Responses to SPRIM TAC Evaluation of ArcNLET

The Septic Plume Investigation and Model Refinement (SPIMR) Technical Advisory Committee (TAC) recently reviewed the ArcGIS-based Nitrate Load Estimation Toolkit (ArcNLET) and its applications at Eggleston Height and Julington Creek neighborhoods in Jacksonville. TAC released on 8/10/2012 a review memo summarizing the review process, conclusions, and recommendations. After receiving the memo, the ArcNLET development team at the Florida State University seriously considered the TAC conclusions and recommendations. This file summarizes the responses of the FSU team to the review memo, including clarification on possible misunderstanding of TAC, investigation on problems pointed out by TAC, and future work to address the recommendations. The FSU team appreciates the TAC for their review and recommendations, and look forward to an opportunity of meeting with TAC to discussion the reviews and responses.

Below are the responses of the FSU team to the four TAC recommendations. The recommendation is copied verbatim in Calibri font of size 11; FSU's responses are in Times New Roman font of size 12.

Response to Recommendation 1

Surface-water drainage network effects on the groundwater gradient and resultant flow path-lines are not fully recognized in the model, presumably due to the gradient smoothing operation. In both the Eggleston and Julington Model, ditches which intersect groundwater were found not to be receiving groundwater discharge.

a. To address the flow path-line issue, ArcNLET algorithms should be adjusted such that resultant flow path-lines conform to expectations that localized groundwater-table depression occurs near wet ditches and the local flow path-lines are generally perpendicular to such ditches. The Eggleston and Julington cases should then be rerun leaving all other parameters unchanged to determine the impact of the flow path-line correction on results. Concurrently, MODFLOW or equivalent hydraulic gradient grids should be prepared and used as input to the fate and transport modules of ArcNLET for both Eggleston and Julington and compared to the flow path corrected result to give an indication of the sensitivity.

b. Field verification of the presence and hydraulic condition of ditches also should be performed. For example, based on detailed review by the TAC, it appears that one possibly intermittent ditch in the Julington model may have been missed (Appendix D, Figure 5); even though the ditch may be intermittent, it could still be a (very) significant transport pathway for nitrogen-laden water.

Clarification: For the problem raised by TAC that "in both the Eggleston and Julington model, ditches which intersect groundwater were found not to be receiving groundwater discharge", TAC probably misunderstood the modeling results documented in ArcNLET application manual (Wang et al., 2011). Figure 1 for Eggleston Height (Figure 4-6 of the ArcNLET application manual) shows that ditches do receive groundwater discharge. For example, ditches with indices of 298, 292, 309, 287, 314, 310, 308, 294, 296, 300, and 390 all receives nitrate loads larger than 0.5 kg/day.

Reference: Wang, L., M. Ye, J.F. Rios, and P.Z. Lee (2011), ArcNLET: An ArcGIS-Based Nitrate Load Estimation Toolkit: Application Manual, Technical report prepared for the Florida Department of Environmental Protection, Tallahassee, FL. The report is available online at http://people.sc.fsu.edu/~mye/ArcNLET/application_manual.pdf.

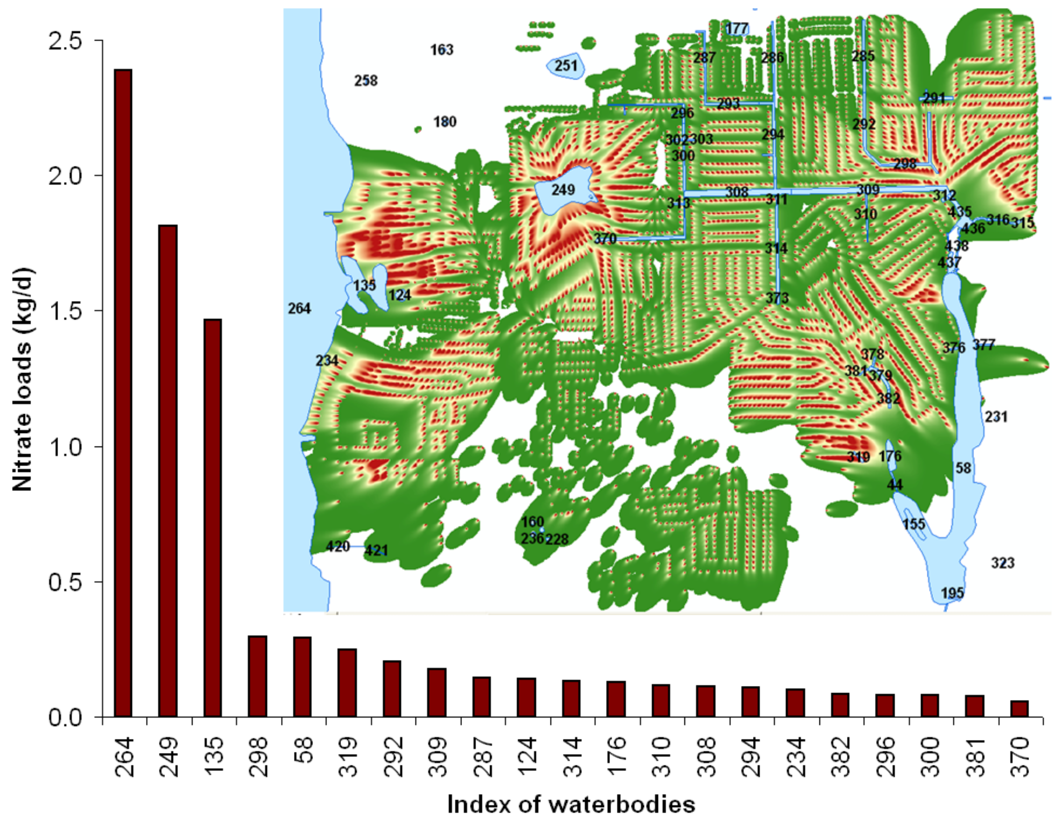


Figure 1. Simulated nitrate plumes and loads to target waterbodies. Loads less than 0.05 kg/d are not shown. The figure is copied from the ArcNLET application manual (Wang et al., 2011).

Investigation: The actual concern of TAC is that "<u>why groundwater from certain septic systems does not flows into the nearby ditches</u>". This is related to the conceptual model of groundwater flow based on which ArcNLET modules of Groundwater Flow and Particle Tracking are developed. In the current conceptual model, the ditches do not control local groundwater flow, because the relation between the ditches and groundwater flow is largely unknown. In other words, groundwater is controlled by hydraulic head of the neighborhood scale, whose shape is approximated by the smoothed DEM generated by ArcNLET. While TAC's expectation that "localized groundwater-table depression occurs near wet ditches" is reasonable, it appears to be an expert judgment in nature and field data is lack at this stage to support the expectation.

Certain existing monitoring data actually suggest a different relation between the ditches and groundwater. Taking well AM-MW-3 at Eggleston Height as an example, its monitoring data plotted in Figure 4-2 of ArcNLET Application Manual (Wang et al., 2011) indicates that the hydraulic head is lower than 8m, whereas the LiDAR DEM data (provided by Rick Hicks at FDEP) indicates that the bottom elevation of the nearest ditch is higher than 11m. In other words, the ditch bottom is 3m higher than monitored water table. We thus view the TAC's expectation as a hypothesis and suggest conducting further investigation on it in the future.

Figure 2 illustrates groundwater flow in the current groundwater conceptual model in which the ditches do not control local groundwater flow. The blue lines in the figure represent flow paths from septic tanks (red square) estimated by ArcNLET using smoothing factor of 60. Three profiles of DEM along the black line marked in the figure are plotted; the black line intersects two ditches. Examining the three profiles shows that:

(1) The profile at the left is based on the original LiDAR DEM with 5×5 ft^{2}resolution (provided by Rick Hicks at FDEP), and the two ditches are revealed as the two deep valleys on the profile. It suggests that the LiDAR DEM is able to reflect ditches, including intermittent ditches, at the local scale. The LiDAR DEM is reprojected to NAD_1983_UTM_Zone_17N coordinate system, and the unit of elevation is converted from foot to meter. The raster file used to generate the profile is "duval5_nn_proj_m.img".

(2) The profile in the middle is for the resampled DEM, from 5×5 ft^2 to 10×10 m^2 resolution, used in the ArcNLET modeling reviewed by TAC. The resampling is to save computational time of ArcNLET modeling, as documented in Section 2.1 of ArcNLET application manual. The profile of the smoothed DEM shows that the resampling resolution is too coarse for the two narrow ditches in that the two ditches are not retained. This problem was reported in the application manual that "the tradeoff between finer resolution and reasonable computational time is determined by users to meet their specific project needs". The solution to this problem is to increase the resampling resolution; in the discussion below, the resolution is empirically increased from 10×10 m^2 to 5×5 m^2.

(3) The profile at the right is the smoothed DEM obtained after 60 times of smoothing of the resampled DEM. While large-scale spatial variability is preserved, local-scale variability disappears after the smoothing. As a result, for septic systems located down-gradient of (right to) the peak shown in the profile, groundwater from them flow in the down-gradient direction, i.e., to the right. This explains why groundwater flow from certain septic tanks does not flow into nearby ditches. As shown below, smoothing is the dominant reason for the disappearing ditches, even when ditches are retained in the resampled DEM.

The above observations are the basis for the proposed solution below to meet the expectation of TAC that “localized groundwater-table depression occurs near wet ditches”.

Note that the smoothed DEM is not a default output raster file of ArcNLET. To produce it, one needs to select “Output Intermediate Calculations” under “Settings” of ArcNLET menu. A number of intermediate raster files will be generated and their names start with “tmp_” indicating temporary files. The smoothed DEM file is called “tmp_smoothedDEMxxxxxxxxxxxxxxxxxx”, where xxxxxxxxxxxxxxxxxx is a series of random numbers generated by the computer. Users may save the smoothed DEM using the Expert Raster Data function of ArcGIS. We will later on modify ArcNLET to output the smoothed DEM as a default raster file.

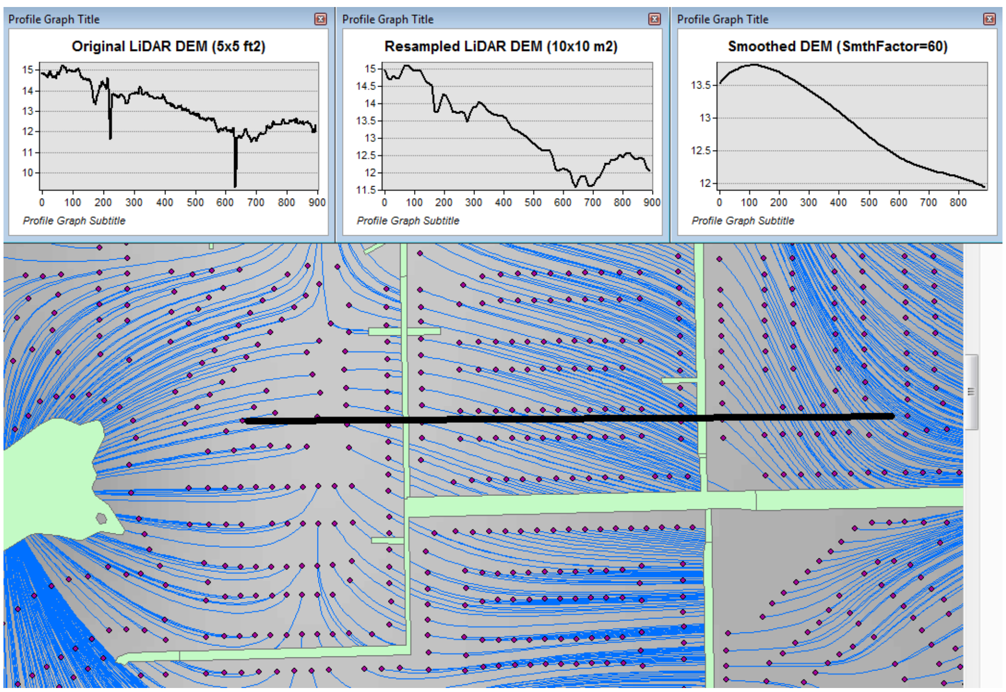


Figure 2. Simulated flow paths (blue lines) from septic tanks (red squares) by running ArcNLET with smoothing factor of 60. The three profiles along the black line marked in the figure are: the original LiDAR DEM of 5 × 5 ft^2 resolution (left), the resampled LiDAR DEM of 10 × 10 m^2 resolution (middle), and the smoothed DEM (right) based on the resampled LiDAR DEM. The flow paths are estimated based on the smoothed DEM.

Solution: The proposed solution is to build the ditches into the smoothed DEM so that the ditches control the shape of approximated water table and subsequently groundwater flow paths. Specifically speaking, the proposed solution is implemented in the following procedure:

Step 1: When resampling the LiDAR DEM, determine appropriate resolution so that local ditches are retained in the resampled DEM. Although this step may be automated, it remains empirical at this stage. We present below the results for the resolution of 5×5 m^2.

Step 2: Extract the elevations of water bodies, including the ditches, from the resampled DEM. This can be done by using the Extract by Mask feature of the Spatial Analyst Tools of the ArcGIS Toolbox. The extracted elevations will be merged into the smoothed DEM so that the ditches can control groundwater flow paths calculated from the smoothed DEM.

Step 3: Conduct smoothing by running the Groundwater Flow module of ArcNLET. As shown below, the ditches may disappear after the smoothing, although they are retained in the resampled DEM in Step 1. Since the smoothed DEM is needed for the next step, we need to save the temporal output file of smoothed DEM as discussed above.

Step 4: Add the extracted elevation of water bodies obtained in Step 2 to the smoothed DEM obtained in Step 3. This can be done using the Mosaic function of Data Management Tools of ArcGIS Toolbox. This step warrants that the smoothed DEM at ditches is lower than that of nearby septic tanks. However, since the ditch elevations are not used to calculate hydraulic gradient, the hydraulic gradient is still the same as that of Step 3.In other words, the ditches still do not control groundwater flow paths toward the ditches.

Step 5: Conduct another round a smoothing in ArcNLETso that the ditches added in Step 4 are used to calculate hydraulic gradient near the ditches. The number of smoothing should be small in this step, because a large value of smoothing factor may eliminate the ditches again. This step changes hydraulic gradient near the ditches.

Step 6: Run ArcNLET to calculate groundwater flow paths. If the flow paths are not satisfactory, one may need to repeat Steps 4 and 5 until the expectation is met. More repeating will result in more control of the ditches on groundwater flow paths. If measurements of hydraulic head are available, they should be used as the criteria to determine when to stop the iterative process.

While this procedure is empirical in nature, it may be automated if the procedure is accepted. For example, the water body elevation can be added into the smoothed DEM automatically before each time of smoothing. However, since this is tantamount to changing the current conceptual model of groundwater flow, it will not be implemented until the conceptual model is finalized.

Results: Similar to Figure 2, Figure 3 plots the simulated groundwater flow path and several profiles corresponding to the steps above. The results are for the resolution of 5×5 m^2 in the resampled DEM. Below is the discussion of the profiles:

(1) The profile at the left of row 1 is based on the original LiDAR DEM with 5×5 ft^2 resolution provided by Rick Hicks at FDEP. It is the same as the same profile shown in Figure 2. The raster file used to generate the profile is “duval5_nn_proj_m.img”.

(2) The profile in the middle of row 1 is based on the resampled DEM produced in *Step 1* above by resampling the LiDAR DEM to the resolution of 5×5 m^2 (the resulting raster file is “lidardem_5m.img”). The profile shows that the two ditches are retained with this resolution, while small-scale variability disappears after the resampling.

(3) The profile at the right of row 1 is the smoothed DEM of ArcNLET using smoothing factor of 60, the result of *Step 3*. It shows that, due to the smoothing, the two ditches disappear again although they were retained in Step 1, suggesting that smoothing is the main reason for disappearing ditches. The raster file used to generate the profile is “tmp_smoothedDEM634818550580512090.img”, a temporal file generated by ArcNLET as discussed above. This file is then saved as “smoothedDEM_60.img”.

(4) The profile at the left of row 2 is the DEM after adding the extracted elevations of water bodies to the smoothed DEM. The extracted elevation file is “WB_extract_lidar_m.img” obtained in *Step 2* above. Because of the use of Mosaic function of ArcGIS, the resulting raster file is still “smoothedDEM_60.img”, which is the result of *Step 4*. The profile shows the two ditches. Since the ditches have not been used to calculate hydraulic gradient, the gradient is the same as that of Step 3. As a result, for the left ditch, groundwater flow paths from the septic tanks right to the ditch are rightward not leftward to the ditch.

(5) The profile in the middle of row 2 is the DEM after smoothing the DEM (smoothedDEM_60.img) twice (smoothing factor of ArcNLET being 2); the raster file used to generate this profile is “smoothedDEM60_WB_2.img”. This profile shows that, after the ditches elevation is used for the smoothing, the hydraulic gradient near the ditches are changed. Take again the left ditch as an example. Before the smoothing, the hydraulic gradient right to the ditch is toward right; after the smoothing, the gradient at close vicinity of the ditch becomes leftward, implying that groundwater flows into the ditch.

(6) The profile at the right of row 2 is based on the raster file“smoothedDEM60_WB_2_WB.img” obtained by adding the water body elevations to “smoothedDEM60_WB_2.img”.

(7) The profile of row 3 is based on the raster file “smoothedDEM60_WB_2_WB_2.img” obtained after smoothing the DEM “smoothedDEM60_WB_2_WB.img” twice using ArcNLET. Since this profile is similar to that in the middle of row 2, we decide to use flow velocity corresponding to “smoothedDEM60_WB_2_WB_2.img” for the calculation of flow paths.

Evaluation: The modeling results are further evaluated to compare the groundwater flow paths and estimated nitrate load before and after implementing the solution. While the same parameter values are used for estimating the flow fields and nitrate loads, this is not ideal because the change of flow paths may require recalibrating model parameters including hydraulic conductivity, dispersivity, source plane concentration, and the first-order decay coefficient. The calibration may change the parameter values.

Figure 4 plots the simulated groundwater flow paths before (top) and after (bottom) implementing the proposed solution. The figure at the bottom would meet TAC's expectation better because groundwater from septic tanks flows into nearby ditches. However, it is worth mentioning that the modeling results need to be further evaluated using field data.

Figure 5 compares the estimated nitrate load before (top) and after (bottom) implementing the proposed solution. While the load estimates before implementing the proposed solution should be identical to those shown in Figure 1, some differences are observed. This may be due to the use of different datasets, and efforts will be spent to regenerate Figure 1. However, this should not affect the comparison discussed in this file. Figure 5 shows dramatic difference before and after implementing the proposed solution. The total amount of load increases from 7.8 to 62.6 kg/d. The load estimates of individual water bodies also change dramatically. Take ditch 309 as an example, its load increases from 0.17 kg/d to 10.08 kg/d. These changes are not surprising because of the change of flow paths. Figure 6 plots the simulated nitrate plumes before (top) and after (bottom) implementing the proposed solution. The nitrate concentrations near the ditches increase after implementing the proposed solution due to the short paths.

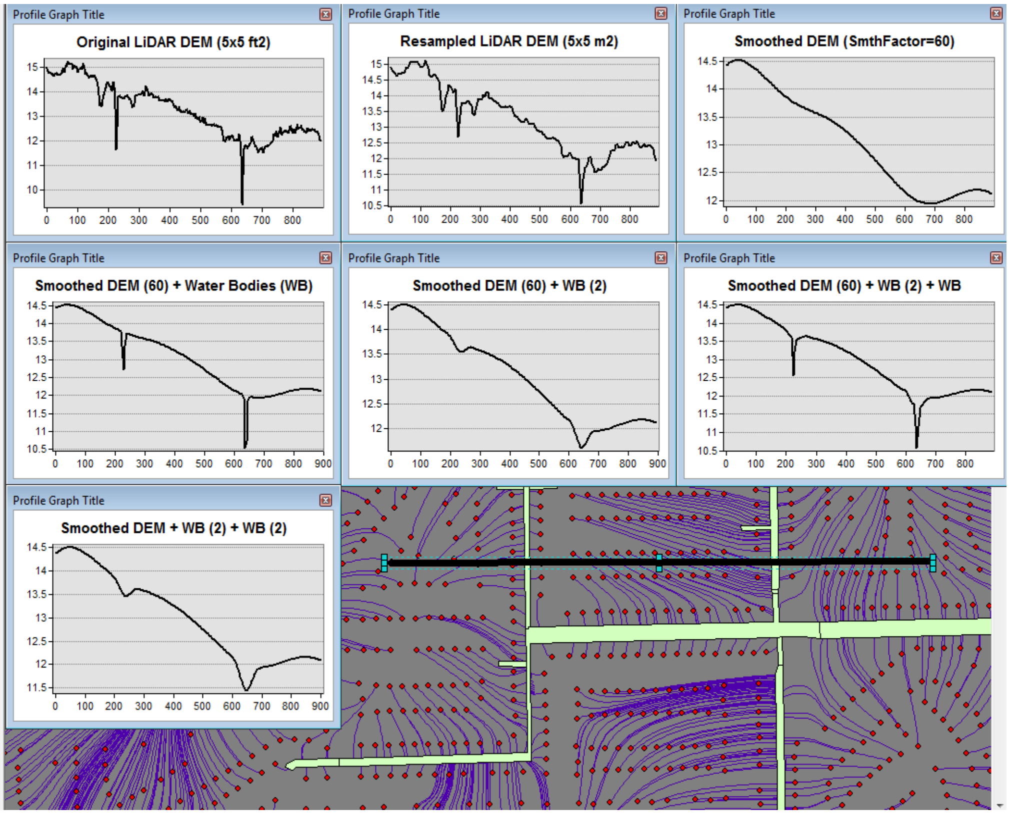


Figure 3. Simulated flow paths (blue lines) from septic tanks (red squares) by running ArcNLET with smoothing factor of 60. The seven profiles along the black line marked in the figure are: the original LiDAR DEM of 5 × 5 ft^2 resolution (left of row 1), the resampled LiDAR DEM of 5 × 5 m^2 resolution (middle of row 1), the smoothed DEM (right of row 1) based on the resampled LiDAR DEM, the smoothed DEM with ditch elevation added (left of row 2), the smooth DEM after two times of smoothing (middle of row 2), the smoothed DEM after two times of smoothing with ditch elevation added (right of row 2), and the smoothed DEM with another two times of smoothing (row 3). The flow paths are estimated based on the smoothed DEM corresponding to the profile of row 3.

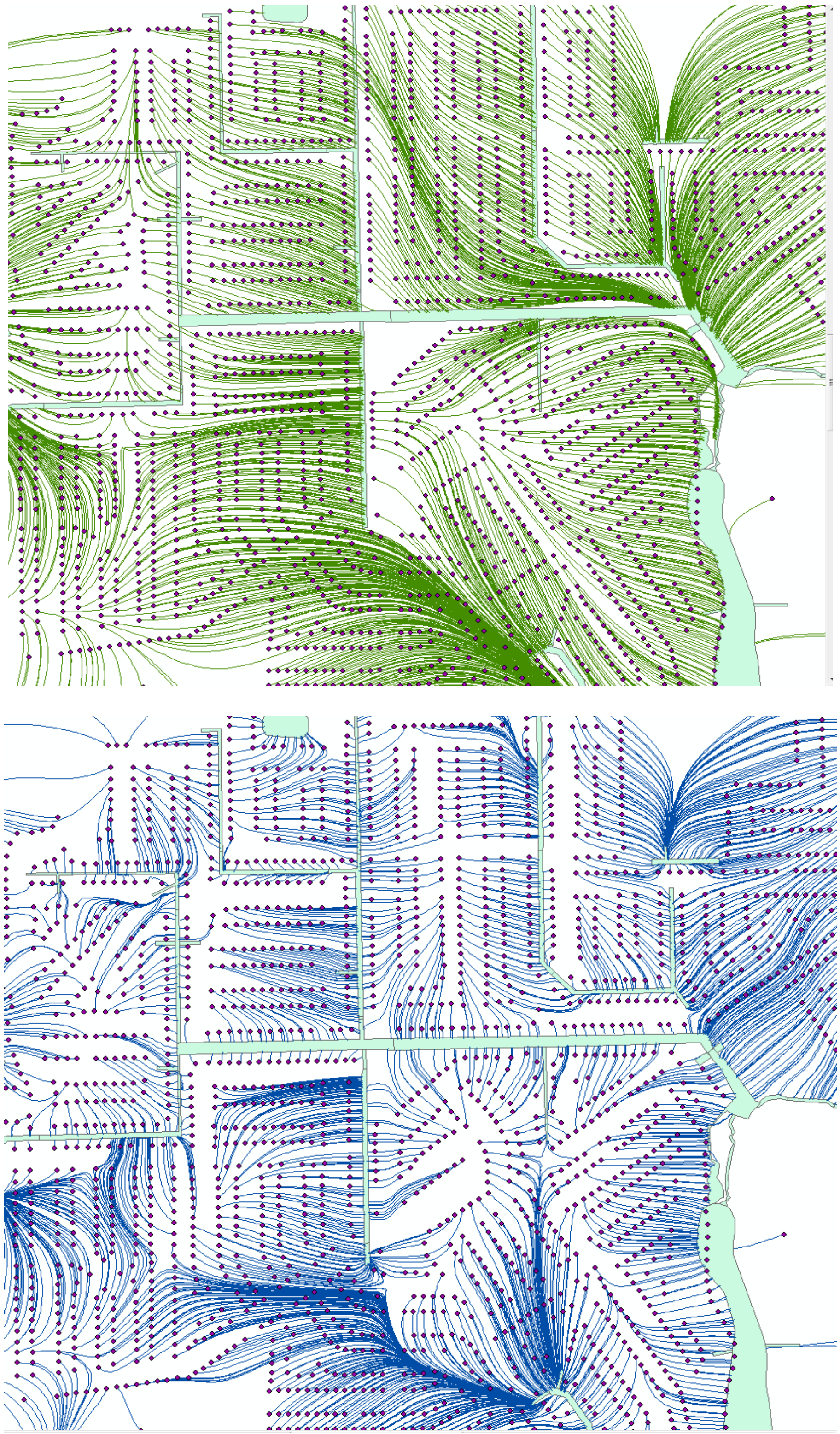


Figure 4. Simulated groundwater flow paths before (top) and after (bottom) implementing the solution described above.

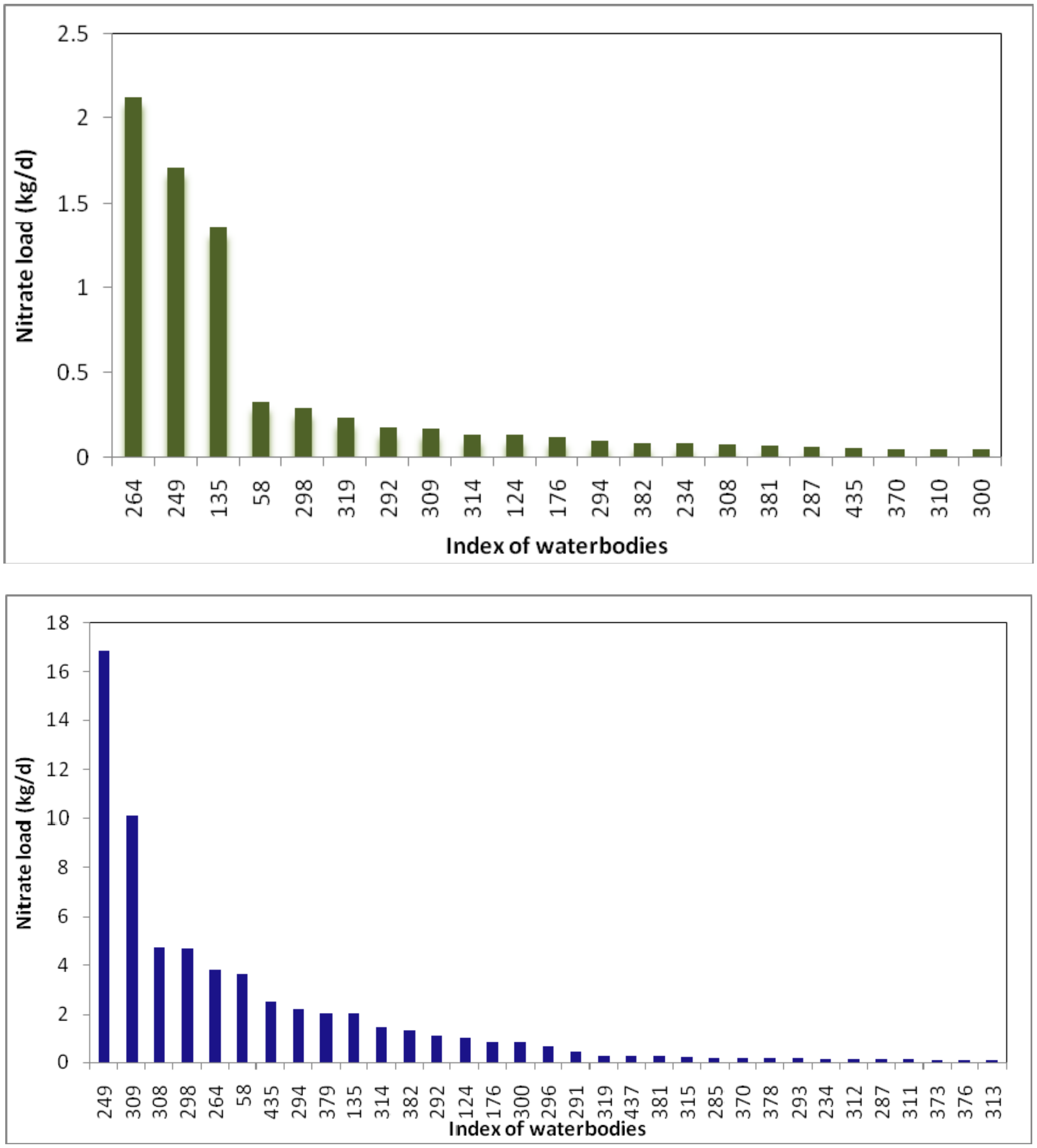


Figure 5. Estimated nitrate load before (top) and after (bottom) implementing the proposed solution (the water bodies receiving nitrate load less than 0.05 kg/d are not shown).

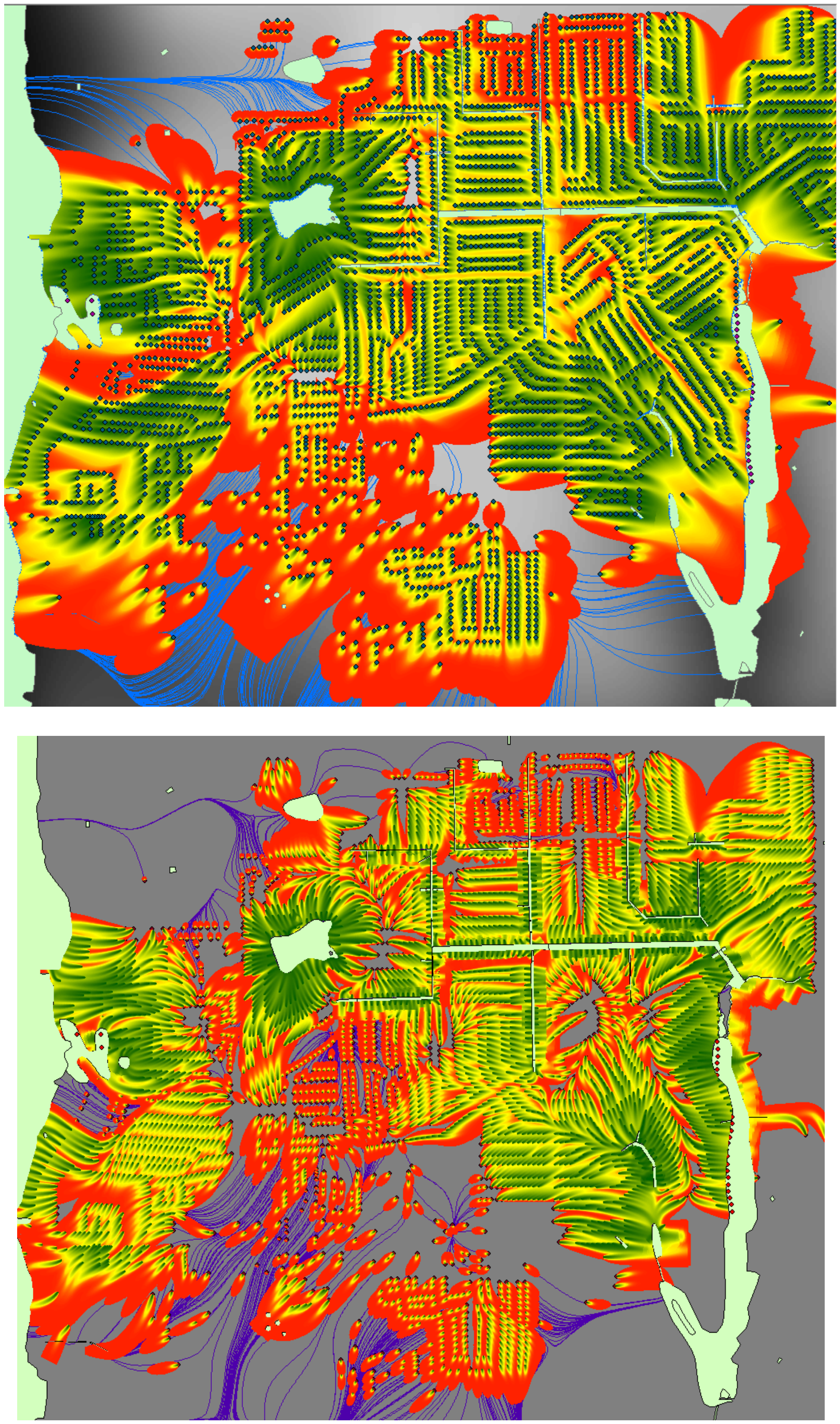


Figure 6.Simulated nitrate plumes before (top) and after (bottom) implementing the proposed solution.

About using MODFLOW: The TAC report suggests using MODFLOW for the flow modeling and using MODFLOW-based hydraulic head (or gradient) for calculating the flow paths. Using MODFLOW-based hydraulic head in ArcNLET is straightforward; one can first convert the MODFLOW-based hydraulic heads into a raster file and then use the file as the DEM raster file and run ArcNLET using smoothing factor of zero. However, we are concerned about time and effort of preparing a MODFLOW simulation as well as usefulness of the MODFLOW modeling results. Although several softwares (public-domain or commercial) with graphic user interfaces have been developed to facilitate setup of MODFLOW packages, significant amount of time and effort is still necessary, in particular when the number of neighborhood is relatively large as in the TMDL calculation. More importantly, due to data scarcity, we doubt that MODFLOW modeling results would be better. For example, in MODFLOW modeling, if one does not treat the ditches as the first or third type of boundary condition (e.g., drain), the ditches cannot control local-scale groundwater flow, and groundwater flow near the ditches is still controlled by the neighborhood-scale hydraulic gradient. However, implementing the first or third type of boundary condition requires knowing water levels in the ditches. Since the water levels are unknown, certain assumptions must be made, which diminishes usefulness of the MODFLOW results. In other words, the MODFLOW modeling results cannot be used as a basis for evaluating ArcNLET modeling results. Nevertheless, it is possible to select one or two neighborhoods to set up MODFLOW models and at the meantime to conduct a field investigation for measuring water level in the ditches.

About flow paths perpendicular to ditches: For TAC's expectation that "the local flow path-lines are generally perpendicular to such ditches", this is true if the ditch is simulated as a constant head boundary, assuming that the ditches are wet. However, if a ditch is dry, it is a seepage boundary at which pressure head is zero and hydraulic head equals to elevation. In this case, groundwater flow paths may not be perpendicular to the ditches. An analogy is that groundwater flow paths are not perpendicular to water table. On the other hand, given that ArcNLET adopted a number of simplification and approximation to accelerate computational efficiency, it is not considered to be critical whether ArcNLET-simulated flow paths are perpendicular to the ditches.

About missing of one possibly intermittent ditch: While the comment is not entirely clear to us (it is unknown which ditch is referred to in Figure 5 of Appendix D of the TAC report), there could be three reasons for possibly missing an intermittent ditch. First, the ditch might not be included in the ditch layer that was provided by the City of Jacksonville (through FDEP) and used in our modeling. The second reason is that the ditch may not be reflected in the LiDAR DEM, which is the basis of the ArcNLET modeling. The last reason is that the ditch may be missed during the resampling of the LiDAR DEM, as shown in Figure 2. Regardless of the reasons for the possibly missing intermittent ditch, the problem can be easily resolved by the field investigation suggested by TAC. Once the missing intermittent ditch is identified in field investigation, it can be added to the ditch layer or the LiDAR DEM, if the first two reasons are true. Otherwise, we can conduct a new resampling with finer resolution as discussed above.

Response to Recommendation 2

Using hydraulic conductivity values reported in the lowest soil horizon of the Soil Survey as a proxy for aquifer hydraulic properties can result in large errors. Comparisons of the Soil Survey data to slug test data available from Petroleum Clean Up site data in Eggleston and a location near Julington suggest that differences are as large as factors of 9.8, and 2.4, respectively (soil survey values less than measured).

a. Currently there is not a recommendation to address data limitations due to using the soil survey as a proxy for aquifer properties. Upon resolution of critical items and during evaluation of a proposed monitoring program, this item may be further addressed.

Clarification: We probably did not make us clear about the reason of using soil survey data as a proxy for aquifer hydraulic property. It is not required by ArcNLET. The soil data were the only source available to us when we conducted the modeling. ArcNLET is flexible to use any values of hydraulic conductivity including those from the slug test mentioned in the TAC review. We hope that a field investigation can be conducted to obtain more site-specific values of hydraulic conductivity.

Response to Recommendation 3

Seasonality as time-varying condition cannot be captured in a steady-state model. A recent study in Jacksonville has found higher nitrate loading in streams during the wet season than in the dry season, and wet season fecal counts twice that of the dry season (Ouyang, 2011). Similarly, intermittent streams and ditches which intercept groundwater flow in the wet season but not in the dry can only be considered as either flowing or dry in a steady state model.

a. The Eggleston and Julington models should be run for wet and dry conditions to assess if a steady-state average condition approach yields the average load of the two conditions[1]. Intermittent streams and ditches should be explicitly considered. These and similar simulations should assess if seasonal effects are significant.

Response: We agree with TAC that time-varying condition cannot be captured in a steady-state model. In line with this, for TAC's suggestion of running the model for wet and dry seasons, we would like to add that even this cannot capture annual-varying condition because of annual variation of hydraulic conditions. For example, which year's dry and wet conditions should be used in the TAC suggested model run. The fundamental question is to what extent TAC expects the ArcNLET model to represent reality. It is not realistic to expect that a simplified model like ArcNLET to fully represent reality.

To address the comment on seasonal variation, we propose to run ArcNLET for the dry and wet seasons. However, the flow and transport conditions for the two seasons are largely unknown at this moment. These conditions should be characterized first before running the models, because we can only simulate what we understand. While existing monitoring data can be used for the site characterization, it is necessary to collect more data for a better understanding.

Explicitly considering intermittent streams and ditches is straightforward in ArcNLET, as long as they are included in the water body layer.

Question to TAC: We have a question regarding the sentence in the TAC report that "A recent study in Jacksonville has found higher nitrate loading in streams during the wet season than in the dry season, and wet season fecal counts twice that of the dry season (Ouyang, 2011)." The study of Ouyang and Zhang (2012) is for groundwater data, but the TAC report indicates that it is for "nitrate loading in stream". In addition, Ouyang and Zhang (2012) did not report any fecal data collected from Jacksonville. More importantly, their analysis of groundwater data actually suggests that seasonable variation of NOx concentration (average over individual sites) is relatively small. Their Figure 7, copied below, shows that there is negligible variation in the four seasons in Arlington Manner, Julington Forest Subdivision, Manor Del Rio. It would be useful if the TAC report could elaborate the rational of the TAC's conclusion regarding the seasonable variation based on the study of Ouyang and Zhang (2012).

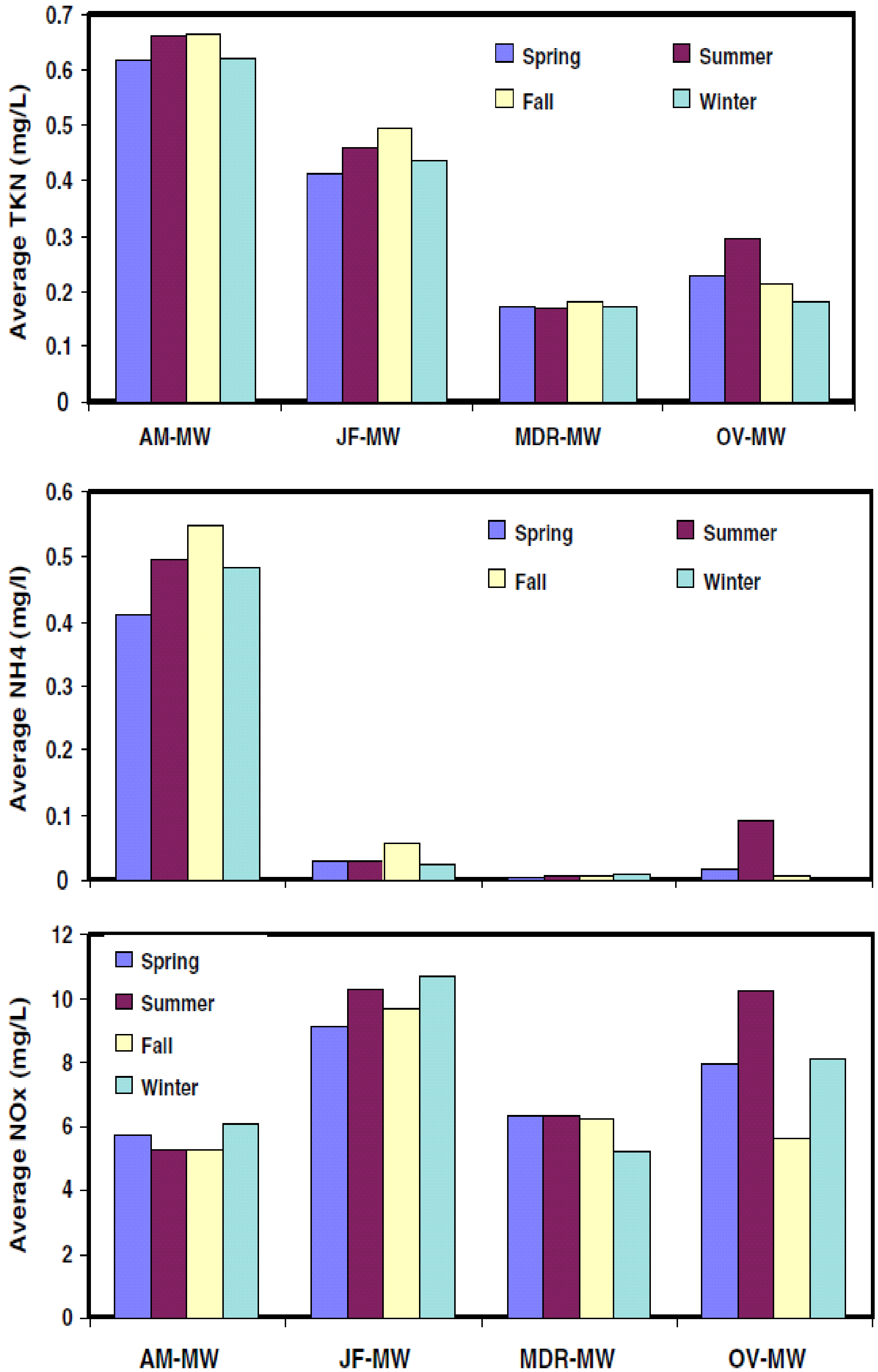
We found in Ouyang and Zhang (2012) the following sentences in introduction that seem to be closely related to the TAC conclusion:

"Arnade (1999) reported that about 40,000 residents in Palm Bay, Florida, rely on septic tanks as a means of sewage disposal and on wells as a drinking water source. The high level of precipitation (>63 cm) during the months of July to September and the presence of porous sandy soils result in high water tables and septic tank overflows. Sixty residential wells in Palm Bay were tested for fecal coliform, nitrate, and phosphate to determine if the seasonality has a significant effect on the correlation between these parameters and the proximity of wells to septic tanks. This author found that groundwater samples collected at all distances from septic tanks during the wet season (July to September) contained twice as many fecal coliforms and higher concentrations of nitrates compared to samples collected during the dry season (October to June)."

These sentences are not a conclusion of Ouyang and Zhang (2012) but an introduction of the work of Arnade (1999) for Palm Bay, not Jacksonville. Regarding nitrate concentration, the data of Arnade (1999) actually showed that nitrate concentration is higher in dry season than in wet season at locations 12-18m distance to septic tank. This is not surprising if we consider transformation of ammonium and nitrate; in dry season, more ammonium can be transformed into nitrate.

Reference: Arnade, L.J. (1999), Seasonal correlation of well contamination and septic tank distance, Ground Water, 37(6), 920-923.

Fig. 7 Seasonal variations of shallow groundwater nitrogen species



Response to Recommendation 4

The denitrification processes in the simulation model do not consider TKN; however, TKN is believed to be important, especially for systems in a high water table condition as is common in parts of Jacksonville during wet conditions. While a variety of sources of nitrogen exist and may be reflected in monitoring data, the model assumes that all of it is sourced from septic systems.

a. TKN processes should be added to the model and the methodology to distinguish other sources from septic system clarified.

Clarification: ArcNLET assumes that all nitrogen transports in groundwater in the form of nitrate. This actually will overestimate nitrate load from septic systems to surface water bodies, because groundwater movement of TKN is limited due to retardation (Bohlke et al., 2006) and considering TKN and nitrate separately will reduce the load estimate.

Reference: Bohlke, J. K., R. L. Smith, and D. N. Miller (2006), Ammonium transport and reaction in contaminated groundwater: Application of isotope tracers and isotope fractionation studies, Water Resour. Res., 42, W05411, doi:10.1029/2005WR004349.