Florida Onsite Sewage Nitrogen Reduction Strategies Study

Task D.10

Validate/Refine Complex Soil Model

White Paper

June 2014

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In association with:

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TASK D.10
WHITE PAPER

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Prepared for:

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Section 1.0
Background

1.0 Background

As part of Task D for the Florida Onsite Sewage Nitrogen Reduction Strategies (FOS-NRS) Study, validation and refinement of the complex soil model developed in Task D.8 (STUMOD-FL) is required. Validation was completed through corroboration/calibration of the model to field data from the University of Florida Gulf Coast Research & Education Center (GCREC) and the University of South Florida Lysimeter Station. Task D.10 involved this revision / improvement which has occurred throughout the project period based on findings from D.9 (Complex Soil Model Performance Evaluation), availability of field observation (e.g., data), and completion of literature reviews. The product of these revisions is a refined version of STUMOD-FL (PRv2). This white paper was prepared by the Colorado School of Mines (CSM) to document completion of Task D.10. Descriptions included herein are intended to highlight Task D progress with final reporting to be conducted as part of Tasks D.16 and D.17.

The basis of the complex soil model, STUMOD-FL (Soil Treatment Unit Model), is a spreadsheet model developed from fundamental principles of water movement and contaminant transport. The model assumes continuous, steady state effluent application and infiltration. As infiltration reaches steady state, the pressure profile or soil moisture profile does not change with time and a steady state concentration with depth is computed based on Monod reaction rates for nitrification and denitrification correlated to the soil moisture profile. Default parameters for Florida soils have been incorporated including a lookup table that lists the most prevalent soils and representative soil classification. The conceptual framework and theory incorporated into STUMOD-FL was described in the Task D.8 deliverable.

Section 2.0
Refinements to STUMOD-FL

The draft model (Task D.9) under predicted nitrogen removal through denitrification particularly in sandy soils and over predicted nitrogen removal in clayey soils. Studies have shown that nitrification occurs in the first foot of soil below the infiltrative surface, provided that the water table is not present and the soil zone is unsaturated. The field data from the GCREC site illustrated similar behavior of faster nitrification which occurred in less than a foot from the infiltrative surface. For most soil types, the original STUMOD predicted ammonium concentrations at deeper depth especially with increased loading rates. This was addressed in STUMOD-FL considering both parameter inputs and modifications in the model. Comparison of the refined model (STUMOD-FL) to field data obtained from Florida GCREC site data showed that substantial improvements were achieved in model prediction of the nitrification and denitrification processes (see Task D.9). These modifications include refining model parameters relevant to nitrification and denitrification soil moisture response function, temperature, depth distribution of suction and soil moisture, and introduction of a shallow water table option. The optimum nitrification and denitrification rates obtained from a previous study (McCray et al., 2010) were not altered, however, the soil types and van Genuchten parameters corresponding to the soil types were revised to Florida specific soil conditions as described in the previous reports (Task D8). The current revised STUMOD-FL also provides a user defined water table option as well as a water table location based on a water table fluctuation model. The revisions are discussed in the subsequent section below.

2.1 Nitrification Response Function

Soil moisture content has a large influence on the diffusivity of gases and thus on the availability of oxygen to the nitrifying microbes. It is well understood that nitrification is an aerobic process; hence nitrification is limited in nearly saturated soils, provided that the oxygen has been consumed. Furthermore, at low moisture contents the substrate (ammonium and aqueous CO_2) diffusion between soil pores is limited because of poor connectedness of “wet” soil pores. Thus, low moisture content can limit or disable nitrification as well. The conceptual model for nitrification soil moisture function is thus a function with a peak nitrification at intermediate water contents, where both oxygen diffusion and ammonium diffusion reach an optimal balance, and low nitrification at low and high water contents (Equation 2-1).

$$f_{sw} = \begin{cases} f_s + (1 - f_s)\left(\dfrac{1 - s}{1 - s_h}\right)^{e_2} & s_h < s \le 1 \\ 1 & s_l \le s \le s_h \\ f_{wp} + (1 - f_{wp})\left(\dfrac{s - s_{wp}}{s_l - s_{wp}}\right)^{e_3} & s_{wp} \le s < s_l \end{cases} \qquad (2\text{-}1)$$

where f_{sw} is the saturation-dependency function (given values between 0 and 1), f_s is the value of f_{sw} at full saturation, f_{wp} is the value of f_{sw} at the wilting point, s_h is the upper saturation boundary for optimal nitrification, s_l is the lower saturation boundary for optimal nitrification, s_{wp} is the saturation level at the wilting point, s is the actual soil saturation, and e_2 and e_3 are fitting exponents. The moisture dependency function adjusts the optimum nitrification rate based on the soil moisture content. A previously determined median rate of 56 mg N per L of soil water content per day as STUMOD-FL default input for all soils from a range of reported nitrification rates (McCray et al., 2010) was used as the maximum rate that would occur when factors contributing to nitrification are optimal. Parameters relevant to the nitrification soil moisture function were revised based on observed attenuation of ammonium in sandy and clayey soils to improve limitations of the nitrification function and the method employed to derive the parameters. In the previous WERF study (McCray et. al., 2010), parameterization of the nitrification equation was completed using available literature data. Data points were extracted from several articles that reported nitrification rates as a function of water filled porosity, and were fitted to the equation above using the Excel Solver tool. In the previous report, the different soils were parameterized separately by soil type. However, because the available data did not cover all existing soil textures, a lumped parameter value was then calculated. The parameters for the nitrification water-dependency equation were calculated by weighting the parameter values obtained for the individual soil types using the R^2 value for each soil type as a weighting factor to give more weights to soil types with a higher R^2.

A different approach was followed in the current study. Instead of parameterizing each soil type separately and weighting, lumped parameter values were calculated using the data from all soil types. The revised parameters improved the predicted nitrification and resulted in lower sum of squared error and improved the model-evaluation statistic, R^2. The revised parameters also improved STUMOD-FL and HYDRUS-2D predictions of nitrification and ammonium concentration with depth (Task D.9). The modified parameters incorporated into STUMOD-FL are given below in Table 2.1

Table 2.1
Fitted Parameters for the Nitrification Moisture Dependency Function

Parameter	e_2	e_3	s_{wp}	f_s	f_{wp}	s_l	s_h
Value	1.0	1.0	0.0	0.0	0.0	0.50	0.85

2.2 Denitrification Response Function

Just like nitrification, the maximum denitrification rate is adjusted for soil moisture content. The maximum denitrification rates under optimal conditions were previously determined (McCray et al. 2010). The assumption was that denitrification is expected to reach a maximum at fully saturated conditions (i.e. when the water filled porosity (WFP) is 100%). The maximum denitrification rates were compiled from the rates reported in the literature when the WFP was 100%. The soil moisture dependency function is given by:

$$f_{sw,dn} = \begin{cases} 0 & s < s_{dn} \\ \left(\dfrac{s - s_{dn}}{1 - s_{dn}}\right)^e & s \geq s_{dn} \end{cases} \tag{2-2}$$

where $f_{sw,\,dn}$ is the saturation-dependency function (given values between 0 and 1), s_{dn} is a threshold saturation value for denitrification, s is the actual soil saturation (θ/θ_s), and *e* is a fitting exponent. Thus, the two important parameters that control the response to soil moisture fluctuation are the threshold saturation value for denitrification (s_{dn}) and the fitting exponent (e). The optimized threshold value was set to zero based on previous work (McCray et al, 2010). It was suggested that most researchers place the threshold moisture content for denitrification at the 50%-80% WFP range (Bergstrom & Beauchamp, 1993; Grundmann & Rolston, 1987; Machefert & Dise, 2004; Wang et al, 2005). However, this previous work also showed that denitrification moisture curves with low threshold values and a large exponent value are similar to curves with mid-ranged threshold moisture values and small exponent values. Additionally, based on reported denitrification rates (Tucholke et al., 2007), some denitrification occurs when the WFP is even below 50%; this is explained by presence of anaerobic micro-sites in soils that persist even under low soil moisture contents. Given these findings, the threshold value was set to zero. In the previous work, the value for fitting exponent (*e*) was determined based on observed denitrification rates and water filled porosity only. The effect of exponent values was not evaluated in the context of calibration or comparison of observed nitrate removal to model simulated nitrate removal. The exponential parameter *e* is a measure for the steepness of the curve, and is typically greater than zero. Special cases for *e* are: *e* = 0, which gives a step function

for $f_{sw,dn}$ where $f_{sw,dn}$ = 0 below a threshold moisture content and $f_{sw,dn}$ = 1 above the threshold value (Heinen, 2006). Different models have adopted different values for the fitting exponent (*e*) (e.g., CREAMS-NT a value of 0, DRAINMOD a value of 2.0) with ranges from 0 to 2.5 as described in Heinen (2006). The ranges used in DRAINMOD sensitivity analysis were from 1.5 to 2.5. As stated earlier, model predicted nitrate removal in sandy soil was considerably lower (<5% at 2 ft) than the field observations that ranged between 5-25%. The original fitting exponent value of 2.86 and threshold value of zero resulted in a low soil moisture adjustment factor (f_{sw}), near zero for a WFP values of 40% or less. The steady state WFP value is less than 40% for a 2 cm/d loading rate for sandy soils. The soil moisture adjustment factor and the overall removal were determined to be sensitive to the fitting exponent value. Thus, the fitting exponent was revised in STUMOD-FL to reflect field observations for nitrate removal by soil texture. Default values of 1.5 and 2.5 were used for sandy and clayey soils, respectively in STUMOD-FL.

2.3 Soil Temperature Response Function

Nitrogen transformation rates have been generally observed to increase with temperature to a maximum value at about 25°C, and then decline with subsequent increases in temperature thereafter (Avrahami et al, 2003; Brady & Weil, 2002; Grundmann et al, 1995; Malhi & McGill, 1982). Thus, nitrification and denitrification rates are non-linear functions of temperature. The general shape of the function for both nitrification and denitrification is a Gaussian-type bell-curve, with a peak corresponding to the optimum temperature for nitrification and denitrification (T_{opt}) set at 25°C. The width of the curve is determined by the parameter, β (Figure 2.1). To incorporate the impact of a variable soil temperature on the nitrogen transformation rates, the following equation was used:

$$f_t = \exp\left[-0.5\beta T_{opt} + \beta T\left(1 - \frac{0.5T}{T_{opt}}\right)\right] \tag{2-3}$$

where f_t is the temperature-dependency function (with values between 0 and 1), T is the temperature, T_{opt} is the optimum temperature for nitrification and denitrification, and β is a fitting parameter. Kirschbaum (1994) detrmined that a β value of 0.186 produced a good fit for observed data. Because of this, a β value of 0.186 was used in STUMOD- FL.

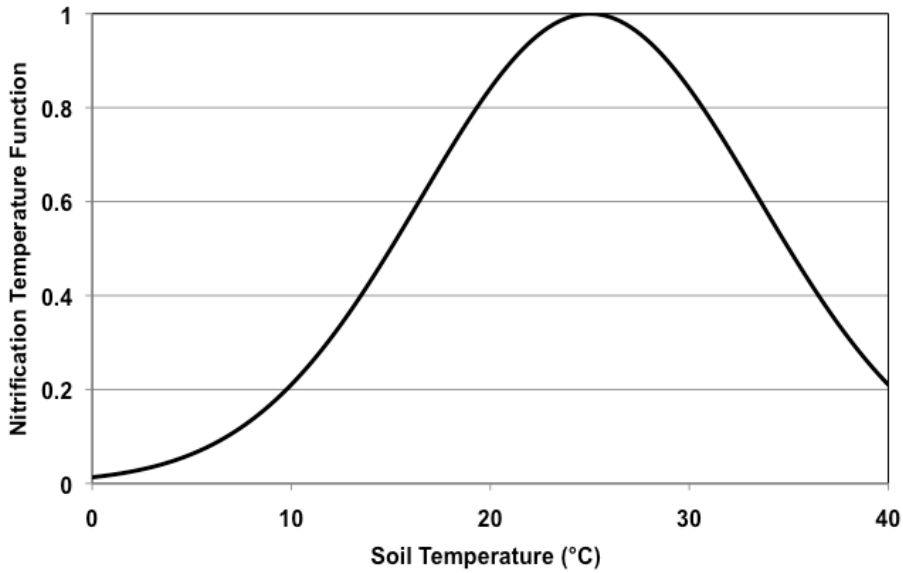

Figure 2.1: Soil Temperature Response Function (from McCray et al., 2010)

Previous studies related the parameter Q_{10} to changes in temperature (Malhi et al 1990; Stanford et al. 1975, Kirschbaum, 1995). Q_{10} is a measure of the increase or decrease in microbial activity when temperature is changed by 10°C. While Q_{10} values can range significantly, research has shown that Q_{10}=2 is typical (Addiscott, 1983; Campbell et al, 1984). A value of Q_{10}=2 means that the rate of microbial activity doubles when temperature changes by 10 °C. With an optimum temperature of 25°C, the temperature function implemented in STUMOD-FL increased the rate of transformation by a factor of 2 when temperature was increased by 10°C. The default soil temperature value for Florida (22°C) was relatively high compared to other regions in the US and close to the optimum value of 25°C. Because of this the effect of temperature is not significant for STUMOD-FL outputs, though it is an important parameter in other regions of the country.

2.4 Distribution of Suction in the Soil Profile

In STUMOD, the pressure profile is calculated as a function of the hydraulic loading rate, saturated hydraulic conductivity and Gardner's alpha parameter (α_G). The ultimate goal of calculating pressure head is to calculate the moisture distribution corresponding to the suction head because soil moisture content is a factor considered in the calculation of nitrification and denitrification. Typical ranges for α_G are 0.001 cm^{-1} to 1 cm^{-1} based on the experimentally determined values for several soil textures (Tartakovsky et al., 2003). In STUMOD-FL the default α_G value for different soil types was further refined to obtain soil

moisture and pressure distribution corresponding to soil moisture and pressure profile obtained from a HYDRUS-2D model for identical loading rates.

2.5 Water Table Fluctuation Model

In STUMOD-FL, the user can either input a known water table depth or use the water table fluctuation model to obtain a water table depth. During evaluation, the water table fluctuation model, presented in Task D.8, was modified to better fit observed water table fluctuations. The water table fluctuation model can be implemented within STUMOD-FL by two methods. If the user has access to historical water table fluctuation and precipitation data the model will conduct an auto-calibration to extract parameter values for the water table fluctuation equation. In the event that the user has precipitation data only, the model will extrapolate parameter values for the water table fluctuation equation stored within STUMOD-FL via inverse distance weighting to the location the user has specified as described in Task D.8.

During the evaluation process it was noted that the water table fluctuation model predicted the water table deeper than the observed water table. Further analysis indicated that the mathematical equation used to calculate the position of the water table was biased by the amount of historical data (50 years) used to derive the relationship. Dry periods during the 50 years of data that were used cause the model to be biased towards dry periods. To improve model performance the data was re-evaluated to select only average water years, thus excluding the influence of dry and wet years. This has improved the water table fluctuation model performance which now better predicts the location of the water table under average water year conditions.

2.6 Plant Uptake

In STUMOD-FL water and nutrient uptake are affected by both soil moisture and root distribution. After further evaluation of model performance, the root distribution function was modified which improved model stability. A large number of functions for root distribution have been proposed and used, including constant, linearly decreasing, and exponential functions. A constant root density function uses a simplified assumption that roots are distributed equally throughout the root depth. The linear and exponential models represent a linear and exponential decrease of root density from soil surface to the maximum root depth. In the initial version of STUMOD-FL, an exponential function by Gale and Grigal (1987) was used given by $Y/Y_T=1-b^z$ where Y/Y_T is the cumulative root distribution from the soil surface down to rooting depth, z is the depth varying from zero to the maximum root depth (z_{max}), and b is a vegetation specific parameter for root distribution. One limitation of this function is that it is sensitive to the b value. Hence, it requires selection of

appropriate values depending on the vegetation type and the maximum root depth to obtain the correct distribution of roots throughout the root depth. If appropriate values are not selected, roots may be distributed too shallow. In this case, all the roots could be distributed within a fraction of the true root depth. There is not sufficient data in the literature to parameterize the function. Thus, in the initial version of STUMOD-FL a function was incorporated to automatically calculate a value for b that will result in a cumulative root distribution value (Y/Y_T) of 1 at z_{max} based on user input root depth. However, model calculated b values distributed most of the roots close to the ground surface and in some cases the iteration to calculate the b value caused instability in the model. Thus, the root distribution function was modified to a linear function. The linear function requires the root depth only and results in a linear decrease in the root density from a maximum at the ground surface to zero at user input root depth. The plant uptake and reduction in concentration due to plant uptake were similar for both root distribution functions although the distribution of the uptake was different. For the exponential root distribution, most of reductions occurred near the infiltrative surface compared to the linear function.

2.7 User Input for Layers

During subsequent testing of STUMOD-FL it was noted that it was necessary to simplify the graphical user interface (GUI) to avoid user errors inputting the data. There are several options available to the user to define the location of the water table, the number of soil layers, plant nutrient uptake and method of obtaining temperature inputs for calculation of evapotranspiration. It was determined that the GUI could be simplified if these options were active only when they were being utilized.

The STUMOD-FL GUI was redesigned to visibly inactivate those options that are not being used and activate the options that are, drawing the user's attention to those areas where input is required. The water table option will activate the area of the GUI that takes input for calculating the location of the water table and inactivate the input box for a user-defined water table. Also soil layers 2 and 3 remain inactive when only one layer is selected, but when multiple layers are selected the appropriate number of layers become active. The user is also prompted by a pop up box to proceed to layers 2 or 3, depending on their selection, to enter the soil properties for those layers.

The method utilized by STUMOD-FL for the default thickness of each soil layer was also modified. The previous version of STUMOD-FL assigned the first layer a default thickness equal to the entire soil profile and subsequent layers a thickness of 0. This approach was modified so that the total soil profile is divided evenly between the number of soil layers for the default condition. This is important for users who are learning to use STUMOD because they will note a difference in STUMOD-FL outputs with multiple layers whereas previously no difference would exist unless the user knew to change the default thickness.

The temperature and plant uptake input options were also modified to activate the appropriate input locations for each option ensuring the user does not incorrectly enter the data.

Additional modifications are being incorporated to the STUMOD-FL GUI. One of the modifications is that for most of the inputs, the input boxes will be inactive if the user chooses to use default values except for common inputs such as soil type, water table depth, hydraulic loading rate and effluent concentration. But if the user wants other inputs, they can activate the input boxes by choosing ‘user input values’. Often the most effective method to learn a new software program is by trial and error which is why these modifications to the GUI were critical.

2.8 Summary

STUMOD was modified for Florida specific conditions and the tool was refined to better fit observed data. STUMOD-FL is the product of these modifications. A few of the modifications were added prior to evaluations conducted in Task D.9 because of observed short comings based on literature values on nitrate removal. Other modifications were incorporated in STUMOD-FL during Task D.9 evaluation because obvious modifications were needed. Parameters for soil moisture and temperature dependence functions for nitrification and denitrification were revised based on literature data, and observed nitrogen removal. A look-up table with default soil classification was added for the most prevalent soils in Florida. Parameter values in the soil temperature function were modified to fit observed data from other field studies. Modifications to hydrologic subroutines in STUMOD-FL include: the pressure distribution function, travel time calculation, and the water table fluctuation model. Options were also added to give users more flexibility to better characterize the site specific soil and hydrologic conditions.

Section 3.0
Validation of STUMOD-FL

Because any modifications to STUMOD-FL should be corroborated and validated against field observations and the conceptual model, the changes that now characterize STUMOD-FL have been evaluated by the same methods detailed in Task D.9. Results from evaluation and corroboration indicate that STUMOD-FL agrees with the conceptual model that was used to construct it and model outputs generally agree with field observations. Data from Task C home sites could not be used for Task D.10 since vadose zone monitoring was not conducted. Groundwater data from home sites will be used in Task D.12 for performance evaluation of the combined complex soil / aquifer models. Further modification of STUMOD-FL requires additional field data, preferably from other locations throughout Florida, so as to not bias the model to site specific conditions.

Section 4.0
Nomographs

The revised version of STUMOD-FL (Task D.10) was used to prepare a series of nomographs of the same conditions represented in Task D.7. Because STUMOD-FL is a 1D model, it cannot capture unequal loading rates and/or variable inputs (e.g., rainfall, diurnal variations). The different hydraulic loading rates used in the unequal distribution scenarios have been included in the nomographs, but differing HLRs applied to the same soil in a single STUMOD-FL simulation is not possible.

Table 4.1
Summary of Conditions Illustrated in Nomographs from STUMOD-FL Simulations

Task D.7 Scenario ID	Summary of Conditions[1]					Nomograph Illustrating STUMOD-FL Output
	Dist Config	Soil Texture	Eff Quality	Depth to Water Table (ft)	HLR[3] (cm/d)	
1	T-E	SCL	STE	1	0.98	Figure 4.1
2	T-UE	SCL	STE	1	1.97	Figure 4.1
3	B-E	SCL	STE	1	2.17	Figure 4.1
4	B-UE	SCL	STE	1	4.34	Figure 4.1
5	T-E	LPS	STE	1	1.68	Figure 4.1
6	T-UE	LPS	STE	1	2.67	Figure 4.1
7	B-E	LPS	STE	1	3.37	Figure 4.1
8	B-UE	LPS	STE	1	5.35	Figure 4.1
9	T-E	MPS	STE	1	1.68	Figure 4.1
10	T-UE	MPS	STE	1	2.67	Figure 4.1
11	B-E	MPS	STE	1	3.37	Figure 4.1
12	B-UE	MPS	STE	1	5.35	Figure 4.1
13	T-E	SCL	STE	2	0.98	Figure 4.2
14	T-UE	SCL	STE	2	1.97	Figure 4.2
15	B-E	SCL	STE	2	2.17	Figure 4.2
16	B-UE	SCL	STE	2	4.34	Figure 4.2
17	T-E	LPS	STE	2	1.68	Figure 4.2
18	T-UE	LPS	STE	2	2.67	Figure 4.2
19	B-E	LPS	STE	2	3.37	Figure 4.2
20	B-UE	LPS	STE	2	5.35	Figure 4.2
21	T-E	MPS	STE	2	1.68	Figure 4.2
22	T-UE	MPS	STE	2	2.67	Figure 4.2
23	B-E	MPS	STE	2	3.37	Figure 4.2
24	B-UE	MPS	STE	2	5.35	Figure 4.2
25	T-E	SCL	STE	6	0.98	Figure 4.3
26	T-UE	SCL	STE	6	1.97	Figure 4.3
27	B-E	SCL	STE	6	2.17	Figure 4.3
28	B-UE	SCL	STE	6	4.34	Figure 4.3
29	T-E	LPS	STE	6	1.68	Figure 4.3
30	T-UE	LPS	STE	6	2.67	Figure 4.3
31	B-E	LPS	STE	6	3.37	Figure 4.3
32	B-UE	LPS	STE	6	5.35	Figure 4.3
33	T-E	MPS	STE	6	1.68	Figure 4.3
34	T-UE	MPS	STE	6	2.67	Figure 4.3
35	B-E	MPS	STE	6	3.37	Figure 4.3
36	B-UE	MPS	STE	6	5.35	Figure 4.3
37	T-E	SCL	STE	FD	0.98	Figure 4.4
38	T-UE	SCL	STE	FD	1.97	Figure 4.4
39	B-E	SCL	STE	FD	2.17	Figure 4.4
40	B-UE	SCL	STE	FD	4.34	Figure 4.4

Table 4.1(con't)
Summary of Conditions Illustrated in Nomographs from STUMOD-FL Simulations

Task D.7 Scenario ID	Summary of Conditions[1]					Nomograph Illustrating STUMOD-FL Output
	Dist Con-fig	Soil Texture	Eff Quality	Depth to Water Table (ft)	HLR[3] (cm/d)	
41	T-E	LPS	STE	FD	1.68	Figure 4.4
42	T-UE	LPS	STE	FD	2.67	Figure 4.4
43	B-E	LPS	STE	FD	3.37	Figure 4.4
44	B-UE	LPS	STE	FD	5.35	Figure 4.4
45	T-E	MPS	STE	FD	1.68	Figure 4.4
46	T-UE	MPS	STE	FD	2.67	Figure 4.4
47	B-E	MPS	STE	FD	3.37	Figure 4.4
48	B-UE	MPS	STE	FD	5.35	Figure 4.4
49	T-UE	MPS	NE	2	2.67 & 5.35	Figure 4.5
50	T-UE	MPS	NE	6	2.67 & 5.35	Figure 4.5
51	T-UE	LPS	NE	2	2.67 & 5.35	Figure 4.5
52	T-UE	LPS	NE	6	2.67 & 5.35	Figure 4.5
53	B-UE	MPS	NE	2	1.68 & 3.37	Figure 4.5
54	B-UE	MPS	NE	6	1.68 & 3.37	Figure 4.5
55	B-UE	LPS	NE	2	1.68 & 3.37	Figure 4.5
56	B-UE	LPS	NE	6	1.68 & 3.37	Figure 4.5
57	T-UE	SCL	NE	6	2.17 & 4.34	Figure 4.5
58[2]	T-UE	LPS 0-2 ft; SCL 2-8 ft	STE	2	2.67 & 5.35	none[3]
59[2]	T-UE	LPS 0-2 ft; SCL 2-8 ft	STE	6	2.67 & 5.35	none[3]
60[2]	T-UE	LPS 0-4.083 ft; SCL 4.083-8 ft	STE	6	2.67 & 5.35	Figure 4.6
61[2]	T-UE	LPS 0-5.25 ft; SCL 5.25-8 ft	STE	6	2.67 & 5.35	Figure 4.6
62[2]	T-UE	MPS 0-4.083 ft; SCL 4.083-8 ft	STE	6	2.67 & 5.35	Figure 4.6
63[2]	T-UE	MPS 0-5.25 ft; SCL 5.25-8 ft	STE	6	2.67 & 5.35	Figure 4.6
64[2]	T-UE	SCL 0-4.083 ft; MPS 4.083-8 ft	STE	6	2.67 & 5.35	Figure 4.6

[1] *Distribution Configuration: T-E, trench, equal; T-UE, trench, unequal; B-E, bed, equal; B-UE, bed, unequal.*
Soil Texture: SCL, sandy clay loam; LPS, less permeable sand; MPS, more permeable sand.
STE as 60 mg-N/L NH_4 + 0 mg-N/L NO_3; NE as 15 mg-N/L NH_4 + 15 mg-N/L NO_3
Depth to water table below the infiltrative surface. FD = free drainage.

[2] *Soil texture depth intervals are relative to ground surface (note, trench bottom is located at 2 ft below ground surface).*

[3] *STUMOD-FL is a 1D model and therefore cannot capture sidewall effects or unequal loading. For unequal loading, STUMOD-FL was run twice for nomographs.*

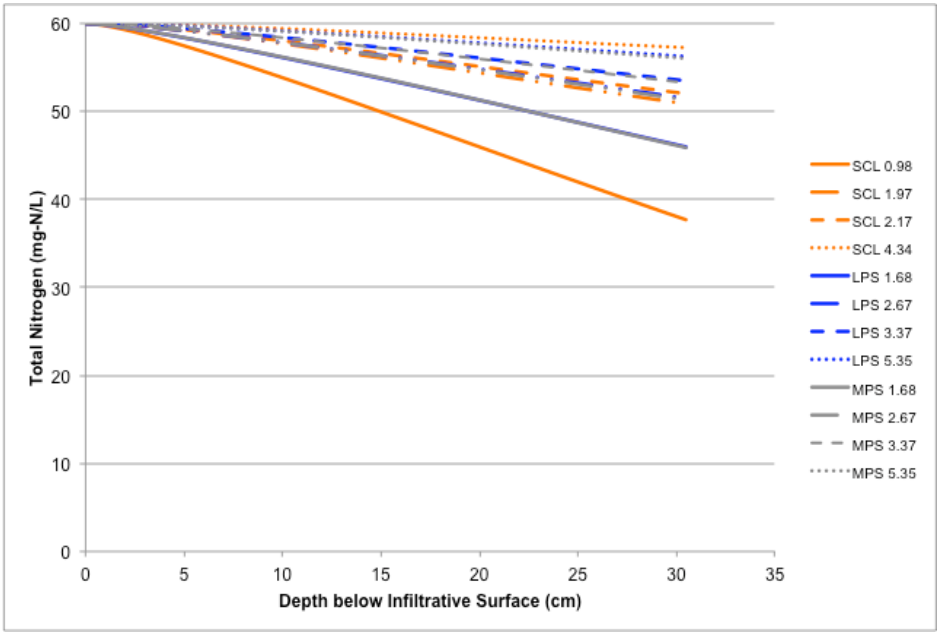

Figure 4.1: Nomograph of STUMOD-FL simulation outputs for 1 ft water table depth scenarios (see Table 4.1, runs 1-12)

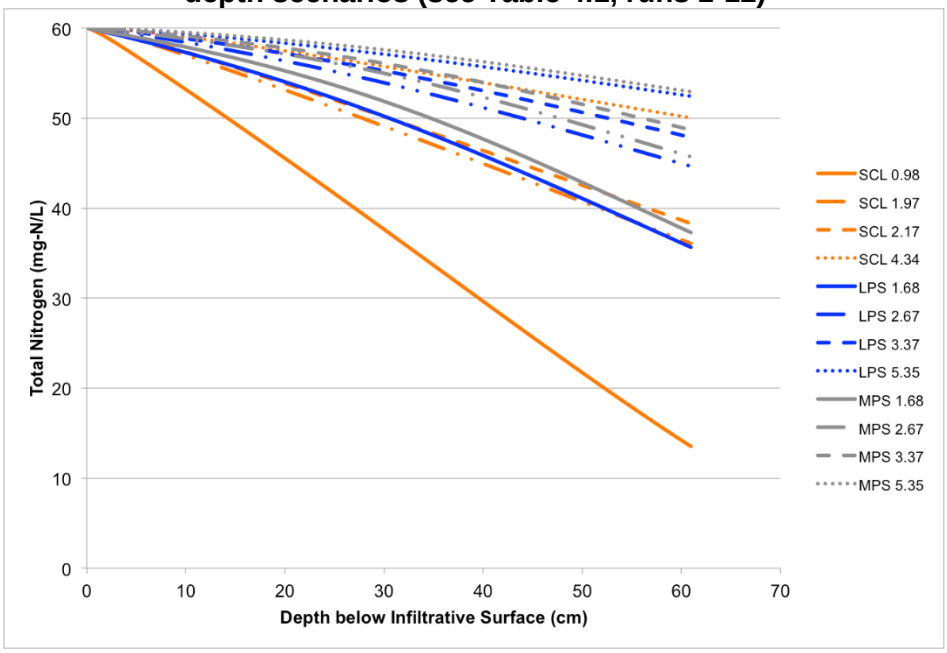

Figure 4.2: Nomograph of STUMOD-FL simulation outputs for 2 ft water table depth scenarios (see Table 4.1, runs 13 - 24)

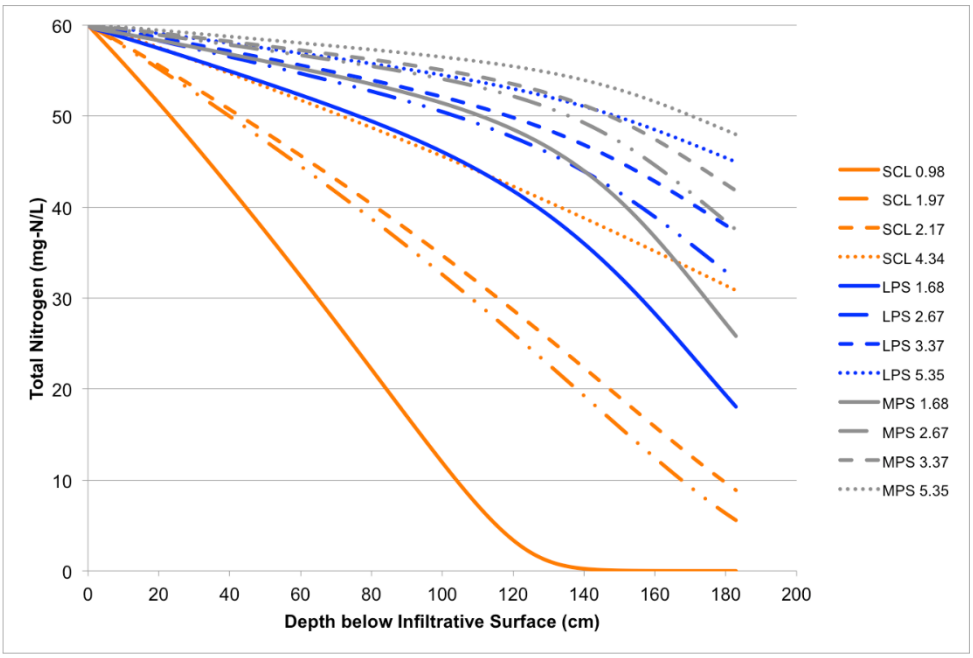

Figure 4.3: Nomograph of STUMOD-FL simulation outputs for 6 ft water table depth scenarios (see Table 4.1, runs 25 - 36)

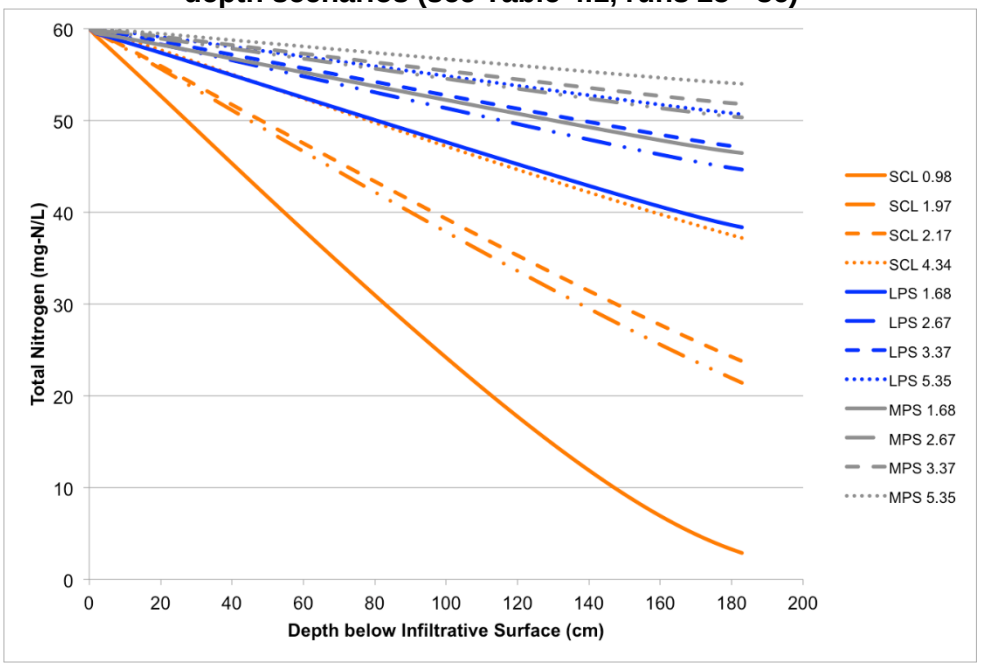

Figure 4.4: Nomograph of STUMOD-FL simulation outputs for deep water table scenarios (free drainage) (see Table 4.1, runs 37 - 48)

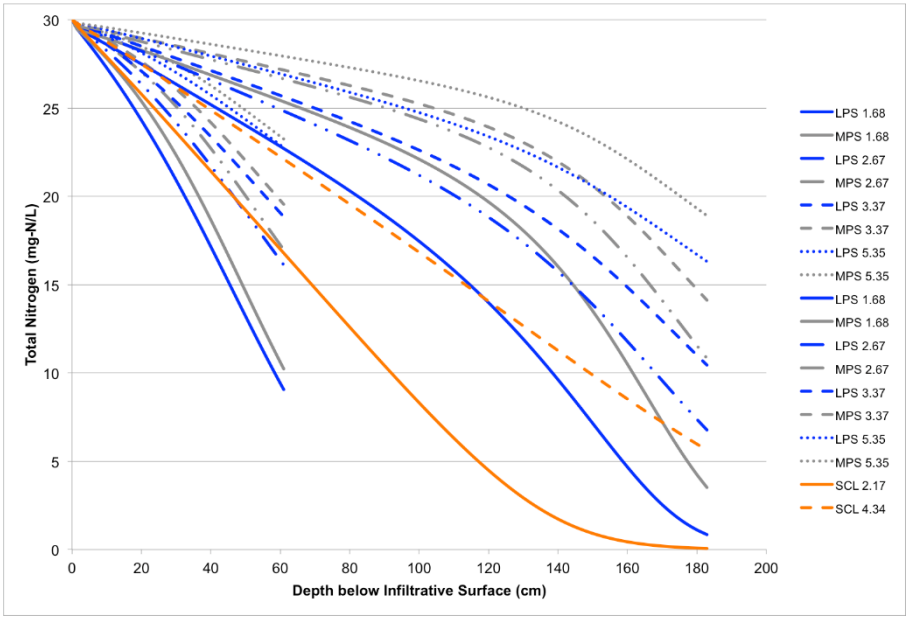

Figure 4.5: Nomograph of STUMOD-FL simulation outputs for scenarios with nitrified effluent (see Table 4.1, runs 49 - 57)

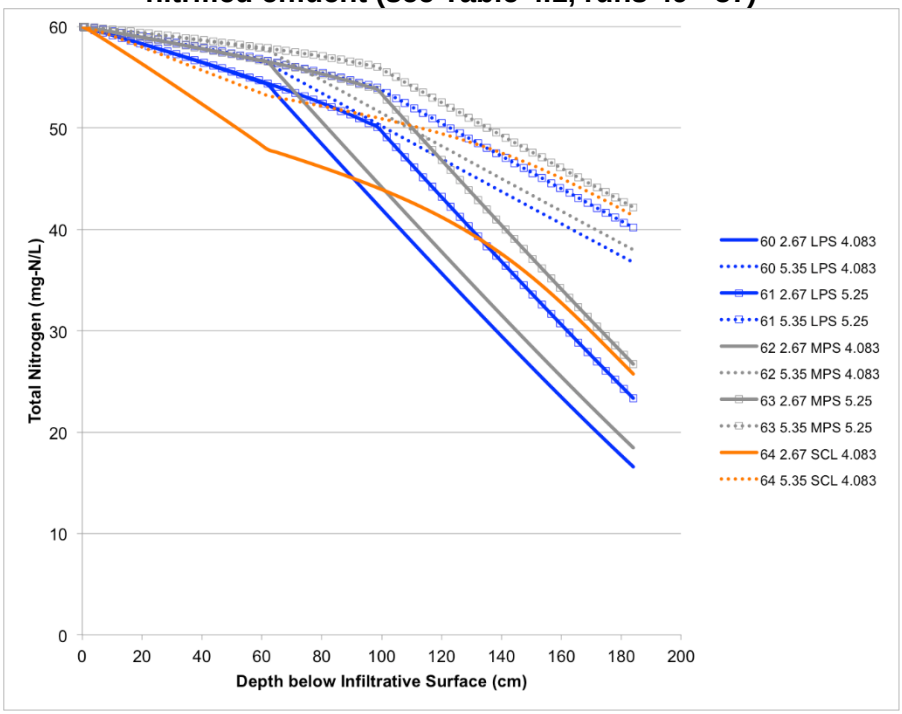

Figure 4.6: Nomograph of STUMOD-FL simulation outputs for scenarios with layered soils. Note legend reflects scenario (e.g., 60), HLR (e.g., 2.67 cm/d), soil texture (e.g., LPS), and extent of top layer below the infiltrative surface (e.g., 4.083 ft). (see Table 4.1, runs 60 - 64)

Section 5.0
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