites has the same averaged properties.

For the Multiple Sites II, outputs are provided for a user specified down gradient location only. These outputs include mass flux from each site, total mass flux to the site, and fraction of mass removed for each site. When the lumped parameter approach is used, the outputs are the total mass flux and fraction of mass removed.

### **2.3 STUMOD-FL-HPS Multiple Spatial Inputs Calibration/Corroboration**

The scope of work for FOSNRS Task D.14 specified that the multiple spatial input model would be calibrated using existing data from a development-scale plume, based on metrics such as average concentration in the plume or mass flux crossing a boundary. We are not aware of any such data set that would enable calibration/corroboration. The limi-

tations of corroboration using simple tools have been discussed in the FOSNRS Task D.9, D.12 and D.13 reports. Given these limitations and the lack of suitable development-scale data, calibration/corroboration was not conducted. Instead, effort was put toward developing and incorporating in STUMOD-FL-HPS several approaches to evaluate multiple sites. Each approach is tailored for ease (number of inputs and length of run time) to serve as a larger scale screening tool based on the question of interest and available data.



## Section 3.0

### References

---

- Aller, L., T. Bennet, J.H. Leher, R.J. Petty, and G. Hackett (1985). DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential using Hydrogeological Settings. EPA 600/2-87-035: 622.
- Arthur, J.D., A.E. Baker, J.R. Cichon, A.R. Wood and A. Rudin (2007). Florida Aquifer Vulnerability Assessment: Florida Geological Survey Bulletin 67, (3 plates) 150 p.
- Aziz, C. E., J. R. Newell, P. H. Gonzales, C. T.P., and S. Y-W. (2000), BIOCHLOR Version 1.0 User's Manual, edited, U.S. EPA.
- Beven, K., and P. Young (2013). A guide to good practice in modeling semantics for authors and referees, *Water Resources Research*, 49(8): 5092-5098.
- Conan, C., F. Bouraoui, N. Turpin, G. de Marsily, and G. Bidoglio (2003). Modeling flow and nitrate fate at catchment scale in Brittany (France), *Journal of Environmental Quality*, 32(6): 2026-2032.
- Cui, C. (2014). GIS-Based Nitrogen Removal Model for Assessing Florida's Surficial Aquifer Vulnerability from Onsite Wastewater Treatment Systems. M.S. Thesis. Geology and Geological Engineering, CSM Golden, CO.
- Domenico, P. A., and G. A. Robbins (1985). A new method of contaminant plume analysis, *Ground Water*, 23(4), 476-485.
- EarthSTEPS, LLC and GlobalMind (2009). Statewide Inventory of Onsite Sewage Treatment and Disposal Systems in Florida. Final Report prepared for the Florida Department of Health. [http://www.floridahealth.gov/healthy-environments/onsite-sewage/research/\\_documents/research-reports/\\_documents/inventory-report.pdf](http://www.floridahealth.gov/healthy-environments/onsite-sewage/research/_documents/research-reports/_documents/inventory-report.pdf). Accessed December 2013.
- Geza, M., K.S. Lowe, and J. McCray (2014). STUMOD- a tool for predicting fate and transport of nitrogen in soil treatment units. *Environmental Model and Assessment*, 19(3): 243-256.
- Jenks, George F. (1967). The data model concept in statistical mapping, *International Yearbook of Cartography*, 7: 186-190.

- Jeong, J., C. Santhi, J. G. Arnold, R. Srinivasan, S. Pradhan, and K. Flynn (2011). Development of algorithms for modeling onsite wastewater systems within SWAT, *Transactions of the ASABE*, 54(5): 1693-1704.
- Jury, W.A., D.D. Focht, and W.J. Farmer (1987). Evaluation of pesticide ground water pollution from standard indices of soil-chemical adsorption and biodegradation, *Journal of Environmental Quality*, 16(4): 422-428.
- Kinzelbach, W., W. Schafer, and J. Herzer (1991). Numerical modeling of natural and enhanced denitrification processes in aquifers, *Water Resources Research*, 27(6): 1123-1135.
- Lee, M. S., K. K. Lee, Y. J. Hyun, T. P. Clement, and D. Hamilton (2006). Nitrogen transformation and transport modeling in groundwater aquifers, *Ecological Modeling*, 192(1-2).
- McCray, J. E., M. Geza, K. Lowe, M. Tucholke, A. Wunsch, S. Roberts, J. Drewes, J. Amador, J. Atoyan, D. Kalen, G. Loomis, T. Boving, and D. Radcliffe (2010). Quantitative Tools to Determine the Expected Performance of Wastewater Soil Treatment Units: Guidance Manual. Publisher: Water Environment Research Foundation. 198 p.
- Newell, C. J., R. K. McLeod, and J. R. Gonzales (1996), BIOSCREEN Natural Attenuation Decision Support System User's Manual Version 1.3, edited, U.S. EPA.
- Rao, P.S.C., A.G. Hornsby, and R.E. Jessup (1985). Indices for ranking the potential for pesticide contamination of groundwater. *Soil Crop Science Society Florida Proceedings*, 44: 1-8.
- Rios, J. F., M. Ye, L. Wang, P. Z. Lee, H. Davis, and R. Hicks (2013), ArcNLET: A GIS-based software to simulate groundwater nitrate load from septic systems to surface water bodies, *Computers & Geosciences*, 52(0): 108-116.
- Srinivasan, V., T. P. Clement, and K. K. Lee (2007), Domenico solution - Is it valid? *Ground Water*, 45(2): 136-146.