ArcNLET: An ArcGIS-Based Nitrate Load Estimation Toolkit

Application Manual

Manuscript Completed: July 2011

Revised: January 13, 2014

Prepared by

Liying Wang[1], Ming Ye[1], J. Fernando Rios[1] and Paul Lee[2]

[1]Department of Scientific Computing, Florida State University, Tallahassee, FL 32306

[2]Groundwater and Springs Protection Section, Florida Department of Environmental Protection, Tallahassee, FL 32399

Rick Hicks, FDEP Contract Manager

Prepared for

Florida Department of Environmental Protection

Tallahassee, FL

Revision Sheet

Release No.	Date	Revision Description
Rev. 1.0.0	July 6, 2011	Initial release
Rev. 1.0.1	January 14, 2014	Update the process of generating heterogeneous maps of hydraulic conductivity and porosity using Microsoft Access

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION AND ORGANIZATION OF THE MANUAL

This manual describes several advanced topics of using the ArcGIS-Based Nitrate Load Estimation Toolkit (ArcNLET) to simulate the fate and transport of nitrate originating from septic systems and to estimate the nitrate load to surface water bodies such as lakes and rivers. The advanced features of ArcNLET will be described in this manual through two real-world applications in the Eggleston Heights and Julington Creek neighborhood in Jacksonville, FL. The underlying model of nitrate fate and transport and the associated algorithmic implementation is described in detail in the technical manual (Rios et al., 2011). The installation and basic usage of this software is described in the user's manual (Rios et al., 2011).

Readers of this manual should be familiar with the basics of working with ArcGIS 9.3 and ArcNLET and have basic understanding of scientific and hydrological terminology.

The structure of the manual is as follows: the manual begins with a sensitivity study of the model in Chapter 2 which provides the guidelines of model calibration. The procedure of processing LiDAR data to produce a digital elevation model layer (DEM) and generating of heterogeneous hydraulic conductivity and soil porosity layers for this software will be discussed in Chapter 3. In Chapter 5, two example problems will be described, followed by model calibration procedure, and finally the results of nitrate loads estimation based on calibrated parameters will also be shown in this chapter.

2 PREPARATION OF INPUT FILES

The procedures of preparing DEM layer based on National Elevation Dataset (NED), water body layer based on National Hydrology Dataset (NHD) and homogenous hydraulic conductivity and porosity layers using raster calculator tool of ArcGIS are fully described in the user's manual of this software. However, more reliable nitrate load estimation may entails improving accuracy of NED and NHD data. This manual describes how to achieve this using LiDAR data by using its high resolution. On the other hand, for nitrate load estimation at a relatively large modeling domain, using heterogeneous zones for hydraulic conductivity and porosity parameters is necessary to reflect variability of the site-specific hydrologic conditions. This manual will elaborate on how to do so based on soil survey data. For illustration purposes, examples for the Eggleston Heights and Julington Creek neighborhoods in Jacksonville, FL, are used in the discussions below.

2.1 Processing of LiDAR data

LiDAR DEM is used at the both Eggleston Heights and Julington Creek neighborhoods. The necessity of using LiDAR DEM instead of NED DEM data is demonstrated at the Eggleston Heights neighborhood. There are many ditches and artificial canals in this area (Figure 2-1, left), but many of them are narrower than 10m (the 1/3 arc second resolution of the NED DEM used in the user's manual). As a result, such ditches and canals (e.g. that highlighted in Figure 2-1, left) cannot be reflected in the NED DEM data (Figure 2-1, right).

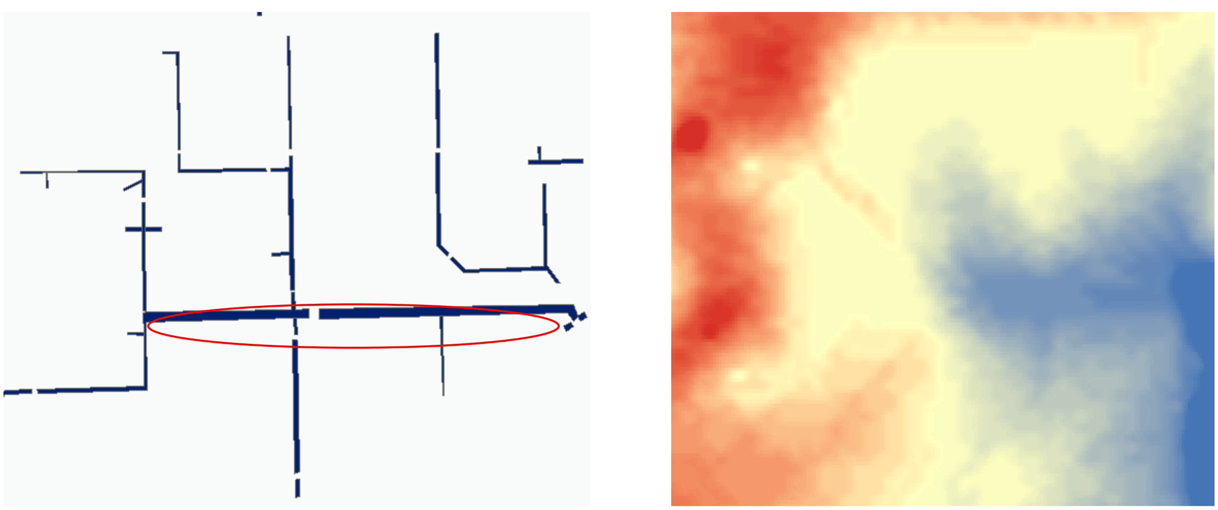


Figure 2-1 Ditches coverage (left) and NED DEM map (right) of 1/3 Arc Second resolution. The ditches (e.g., that highlighted in the red ellipse) cannot be reflected in the DEM data.

The LiDAR data with a horizontal resolution of 5 × 5 ft^2, as shown in Figure 2-2 left, is capable of representing the ditches, taking the one in red ellipse in Figure 2-1 left and Figure 2-2 left as an example. As explained in the technical manual (Rios et al., 2011), DEM data of finer resolution always has highly intense fluctuation of elevation and the fluctuation is inconsistent with of the water table. On the other hand, it takes longer computation time to smooth DEM data of higher resolution (see the details of smoothing in the technical manual of Rios et al., 2011). Therefore, the LiDAR DEM needs to be processed to reduce the resolution. In this study, the targeted resolution is 10 × 10 m^2, which is consistent with that of the example data associated with the user's manual., The processed LiDAR DEM is shown in Figure 2-2 right, in which the ditch in the red ellipse is preserved. The ditches and canals can be better preserved, if the target resolution of the processing is smaller. However, as explained before, a finer resolution may result in longer computation time of smoothing. The tradeoff between finer resolution and reasonable computation time is determined by users to meet their specific project needs.

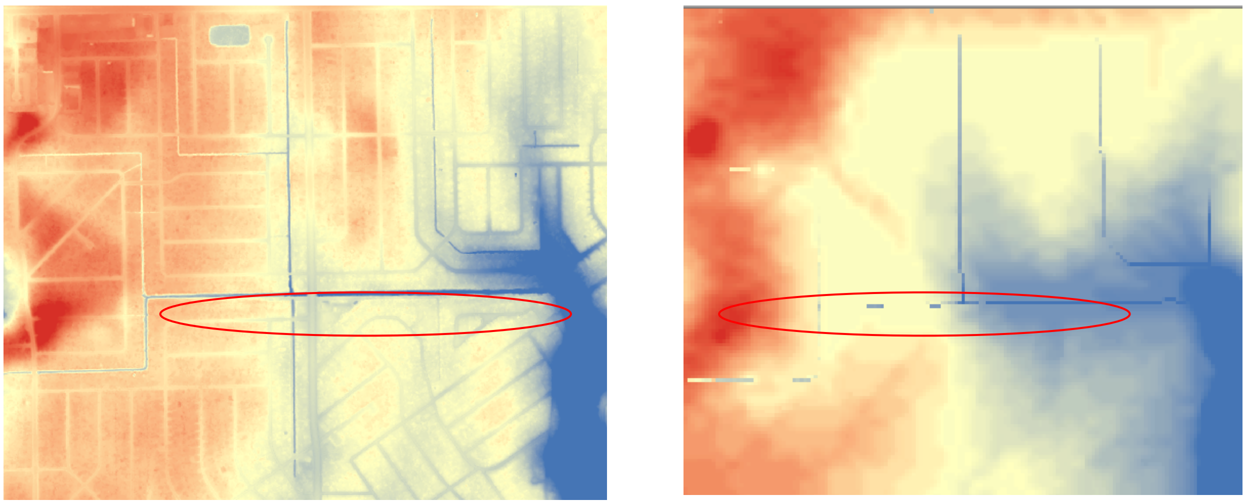


Figure 2-2 LiDAR data before (left) and after (right) re-projecting to change resolution from 5 × 5 ft^2 to 10 × 10 m^2. The ditch highlighted in the red ellipse is preserved after the re-projecting

Changing the resolution from 5 × 5 ft^2 to 10 × 10 m^2 is done using the Projections and Transformations → Data Management Tools → **project raster tool**. As shown in Figure 2-3, when using this tool, the cell size is changed to 10 and the resampling technique of nearest neighbor assignment is used. The same tool is used for re-projection in Section 4.3.2 of the user's manual, which has more details of using it.

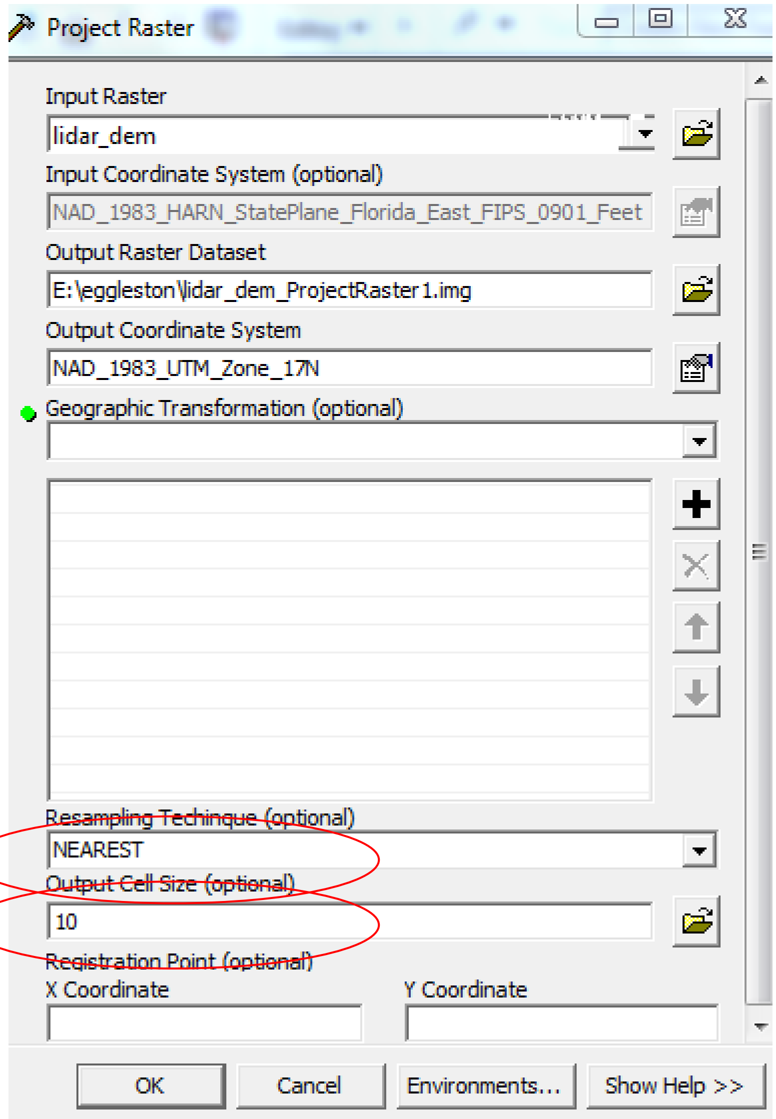


Figure 2-3 Re-projecting the LiDAR data to a coarser resolution of 10 10 × 10 m^2 (outpur cell size).

2.2 Use LiDAR DEM to Update NHD Data of Water Bodies

Generally speaking, the accuracy of the water body layer downloaded from the USGS National Hydrography Dataset (NHD) can meet the requirements of ArcNLET, and the NHD data can be used directly in ArcNLET. However, at some areas, errors in NHD data in terms of water body locations may cause inaccurate flow path generated by the Particle Tracking Module of ArcNLET. In this case, we suggest updating the NHD data using the LiDAR DEM. An example is shown in Figure 2-4. In the top-left figure, the LiDAR DEM shows a lower elevation area within the green circle, which appears to be a pond/lake in the Google map shown at the top right of Figure 2-4. However, this water body does not exist in the NHD map. Instead, only a segment of misplaced flow line (the blue line in the figure) exists in this area. Because of the mismatch between the LiDAR DEM and the NHD data, as shown in the top-left figure and the enlarged figure at the bottom of Figure 2-4, the simulated flow paths of ArcNLET cannot reach the water body shown as a flow line in Figure 2-4. The trapped flow paths are physically unreasonable and may cause error in the nitrate load estimation. Therefore, the NHD data needs to be updated so that the location and shape of the water can be accurately represented. In this manual, the update is conducted using the LiDAR DEM manually. This is done by first generating an evaluation contour map based on the LiDAR DEM using the **Spatial Analyst Tools→ Surface → Contour** tool, as shown in Figure 2-5. Based on the generated contour, one can update the water body map using the **Editor** tool of ArcGIS. The water bodies map before and after the updating are shown in Figure 2-6. After updating, the simulated flow paths of ArcNLET are more smooth and physically reasonable (shown in Figure 2-7).

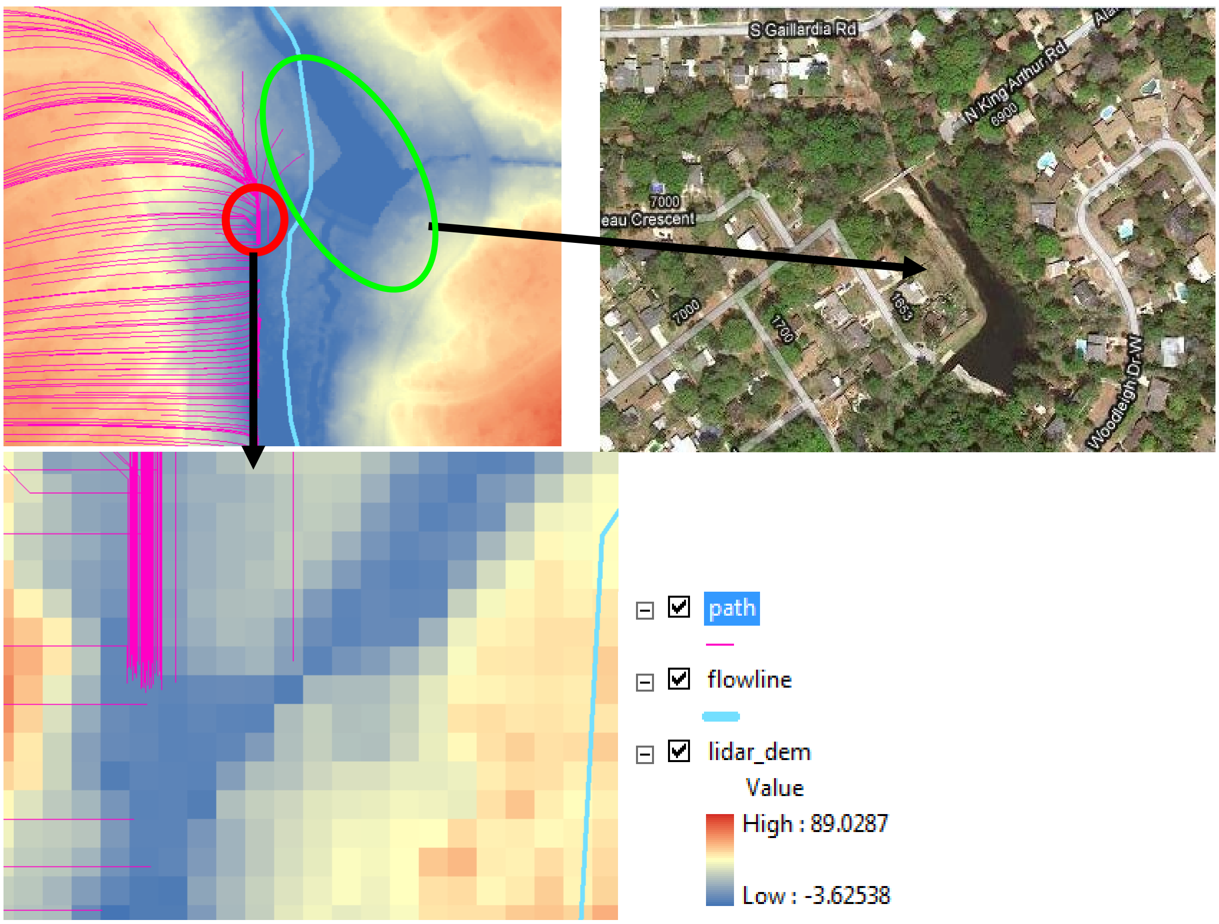


Figure 2-4 LiDAR DEM, NHD, simulated particle path and Google map at an area within Eggleston Heights neighborhood, Jacksonville, FL. In the legend, the path is the flow path calculated by the particle tracking module of the software, the flowline is from NHD data, and lidar_dem is LiDAR DEM of 5 × 5 resolution.

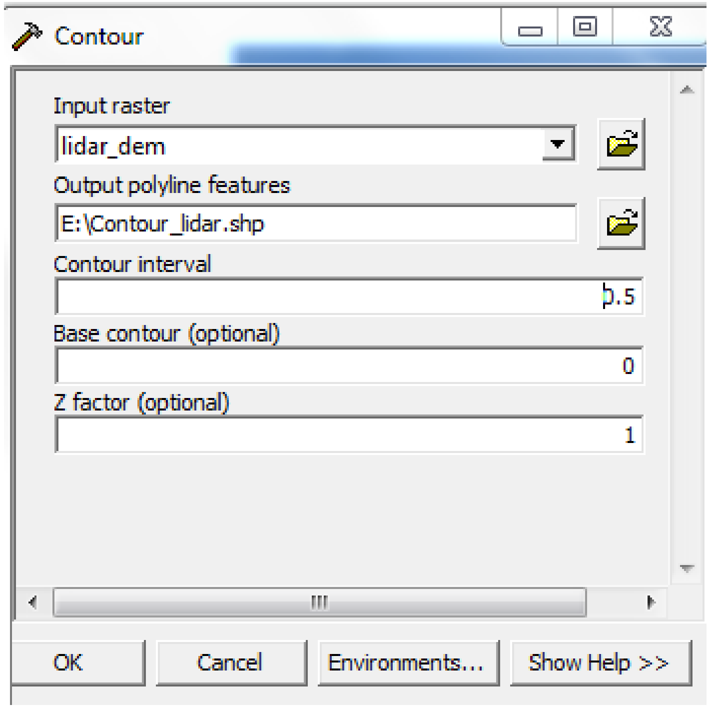


Figure 2-5 Generating elevation contour based on LiDAR DEM.

Figure 2-6 Waterbody map before (left) and after (right) updating.

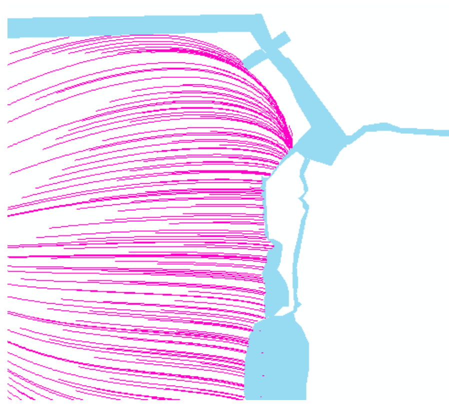


Figure 2-7 Simulated flow paths of ArcNLET after updating the waterbody polygon file

2.3 Generating Heterogeneous Hydraulic Conductivity and Soil Porosity Maps

The heterogeneous hydraulic conductivity and porosity maps are generated in three steps based on soil survey database. The first step is to download the soil database; the second is to assign the values of hydraulic conductivity and porosity contained in the database to corresponding boundary polygons of soil map units defined in the database; the last step is to convert the polygon file to a raster file.

2.3.1 Download of soil database

The hydraulic conductivity and soil porosity data can be downloaded from the Soil Survey Geographic (SSUGO) database available at http://soildatamart.nrcs.usda.gov/, the Soil Data Mart (SDM) of the Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture. Figure 2-8 shows the homepage of SDM where the soil database is downloaded. The PDF file entitled “Soil Data Mart - Purpose and Procedures” shown in Figure 2-8 explains the purpose of SDM and procedures of downloading the soil data, and is useful to new users.

The steps of downloading the data are given below for the readers’ convenience.

(1) Click the Select State button (Figure 2-8).

(2) Select the state of interest and click the Select Survey Area button (Figure 2-9).

(3) Select a soil survey area and click the Download Data button (Figure 2-10).

(4) Select desired options of data format (tabular and/or spatial data), provide your email address at the bottom of the page, and click on Submit Request button (Figure 2-11).

(5) Check your email account for URL address and instructions of downloading the zip file of requested data.

The process of data download is completed now. Documentations of the downloaded data can be found by clicking the SSURGO Metadata tag on the top of the webpage shown in Figure 2-12. These documents contain information about content, format and usage of the downloaded data.

Unzipping the downloaded zip file using WinZip (or an equivalent application) into a directory yields two text files, a XML file, a template Microsoft Access database file, and two subdirectories. The structure of the directory is described in the text file, **README.txt**. The two subdirectories are “**tabular**” and “**spatial**” containing any tabular and spatial data requested from the SSURGO database.

The soil tabular data cannot be easily used without importing it into the Microsoft Access database. The README.txt file explains the procedure of importing the tabular data. Below is a paragraph copied and slightly modified from the README.txt file for the importing:
“*When you open a SSURGO template database, the Import Form should display automatically if there are no Microsoft Access security related issues. To import the soil tabular data into the SSURGO template database, enter the location of the "tabular" directory into the blank in the Import Form. Use the fully qualified pathname to the "tabular" directory that you unzipped from your export file. For example, if your export file was named wss_aoi_2012-09-24_12-59-37.zip*

and you unzipped the file to C:\soildata\, the fully qualified pathname would be C:\soildata\wss_aoi_2012-09-24_12-59-37\tabular. The pathname between C:\soildata\ and \tabular varies by export type. It also varies for Area of Interest exports by export date and time, for SSURGO exports by the selected soil survey area, and for STATSGO2 exports by your selection of data for the entire U.S. or for a single state. After entering the fully qualified pathname, click the "OK" button. The import process will start. The duration of the import process depends on the amount of data being imported. Most imports take less than 5 minutes, and many take less than 1 minute".

Once the import process completes, the Soil Reports Form should display. More information and instructions of using the database is available by double clicking the report entitled "**How to Understand and Use this Database**" after the importing.

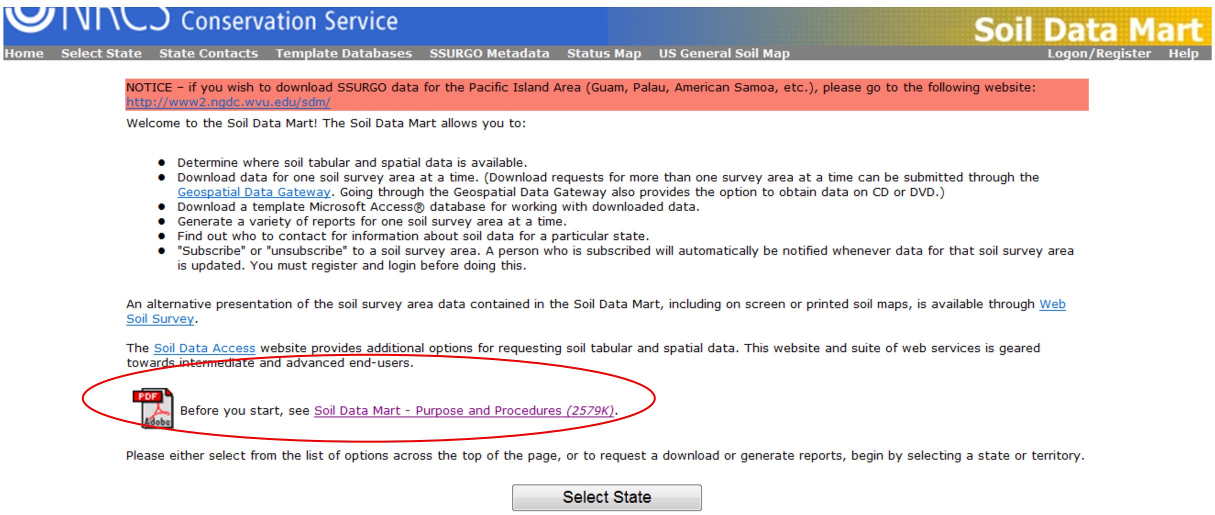
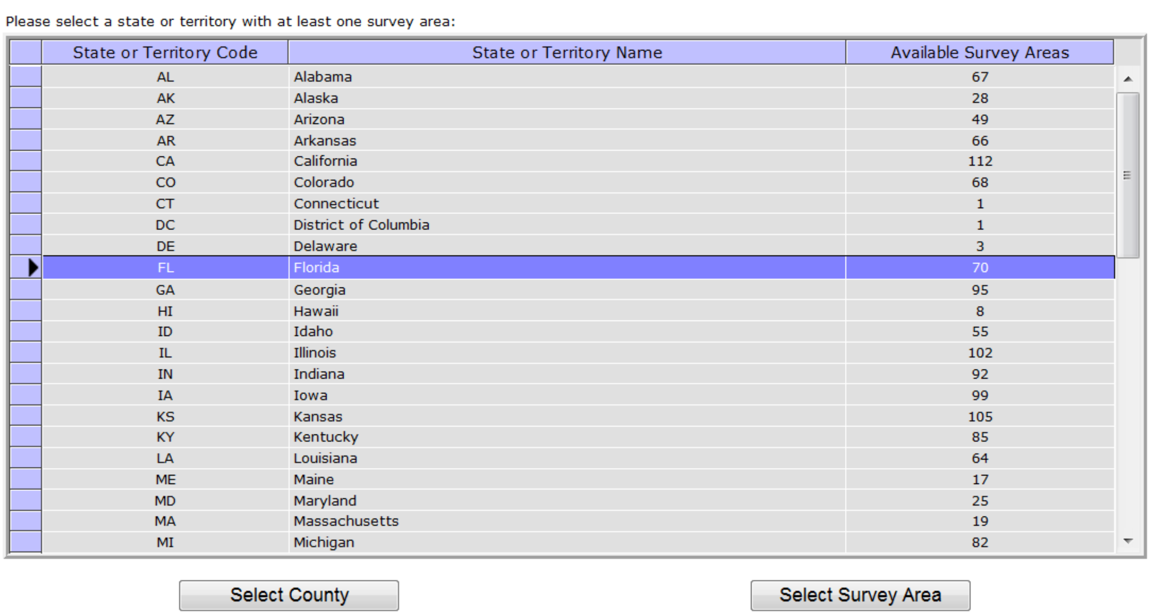
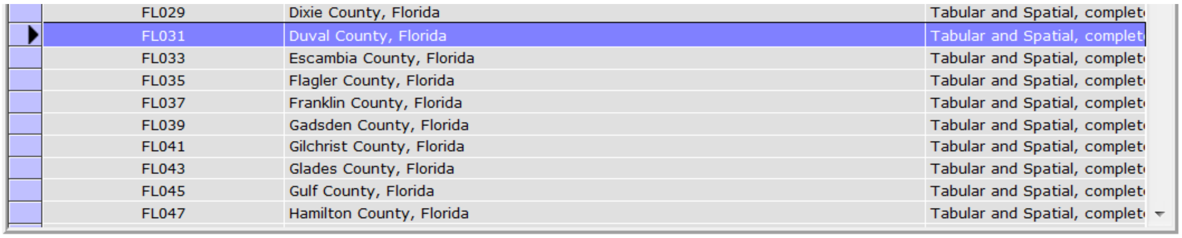


Figure 2-8 Homepage of SDM.



State or Territory Code	State or Territory Name	Available Survey Areas
AL	Alabama	67
AK	Alaska	28
AZ	Arizona	49
AR	Arkansas	66
CA	California	112
CO	Colorado	68
CT	Connecticut	1
DC	District of Columbia	1
DE	Delaware	3
FL	Florida	70
GA	Georgia	95
HI	Hawaii	8
ID	Idaho	55
IL	Illinois	102
IN	Indiana	92
IA	Iowa	99
KS	Kansas	105
KY	Kentucky	85
LA	Louisiana	64
ME	Maine	17
MD	Maryland	25
MA	Massachusetts	19
MI	Michigan	82

Figure 2-9 Select a state



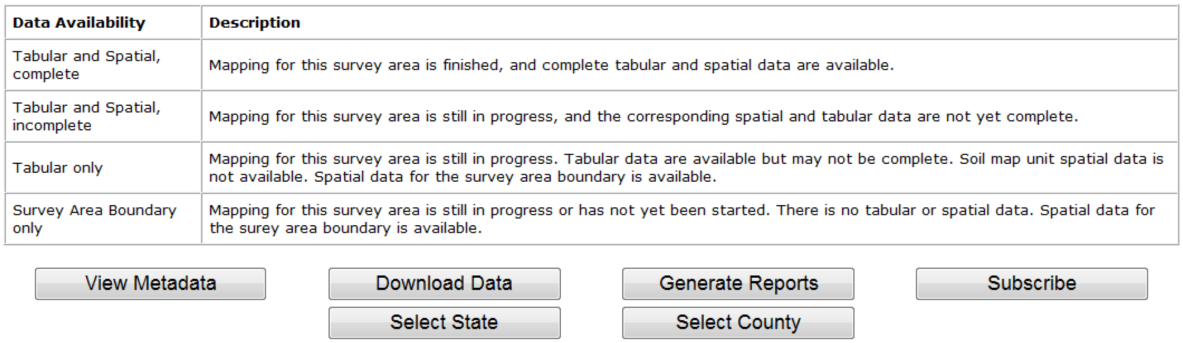


Figure 2-10 Select the interested soil survey area.

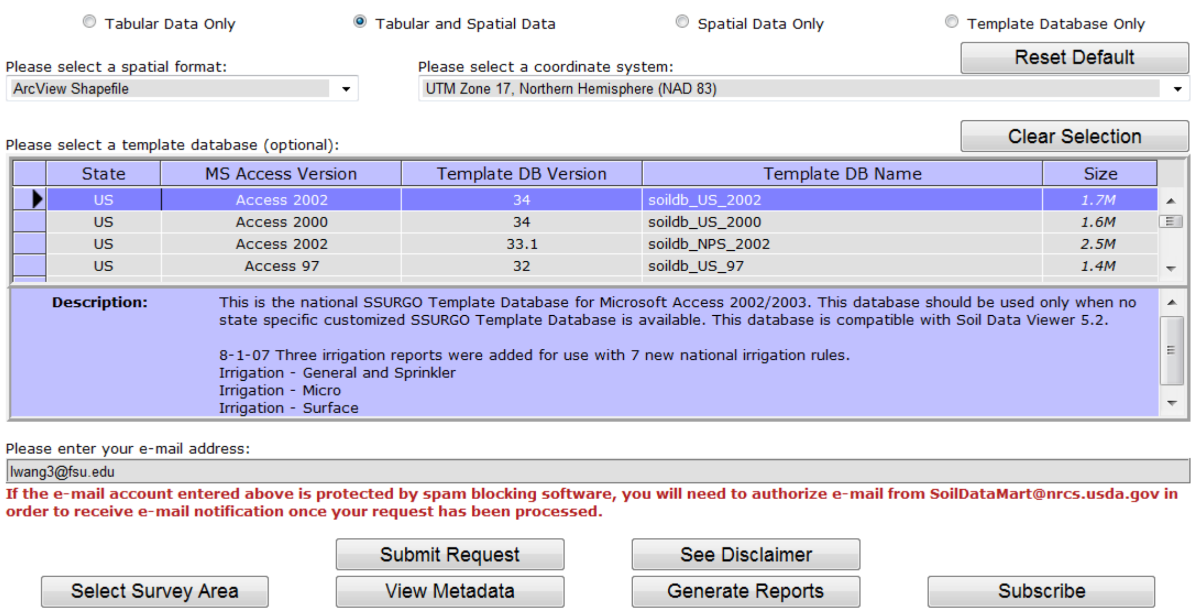


Figure 2-11 Download data page.

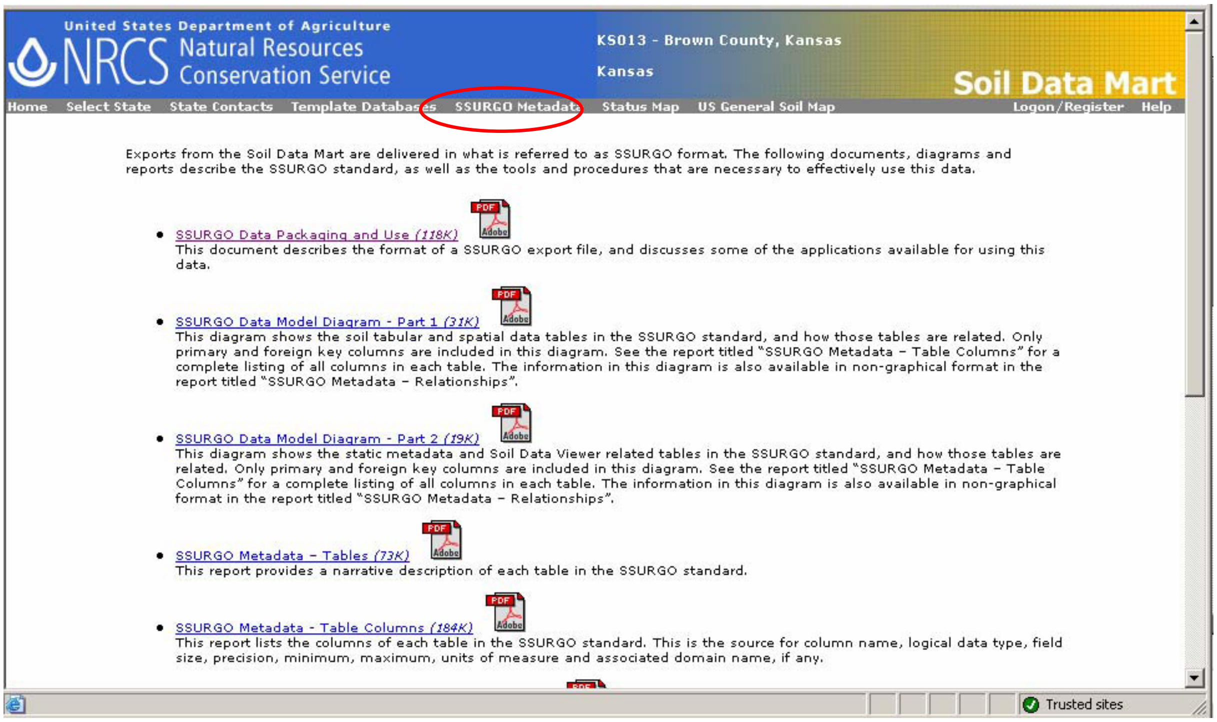


Figure 2-12 Data documents page.

2.3.2 Generation of heterogeneous polygons of hydraulic conductivity and porosity

The Access database file generated above is used in ArcGIS to generate the maps of heterogeneous hydraulic conductivity and porosity. One needs to open three files in ArcGIS: the map unit boundary polygons file "**soilmu_a_ssasymbol.shp**" from the directory "spatial" (ssasymbol being the symbol of the corresponding soil survey area), the component table file "**component**" in the Access database, and the horizon table file "**chorizon**" from the Access database. Note that the two table files should be opened from the database, not from the tabular directory directly. The table file "**component**" lists the map unit components identified in the referenced map unit and selected properties of each component. The table file "**chorizon**" lists the soil sampling horizons and related data such as hydraulic conductivity and soil porosity for the referenced map unit components. To help understand the relations between the three files, below is an excerpt from the document entitled "**SSURGO Data Package and Use.pdf**" (the first one shown in Figure 2-12):

"Map units are typically made up of one or more named soils. Other miscellaneous land types or areas of water may be included. These entities and their percent compositions make up the map unit components and define the map unit composition. Soil components are typically composed of multiple horizons (layers). Component attributes must be aggregated to a map unit level for map visualization. Horizon attributes must be aggregated to the component level, before components are aggregated to the map unit level."

This paragraph indicates that, to generate heterogeneous maps of hydraulic conductivity and porosity, one needs to start from horizon attributes, aggregate them to the component level, and then aggregate components to the map unit level.

The first step is to locate the values of hydraulic conductivity and soil porosity from the horizon attributes. The low, representative, and high values of hydraulic conductivity (in the unit of μm/s) are listed in three columns "**ksat_l**", "**ksat_r**" and "**ksat_h**" in the horizon table file "**chorizon**". While the representative values are recommended for use in modeling, the low and high values of hydraulic conductivity provide a reference of parameter ranges for model calibration. The three values of hydraulic conductivity are available for most of the soil horizons. Since the unit of hydraulic conductivity is μm/s, it needs be converted to m/d so that the values of hydraulic conductivity can be used directly in ArcNLET. This can be done by using the Access update query function, and the details of the operation can be found at http://office.microsoft.com/en-us/access-help/change-existing-data-by-using-an-update-query-HP005188088.aspx, accessible as of 1/11/2014.

The table also includes columns "**wsatiated_l**", "**wsatiated_r**" and "**wsatiated_h**" for the low, representative, and high values of porosity. Sometime, only the representative values of porosity are available. For some datasets, the three columns of porosity are empty and filled with the string <Null>. In this situation, porosity can be evaluated as $1 - (D_B/D_P)$, where D_B and D_p are bulk density and particle density, respectively. The representative, low, and high values of bulk density (in the unit of gcm^{-3}) can be found in columns "**dbovendry_r**", "**dbovendry_l**", and "**dbovendry_h**" in the "chorizon" table. However, it happens sometimes that column "**dbovendry_r**" is complete but columns "**dbovendry_l**", and "**dbovendry_h**" are incomplete. The particle density values can be found in column "**partdensity**". If the column is filled with string <Null>, it is reasonable to use the value of 2.65 g/cm^3, commonly used in soil physics. The calculation of porosity needs to be performed within the Microsoft Access database by using the update query function. The low and high values of porosity should be calculated via formulae [wsatiated_l]=1-[dbovendry_h]/[partdensity] and [wsatiated_h]=1-[dbovendry_l]/[partdensity], respectively.

The aggregation from horizons to components and finally to units can be done either in ArcGIS manually or in Access automatically (although not fully). We here give the ArcGIS- and Access-bases procedures in parallel below.

The next step is to aggregate the values of hydraulic conductivity and porosity (horizontal attributes) to the component level. Since this manual considers nitrate transport in groundwater (not in vadose zone), only the values for the deepest horizon are extracted for the aggregation. Representative horizon depth can be determined from the two columns "**hzdept_r**" and "**hzdepb_r**" in the horizon table file "**chorizon**". The former column contains the distance from land surface to the upper boundary of the soil horizon, and the latter to the base of the horizon. The aggregation needs the column "**cokey**" in the horizon table file, which is a non-connotative string of characters used to uniquely identify a record in the component table file. After the hydraulic conductivity and soil porosity values of the deepest horizon of every component are extracted, the "**cokey**" column is used to join the extracted table to the component table. The manual procedure of aggregating the hydraulic conductivity and soil porosity from the horizon level to the component level within ArcGIS is as follows:

(1) Open the horizon table in ArcMap.

(2) Select records of the deepest horizon for all the components using the "**hzdept_r**" and "**hzdepb_r**" fields.

(3) Use the "**cokey**" field to identify every component and ensure that only one horizon is selected for a specific component.

(4) Export the selected records to a new table (Figure 2-13) and name it as "**agg_horizon**" (or any name of the user's preference) as shown in and Figure 2-14.

In this way, the horizon values are aggregated to the component level within ArcGIS.

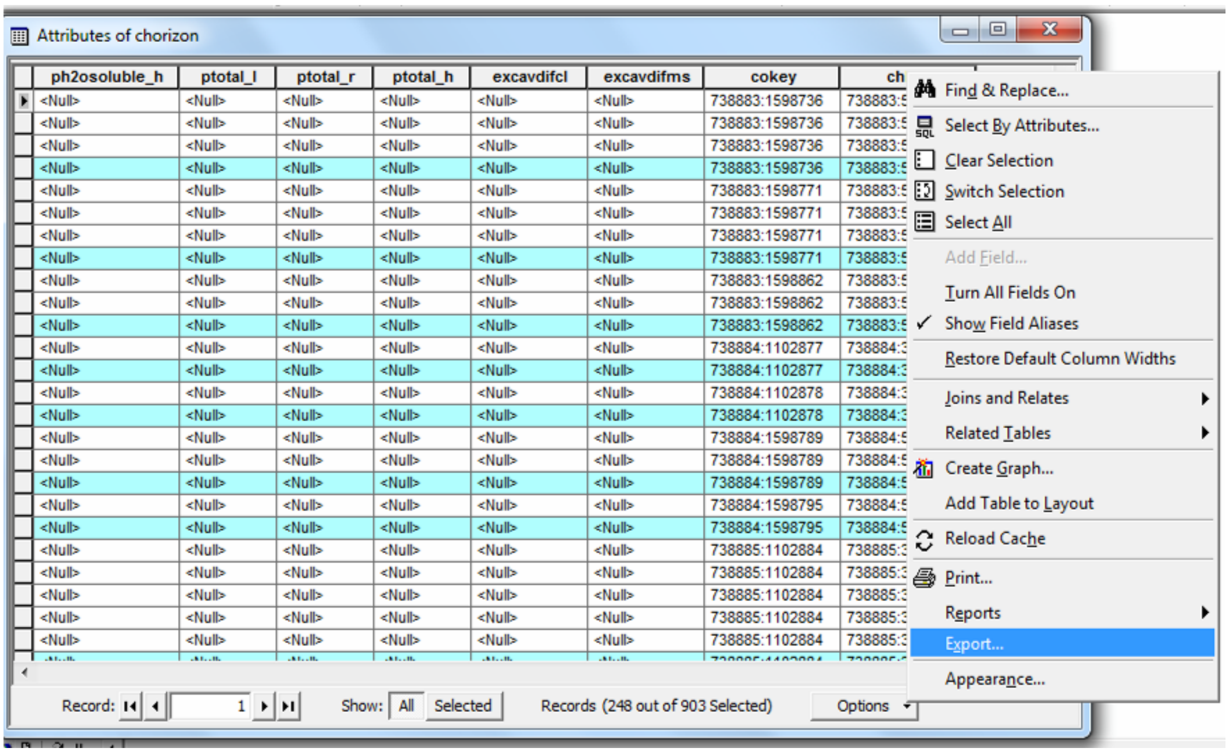


Figure 2-13 Export selected records.

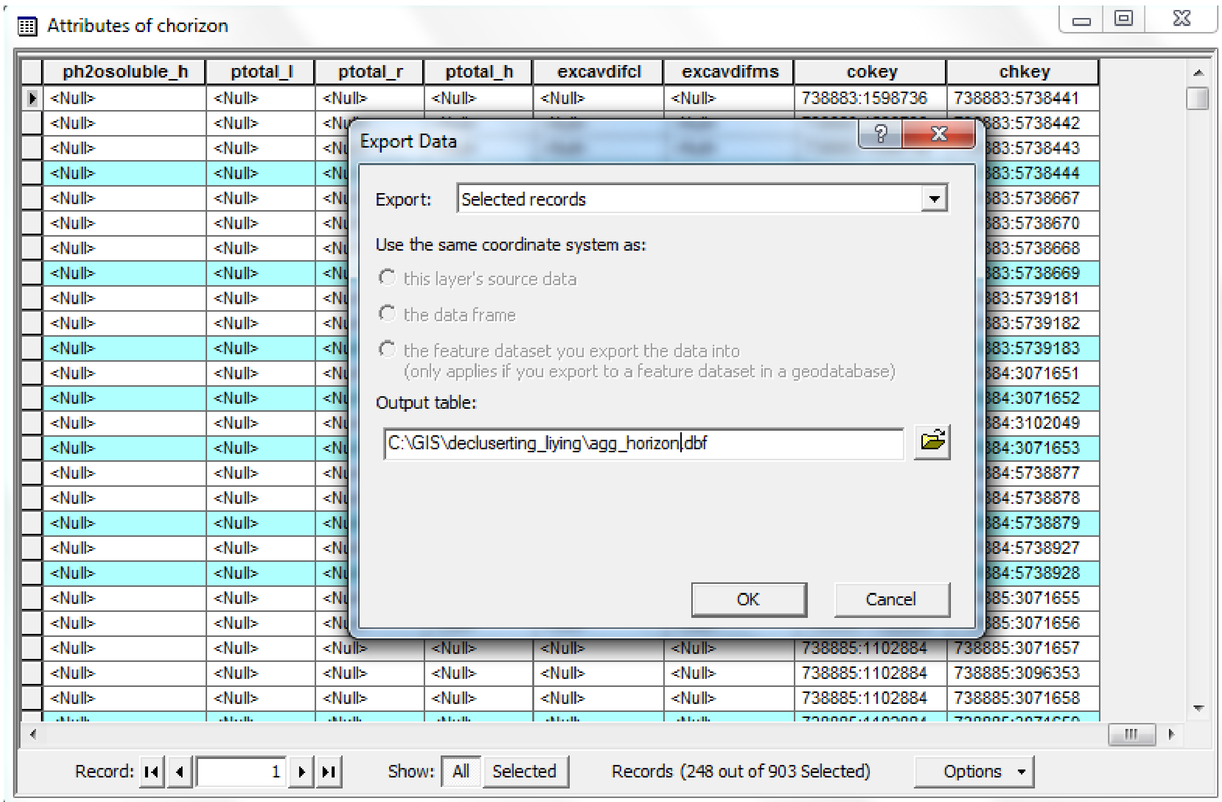


Figure 2-14 Export selected records to a new table.

The manual procedure above can be automated using the query function of Microsoft Access as described below:

(1) Open the SSURGO database in Access.

(2) Query for the fields of "**cokey**" and "**hzdepb_r**", and identify the "**hzdepb_r**" values for each component (i.e., "cokey"). Ensure that the identified values are unique. While this step may sound tedious, it only take couple minutes for a dataset of a county, because the number of components in not large. A more sophisticated query operation (e.g., using pivot table) may make this step more automatic.

(3) Use the identified "**hzdepb_r**" values as criteria to query for the fields of "**cokey**", "**hzdepb_r**", "**ksat_r**", and "**wsatiated_r**".

(4) Save the query as "**horizonQ**" and table as "**agg_horizon**" in Access (the user can choose any names; we use the same name of the ArcGIS operation to keep consistent). More details of generating the table can be found at http://office.microsoft.com/en-us/access-help/save-the-results-of-a-select-query-HA010205133.aspx, accessed as of 1/11/2014. The "**agg_horizon**" table can be opened in ArcGIS and manipulated as described below.

(5) Examine table "**agg_horizon**" to ensure that there is only one "**hzdepb_r**" value for each cokey. Redundant "**hzdepb_r**" values for a cokey may exist because the component may have multiple "**hzdepb_r**" values specified in step (3). For example, if a component 8164501 (an arbitrary number) has two horizons whose bottom depths are 198cm and 300cm, respectively, and the two depths are also specified in step (3), then the two records with the same cokeys appear in agg_horizon. For multiple records with the same cokeys, only keep the record with the largest "**hzdepb_r**" value.

In this way, the horizon values are aggregated to the component level within Access.

Within ArcGIS, we add the “**agg_horizon**” table to ArcMap, and append it to the component table through the field “**cokey**” using the table join function, as shown in Figure 2-15. Then export all the records in component table, including the appended attribute, to a new table (“**component_user**” in this manual) for editing. Now the component level data need to be aggregated to the map unit level. As described before, “map units are typically made up of one or more named soils … these entities and their percent compositions make up the map unit components and define the map unit composition”. The field “**majcompflag**” in the component table indicates whether a component is a major component in the map unit. In this manual, for the map unit that has only one major component with the largest percent composition, the hydraulic conductivity and porosity of the major component are used for the map unit. If there are more than one major component, the hydraulic conductivity and porosity values are averaged over all the major components in the map unit. The averaging weights are normalized from the percent composition (given in the field “**comppct_r**”) of the major components. The weighted averages can be calculated using EXCEL manually, and the procedure is given below. The procedure of aggregating the hydraulic conductivity and porosity from the component to the map unit level within ArcGIS is summarized as follows:

(1) Select all the records whose “**majcompflag**” field is “yes” in “**component_user**”, and export the selected records to a new table (“**agg_component**” in this manual) using the same procedure shown in Figure 2-13 and Figure 2-14.

(2) Aggregate the hydraulic conductivity and porosity for the records that have the same “**mukey**” field values in **agg_component** table, where **“mukey**”, similar to “**cokey**” is a non-connotative string of characters used to uniquely identify a record in the mapunit Table.

(3) Join the modified **agg_compoment** table to the attribute table of mapunit polygon file “**soilmu_a_ssasymol**” based on the field “**mukey**” using the same procedure shown in Figure 2-15. After this, the hydraulic conductivity and soil porosity are aggregated from the component to the map unit level.

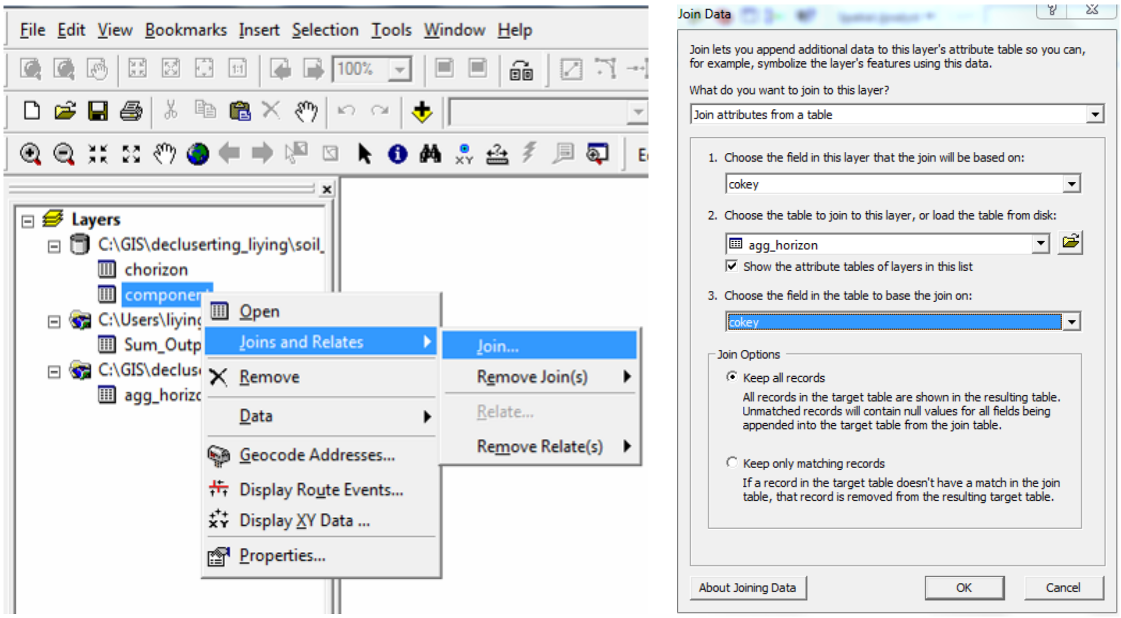


Figure 2-15 Append the agg_horizon table to the component table.

Within Access, the procedure of joining tables “**component**” and “**agg_horizon**” to generate table “**component_user**” can be done in the following procedure:

(1) Click “Query Design” in “Create” ribbon.

(2) Choose tables “agg_horizon” and “component”. The two tables are linked automatically via the field “**cokey**”. If this is not done automatically, one can do this manually by dragging “**cokey**” in one table and drop it in another table.

(3) Select for the query fields “**ksat_r**” and “**wsatiated_r**” in table “**agg_horizon**” and fields “**mukey**”, “**majcompfalg**”, “**comppct_r**”, and “**cokey**” in table “**component**”. The “**cokey**” field is selected to ensure that unique records (with unique cokeys) are selected.

(4) Use the filtering criterion “=Yes” for field “**majcompfalg**” so that only hydraulic conductivity and porosity of the major components of a unit are used for calculating the weighted averages. This is to avoid extremely large values of no-major components.

(5) Use the Sorting function for “**mukey**”. This is optional, just for the convenience of examining the data of the same unit. It happens often that an individual unit has only one major component.

(6) Save the query as “**componentQ**” and the resulting table as “**component_user**”.

With the “**component_user**” table generated above, we use the Access pivot table to aggregate hydraulic conductivity and porosity from the components to units:

(1) Select “**component_user**” table and then click “pivot table” in “more forms manual” of the “Create” ribbon.

(2) Drag first “**mukey**” to the row fields and then “**comppct_r**”, “**ksat_r**”, and “**wsatiated_r**” to data fields of the pivot table.

(3) Click “Formulas” and choose “Create Calculated Detail Field”.

(4) Create new field “**weighted_ksat**” using the formula “[ksat_r]*[comppct_r]” and new field “**weighted_por**” using the formula “[wsatiated_r]*[comppct_r]”.

(5) Calculate sum of all the fields.

(6) Save the pivot table to "**agg_component**" as a form.

At last, choose the option of "Hide details" of the "mukey" field, and copy the form to EXCEL to evaluate the weighted average. For example, weighted average of ksat is the sum of weighted_ksat divided by the sum of weighted comppct_r. The EXCEL file is just a temporary file that does not need to be saved. The next step is to create the "**agg_component**" table in the following steps:

(1) Create a new table and save it as "**agg_component**".

(2) Design the table using the information (e.g., data type) in table "**component_user**" for "**mukey**", "**ksat_r**", and "**wsatiated_r**" fields.

(3) Copy from the temporary EXCEL file above the columns of "**mukey**", "**ksat_r**", and "**wsatiated_r**".

The "**agg_component**" table can be imported into ArgGIS and joined with "**soilmu_a_ssasymol**", as described above. Note that the joined attribute table needs to be saved before converting the polygon to raster in Section 2.3.3 below.

Other options of aggregating the data to the map unit level are given in the data document available at http://soildatamart.nrcs.usda.gov/documents/SSURGODataPackagingandUse.pdf. After the aggregation, deleting unwanted fields and exporting "**soilmu_a_ssasymbol**" to a new shapefile (called "**parameter_polygon**" in this manual) leads directly to the heterogeneous polygon files of hydraulic conductivity and porosity. These polygon files can be visualized and modified in ArcMap. Figure 2-16 shows the hydraulic conductivity map generated for the Duval County, FL.

Note that the hydraulic conductivity and porosity fields of some map units are empty (the map units may have miscellaneous areas, such as water body and urban land). In this case, the hydraulic conductivity and porosity values of these map units need to be added manually before the conversion; otherwise errors may be caused when running ArcNLET. One may use the values of a neighbor map unit. Note that the unit for the hydraulic conductivity is *μm/s* in the downloaded database.

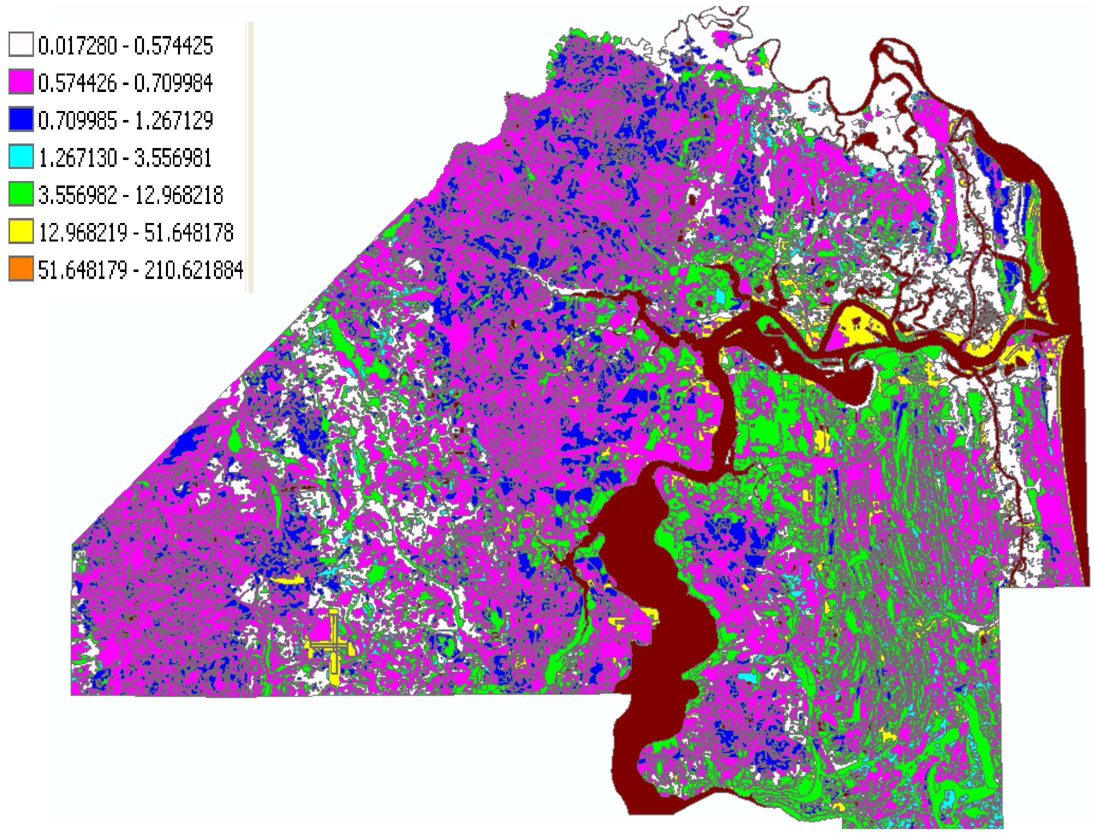


Figure 2-16 Heterogeneous hydraulic conductivity map based on soil map unit for the Duval County, FL.

2.3.3 Conversion of polygon into raster files

The polygon file needs to be converted to a raster file for use in ArcNLET. This can be done using the "polygon to raster" function of ArcGIS, as shown in Figure 2-17. The generating of soil porosity raster file follows exactly the same way except for using "**wsatiated_r**" as **value field** (shown in Figure 2-17) instead of "**ksat_r**".

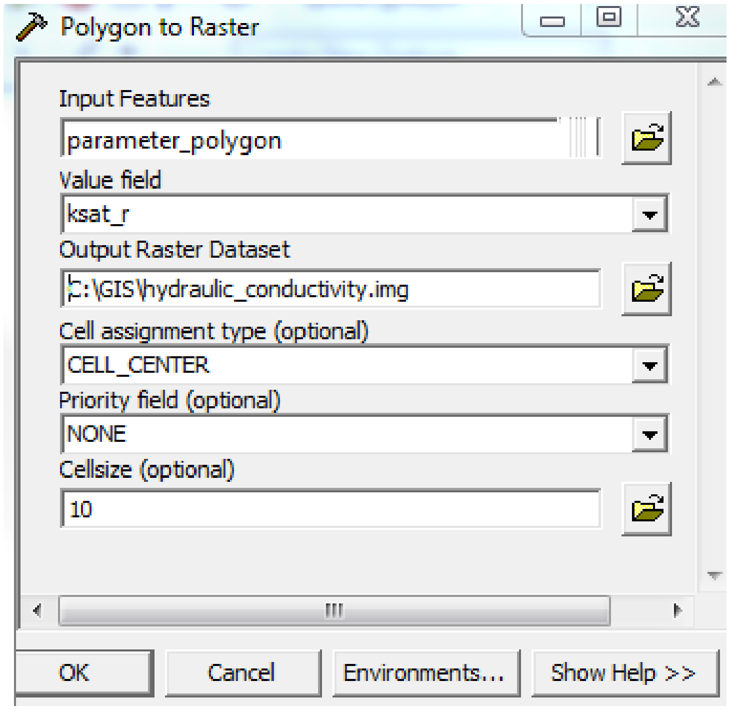


Figure 2-17 Convert polygon to raster file.

3 SENSITIVITY ANALYSES

As explained in the technical manual (Rios et al., 2011), the nitrate concentration is evaluated in ArcNLET using the two-dimensional, steady-state version of the solution of Domenico (1987) for the advection-dispersion equation. It is

$$
\begin{aligned}
&C(x,y) = \frac{C_0}{2} F_1(x) F_2(y,x) \\
&F_1 = \exp\left[\frac{x}{2\alpha_x}\left(1-\sqrt{1+\frac{4k\alpha_x}{v}}\right)\right] \qquad (3\text{-}1) \\
&F_2 = erf\left(\frac{y+Y/2}{2\sqrt{\alpha_y x}}\right) - erf\left(\frac{y-Y/2}{2\sqrt{\alpha_y x}}\right)
\end{aligned}
$$

where C [ML^{-3}] is simulated nitrate concentration at location (x,y), α_x [L] is longitudinal dispersivity, α_y [L] is horizontal transverse dispersivity, [L]; k [T^{-1}]is the first order decay coefficient, v [LT^{-1}] is groundwater seepage velocity in the longitudinal direction, Y [L] is the width of the source plane respectively, and C_0 [ML^{-3}] is the nitrate concentration at the source plane. The seepage velocity is evaluated in the groundwater flow model that uses hydraulic conductivity, porosity, and a smoothing factor used to process DEM for obtaining the shape of water table. As a summary, ArcNLET has a total of seven parameters: the smoothing factor, hydraulic conductivity, porosity, longitudinal dispersivity, horizontal transverse dispersivity, first-order decay coefficient, and source nitrate concentration. Both local and global sensitivity analyses are performed to identify the parameters most critical to the simulated nitrate concentration. The local sensitivity reveals the relationships between the simulated nitrate concentration and individual parameters. The global sensitivity is more robust since it considers interactions between the parameters and nonlinearity of the concentration with respect to the parameters. For simplicity, the sensitivity to the smoothing factor, hydraulic conductivity and porosity is not evaluated. Instead, the sensitivity to seepage velocity is calculated as a surrogate.

3.1 Local Sensitivity

The local sensitivity is the derivative of the nitrate concentration to an individual parameter calculated for certain nominal parameter values. In this study, the nominal parameter values and their sources are as follows:

(1) Seepage velocity: v = 0.2 m/d. This is the representative value of the domains of interest.

(2) Source plane concentration: C_0 = 40 mg/L. This value is from a review article of McCray et al. (2005).

(3) First-order decay coefficient: k = 0.008/day. This value is from a review article of McCray et al. (2005).

(4) Longitudinal dispersivity: α_x = 2.113 m. This value is from the work of Davis (2000) at a vicinity site in Jacksonville, FL.

(5) Horizontal transverse dispersivity: α_x = 0.234 m. This value is from the work of Davis (2000) at a vicinity site in Jacksonville, FL.

(6) Source plane length: Y = 6m. This value is a normal length of the drain field of a septic system.

(7) X coordinate: X = 30m. This is an arbitrary value selected for the demonstration.

By virtue of the analytical solution (3-1), analytical expressions of the local sensitivity can be easily derived. The local sensitivity to the source plane nitrate concentration is

$$\frac{\partial C}{\partial C_0} = \frac{F_1 F_2}{2} > 0. \tag{3-2}$$

It suggests that there is a positive linear relationship between the simulated nitrate concentrations with the source plane nitrate concentration. This is illustrated in Figure 3-1 for two y values the nominal parameters values listed above. The equation and figure shows that increase of the source plane nitrate concentration will increase the simulated concentration within the plume. The increase us larger at locations closer to the plume center line (y=0m).

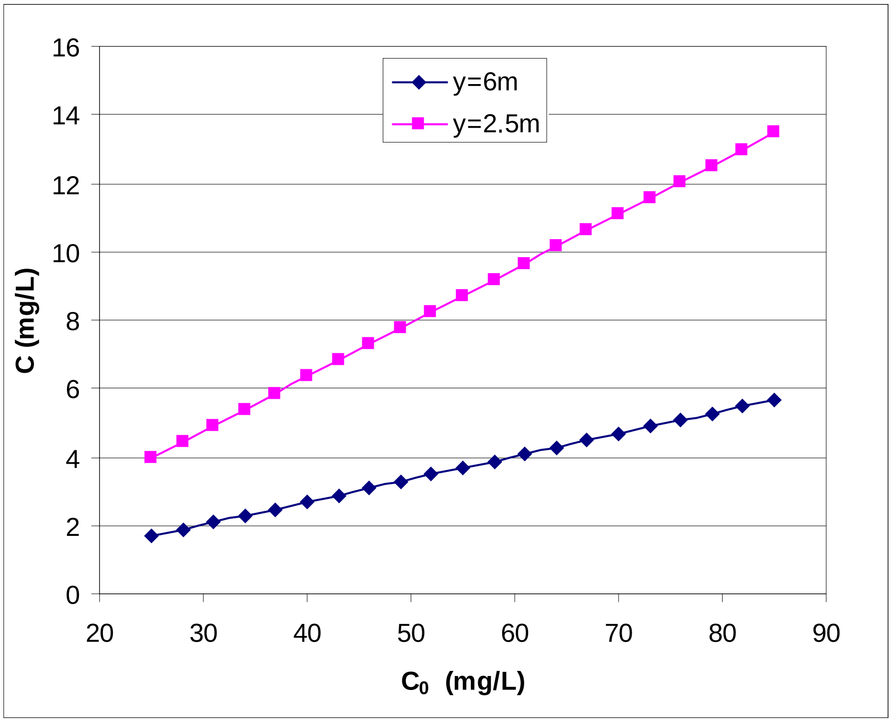


Figure 3-1 Relationship between source plane nitrate concentration and simulated nitrate concentration at two locations of *y* for illustration.

The local sensitivity to the first-order decay coefficient is

$$\frac{\partial C}{\partial k} = \frac{C_0}{2} F_1 F_2 \frac{-x}{v\sqrt{1+\frac{4k\alpha_x}{v}}} < 0 \,. \tag{3-3}$$

It suggests a negative relationship with the simulated concentration, as demonstrated in Figure 3-2. In other words, increase of the first-order decay coefficient will result in decrease of the simulated concentration within the plume. The decrease is more rapid at locations closer to the plume center line (y=0m).

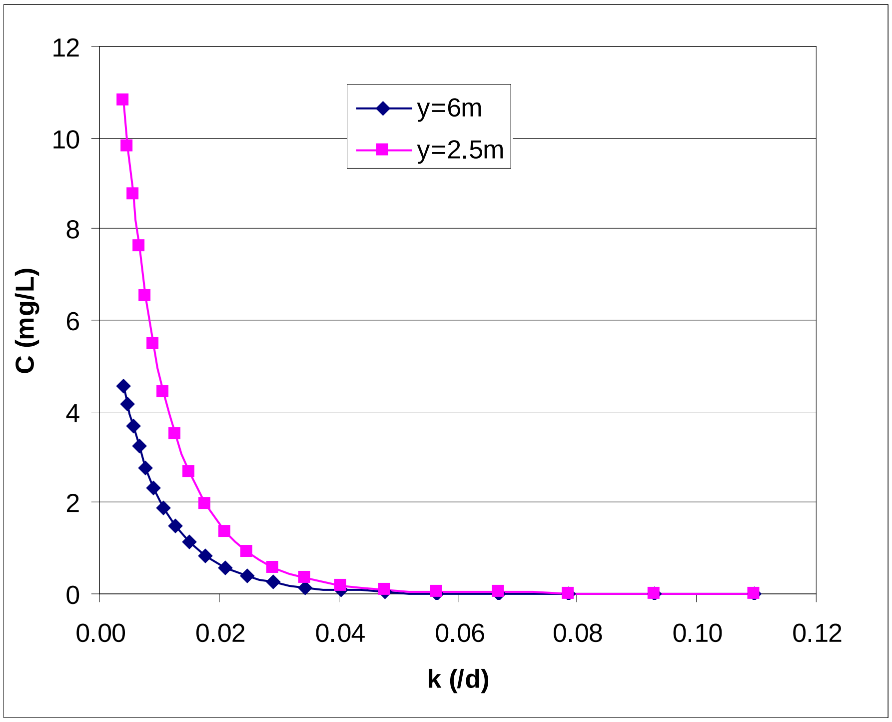


Figure 3-2 Relationship between first-order decay coefficient and simulated nitrate concentration at two locations of *y* for illustration.

The analytical expressions of sensitivity to the seepage velocity

$$\frac{\partial C}{\partial v} = \frac{C_0}{2} F_1 F_2 \frac{kx}{v^2\sqrt{1+\frac{4k\alpha_x}{v}}} > 0 \tag{3-4}$$

suggests a positive relationship with the simulated concentration. Figure 3-3 shows that increase of the velocity is associated with increase the simulated concentration within the plume. The increase is more rapid at location closer to the plume center line (y=0m).

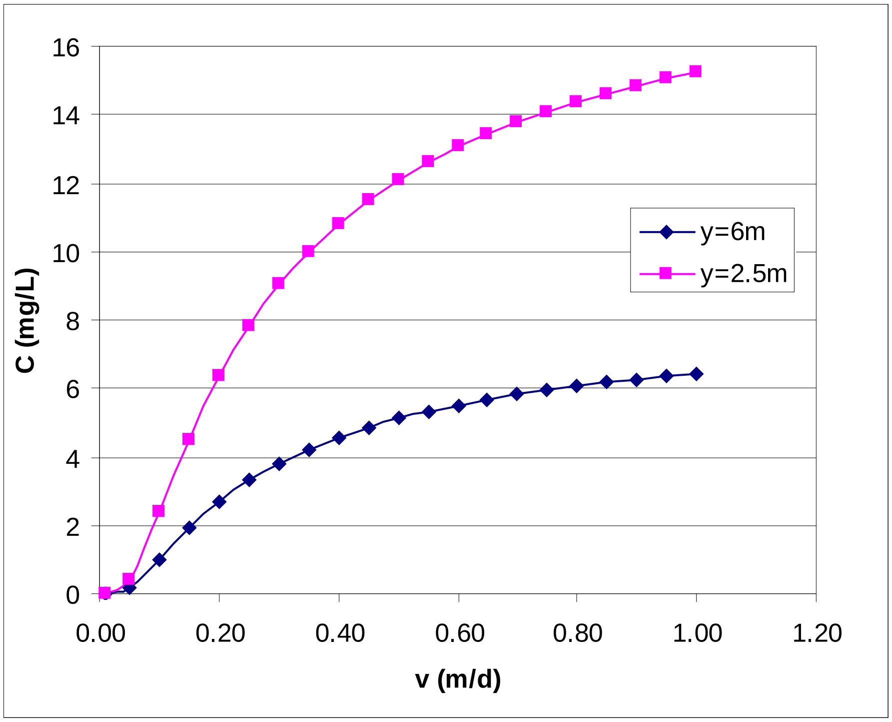


Figure 3-3 Relationship between average flow velocity and simulated nitrate concentration at two locations of *y* for illustration.

The analytical expression of sensitivity to the longitudinal dispersivity

$$\frac{\partial C}{\partial \alpha_x} = \frac{C_0}{2} F_2 F_1 \frac{2xk^2}{v^2 \sqrt{1+\frac{4k\alpha_x}{v}}\left(\frac{2k\alpha_x}{v} + 1 + \sqrt{1+\frac{4k\alpha_x}{v}}\right)} > 0 \qquad (3\text{-}5)$$

indicates that increasing the longitudinal dispersivity causes increase of the simulated concentration within the plume. Figure 3-4 shows that the increase is more rapid at locations closer to the plume center line (y=0m).

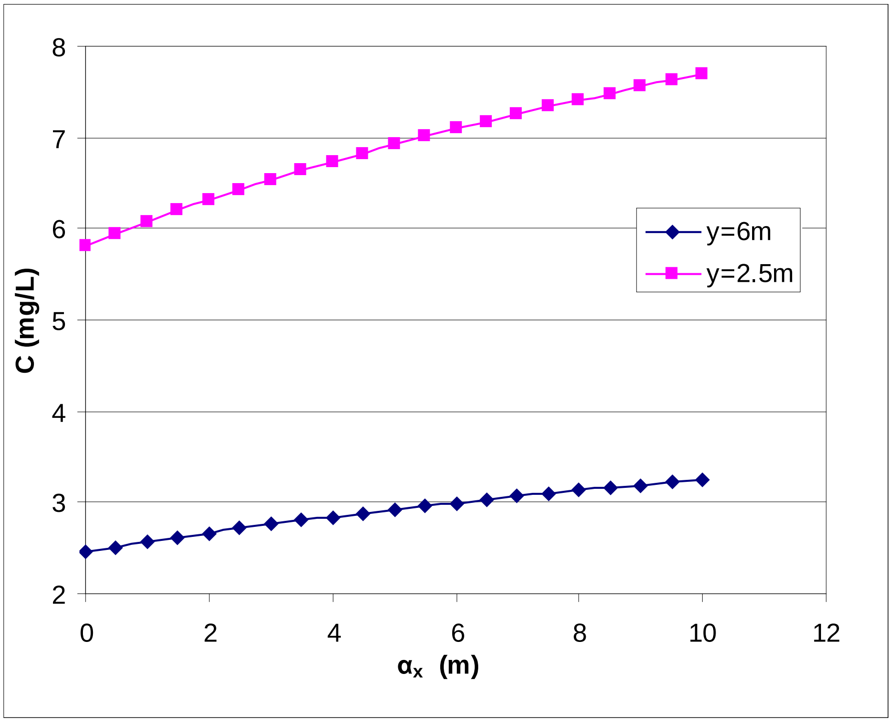


Figure 3-4 Relationship between longitudinal dispersivity and simulated nitrate concentration at two locations of *y* for illustration.

The sensitivity to the horizontal transverse dispersivity is more complicated. The analytical expression

$$\frac{\partial C}{\partial \alpha_y} = \frac{C_0}{2} F_1 \frac{1}{2\sqrt{\pi x}} \alpha_y^{-(\frac{3}{2})} \exp\left(-\frac{y^2 + 0.25Y^2}{4\alpha_y x}\right)$$
$$\times \left[(y - 0.5Y)\exp\left(\frac{0.5yY}{2\alpha_y x}\right) - (y + 0.5Y)\exp\left(-\frac{0.5yY}{2\alpha_y x}\right) \right]$$
$$= \begin{cases} \geq 0 & \alpha_y \leq \dfrac{0.5Yy}{x\ln\left(\dfrac{y+0.5Y}{y-0.5Y}\right)}, y > 0.5Y \\ \leq 0 & \alpha_y \geq \dfrac{0.5Yy}{x\ln\left(\dfrac{y+0.5Y}{y-0.5Y}\right)}, y > 0.5Y \\ < 0 & 0 \leq y \leq 0.5Y \end{cases} \qquad (3\text{-}6)$$

shows that the relationship between the simulated nitrate concentration and the parameter depends on the length of the source plane (Y) and the location (x and y) in the plume. In addition, there is a threshold value, $0.5Yy \Big/ x \ln\left(\dfrac{y+0.5Y}{y-0.5Y}\right)$. When the horizontal transverse dispersivity is smaller than the threshold value, the relationship is positive, but becomes negative of the threshold value is exceeded. This is demonstrated in Figure 3-5 for two different locations.

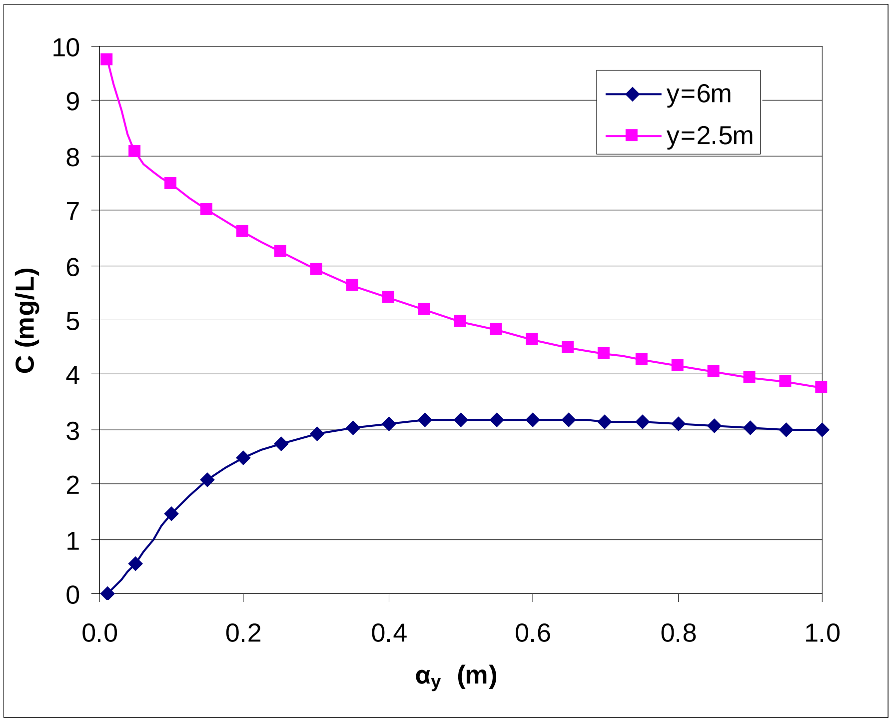


Figure 3-5 Relationship between horizontal transverse dispersivity and simulated nitrate concentration at two locations of *y* for illustration.

As a summary, the local sensitivity analyses indicate that the simulated concentration is an increasing function of the source plane concentration, flow velocity, and longitude dispersivity, but a decreasing function of the decay coefficient. The relationship with the horizontal transverse dispersivity depends on the parameter value and the locations where concentration is evaluated. These results are physically reasonable. For example, a large value of the decay coefficient means more denitrification and thus small values of simulated concentration. The relationships serve as guidelines for adjusting model parameters to match field observations of nitrate concentration during the model calibration by trial and error.

3.2 Global Sensitivity

The local sensitivity has two drawbacks. First, it only addresses individual parameters and does not consider joint effects of multiple parameters on model simulations. In addition, it is limited to the first-order derivative and cannot reflect nonlinear effects of model parameters on model simulations. To resolve these problems, the global sensitivity method of Morris (Morris 1991) is used. The method is briefly described here, and more details are referred to Morris (1991) and Saltelli et al. (2004). It is a screening method to determine the factors (e.g., model parameters) that have significant effect on model outputs (e.g., nitrate concentration). The method is based on the elementary effect calculated for the *i*-th model input as

$$d_i(\mathbf{P}) = \frac{f(P_1, ..., P_{i-1}, P_i + \Delta, P_{i+1}, ..., P_k) - f(\mathbf{P})}{\Delta} \tag{3-7}$$

where $\mathbf{P}=\{P_1, \ldots, P_k\}$ are model inputs, f is model output, and Δ is predetermined multiplier of the *i*-th model input. After r Morris runs (r = 10,000 in this study), the absolute mean effect μ_i and standard deviation σ_i are calculated for P_i. The mean effect, μ_i, measures the influence of parameter P_i on the model output; a high mean value indicates large overall influence. A high standard, σ_i, suggests that the parameter is either interacting with other parameters or has a high nonlinear effect on the output (Morris 1991).

The Morris analysis is conducted using software DAKOTA (Adams et al. 2009), and ranges of model parameters needed for the global sensitivity analysis are listed in Table 3-1. The range of the flow velocity is determined from the simulated values in the areas of interest described in the next section. For the longitudinal dispersivity, a calibration for modeling fate and transport of chlorinated organic compounds at a vicinity site (U.S. Naval Air Station in Jacksonville) yielded a value of 2.1 m (Davis 2000). Since the longitudinal dispersivity typically ranges over 2-3 orders of magnitude (Gelhar et al. 1992), the range of 0.21m ~ 21.0 m is used. Since the horizontal transverse dispersivity is approximately one order of magnitude smaller than the longitudinal dispersivity, the range of 0.021-2.1 m is used. The value of the first-order decay coefficient and source nitrate concentration is based on the ranges provided by McCray et al. (2005).

Flow velocity, v (m/d)	0.01-0.50
Longitudinal dispersivity, α_x (m)	0.21-21.0
Horizontal transverse dispersivity, α_y (m)	0.021-2.1
First-order decay coefficient, k, (1/d)	0.004-2.270
Source plane concentration, C_0, (mg/l)	25-80

Table 3-1 Range of parameter values used in Morris analysis

As the global sensitivity varies in space, the global sensitivity is conducted at 72 selected location distributed in the domain used for the sensitivity analysis. At each location, the two most critical parameters are selected based on the mean and variance of the elementary effect of the parameters. Figure 3-6,plots the mean and variance for all the parameters at location x = 10m and y = 1.0m as an example. The first-order decay coefficient and flow velocity are determined to be most critical; Table 3-2 lists the selected parameters at the 72 locations. It suggests that the simulated concentration is most sensitive to source plane concentration and flow velocity at locations close to the source; at locations with certain distance to the source plane but close to flow path, the two most critical parameters are the first-order decay coefficient and flow velocity; when the location is relatively far away from the flow path, the two most critical parameters are the horizontal transverse dispersivity and the first-order decay coefficient. The sensitivity to flow velocity is equivalent to the sensitivity to hydraulic conductivity and porosity, mainly to hydraulic conductivity. These physically meaningful results provide better guidelines for the trial-and-error based model calibration than the results of local sensitivity analysis.

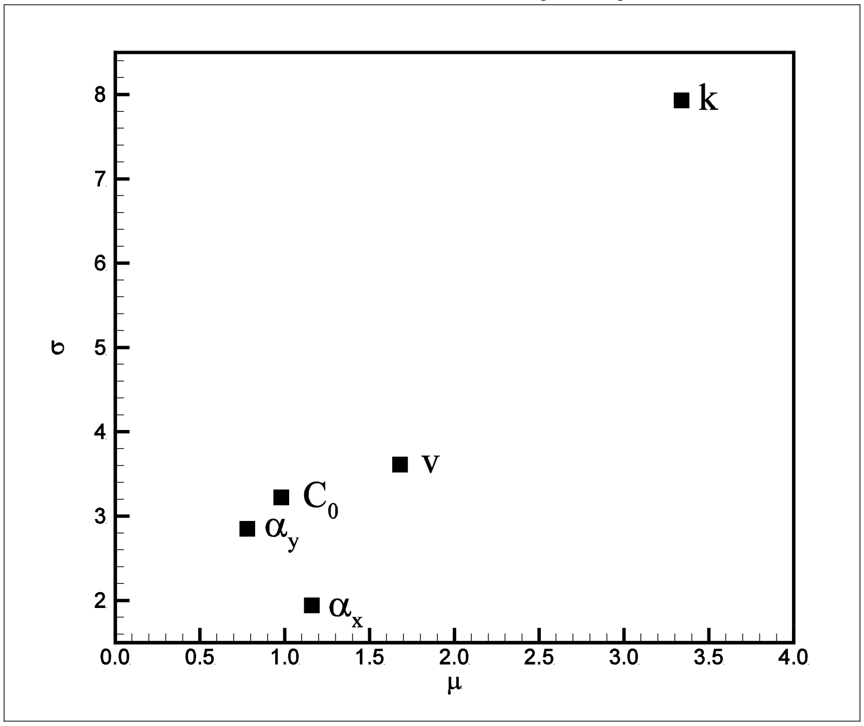


Figure 3-6 Mean and variance of the elementary effect of five parameter at location *x* = 10 m and *y* = 1 m.

x(m) / y(m)	0.0001	5	10	15	20	30	40	50
0	C_0, v	k, v	k ,v	k, v	k, v	k, v	k, v	k, v
1	C_0, v	k, v	k ,v	k, v	k, v	k, v	k, v	k, v
2	C_0, v	k, v	k ,v	k, v	k, v	k, v	k, v	k, v
3	C_0, v	k, v	k ,v	k, v	k, v	k, v	k, v	k, v
4	/	k, v	k ,v	k, v	k, v	k, v	k, v	k, v
6	/	k, v	k ,v	k, v	k, v	k, v	k, v	k, v
8	/	k, α_y	k ,v	k, v	k, v	k, v	k, v	k, v
10	/	α_y, k	k, α_y	k, α_y	k, v	k, v	k, v	k, v
12	/	α_y, k	k, α_y	k, α_y	k, α_y	k, v	k, v	k, v

Table 3-2 The two most critical parameters at 72 selected locations within the nitrate plume.

4 MODEL CALIBRATION

4.1 Study Areas and Field Observations

ArcNLET is used to estimate nitrate load from septic systems to surface water bodies in the Eggleston Heights and Julington Creek neighborhoods in Jacksonville. By 2008, a total of 3,517 septic tanks had been installed in the Eggleston Heights area. Nitrogen isotope analyses show that the septic systems are the major source of the nitrate in this area. Part of the neighborhood, 393 septic systems, and the locations of four monitoring wells are shown in Figure 4-1 (left). There are a total of 1,978 septic systems in the Julington Creek neighborhood. Part of the Julington Creek neighborhood, 593 septic systems, and the locations of 13 monitoring wells are shown in Figure 4-1 (right). Isotope analyses show that in this neighborhood both septic systems and fertilizer applied to lawns are major sources of the nitrate. The targeted surface water bodies of nitrate load include rivers, creeks, lakes, ponds, ditches, and swamps.

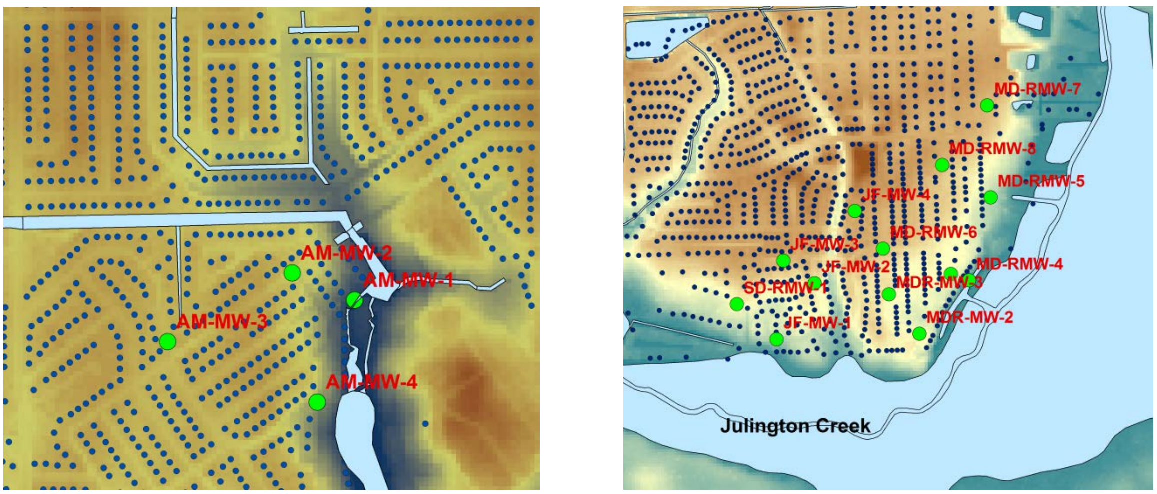


Figure 4-1 Locations of monitoring wells (green circles) and septic tanks (blue points) in Eggleston Heights (left) and Julington Creek (right) Neighborhood.

With support of the Florida St. Johns River Water Management District (SJRWMD), observations of water level depth and nitrate concentration have been collected. A total of 136 observations of water level depth and 143 observations of nitrate concentration were collected from the four monitoring wells within the Eggleston Heights neighborhood during the period from 2005 to 2010. A time series of the data for every well is plotted in Figure 4-2, in which water level depth was converted into hydraulic head. Despite fluctuations, the head observations (Figure 4-2 a) are relatively stable, indicating that it is reasonable to assume steady-state flow for this area. The concentration observations (Figure 4-2 b) have more significant fluctuations due to the complex nitrogen transport and transformation mechanism. However, there is no trend observed in the concentration data, suggesting that it is also acceptable to use the steady-state transport model. At the Julington Creek neighborhood, a total of 451 observations of water level depth and 484 observations of nitrate concentration were collected from the 13 monitoring wells during 2003 to 2010 in Julington Creek. For the demonstration purpose, a time series of the data from 4 out of 13 monitoring wells are plotted in Figure 4-2, in which water level depth were converted into hydraulic head. Similar to the Eggleston Heights, the head observations (Figure 4-2 c) are relatively stable; the concentration observations (Figure 4-2 d) have more significant fluctuation. Therefore, during the model calibration, the means of head and concentration observations are used as calibration targets. For the concentration, minimum and maximum as well as lower and upper quartiles of the observations are also used to evaluate the calibration results.

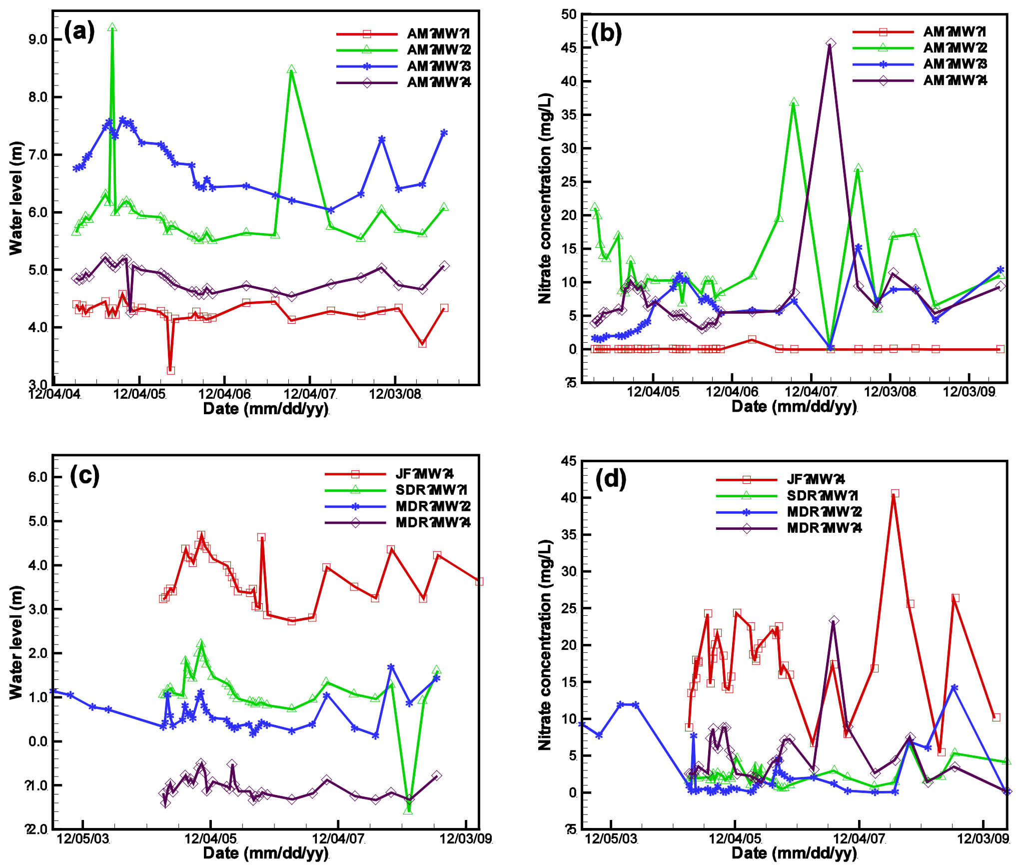


Figure 4-2 Time series of observations of (a) hydraulic head and (b) nitrate concentration for Eggleston Heights and (c) hydraulic head and (d) nitrate concentration for Julington Creek neighborhood.

4.2 Calibration Procedure

Generally speaking, model calibration is to match the simulated nitrate concentration to the observed ones by adjusting the model parameters. Model calibration in this study is necessary due to lack of characterization data for describing hydrogeologic conditions of the modeling domains. For example, except the hydraulic conductivity and porosity downloaded fro SSURGO database, there is no other parameter measure available. The only site-specific measurements are the particulate organic carbon (POC) content collected from the Eggleston Heights and Julington Creek neighborhoods at the top 1.5 m saturated zone. The data shows that the average POC content is 0.35% and 1.08% at the Eggleston Heights and Julington Creek neighborhoods, respectively. According to Anderson's (1998) that denitrification rate is positively correlated with POC content, he higher POC content in the Julington Creek area suggests a higher denitrification rate. This will be taken as prior information of the model calibration.

The trial-and-error model calibration starts from the Eggleston Height neighborhood by evaluating nitrate concentration in the modeling domains using smoothing factor of 60, heterogeneous hydraulic conductivity and porosity downloaded from the SSURGO database, longitude dispersivity α_x of 2.113 m (Davis 2000), α_y of 0.234 m (Davis 2000), C_0 of 40 mg/L (McCray et al. 2005), and first-order decay coefficient k of 0.025/d (McCray et al. 2005). The most sensitive parameters identified in the sensitivity analyses are subsequently adjusted to obtain improved fit between the simulated and observed nitrate concentration. The sensitivity to seepage velocity is reflected by adjusting hydraulic conductivity because it plays the most important role of determining the magnitude of the velocity.

The detailed procedure of model calibration within ArcNLET is as follows:

(1) Generate heterogeneous hydraulic conductivity and porosity layers as described in Chapter 2 of this manual and prepare the DEM, water body and septic tanks layers as described in this and the User's Manual.

(2) Calibrate the flow model first by adjusting the smoothing factor and using the mean hydraulic head observations at the monitoring wells as the calibrated targets. Since ArcNLET does not simulate hydraulic head but hydraulic gradient, the goal of adjusting the smoothing factor is to obtain a linear relationship between the smoothed DEM (which is an intermediate output layer of Groundwater Flow module, described in detail in the user's manual) and the calibration targets values at the observation wells. It is critical that the slope of the linear relationship is close to 1.0 so that the shape of the smoothed DEM mimics the shape of the water table. Note that hydraulic conductivity is not calibrated in this step unless observations of groundwater velocity are available.

(3) Calibrate the transport model using trial-and-error by adjusting the first-order decay coefficient, hydraulic conductivity, dispersivities, and source concentration. The goal of the calibration is to match the simulated nitrate concentration to the mean observations at the monitoring wells. Due to the complex nature of nitrate transport and simplicity of the model behind ArcNLET, it is not likely that the match is achieved at all the wells. A reasonable expectation that the simulated nitrate concentration fall in the inter-quartile range or the range of maximum and minimum observations at each well. Given that multiple septic systems can impact nitrate concentration at a monitoring wells, the results of the global sensitivity analysis are important guidelines to adjust different parameters for different septic systems. Using homogenous values of the first-order decay coefficient, dispersivities and source concentration is recommended because they may be considered as representative values of the modeling domain. It is recommended to adjust the hydraulic conductivity within the ranges of high and low values given in the soil survey data mentioned in Chapter 2.

Based on our experience, the model calibration for the flow model is relatively easy. In a contrast, the calibration of the transport model may be time consuming and require solid understanding of the nitrate transport from the hydrogeologic point of view.

4.3 Calibration Results

For the Eggleston Heights neighborhood, using a smoothing factor of 60, the smoothed DEM agrees well with the observed hydraulic head at the monitoring wells. As shown in Figure 2-1Figure 4-3 a, the linear correlation coefficient between the two quantities is 0.93 and the slope of the linear regression is close to 1.0. After adjusting the hydraulic conductivity of several specific zones and using the longitudinal dispersivity (α_x) of 10.0 m, horizontal transverse dispersivity (α_y) of 1.0 m, source plane concentration (C_0) of 80 mg/L and the first-order decay coefficient (k) of 0.005 1/d, the simulated nitrate concentrations of the four monitoring wells are close to the mean observations (Figure 4-3 b). Figure 4-4 compares the initial and adjusted hydraulic conductivity in the zones at the vicinity of the monitoring wells. The hydraulic conductivity is dramatically increased at two zones in order to obtain good match between the simulated and observed concentrations. In this software, the average flow velocity is calculated as dividing the flow path distance by the total travel time of all the segments, which makes the calculated average flow velocity dominated by the flow path segment that has smallest velocity. Therefore when the flow paths include some segments that go through an area where hydraulic conductivity is really small, the average flow velocity would be very small too. In Eggleston heights, when using the initial hydraulic conductivity, the simulated concentrations are much smaller than the measured ones due to small average flow velocity, which is caused by these two dominate soil zones with low hydraulic conductivity. To match the measurements, the hydraulic conductivity of these two zones is increased dramatically during the calibration.

Using the calibrated parameters of the Eggleston Heights neighborhood as the starting values, the model calibration is performed for the Julington Creek neighborhood. The smoothing factor is changed to 100, and he smoothed DEM agrees well with the observed hydraulic head at the monitoring wells, as shown in Figure 4-3 c. After adjusting the hydraulic conductivity of several specific zones (shown in Figure 4-4) and using the longitudinal dispersivity (α_x) of 10.0m, horizontal transverse dispersivity (α_y) of 1.0m, source plane concentration (C_0) of 100 mg/L, and the first-order decay coefficient (k) of 0.012 1/d, the simulated nitrate concentrations are close to the mean observations at seven out of thirteen wells. The simulated nitrate concentrations are within the maximum-minimum range of the observed concentrations at eleven wells (Figure 4-3 d). Comparing Figure 4-4 and Figure 4-5 shows that the change of hydraulic conductivity during the calibration is smaller at the Julington Creek than at the Eggleston Heights neighborhood.

4.4 Nitrate Loads Estimation Based on Calibration

The calibrated model was used to estimate nitrate load to surface water bodies from the 3,495 septic tanks in the Eggleston Heights neighborhood and 1,924 septic systems in the Julington Creek neighborhood. For the Eggleston Heights, the estimated input load to groundwater is 115.4 kg per day, 92.5% of which (about 106.8kg) is lost due to denitrification everyday. The remaining 7.5% (about 8.6 kg) is the nitrate load to surface water bodies. For the Julington Creek neighborhood, the estimated nitrate input load to groundwater is 59.4 kg per day, 97.6% of which (about 58.0 kg) is lost due to denitrification. The remaining 2.4%, (about 1.4 kg) is the nitrate load to the surface water bodies.

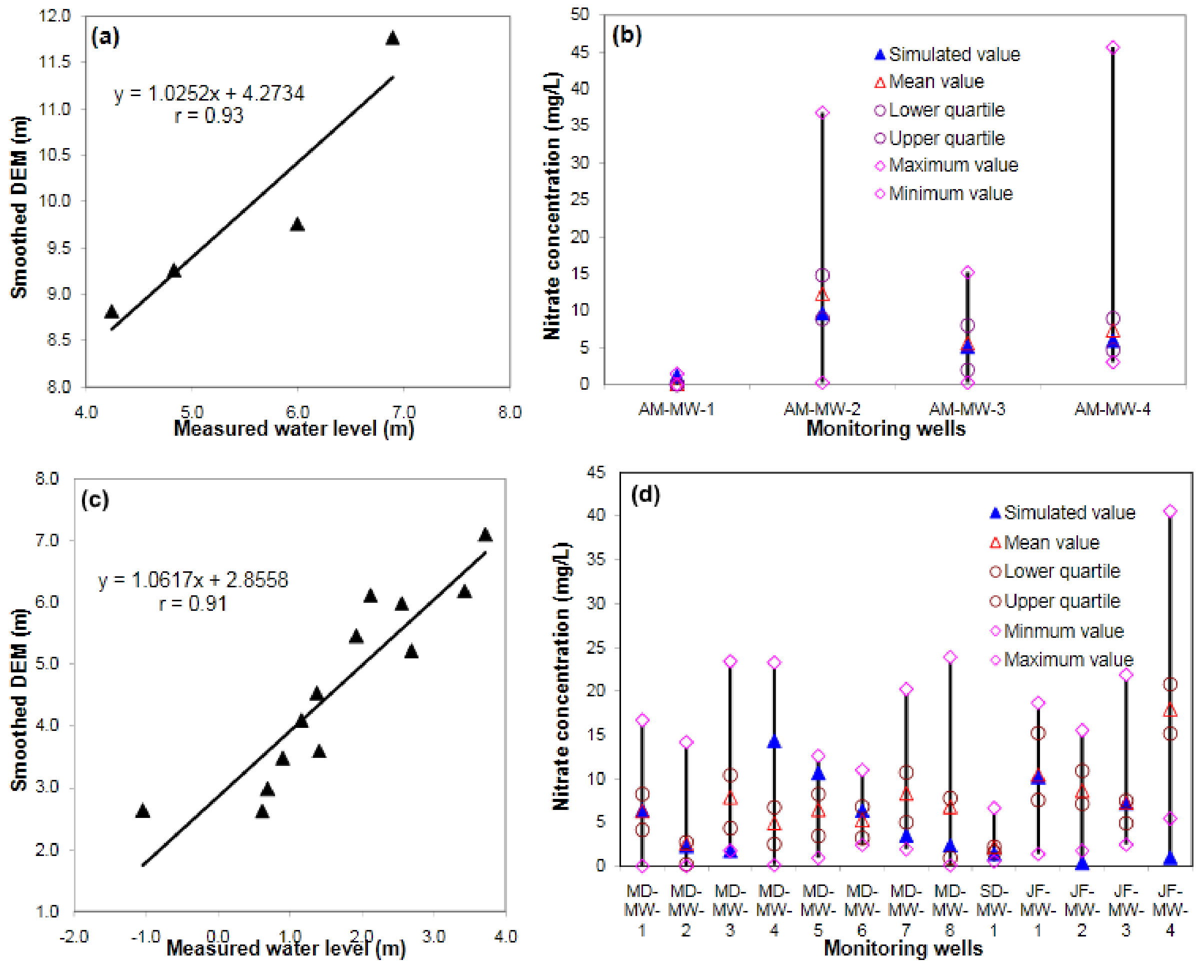


Figure 4-3 The calibrated results for (a) hydraulic gradient and (b) nitrate concentration for Eggleston Heights neighborhood and (c) hydraulic gradient and (d) nitrate concentration for Julington Creek neighborhood.

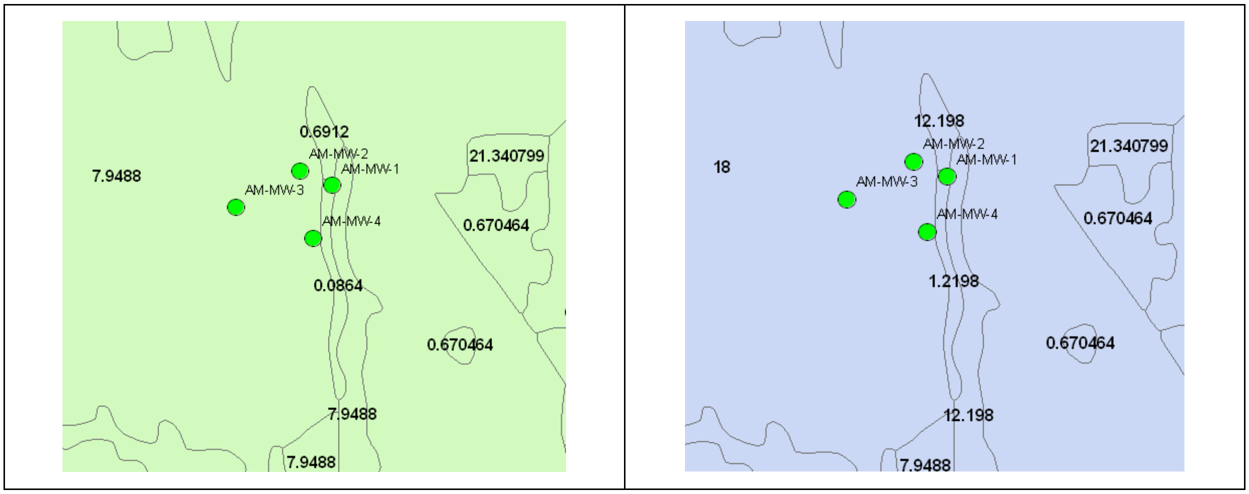


Figure 4-4 Zonal values of initial (left) and calibrated (right) hydraulic conductivity for Eggleston Heights.

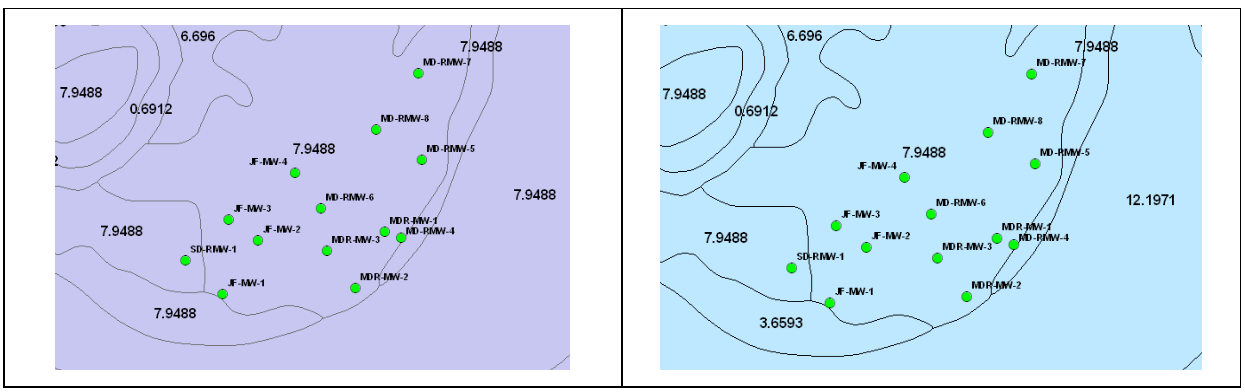


Figure 4-5 Zonal values of initial (left) and calibrated (right) hydraulic conductivity for the Julington Creek neighborhood.

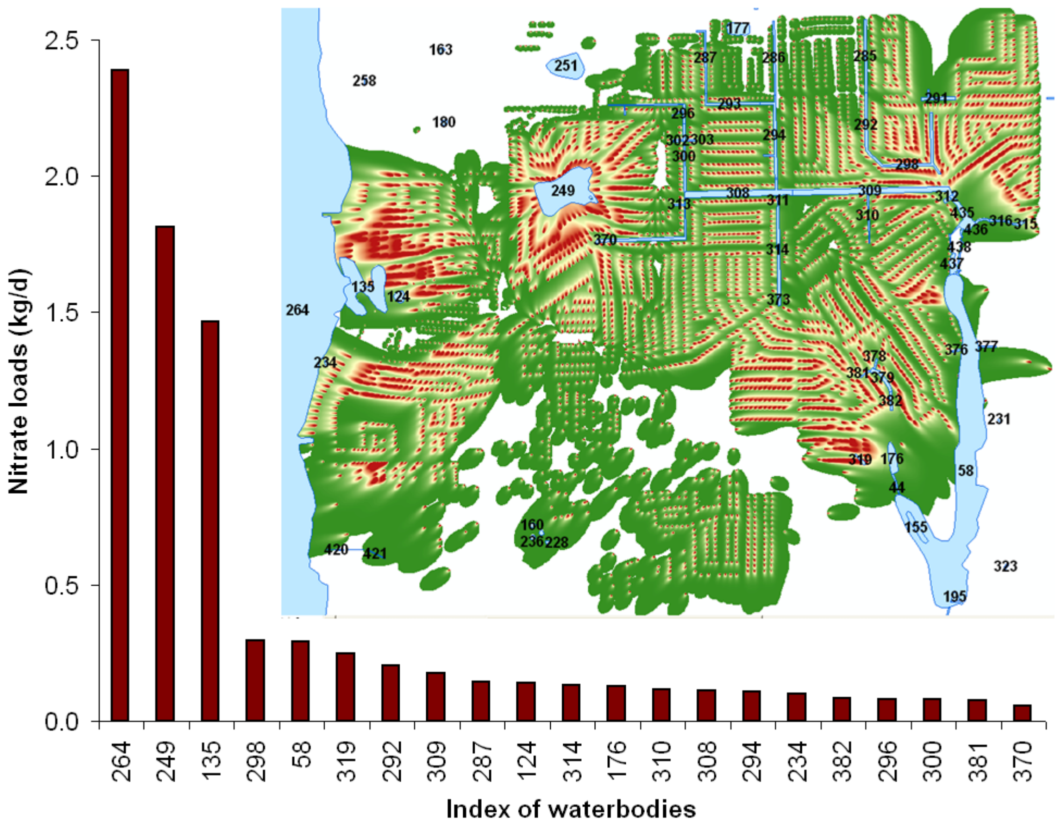


Figure 4-6 The nitrate loads to target waterbodies and plumes (those waterbody targets with nitrate loads less than 0.05kg/d are not shown)

Figure 4-6 plots for demonstration the nitrate plumes and the estimated loads to different water bodies at Eggleston heights neighborhood. It shows that the estimated nitrate load to the water bodies with indices 264, 249 and 135 are the largest, as the three water bodies receive about 66% of the total load. Water body 264, corresponding to the St. Johns River, receives the highest load because of its large area and high hydraulic conductivity. According to the particle tracking simulation, this water body is the target of 776 septic systems. The hydraulic conductivity of the two main soil zones around this water body is 21.34 and 7.95 m/d. Water body 249, representing Lake Lucina, is the target of 430 septic systems and it is surrounded by a soil zone with hydraulic conductivity of 12.20 m/d. Water body 135 is a swamp and it is the target of 97 septic systems. This water body receives a large load because of its lower elevation and resulting higher simulated flow velocity. Summarizing the above, it can be concluded that the load estimation is consistent with the hydrogeologic information of the area.

However, the quality of the load estimates cannot be evaluated directly, since there is no on-site observation of the load. An indirect way of evaluating the load estimate is to compare the estimated average load to the groundwater per septic system with other estimates in literature. The U.S. EPA Onsite Wastewater Treatment Systems Manual (Table 3-8, U.S. EPA, 2002) estimates 11.2 g of nitrogen per person per day as the average total nitrogen contribution to septic systems. According to the 2007 America's Families and Living Arrangements (Rose et al. 2009), the average household size is approximately 2.6 persons per household in U.S. This equates to an average of 29.12 g nitrogen per home per day discharged to septic systems. A 10% reduction of nitrogen through volatilization of ammonia and solids removal as septage is estimated by Anderson (2006), who also estimated a 25% reduction of nitrogen due to denitrification as the wastewater percolates through the unsaturated zone. Therefore, about 20g nitrogen per septic system per day is discharged to the groundwater. Based on the assumption that all the nitrogen enters the groundwater is in nitrate form, this value is used as the reference value for the comparison with the estimated average source input load of one single septic system in these two examples. At the Eggleston Heights, the estimated source input load to groundwater from the 3,495 septic systems is 115.4kg per day; the average nitrate load for every septic system is about 33g per day. It is about 31g per day per septic systems for the Julington Creek neighborhood with 1,924 septic systems. While these average values are higher than the estimated 20g based on literature data, they appear to be in reasonable ranges, considering the variability of household size, different drainage conditions, and heterogeneous hydrogeologic properties.

5 CONCLUSIONS

This manual includes several advanced topics of using ArcNLET for estimating nitrate load from septic systems to surface water bodies. Detailed operations at the Eggleston Heights and Julington Creek neighborhoods are provided. The advanced topics include:

(1) Use LiDAR DEM instead of NED DEM from the USGS database. Using the LiDAR DEM is necessary to preserve the narrow ditches and canals at the Eggleston Heights that cannot be reflected in the NED DEM of course resolution.

(2) Use LiDAR DEM to update NHD water body data. This update is done manually and only conducted for a small area at the Eggleston Heights neighborhood where water bodies are found not to be accurately represented and simulated flow paths appear to be physically unreasonable.

(3) Generate heterogeneous raster files of hydraulic conductivity and porosity based on dataset downloaded from the SSURGO soil database. While the procedure is cumbersome, the operation should be relatively easy for advanced GIS users.

(4) Conduct local and global sensitivity analysis to identify parameters that are critical to the simulated nitrate concentration. Conclusions of the sensitivity analysis, especially those of global sensitivity analysis, are general and should be applicable to other modeling sites.

(5) Calibrate the model within ArcNLET to match simulated nitrate concentration to the calibration targets such as the mean of observed hydraulic head and nitrate concentration. The calibration of the both flow and transport models is described in the manual. The calibrated results appear to be reasonable, consistent with site hydrogeologic conditions and literature data. However, it should be noted that the calibration processes and results may be different for different modeling areas. In addition, the estimated nitrate load should be used with caution, since ArcNLET is designed as a screening tool based on a simplified model.

REFERENCES

Anderson, D.L., Hazen, P.E. and Sawyer, P.C. (2006). A Review of Nitrogen Loading and Treatment Performance Recommendations for Onsite Wastewater Treatment Systems (OWTS) in the Wekiva Study Area.

Anderson, D. L. 1998. Natural Denitrification In Groundwater Impacted by Onsite Wastewater Treatment Systems. In: On-Site Wastewater Treatment, Vol. 8. D. M. Sievers, Ed. ASAE Publ. 03-98, American Society of Agricultural Engineers, St. Joseph, MI. pp. 336-345.

Davis, J. H. 2000. Fate and Transport Modeling of Selected Chlorinated Organic Compounds at Operable Unit 3, U.S. Naval Air Station, Jacksonville, Florida. U.S. Geological Survey, Tallahassee FL. Open-file report 00-255.

Gelhar, L. W., Welty, C., and Rehfeldt, K. R. 1992. A critical review of data on field-scale dispersion in aquifers. Water Resources Research 28, 7, 1955–1974.

Laak, R. 1982. A passive denitrification system for on-site systems. p. 108-115. In: On-Site Wastewater Treatment, ASAE Publ. 10-82, American Society of Agricultural Engineers, St. Joseph, MI.

McCray, J. E., Kirkland, S. L., Siegrist, R. L., and Thyne, G. D. 2005. Model parameters for simulating fate and transport of on-site wastewater nutrients. Ground Water 43, 4, 628–639.

Morris, M.D. 1991. Factorial Sampling Plans for Preliminary Computational Experiments, Technometrics, 33(2), 161-174.

Pell, M. and F. Nyberg. 1989. Infiltration of Wastewater in a Newly Started Pilot Sand-filter System: III. Transformation of Nitrogen. J. Envrion. Qual. 18:463-467.

Rios, J.F et al., 2011. ArcNLET: An ArcGIS-Based Nitrate Load Estimation Toolkit, Technical Manual. http://people.sc.fsu.edu/~mye/ArcNLET/technical_manual.pdf.

Rios, J.F et al., 2011. ArcNLET: An ArcGIS-Based Nitrate Load Estimation Toolkit User’s Manual. http://people.sc.fsu.edu/~mye/ArcNLET/users_manual.pdf.

Sherman, K.M. and D.L. Anderson. 1991. An Evaluation of Volatile Organic Compounds and Conventional Parameters From On-Site Sewage Disposal Systems in Florida. In: On-Site Wastewater Treatment, Vol. 6. J. Converse, Ed. ASAE Publ. 10-91, American Society of Agricultural Engineers, St. Joseph, MI. pp 62-75.

Saltelli, A., S. Tarantola, R. Campolongo, and M. Ratto (2004), Sensitivity Analysis in Practice: A Guide to Assessing Sceintific Models, John Wiley& Sons, Ltd.

U.S. Environmental Protection Agency. 1980. Onsite wastewater treatment and disposal systems. Design Manual. Report No. EPA-625/1-80-012, U.S. Environmental Protection Agency, MERL, Cincinnati, Ohio.