Florida Onsite Sewage Nitrogen Reduction Strategies Study

Task D.7

Simple Soil Tools

White Paper

December 2013

Revised May 2014

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TASK D.7
WHITE PAPER

Simple Soil Tools

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Section 1.0
Background

1.1 Background

Task D of the Florida Onsite Sewage Nitrogen Reduction Strategies Study includes development of simple tools (Task D.7) to aid evaluation of nitrogen reduction in Florida soils. The approach implemented included set-up and model runs of HYDRUS-2D for selected conditions representative of common Florida onsite wastewater treatment systems OWTS (also referred to as OSTDS) operating conditions. The simple tools are a series of look-up tables with the results from the model simulations summarized in tabular form to enable estimation and comparison of nitrogen removal. In addition, over 60 graphical displays from the HYDRUS-2D model simulations are provided. Corroboration of the results to data collected at the University of South Florida Lysimeter Station and the University of Florida Gulf Coast Research and Education Center (GCREC) was also completed. This report has been prepared by the Colorado School of Mines (CSM) to document the simple tool development, tool use, and the model outputs for Task D.7. The final Task D Guidance Manual will incorporate the decision support framework including the assumptions and limitations of the simple tools as well as how to use the tools.

The purpose of the Task D.7 simple tools is to provide summary tables and illustrations that capture the subsurface behavior under a range of typical OWTS operating conditions in Florida, such that if key operating conditions change, there is a general understanding of the expected affect to treatment performance. HYDRUS-2D was used to simulate these operating conditions to illustrate the behaviors. A simple to use tool is not the same as a simple model. For Task D.7 a complex numerical model (HYDRUS-2D) was used to develop simple to use tools (look-up tables and graphical outputs). While these simple tools are helpful for a wide range of common OWTS operating conditions, there are limitations to the use of these simple tools. Specifically, Task D.7 simple tools may not be sufficient to adequately predict performance at an entirely different site. While simple tools have the benefit of providing insight on OWTS behavior under different operating conditions, there is uncertainty in these simple tools that limits extrapolation to certain scenarios (e.g., predicting nitrogen discharge to sensitive environments, operating conditions significantly different than those represented, and/or sites with environmental complexities). In these cases, it must be recognized that more rigorous numerical modeling specific to the particular site conditions is required. The

user needs to decide if the simple tools provided in Task D.7 are appropriate for a specific site condition or if more rigorous modeling/tools are required.

The understanding of subsurface behavior is critical as there are literally endless conditions for operating systems. However, the fundamental mechanisms that control treatment performance are limited, and therefore multiple examples will not increase the information gained. Specifically the key guiding principles relevant to subsurface behavior and treatment performance are:

1) hydraulic loading rate (HLR) to the soil,
2) effluent quality and composition applied to the soil,
3) soil texture, and
4) depth to groundwater.

The Task D.7 simple tools enable a comparative analysis between operating and/or environmental conditions providing a general understanding of expected treatment performance. There are several underlying assumptions related to the simple tool development and use including:

- This report is specific to unsaturated conditions that reflect the nitrogen expected to reach groundwater (i.e., input to a saturated zone).
- The target audience includes individuals within the OWTS industry with a general understanding of system design and environmental conditions.
- If more precise information is required for specific site conditions, it is recommended that the user conduct more specific modeling (i.e., STUMOD-FL, HYDRUS-2D, etc.).

The approach used to develop the simple tools was based on a factorial design incorporating four distribution configurations, three soil textures and three water table depths. The HLR was not incorporated as a factor, but rather provided by FDOH as a representative HLR for the identified distribution configurations. Additional representative conditions were provided by FDOH. All simulated conditions are summarized in Table 1.1 and Figures 1.1 through 1.4.

Table 1.1
Revised Summary of the Task D.7 HYDRUS-2D Simulations

	Distribution Configuration[1]	Soil Texture	HLR (cm/d)	Effluent Nitrogen Composition (mg-N/L)	Water Table Depth[2]
1	Trenches, equal dist	sandy clay loam	2.17	60 mg-N/L NH_4; 0 mg-N/L NO_3	1 ft below IS
2	Trenches, unequal dist	sandy clay loam	4.34, 2.17, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	1 ft below IS
3	Bed, equal dist	sandy clay loam	0.98	60 mg-N/L NH_4; 0 mg-N/L NO_3	1 ft below IS
4	Bed, unequal dist	sandy clay loam	1.97, 0.98, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	1 ft below IS
5	Trenches, equal dist	less permeable sand	2.67	60 mg-N/L NH_4; 0 mg-N/L NO_3	1 ft below IS
6	Trenches, unequal dist	less permeable sand	5.35, 2.67, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	1 ft below IS
7	Bed, equal dist	less permeable sand	1.68	60 mg-N/L NH_4; 0 mg-N/L NO_3	1 ft below IS
8	Bed, unequal dist	less permeable sand	3.37, 1.68, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	1 ft below IS
9	Trenches, equal dist	more permeable sand	2.67	60 mg-N/L NH_4; 0 mg-N/L NO_3	1 ft below IS
10	Trenches, unequal dist	more permeable sand	5.35, 2.67, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	1 ft below IS
11	Bed, equal dist	more permeable sand	1.68	60 mg-N/L NH_4; 0 mg-N/L NO_3	1 ft below IS
12	Bed, unequal dist	more permeable sand	3.37, 1.68, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	1 ft below IS
13	Trenches, equal dist	sandy clay loam	2.17	60 mg-N/L NH_4; 0 mg-N/L NO_3	2 ft below IS
14	Trenches, unequal dist	sandy clay loam	4.34, 2.17, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	2 ft below IS
15	Bed, equal dist	sandy clay loam	0.98	60 mg-N/L NH_4; 0 mg-N/L NO_3	2 ft below IS
16	Bed, unequal dist	sandy clay loam	1.97, 0.98, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	2 ft below IS
17	Trenches, equal dist	less permeable sand	2.67	60 mg-N/L NH_4; 0 mg-N/L NO_3	2 ft below IS
18	Trenches, unequal dist	less permeable sand	5.35, 2.67, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	2 ft below IS
19	Bed, equal dist	less permeable sand	1.68	60 mg-N/L NH_4; 0 mg-N/L NO_3	2 ft below IS
20	Bed, unequal dist	less permeable sand	3.37, 1.68, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	2 ft below IS
21	Trenches, equal dist	more permeable sand	2.67	60 mg-N/L NH_4; 0 mg-N/L NO_3	2 ft below IS
22	Trenches, unequal dist	more permeable sand	5.35, 2.67, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	2 ft below IS
23	Bed, equal dist	more permeable sand	1.68	60 mg-N/L NH_4; 0 mg-N/L NO_3	2 ft below IS
24	Bed, unequal dist	more permeable sand	3.37, 1.68, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	2 ft below IS
25	Trenches, equal dist	sandy clay loam	2.17	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
26	Trenches, unequal dist	sandy clay loam	4.34, 2.17, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
27	Bed, equal dist	sandy clay loam	0.98	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
28	Bed, unequal dist	sandy clay loam	1.97, 0.98, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
29	Trenches, equal dist	less permeable sand	2.67	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
30	Trenches, unequal dist	less permeable sand	5.35, 2.67, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
31	Bed, equal dist	less permeable sand	1.68	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS

Table 1.1 (cont.)
Revised Summary of the Task D.7 HYDRUS-2D Simulations

	Distribution Configuration[1]	Soil Texture	HLR (cm/d)	Effluent Nitrogen Composition (mg-N/L)	Water Table Depth[2]
32	Bed, unequal dist	less permeable sand	3.37, 1.68, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
33	Trenches, equal dist	more permeable sand	2.67	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
34	Trenches, unequal dist	more permeable sand	5.35, 2.67, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
35	Bed, equal dist	more permeable sand	1.68	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
36	Bed, unequal dist	more permeable sand	3.37, 1.68, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
37	Trenches, equal dist	sandy clay loam	2.17	60 mg-N/L NH_4; 0 mg-N/L NO_3	free drainage
38	Trenches, unequal dist	sandy clay loam	4.34, 2.17, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	free drainage
39	Bed, equal dist	sandy clay loam	0.98	60 mg-N/L NH_4; 0 mg-N/L NO_3	free drainage
40	Bed, unequal dist	sandy clay loam	1.97, 0.98, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	free drainage
41	Trenches, equal dist	less permeable sand	2.67	60 mg-N/L NH_4; 0 mg-N/L NO_3	free drainage
42	Trenches, unequal dist	less permeable sand	5.35, 2.67, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	free drainage
43	Bed, equal dist	less permeable sand	1.68	60 mg-N/L NH_4; 0 mg-N/L NO_3	free drainage
44	Bed, unequal dist	less permeable sand	3.37, 1.68, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	free drainage
45	Trenches, equal dist	more permeable sand	2.67	60 mg-N/L NH_4; 0 mg-N/L NO_3	free drainage
46	Trenches, unequal dist	more permeable sand	5.35, 2.67, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	free drainage
47	Bed, equal dist	more permeable sand	1.68	60 mg-N/L NH_4; 0 mg-N/L NO_3	free drainage
48	Bed, unequal dist	more permeable sand	3.37, 1.68, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	free drainage
49	Trenches, unequal dist	more permeable sand	5.35, 2.67, 0	15 mg-N/L NH_4; 15 mg-N/L NO_3	2 ft below IS
50	Trenches, unequal dist	more permeable sand	5.35, 2.67, 0	15 mg-N/L NH_4; 15 mg-N/L NO_3	6 ft below IS
51	Trenches, unequal dist	less permeable sand	5.35, 2.67, 0	15 mg-N/L NH_4; 15 mg-N/L NO_3	2 ft below IS
52	Trenches, unequal dist	less permeable sand	5.35, 2.67, 0	15 mg-N/L NH_4; 15 mg-N/L NO_3	6 ft below IS
53	Bed, unequal dist	more permeable sand	3.37, 1.68, 0	15 mg-N/L NH_4; 15 mg-N/L NO_3	2 ft below IS
54	Bed, unequal dist	more permeable sand	3.37, 1.68, 0	15 mg-N/L NH_4; 15 mg-N/L NO_3	6 ft below IS
55	Bed, unequal dist	less permeable sand	3.37, 1.68, 0	15 mg-N/L NH_4; 15 mg-N/L NO_3	2 ft below IS
56	Bed, unequal dist	less permeable sand	3.37, 1.68, 0	15 mg-N/L NH_4; 15 mg-N/L NO_3	6 ft below IS
57	Trenches, unequal dist	sandy clay loam	4.34, 2.17, 0	15 mg-N/L NH_4; 15 mg-N/L NO_3	6 ft below IS
58[2]	Trenches, unequal dist	less permeable sand 0-2 ft; sandy clay loam 2-8 ft	4.34, 2.17, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	2 ft below IS
59[2]	Trenches, unequal dist	less permeable sand 0-2 ft; sandy clay loam 2-8 ft	4.34, 2.17, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS

Table 1.1 (cont.)
Revised Summary of the Task D.7 HYDRUS-2D Simulations

	Distribution Configuration[1]	Soil Texture	HLR (cm/d)	Effluent Nitrogen Composition (mg-N/L)	Water Table Depth[2]
60[2]	Trenches, unequal dist	less permeable sand 0-4.083 ft; sandy clay loam 4.083-8 ft	5.35, 2.67, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
61[2]	Trenches, unequal dist	less permeable sand 0-5.25 ft; sandy clay loam 5.25-8 ft	5.35, 2.67, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
62[2]	Trenches, unequal dist	more permeable sand 0-4.083 ft; sandy clay loam 4.083-8 ft	5.35, 2.67, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
63[2]	Trenches, unequal dist	more permeable sand 0-5.25 ft; sandy clay loam 5.25-8 ft	5.35, 2.67, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS
64	Trenches, unequal dist	sandy clay loam 0-4.083 ft; less permeable sand 4.083-8 ft	5.35, 2.67, 0	60 mg-N/L NH_4; 0 mg-N/L NO_3	6 ft below IS

[1] *See Figures 1.1 – 1.4 for graphical representation of the distribution configuration.*

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

Note: Representative scenario conditions 49 - 63 provided by FDOH.

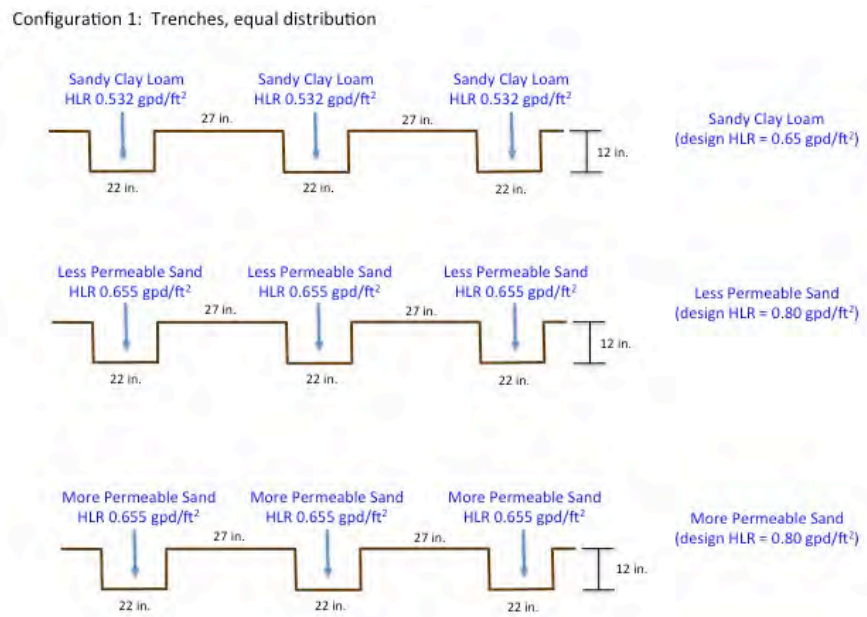

Figure 1.1

Distribution Configuration: Equal loading to trenches

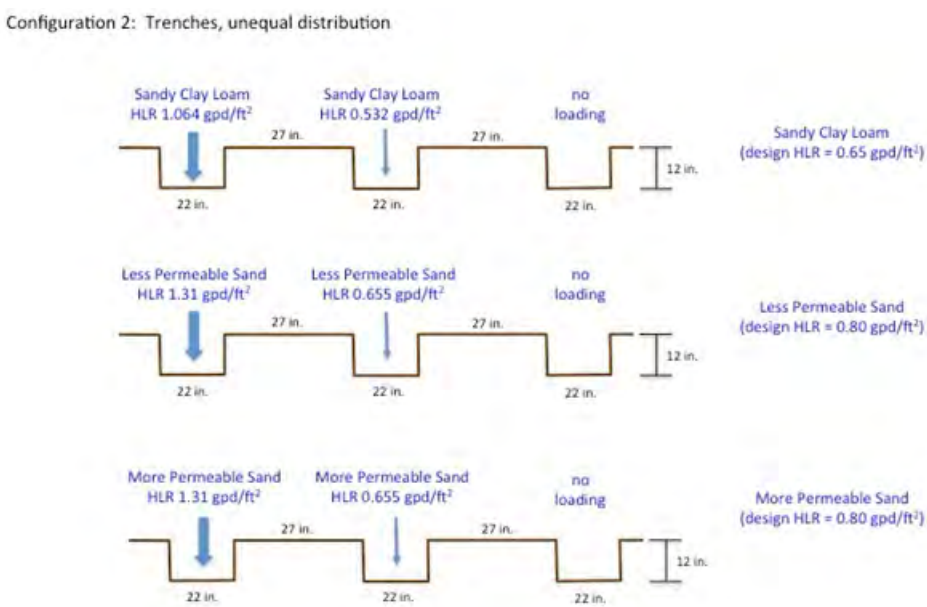

Figure 1.2

Distribution Configuration: Unequal loading to trenches

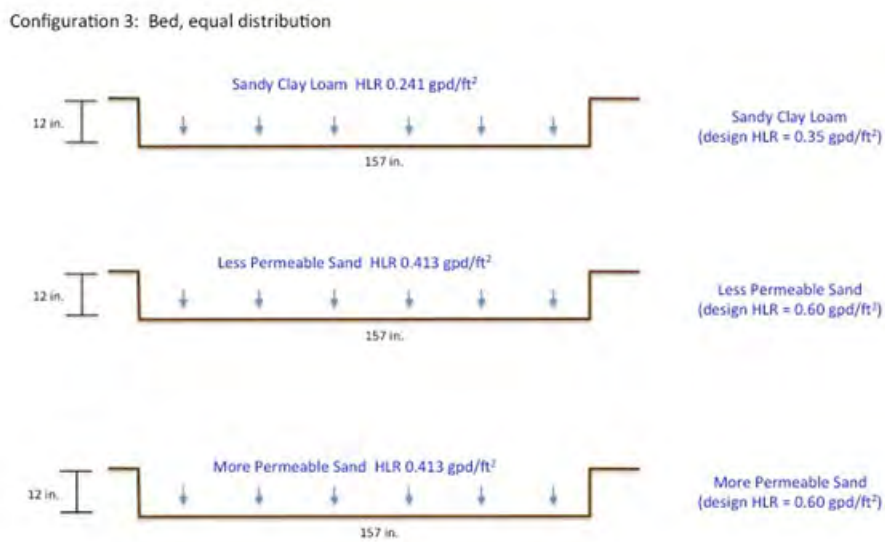

Figure 1.3
Distribution Configuration: Equal loading to beds

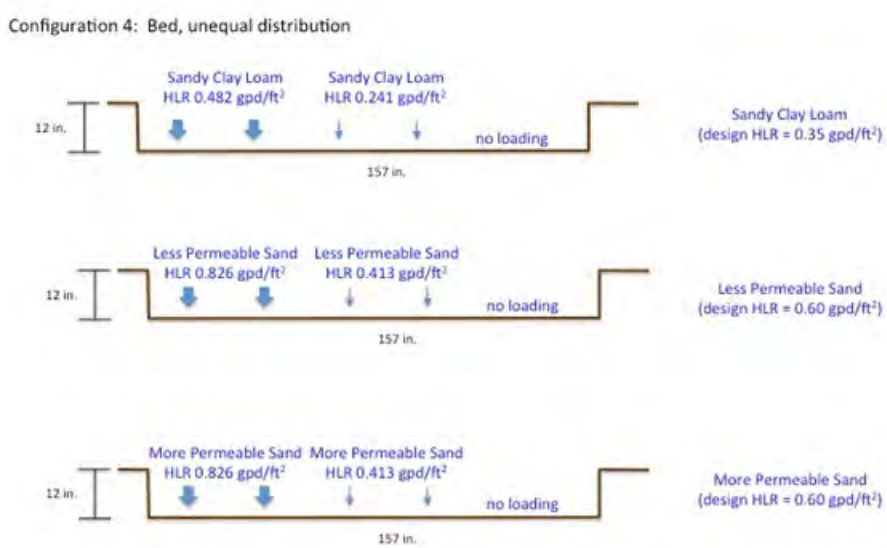

Figure 1.4
Distribution Configuration: Unequal loading to beds

1.2 Relevance and Limitations of Simple Tools

When evaluating OWTS performance, ideally, the simplest tools are the first to be used. These simple tools are best used as screening tools and require little user sophistication, but cannot incorporate many of the complexities associated with different OWTS implementation or treatment processes. The D.7 look-up tables and graphical displays are simple tools developed using steady state HYDRUS-2D simulations. These simple tools are intended to provide insights into expected OWTS behaviors as a result of changes in site specific and operating conditions. A steady state model does not incorporate many of the complexities associated with OWTS treatment processes, nor capture diurnal variations, short term influences, or system perturbations. However, a steady state is still appropriate for the development of the simple tools since the main objective in this case is to get an understanding of the relative differences in responses (concentration at the water table or mass loading) as a result of change in site specific conditions (e.g., soil texture) or operating conditions (e.g., configurations or effluent concentrations).

Corroboration with field data at the USF and GCREC sites showed that including precipitation resulted in lower model estimates of nitrogen flux because of a dilution effect. The simple tools developed based on steady state produced a more conservative estimate (less nitrogen removal or a higher nitrogen flux) representative of what would occur during an extended dry period each year and are desirable from design perspective. As such these simple tools may not be appropriate for decision making, particularly if the health, regulatory, or legal risks associated with the decision are high. If a user is interested in obtaining reliable predictive results for small spatial and temporal resolutions then more complex modeling is required (i.e., use of simple tools is not appropriate). However, the relative impacts based on steady state models are still relevant.

The D.7 simple tools provide an indication of OWTS subsurface behaviors for specific technical assumptions, site conditions, and OWTS operating conditions. Information provided by these simple tools is based on data generated by a numerical model that can incorporate complex treatment and operating conditions. Because the choices for representative OWTS conditions are limited, the user must decide how their OWTS system fits within the limited treatment estimations displayed by the graphics.

Uncertainty exists in all models and model outputs. Even after calibration, there is uncertainty simply because it is unlikely to find error-free observational data and because no simulation model is an entirely true reflection of the physical process being modeled. Transferring models to conditions not accounted for (even if simplified for the modeled condition) results in a higher level of uncertainty. The numerical model used for simple tool development, HYDRUS-2D, has uncertainty in the output results based on the simplifying assumptions built into the model (see Section 2).

For D.7, the model used default parameters developed for three generalized soil textures. Thus, the outputs provide a good understanding of the relative differences due to changes in modeled scenarios (distribution configurations, soil textures, effluent quality,

and water table depths) even though uncertainty remains in the model. Because the distribution configuration combines several factors, some behaviors cannot be directly attributed to a specific factor. Thus, caution should be used in over interpretation due to the number of factors and possible interaction among factors potentially affecting the observed differences in nitrogen removal. However, side-by-side visual inspection is useful to qualitatively illustrate differences in performance.

Section 2.0
Simple Tool Development

2.1 Assessment of Florida Soils

Evaluation of Florida soils was required to determine Florida specific model parameters for the conditions listed in Table 1.1. Several approaches to the assessment were required. First, all soil series were evaluated to determine the general prevalence of various soil textures and specific soil series within Florida. The Cooperative Soil Survey (USDA) data was used for this initial assessment with the results previously reported in Task D.7 25% complete progress report. A summary of the findings is in Appendix A. There were two key findings from this first assessment that led to further assessment: 1) while sand is the predominant soil texture, relatively few soil series encompass the majority of the land area and OWTS installations, and 2) relying on only listed soil texture classification may not capture the properties of the soil affecting transport and transformation below the OWTS.

Based on these preliminary findings, further assessment of the soil series was required to address two goals. The first goal was to enable summarization of the soil data to develop parameters used in HYDRUS-2D during simple tool development and as default parameters that will be used in STUMOD-FL. Because all soil series cannot be incorporated into the STUMOD-FL graphical user interface and evaluation of all soil series with reported data is beyond the budget/scope of this task, the available soil data had to be summarized for determination of default parameters by soil texture. This assessment included determination of descriptive statistics from the data within the Florida Soil Characterization Data Retrieval System (University of Florida, 2007) for individual soil series and pooled soil data based on soil texture. The results from this assessment will be used for default values in the STUMOD-FL graphical user interface (i.e., pooled soil data based on soil texture), to populate look-up tables incorporated into STUMOD-FL (i.e., descriptive statistics and parameter estimation for selected individual soil series), and to determine default parameters in HYDRUS-2D for simple tool development (i.e., data analysis for sandy clay loam).

The second goal was to determine if the sand soil series could be grouped and summarized to better reflect the variability known to exist across Florida sand soil series (e.g., a very fine sand compared to a fine sand). Due to the preponderance of sand textures in Florida, evaluation was required to identify if there were trends within the soils series that would enable grouping and therefore better represent the differences within sand tex-

tures. In addition, to constrain selected conditions for HYDRUS-2D simulations (identified in the scope of work as "not to exceed 60 conditions") several conference calls between the project team and FDOH lead to consensus of selecting 3 different soil textures: two sands and one sandy clay loam. A hierarchical cluster analysis was performed to identify groupings of representative sands. The results from this assessment were used in HYDRUS-2D for simple tool development (i.e., pooled soil data for the two sand groupings). The same set of default parameters will be used in the STUMOD-FL graphical user interface.

Additional assessment of soil properties is beyond the scope and budget of this task (e.g., layers within a soil series) and is the responsibility of future users, of both the simple tools included herein and tools to be developed for the project, depending on the decisions being made. The following describes the approaches for assessing the soil data to meet the two goals described above.

An assessment of soil properties included assimilation of all available data records from the Florida Soil Characterization Data Retrieval System (University of Florida, 2007) sorted by soil textural classification. The data records were then screened for complete data sets (incomplete data sets were removed from further analysis) and depths of less than 5 ft. Complete data sets included measurements of field samples for: sample depth interval; fraction of sand, silt, and clay; particle size distributions for the sand fraction; saturated hydraulic conductivity (K_{sat}); bulk density; and corresponding water contents at suctions of 3.5, 20, 30, 45, 60, 80, 150, 200, 340, and 15,000 cm. Descriptive statistics were then completed on each individual series to determine: minimum value, maximum value, average, median, standard deviation, and the interquartile range (25 and 75th percentiles). All records for a given soil texture (e.g., sandy clay loam, clay, etc.) were then combined and again descriptive statistics were evaluated to determine Florida specific representative properties for the soil texture classification.

Due to the prevalence of sandy soil textures in Florida, and in context of the finding that relatively few soils series comprise the majority of the land area, further evaluation was conducted on sandy soils if the series was ranked in the top 30 of any of three following criteria:

1) most frequently permitted soil series (based on number of recent permits issued),
2) largest areal extent based on total land area (acreage) in Florida, *or*
3) largest areal extent (again based on acreage) within all sand series.

Excluded from the analysis were the Urban series. This approach resulted in analyses of, and parameter estimation for, 40 individual sand series. Table 2.1 summarizes the sand soils series, permit ranking, and areal ranking.

To determine model parameters for sandy clay loam, an individual data record was included for further evaluation based on three criteria:

1) the Florida Soil Characterization Data Retrieval System listed the textural classification as “sandy clay loam”,
2) the series was included in the top 60 frequently permitted soil series, *and*
3) the series was included within the top 60 largest areal extent based on total land area in Florida.

This ensured that the data evaluated was representative of a sandy clay loam even though the series and/or shallow depths might have a higher sand fraction (e.g., Orangeburg, Dothan, etc.). Table 2.2 summarizes the sandy clay loam series, permit ranking, and areal ranking.

The relevant parameters for both HYDRUS-2D and STUMOD-FL are K_{sat}, residual water content (θ_r), water content at saturation (θ_s), and the van Genuchten fitting parameters α and n. K_{sat}, θ_r, and θ_s were obtained from the reported field data described above. Water content at 15,000 cm suction (15 bar) was assumed to represent θ_r and water content at 3.5 cm suction was assumed to represent θ_s. Normally, θ_s should be measured when suction is zero but since that data was not available 3.5 cm suction was deemed appropriate since it is very close to zero. To approximate the van Genuchten parameters (α and n) for the sand textures, the median reported soil moisture values (soil moisture) for each soil series at each suction head were paired. Solver was then executed using the van Genuchten equation while minimizing the sum of the squares (Appendix A, Table A.2). The median values for soil properties and the estimated van Genuchten fitting parameters for each series are summarized in Table 2.3. Model parameter estimation for the sandy clay loam followed the same method, however, due to limited data records for individual soil series, all of the data records were pooled and the median soil moisture was paired with the suction to determine single representative values for sandy clay loam α and n (Table 2.4).

Table 2.1
Listing of Florida Sand Series Evaluated for Parameter Estimation

ID	Soil Series	# of Permits[1]	Ranking based on Permits	Areal Extent (acres)	Ranking within Total Florida Land Area	Ranking within Sand Series only	# of Records Used in Parameter Estimate
1	Adamsville	200	30	137,213	57	49	25
2	Albany	175	36	371,187	19	18	90
3	Alpin	175	37	249,585	33	29	39
4	Apopka	265	17	119,259	64	55	13
5	Arrendondo	235	22	199,867	39	34	26
6	Astatula	1136	4	493,691	8	8	38
7	Basinger	221	25	657,908	6	6	43
8	Blanton	461	10	475,052	10	10	69
9	Bonifay	226	24	234,420	34	30	27
10	Candler	2305	1	839,202	3	3	53
11	Eau Gallie	543	7	465,679	11	11	86
12	Felda	48	74	253,462	31	27	42
13	Floridana	NR[2]	>60	250,303	32	28	15
14	Holopaw	133	43	272,244	28	24	14
15	Immokalee	462	9	910,565	2	2	64
16	Lake	273	16	115,712	67	57	29
17	Lakeland	700	6	739,457	4	4	56
18	Leon	161	39	572,007	7	7	98
19	Malabar	121	47	344,605	20	19	62
--	Matlacha[2]	238	21	78,194	80	66	0
20	Millhopper	216	27	133,846	58	50	46
21	Myakka	1028	5	1,400,072	1	1	76
22	Oldsmar	254	20	297,163	23	21	63
23	Ortega	234	23	157,567	45	39	15
24	Otela	202	29	138,103	55	48	32
25	Paola	531	8	128,181	61	52	43
26	Pineda	184	33	421,044	16	16	63
27	Placid	24	102	267,790	29	25	20
28	Plummer	35	87	438,056	14	14	35
29	Pomello	265	18	216,530	36	32	55
30	Pomona	116	48	440,266	13	13	124
31	Riviera	159	40	491,995	9	9	44
32	Rutledge	23	103	303,268	21	20	11
33	Sapelo	66	66	273,399	27	23	83
34	Smyrna	350	13	714,008	5	5	61
35	Sparr	279	15	162,728	44	38	59
36	St Lucie	257	19	49,231	105	79	22

Table 2.1
Listing of Florida Sand Series Evaluated for Parameter Estimation (cont.)

	Soil Series	# of Permits[1]	Ranking based on Permits	Areal Extent (acres)	Ranking within Total Florida Land Area	Ranking within Sand Series only	# of Records Used in Parameter Estimate
37	Tavares	1554	3	375,455	18	17	54
38	Troup	435	11	459,785	12	12	38
39	Wabasso	200	31	434,075	15	15	79
40	Zolfo	337	14	141,258	53	46	27

[1] *Information on number of recent permits provided by FDOH (2012).*

[2] *Excluded from further analysis – no data records reported in the Florida Soils Characterization Data Retrieval System.*

Table 2.2
Listing of Florida Sandy Clay Loam Series Evaluated for Parameter Estimation

Soil Series	Series Textural Classification[1]	# of Permits[2]	Ranking based on Permits	Areal Extent (acres)	Ranking within Total Florida Land Area	# of Records Used in Parameter Estimate
Blanton	fine sand	461	10	475,052	10	1
Boca	sand	145	41	210,718	37	1
Bonifay	sand	226	24	234,420	34	2
Bonneau	loamy sand	111	49	147,125	51	9
Chaires	fine sand	11	132	221,332	35	5
Chobee	loamy fine sand	12	130	177,511	41	10
Dothan	sandy loam	193	32	297,410	22	10
Eau Gallie	sand	543	7	465,679	11	1
Esto	fine sandy loam	na	na	24,783	155	1
Felda	fine sand	48	74	253,462	31	1
Floridana	sand	17	118	250,303	32	4
Fuquay	sand	125	46	262,070	30	4
Kendrick	loamy sand	97	56	106,231	70	6
Lucy	loamy sand	70	62	133,837	59	5
Mascotte	fine sand	43	78	281,023	26	2
Maxton	loamy sand	2	215	1,739	307	1
Millhopper	sand	216	27	133,846	58	3
Orangeburg	loamy sand	207	28	282,002	25	15
Otela	fine sand	202	29	138,103	55	1
Pelham	loamy sand	93	57	393,382	17	4
Pineda	sand	184	33	421,044	16	1
Pomona	sand	116	48	440,266	13	8
Riviera	sand	159	40	491,995	9	2
Sapelo	fine sand	66	66	273,399	27	2
Sparr	fine sand	279	15	162,728	44	2
Surrency	loamy sand	1	238	284,796	24	3
Tooles	fine sand	2	221	144,731	52	1
Troup	fine sand	435	11	459,785	12	1
Wabasso	fine sand	200	31	434,075	15	6
Waccasassa	sandy clay loam	na	na	27,154	147	2
Winder	loamy sand	43	79	20,2519	38	8

[1] *Soil series textural classification is listed. However, only individual data records within the soil series classification listed as "sandy clay loam" were included in the evaluation.*

[2] *Information on number of recent permits provided by FDOH (2012).*

Table 2.3
Summary of Soil Parameters for Individual Sand Series[1]

Soil Series	Median												Model Fitting Parameters	
	Sand Particle Distribution (%)					Particle Distribution (%)								
	Very Course Sand	Course Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Total Silt	Total Clay	K_{sat} (cm/d)	Bulk Density (g/cm^3)	θ_r (cm^3/cm^3)	θ_s (cm^3/cm^3)	α (1/cm)	n
Adamsville	0	1.9	25.0	51.3	8.4	97.0	1.8	1.1	938.4	1.55	0.62	38.13	0.025	2.92
Albany	0.2	3.2	18.9	50.3	12.4	91.0	6.3	2.3	337.6	1.54	1.36	38.18	0.020	2.25
Alpin	0.1	4.2	25.3	51.4	14.8	95.0	3.5	1.6	615.6	1.52	0.92	38.53	0.023	2.65
Apopka	0.1	1.5	26.9	61.6	6.8	95.8	2.3	2.0	946.8	1.53	1.27	37.74	0.034	2.11
Arredondo	0	2.1	20.2	51.4	11.0	92.6	4.0	2.9	445.2	1.54	1.62	36.11	0.021	2.42
Astatula	0	0.6	12.2	78.9	3.0	98.0	0.9	1.0	1515.4	1.43	0.54	39.54	0.030	2.96
Basinger	0	2.5	24.1	64.5	4.3	97.3	1.2	1.2	567.6	1.58	1.20	36.94	0.020	2.63
Blanton	0.1	3.4	17.0	53.4	11.4	91.4	5.4	2.6	552.0	1.54	1.35	38.92	0.023	2.43
Bonifay	0.5	11.0	32.1	29.7	7.3	87.6	6.0	5.2	195.6	1.61	2.87	35.83	0.032	1.80
Candler	0	0.8	17.6	65.9	6.1	97.3	1.4	1.4	890.4	1.50	0.79	38.56	0.023	3.57
Eau Gallie	0	1.1	16.8	61.6	10.2	95.0	2.8	1.6	342.0	1.53	2.12	38.74	0.017	2.08
Felda	0	1.0	8.2	51.6	13.6	93.6	2.9	3.3	211.8	1.58	2.88	37.97	0.015	2.29
Floridana	0	2.0	35.0	39.3	4.5	90.1	5.5	4.6	184.1	1.59	4.09	40.18	0.015	1.58
Holopaw	0	0.2	3.0	75.2	5.2	92.7	3.4	1.5	295.8	1.54	1.17	38.36	0.017	2.23
Immokalee	0	4.1	36.0	51.4	4.0	97.4	1.6	1.2	717.6	1.54	1.66	38.08	0.026	2.34
Lake	0	1.0	20.0	69.8	5.0	95.0	2.1	2.8	1435.2	1.45	1.63	40.03	0.030	2.52
Lakeland	0.3	9.7	48.0	30.0	2.2	93.6	3.8	2.5	1174.8	1.52	1.20	39.72	0.037	2.38
Leon	0	5.6	30.2	48.8	5.0	94.3	3.8	1.8	481.0	1.53	1.82	38.58	0.026	2.02
Malabar	0	2.4	18.0	63.6	8.0	97.1	1.8	0.9	448.8	1.58	1.31	36.83	0.021	2.43
Millhopper	0	2.8	27.0	50.4	7.2	95.0	2.9	2.2	690.6	1.54	1.30	38.98	0.026	2.41
Myakka	0	1.6	17.3	65.0	7.2	95.3	2.4	2.0	433.2	1.50	2.60	40.96	0.022	2.00
Oldsmar	0	3.8	40.5	40.7	5.0	96.5	2.0	1.5	607.2	1.55	2.07	37.18	0.030	2.06
Ortega	0	0.8	11.5	80.6	3.3	97.6	1.2	1.2	994.8	1.47	0.61	40.10	0.024	3.56

Table 2.3
Summary of Soil Parameters for Individual Sand Series[1] (cont.)

Soil Series	Median												Model Fitting Parameters	
	Sand Particle Distribution (%)					Particle Distribution (%)								
	Very Course Sand	Course Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Total Silt	Total Clay	K_{sat} (cm/d)	Bulk Density (g/cm^3)	θ_r (cm^3/cm^3)	θ_s (cm^3/cm^3)	α (1/cm)	n
Otela	0.1	2.1	16.6	53.4	22.1	94.4	3.8	2.0	397.8	1.58	0.85	37.20	0.016	2.96
Paola	0	6.2	33.6	54.3	1.7	98.2	0.8	1.0	1684.8	1.45	0.85	38.98	0.041	2.68
Pineda	0	2.4	19.0	59.8	4.6	96.1	2.0	1.8	350.4	1.63	1.12	36.21	0.017	2.49
Placid	0	0.9	12.9	52.4	13.3	93.3	3.6	2.9	330.7	1.56	1.68	38.67	0.021	1.76
Plummer	0.1	3.0	18.3	52.2	17.4	92.3	4.5	2.4	232.8	1.57	1.48	38.28	0.017	2.34
Pomello	0	1.6	18.3	65.3	8.1	97.2	1.9	0.9	673.8	1.44	1.60	39.19	0.022	2.80
Pomona	0	1.8	16.9	51.4	14.0	93.4	3.8	2.5	305.2	1.52	2.74	38.02	0.021	1.92
Riviera	0	0.8	11.0	61.6	9.8	93.2	2.4	3.6	310.0	1.60	2.06	38.66	0.017	2.42
Rutledge	0	0.6	3.0	78.4	9.0	90.8	3.7	3.6	102.7	1.56	2.61	36.90	0.016	1.97
Sapelo	0	1.4	11.2	60.0	13.0	92.3	5.2	2.3	294.0	1.51	1.78	39.07	0.019	2.06
Smyrna	0	0.7	11.6	67.4	10.3	94.8	2.9	2.4	438.0	1.47	2.21	40.83	0.021	2.25
Sparr	0	1.4	16.5	52.2	16.6	94.0	3.8	2.2	426.0	1.53	1.46	38.03	0.023	2.32
St Lucie	0	5.0	61.6	30.9	1.0	98.7	0.6	0.5	2170.2	1.46	1.50	39.00	0.060	2.84
Tavares	0	1.3	16.7	68.5	6.6	96.8	1.7	1.6	825.6	1.50	0.74	38.96	0.024	2.97
Troup	1.5	11.0	30.6	37.4	8.9	88.6	5.7	4.0	528.6	1.58	2.01	35.69	0.037	1.90
Wabasso	0	2.2	22.5	48.6	11.7	92.1	3.9	2.1	219.7	1.55	2.75	37.90	0.019	1.90
Zolfo	0	0.8	10.2	70.6	15.6	96.0	2.5	1.3	598.8	1.0	0.89	39.69	0.019	4.21

[1] *Median values listed for soil properties were determined based on complete records in the Florida Soils Characterization Data Retrieval System. Model fitting parameters (α and n) listed were estimated using solver to and the lowest sum of the squares for the van Genuchten equation. See Table 2.1 for how the soil series were included for further assessment.*

Table 2.4
Summary of Soil Parameters for Pooled Sand and Sandy Clay Loam Data Records for HYDRUS-2D Simulations Use to Prepare Simple Tools[1]

Soil Texture	Median												Model Fitting Parameters	
	Sand Particle Distribution (%)					Particle Distribution (%)								
	Very Course Sand	Course Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Total Silt	Total Clay	K_{sat} (cm/d)	Bulk Density (g/cm^3)	θ_r (cm^3/cm^3)	θ_s (cm^3/cm^3)	α (1/cm)	n
Parameters for Sand Groupings based on Hierarchal Cluster Analysis[2]														
Group 1 – More Permeable Sand	0	2.0	21.5	60.0	5.8	96.2	2.1	1.5	670.8	1.51	1.3	38.74	0.024	2.52
Group 2 – Less Permeable Sand	0.1	2.2	17.6	51.9	12.7	92.5	4.4	2.5	352.6	1.55	1.7	37.94	0.020	2.24
Sandy clay loam	0.2	2.1	15.4	36.5	10.4	68.0	6.6	23.8	24.7	1.63	10.0	38.0	0.009	1.84

[1] *Median values listed for soil properties were determined based on complete records in the Florida Soils Characterization Data Retrieval System. Model fitting parameters (α and n) listed were estimated using solver to and the lowest sum of the squares for the van Genuchten equation. Parameters and soil descriptions/textures listed in this table were used for HYDRUS-2D simulation and the preparation of the Task D-7 simple tools (i.e., look-up tables and graphical outputs).*

[2] *Discussion on cluster analysis and grouping of sand characteristics is described on page 2-10.*

A hierarchical cluster analysis was conducted to determine if the sand soil series could be split into two or more distinct subgroups. Hierarchical clustering is a widely used data analysis tool to identify groupings within a data set based on successively merging (or splitting) similar data. There are numerous hierarchical clustering approaches based on different methods to measure the distance between groups/data as well as methods used to link the data into groups. While the choice of the approach will affect the clustering, often multiple approaches are implemented with judgment from the user as to whether the clustering is logical for the data set (MINITAB, 2000). Generally, there is no universal, simple, systematic method for assessing the significance of the clusters (Park et al., 2009). However, the lack of measured "clusteredness" does not mean that the result is not useful (Greenacre 2008, Zadeh 1965). Since the number of clusters is not known at the start, the dendrogram is a useful visual representation of the clustering results that helps to identify logical clusters.

Initial cluster analysis previously completed suggested that the fraction of fine sand and/or the K_{sat} had the most influence on the clustering of sand soil series with four distinct groups discernable. However, this initial analysis did not include additional information from soil series based on permit ranking and included some soils at depths greater than 5 ft below ground surface.

Figure 2.1 shows the output from the subsequent cluster analysis on the median values for each soil series with two distinct subgroups, specifically, a less permeable sand and a more permeable sand. Upon closer inspection of the individual data records, “group 1” is ***generally*** characterized by K_{sat} > 500 cm/d, % very fine sand <10%, and total sand fractions of >95%. “Group 2” is generally characterized by K_{sat} < 500 cm/d, % very fine sand >10%, and total sand fractions of <95%. This is consistent with the previous cluster analysis results.

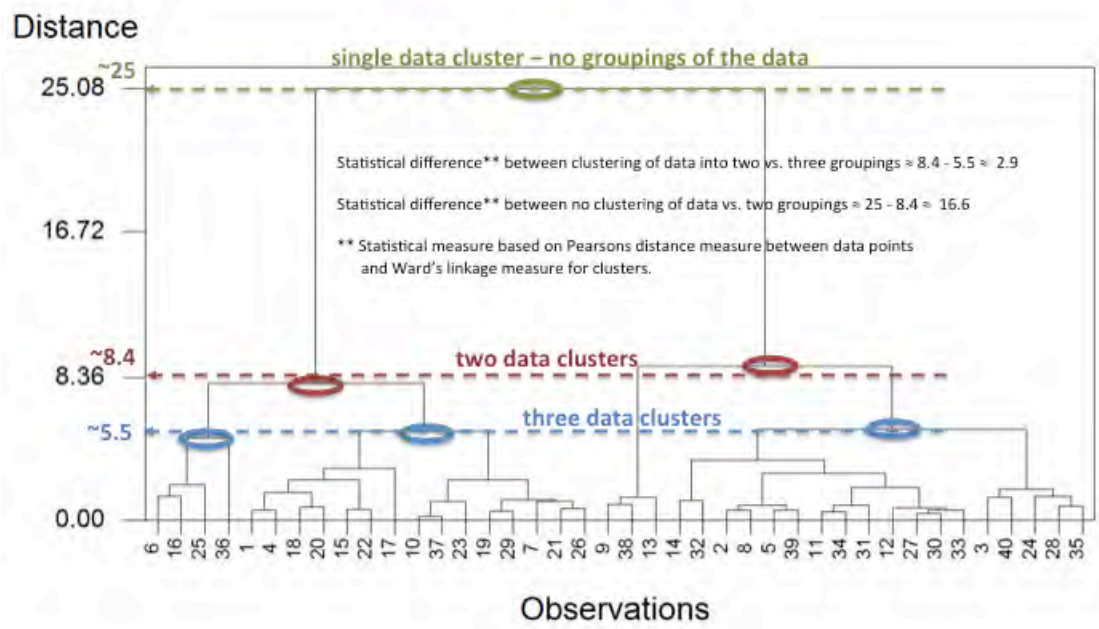

Figure 2.1
Hierarchical cluster analysis dendrogram illustrating two distinct subgroupings within sand soil series
(numbers on the x-axis are soil series identification - e.g., 1 = Adamsville)

It is important to understand that these characteristics for each group are not hard criteria. The hierarchical cluster analysis groups the information into most similar groups, but all the properties are not truly independent as there is interdependence of the properties used to describe a soil series (e.g., K_{sat} is a function of both the fine sand fraction and total sand fraction). Thus, some soil series with a K_{sat} < 500 cm/d might still be clustered into "group 1". A mathematically derived dendrogram (Figure 2.1) illustrates the distance between series with parings closest to each other being most similar (or statistically defined as the least dissimilar) and those farthest from each other as the most different (most dissimilar). For example, in "group 1" the soil series IDs #6 and #16 are the most similar to each other as are soil series IDs #21 and #26 most similar to each other. But, within "group 1" the cluster of #6 and #16 is most different from the cluster of #21 and #26. Thus, "group 1" and "group 2" can be thought of as a natural compromise based on the scale of similarity. Figure 2.1 also illustrates this dissimilarity on the y-axis where the distance between a single cluster and two clusters is ~16.6 (unitless relative measure based on Pearsons distance measure method) while the distal difference be-

tween two clusters and three clusters is ~2.9. Although the clustering approach and data interpretation is subjective, the relative comparison of distance between groups gives confidence that the two groupings shown in Figure 2.1 are different from each other (i.e., 16.6 >> 2.9). The sand series were evaluated using multiple statistical algorithms (multivariate approaches, distance measure methods, and linkage methods) for multiple combinations of characteristics. This ensured clustering of the soil series was similar for each statistical approach, but also helped to identify the characteristics that contributed to the variance. Most significant is the result that each algorithm produced a similar dendrogram although subtle differences within the groupings were observed.

After identification of the sand clusters, representative model parameters were determined by pooling all of the data records from the "group" (either 1 or 2) soil series and determining median values. As described previously, again K_{sat}, θ_r, and θ_s were obtained from the reported field data (median values). To approximate the van Genuchten parameters (α and n), the median reported soil moisture values for each "group" at each suction head were paired, and Solver was then executed using the van Genuchten equation while minimizing the sum of the squares. The median values for each "group" and the estimated van Genuchten fitting parameters for each series are summarized in Table 2.4. These two representative sand soil textures will be incorporated into STUMOD-FL with the default values as determined here and are the basis of the Task D.7 HYDRUS-2D simulations.

2.2 HYDRUS-2D Simulations

HYDRUS-2D (Šimůnek et al., 1999) was used to simulate steady-state unsaturated transport of nitrogen species in saturated soils for the purpose of demonstrating the effect of design and operating conditions on STU performance. HYDRUS has been used for various applications in OWTS (McCray et al., 2000; Beach and McCray, 2004, Doyle et al., 2005, Radcliffe et al., 2005, Pang et al., 2006; Bumgarner and McCray 2007; Heatwole and McCray, 2007; Finch et al. 2008; Radcliffe and West, 2009; Beal et al., 2008). For Task D.7, a modified version of HYDRUS-2D was used that accounts for the effect of aeration via soil moisture content, effect of carbon content, and temperature on treatment allowing assessment of nitrogen transformation under a variety of OWTS loading conditions. The assumptions used in HYDRUS-2D scenario analysis for Task D.7 are described below.

HYDRUS can simulate constant or time-dependent loading rates for a nearly infinite number of combinations of subsurface heterogeneities. HYDRUS-2D simulations were run for selected conditions representative of Florida to illustrate the subsurface affects that can be attributed to changes in operational or environmental conditions. Scenarios

included distribution configurations, soil textures, effluent quality, subsurface heterogeneity and water table depths (Table 1.1, Figures 1.1 - 1.4). For this work, a constant loading rate was used for each simulation as listed in Table 1.1. For most simulations, the effluent was applied to the infiltrative surface of a homogeneous subsoil layer overlain by a lower permeability biozone (simulations 1 - 57). Additional simulations for layered soils were performed within budget and schedule constraints (simulations 58-63) to account for expected subsurface heterogeneity under Florida conditions and demonstrate the effect of vertical heterogeneity.

HYDRUS can also simulate nearly any realistic subsurface flow scenario associated with the water table, including impacts of shallow water tables on soil moisture in the soil (and thus on treatment) and mounding of the water table. To get an understanding of this effect, simulations were run with an assumption of free boundary conditions (i.e., no impact from a deep water table on flow or soil moisture) and with constant head boundary condition at 1, 2, and 6 ft below the infiltrative surface.

Two general effluent qualities were considered: typical STE and nitrified effluent. Based on field monitoring of six sites in Florida the median total nitrogen concentration was 61 mg-N/L with 56 mg-N/L as ammonium nitrogen and 0.7 mg-N/L as nitrate nitrogen (the difference is assumed to be organic nitrogen) (Lowe et al., 2009). However, to simplify the assumption, the input concentration for the HYDRUS-2D runs was 60 mg-N/L as ammonium nitrogen with no nitrate nitrogen. The nitrified effluent, representative of an aerobically treated effluent, was assumed to be partially treated having 15 mg-N/L as ammonium nitrogen and 15 mg-N/L as nitrate nitrogen based on input provided by FDOH.

Both effluent qualities were assumed to have sufficient carbon required for both nitrification and denitrification reactions. Nitrification is the process where ammonium ions are oxidized by autotrophic bacteria (bacteria that obtain their energy from CO2 rather than organic matter). Because soil gas is known to have high concentrations of CO2 (Jury and Horton, 2004), it was assumed that sufficient carbon exists for nitrification, provided that gas diffusion is not inhibited due to high soil water contents. In contrast, a carbon source is necessary for the most common biological denitrification as the heterotrophic denitrifying organisms obtain their energy from the oxidation of organic compounds. While numerous soil denitrification studies have been conducted, few have investigated how the magnitude of denitrification in soil receiving OWTS effluent is influenced by available carbon. Rather, an assumption is typically made that sufficient carbon for the denitrification process is applied to the soil in the effluent. This assumption is valid if both the carbon in the effluent and the soil is biologically active and available at a C:N ratio greater than stoichiometric requirements. It should be recognized that in situations

where carbon is limited, less denitrification is expected to occur resulting in less nitrogen removal in the STU relative to the HYDRUS-2D graphical outputs presented here. It was also assumed that sufficient alkalinity was present and that the pH was within a range where sufficient nitrification and denitrification occurs.

Several parameters are required by HYDRUS-2D to simulate nitrogen transport and transformation (e.g., nitrogen transformation rate constants, ammonium sorption constants, etc.) as summarized in Table 2.5. In general, parameter selection was based on statistical distributions of data obtained in the literature. From these data, mean values with standard deviations or median values with quartiles, and/or the cumulative frequency of parameter values were calculated previously (McCray et al., 2010). Scarcity of data sometimes precluded this approach (e.g., for ammonium sorption constants). A summary of the key parameters used for the Task D.7 HYDRUS-2D simulations is provided in Table 2.6 and described below. Additional detail can found in McCray et al., 2010.

Table 2.5
List of HYDRUS-2D Input Parameters

Parameter	Units	Definition
Hydraulic Parameters		
HLR	cm d^{-1}	Hydraulic loading rate
α	cm^{-1}	Parameter α in the soil water retention function (also referred to as α_{VG})
K_s	cm d^{-1}	Saturated hydraulic conductivity (also referred to as K_{sat})
θ_r	cm^3 cm^{-3}	Residual soil moisture (also referred to as θ_r)
θ_s	cm^3 cm^{-3}	Saturated soil moisture (also referred to as θ_s)
n	-	Parameter n in the soil water retention function
m	-	Parameter m in the soil water retention function
l	-	Tortuosity parameter
Biomat Parameters		
K_b	cm d^{-1}	Biomat hydraulic conductivity
BT	cm	Biomat thickness
Effluent Quality Parameters		
Co-NH_4	mg-N L^{-1}	Effluent ammonium-N concentration
Co-NO_3	mg-N L^{-1}	Effluent nitrate-N concentration
Nitrification Parameters		
$K_{r,max}$	mg-N L^{-1} d^{-1}	Maximum nitrification rate
$K_{m,nit}$	mg-N L^{-1}	Half-saturation constant for ammonium-N
e_2	-	Empirical exponent for nitrification
e_3	-	Empirical exponent for nitrification
f_s	-	Value of the soil water response function at saturation
f_{wp}	-	Value of the soil water response function at wilting point
s_{wp}	-	Relative saturation at wilting point
s_l	-	Relative saturation for biological process (lower limit)
s_h	-	Relative saturation for biological process (upper limit)
β_1	-	Empirical coefficient for temperature function for nitrification (also referred to as β_{nit})
T_{opt}	^oC	Optimum temperature for nitrification
Denitrification Parameters		
V_{max}	mg-N L^{-1} d^{-1}	Maximum denitrification rate
$K_{m,dnt}$	mg-N L^{-1}	Half-saturation constant for nitrate-N
e_{dnt}	-	Empirical exponent for denitrification
s_{dn}	-	A threshold relative saturation (dimensionless)
β_2	-	An empirical coefficient for temperature function (also referred to as β_{dnt})
T_{opt}	^oC	Optimum temperature for denitrification
α_c	-	An empirical exponent for carbon content adjustment

Table 2.5 (cont.)
List of HYDRUS-2D Input Parameters

Ammonium Sorption Parameters		
K_d	L kg^{-1}	Adsorption Isotherm
ρ	kg L^{-1}	Soil bulk density
Soil Temperature Parameters		
T	^oC	Soil temperature
Treatment Depth		
D	cm	Soil depth

Table 2.6
Input Values Used for Preparing Task D.7 HYDRUS-2D Simulations

Parameter	Sandy Clay Loam	Less Permeable Sand	More Permeable Sand	Data Source[1]
Hydraulic parameters				
HLR	Varies - See Table 1.1			
α	0.009	0.02	0.024	FL
K_s	24.7	352.6	670.8	FL
θ_r	0.0995	0.017	0.013	FL
θ_s	0.38	0.3794	0.3874	FL
n	1.84	2.24	2.52	FL
m	0.45	0.55	0.60	FL
l	0.5	0.5	0.5	FL
Biomat parameters				
K_b	0.5	0.5	0.5	L[a]
BT	1	1	1	L[a]
Effluent Quality Input concentrations, Co				
Co NH_4 = 60 mg-N/L (STE), and 15 mg-N/L (nitrified effluent)				
Co NO_3 = 0 mg-N/L (STE), and 15 mg-N/L (nitrified effluent)				
Nitrification Parameters				
$K_{r,max}$	56	56	56	L[m]
$K_{m,nit}$	5.0	5.0	5.0	L
e_2	1.0	1.0	1.0	P
e_3	1.0	1.0	1.0	P
f_s	0.0	0.0	0.0	P
f_{wp}	0.0	0.0	0.0	P
s_{wp}	0.0	0.0	0.0	P
s_l	0.50	0.50	0.50	P
s_h	0.85	0.85	0.85	P
β_1	0.186	0.186	0.186	L
T_{opt}	25	25	25	L
Denitrification Parameters				
V_{max}	2.58	2.58	2.58	P
$K_{m,dnt}$	5	5	5	P
e_{dnt}	2.5	1.5	1.5	P
s_{dn}	0	0	0	P
β_2	0.186	0.186	0.186	L
T_{opt}	25	25	25	L
α_c	0	0	0	L

Table 2.6 (cont.)
Input Values Used for Preparing Task D.7 HYDRUS-2D Simulations

Parameter	Sandy Clay Loam	Less Permeable Sand	More Permeable Sand	Data Source[1]
Ammonium Sorption Parameters				
K_d	1.46	0.35	0.35	L^m
ρ	1.51	1.51	1.51	L
Soil Temperature Parameter				
T	User input soil temperature specific to a region (22 ^oC for Florida).			
Treatment Depth				
D	See Table 1.1 for depth ranges used for free drainage and constant head boundary.			

[1] *FL = median value determined as described in Section 2.1; L^a = mean, based on reported literature values; L^m = median, based on reported literature values; L = literature value from McCray et al., 2010; P = based on parameterization of soil moisture functions for nitrification and denitrification using observed data.*

Ammonium association with soils is an important process in nitrogen transformation. The sorption process is thought to be controlled by cation exchange processes, which depends on the ionic composition of the soil, as well as the ionic makeup of the water. The magnitude of the cation exchange capacity depends on soil texture, types of minerals in the soil and the amount of organic matter. The ammonium sorption coefficients used in the Task D.7 HYDRUS-2D simulations were based on McCray et al., 2010 using a clay-poor value of 0.035 L/kg for less permeable and more permeable sand and using a clay-rich value of 1.46 L/kg for the sandy clay loam. Although ammonification of organic nitrogen can be simulated by the modified version of HYDRUS-2D, all simulations were based on the application of ammonium-nitrogen and nitrate-nitrogen only, the ammonification process was not considered.

Nitrification requires aerobic conditions; the process depends on the oxygen diffusion rates to and from nitrogen transformation sites that depend upon the soil tortuosity and the water content. Previous studies suggested that soil moisture is well related to nitrification and denitrification (Maag and Vinther, 1996; Tucholke et al., 2007) and is used as a surrogate for the many parameters that control oxygen diffusion. Furthermore nitrification is concentration and temperature dependent. Most enzyme-catalyzed biological reactions follow Monod kinetics, where the reaction rate is controlled by the availability of substrate. Monod kinetics thus enables first order kinetics at lower values of nitrogen concentrations, and zero-order kinetics at higher values of nitrogen concentrations. The transition between zero and first order kinetics is set by the half-saturation constant (K_m). A half-saturation constant value of 5 mg L^{-1} was chosen as it simulates zero-order reaction rates, but also resulted in more stable numerical formulations in HYDRUS. In the

soil underlying an OWTS, elevated nitrogen concentrations are transported to groundwater and the transformation rates are expected to be zero order except for greater depths where ammonium concentrations have decreased significantly. The moisture dependency function adjusts the optimum nitrification rate based on the soil moisture content. The adjustment factor (f_{sw}) has a value of 1 for optimum soil moisture conditions and less than 1 for low and high soil moisture conditions, reflecting the observed relationship between nitrification and soil moisture content. When there is excess water, oxygen becomes limiting and nitrification is slowed drastically. Also, when the soil is dry, often defined as the permanent wilting point, nitrification becomes inhibited because of aqueous diffusion limitations. Parameters relevant to the nitrification soil moisture function were revised from McCray et al., 2010 to improve limitations of the nitrification function based on observed attenuation of ammonium in sandy and clayey soils. A complete list of the modified parameters used in the HYDRUS-2D simulations (e_2, e_3, s_{wp}, f_s, f_{wp}, and s_l and s_h) is given in Table 2.6. The temperature response function is similar for both nitrification and denitrification and results in a bell shaped curve with a value of 1 at the optimum temperature (T_{opt}) and a value less than 1 below and above the optimum. Nitrification and denitrification rates are non-linear functions of temperature. However, the default soil temperature value for Florida (22 ºC) was relatively high compared to other regions in the United States and close to the optimum value of 25 ºC. Thus, the effect of temperature is not very significant for the Task D.7 HYDRUS-2D outputs, though it is an important parameter in other regions of the country.

Denitrification is expected to reach a maximum rate at fully saturated conditions. The nitrogen transformation kinetics during denitrification is represented by Monod kinetics allowing first-order kinetics at lower values of nitrogen concentrations, and zero-order kinetics at higher values of nitrogen concentrations (like nitrification, see discussion above). The half-saturation constant value for nitrate transformations ($K_{m,NO3}$) was 5 mg/L as discussed earlier for nitrification. Because the concentration of nitrate nitrogen in the nitrified effluent is typically much greater than the half-saturation constant, zero-order denitrification rates are expected except for at greater depths where nitrate concentration has decreased significantly. The Monod kinetics built into the modified version of HYDRUS used in this task allows switching between zero-order and first-order based on change in concentration with depth and will improve predictions. Again, like nitrification, the maximum denitrification rate is adjusted for soil moisture content as previously determined by McCray et al. 2010. The optimized threshold value was set to zero (McCray et al, 2010), however, the value for fitting exponent (e) was revised. It was determined that the soil moisture adjustment factor was sensitive to the fitting exponent value. For the Task D.7 HYDRUS-2D simulations, default values of 1.5 and 2.5 are used for the fitting exponent, e, for sandy and clay soils, respectively based on literature values and observed and simulated nitrate removal. Finally, again, the temperature

function for denitrification is the same as for nitrification with an optimal temperature for denitrification of 25 ºC. A complete list of the parameters used in the HYDRUS-2D simulations is given in Table 2.6.

Prior to preparing the HYDRUS-2D simulations for each condition, the model was run to determine the duration of run required to reach steady state. Once steady state is reached nitrogen species concentrations at any given location in the domain do not change with time. By evaluating the concentration output from HYDRUS with time and distance, it was determined that steady state was achieved before 150 days. Thus, all simulations were run for a duration of 150 days. Running the simulation beyond 150 days would not change the results, but would require more computational time. All graphical outputs provided as part of Task D.7 are based on 150 day run times.

Section 3.0
Tool Use

3.1 HYDRUS-2D Outputs

A series of simple tools (summary tables and HYDRUS-2D outputs) were prepared to capture subsurface behavior under a range of typical OWTS operating conditions in Florida (Table 1.1). The modified factorial design allows comparison of several outputs where only one condition is varied, thus illustrating the expected behavior. Specifically, the selected conditions enable comparison of the effect of soil texture, depth of the water table, OWTS configuration (trench vs bed; equal vs unequal distribution, modified design HLR vs 2x the modified design HLR), and effluent concentration. Because the distribution configuration combines several factors including different HLRs, the effect of several factors should be considered. Limited simulations illustrate the effect of vertical heterogeneity.

Appendix B contains the complete set of HYDRUS-2D graphical outputs. At the top of each figure is a summary of the operating conditions from Table 1.1. Below the summary are three outputs from the HYDRUS-2D simulation: water content (top), ammonium nitrogen concentration (middle), and nitrate nitrogen concentration (bottom). The scale is consistent (0 - 60 mg-N/L) for all nitrogen concentration outputs on all figures. The scale for water content varies to better illustrate subtle differences in the subsurface soil moisture content. The water content scale is in the fraction of water within the pore space ranging from 0 to 0.38. As the fractional water content increases, the soil becomes more saturated with a maximum water content of 0.38 equivalent to 100% saturation.

Look-up tables are also included in Appendix B that summarize nitrogen concentrations and mass flux at the water table (boundary condition). Values in the look-up tables were calculated as the maximum nitrogen concentration at the water table or as the total mass flux across the entire domain width per linear foot of trench or bed at the water table boundary. Constant head boundary conditions were implemented for water table depths of 1, 2 and 6 ft and maximum nitrogen concentration and total mass flux outputs are provided at 1, 2 and 6 ft depths, respectively. A free drainage boundary condition was implemented for a relatively deeper water table condition only and the maximum nitrogen concentration and total mass flux are provided at 6 ft below the infiltrative surface.

Comparison of selected graphical outputs in Appendix B illustrate the expected behaviors in the subsurface below OWTS due to soil texture (Table B.1), depth to water table (Table B.2), distribution configuration (Table B.3), and effluent composition (Table B.4).

3.1.1 Relative Effect of Soil Texture

The effect of soil texture is generally described by increasing performance at the water table (i.e., higher removal or lower concentrations or lower mass fluxes) as the soil texture becomes finer. As the soil texture gets finer (more permeable sand → less permeable sand → sandy clay loam) the maximum nitrate nitrogen and total nitrogen concentration at the water table decreased for a comparable set of conditions (see Tables B.1 and B.5). The increased performance in fine texture soils could be attributed to increased water content at steady state resulting in improved denitrification. The difference in performance is particularly large for deeper water table conditions. For shallow water table conditions, performance in fine textured soil is limited due to saturated conditions resulting in reduced nitrification.

Comparison of the mass flux at the water table shows the same general trend where the total mass flux of nitrate nitrogen and total nitrogen decreases as the soil texture becomes finer (Table B.6). However, the difference in the total nitrogen mass flux is relatively minor for the less permeable sand compared to the more permeable sand for a water table at 1 ft below the infiltrative surface (e.g., see simulation #12 compared to #8). It is expected that less permeable sand would result in lower mass flux compared to more permeable sand because the relatively high steady state moisture content in less permeable sand would increase denitrification. However, for this scenario (less permeable sand and a 1 ft water table) nitrification is limited due to the shallow depth to groundwater which limits the availability of nitrate available for denitrification especially at higher loading rates (again see simulations #8 and #12). Hence, a significant difference was not observed between these two soil textures with respect to mass flux. Performance benefits from increased moisture content in less permeable sand compared to more permeable sand can only be seen if and when nitrification is not limiting. This is dependent on both depth to the water table and loading rate. The difference in mass loading between the two soil types was larger at a 2 ft water table compared to a 1 ft and even larger at a 6 ft water table. A reduced loading rate would result in higher nitrification in both soil textures leading to relatively better removal in less permeable sand due to increased denitrification (see simulations #5 and #9). This discussion highlights that the simulated mass flux is an interaction of several key factors (soil texture, travel time, loading rate) and scenario comparison requires looking into each of these factors and possible interaction among the factors.

All of the ammonium is converted to nitrate at 6 ft for all soil textures and HLRs. Most of the ammonium is converted to nitrate at the 2 ft depth except for sandy clay loam where some ammonium was observed at 2 ft. However, at 1 ft and particularly for high loading rates, significant ammonium concentrations are remaining for sandy clay loam followed by the less permeable sand. The relatively greater concentration of ammonium in sandy clay loam and less permeable sand compared to more permeable sand was attributed to less nitrification due to high moisture content in the two soil textures. Simulation results show that depth at which complete nitrification occurred varied depending on soil texture, depth to water table and hydraulic loading rate and had a significant effect on overall performance since additional depth/time is required after nitrification although both processes could occur simultaneously.

More variability in the concentration and mass flux of nitrate nitrogen at shallower depths (e.g., 1 ft) than for conditions simulating a deep water table (either 6 ft below IS or free drainage) can be observed (see simulations 29, 30, 32, 33, 34, 35, 36, 41, 42, 44, 45, 47). More consistent and well-defined patterns are observed by soil texture for conditions simulating a deep water table (free drainage) because nitrification occurs well above the water table and the nitrogen flux is controlled by the rate of denitrification which also varies by soil type. These findings are corroborated by field observations where nitrate nitrogen concentrations have been observed to increase at shallow depths below the infiltrative surface followed by decreasing concentrations with greater depth. Lower steady state soil moisture contents in more permeable sand compared to less permeable sand and sandy clay under most operating conditions is expected to increase nitrification. Under operating conditions where saturation occurs regardless of soil texture (e.g., high water table and high loading rates), steady state moisture content is not much different between soil textures. Under this condition, nitrification is limited for all soil textures. If the effluent were nitrified before application, the travel time becomes more important. If the loading rate is low, even under a shallow water table condition, relatively more nitrification may occur in the coarser soil texture soils compared to finer texture soil and may result in a relatively lower total nitrogen concentration at the water table in the coarser texture soils.

This variability within the soil prior to nitrogen reaching the groundwater is attributed to a combination of differences in the soil moisture water content, depth to water table, and water velocity. For example, as the HLR increases the soil moisture content increases which results in lower nitrification rates but the soil water velocity also increases. At higher loading rates, even the more permeable sand scenarios suggest relatively higher ammonium nitrogen concentrations at depth because reduced travel times (higher velocity) shorten the reaction time for nitrification reactions. In contrast, in the sandy clay loam the relatively higher moisture content is more important in limiting nitrification.

The travel time is also reduced with increasing loading rate, however, the degree of saturation remains as the major factor limiting nitrification. Although the complexity and interaction of these three factors on nitrogen removal as affected by soil texture cannot be directly sorted out based on these limited Task D.7 HYDRUS-2D simulations, the overall trend of increased nitrogen removal at the water table as the soil texture becomes finer is apparent and consistent.

3.1.2 Relative Effect of the Water Table Depth

The effect of the water table depth is generally described by increasing performance at the water table (i.e., higher removal or lower concentrations or lower mass fluxes) as the depth to the water table increases (Table B.7). The mass flux better shows this trend where decreasing nitrogen mass flux is observed in scenarios with increasing depths to groundwater (Table B.8). Comparison of nitrate nitrogen mass flux shows that the speciation of nitrogen reaching the groundwater changes. The nitrate mass flux is higher for scenarios with a 2 ft water table compared to the nitrate mass flux for scenarios with a 1 ft water table for the unequal distribution configurations. This is because nitrification is limited for 1 ft water table conditions and nitrogen remains in the form of ammonium. The reverse is true for ammonium nitrogen; ammonium mass flux is higher for scenarios with a 1 ft water table compared to scenarios with a 2 ft water table for the same reason. Because HYDRUS-2D assumes total nitrogen is equal to nitrate plus ammonium (i.e., organic nitrogen is assumed as zero) and the ammonium nitrogen is largely sorbed or transformed within the top 1 ft, the total nitrogen mass flux for scenarios with a 2 ft water table is less than the scenarios with the same conditions but with a 1 ft water table as expected.

The effect of the capillary zone above the water table can be seen by comparing nitrogen concentrations and mass flux from scenarios with a water table at 6 ft below the infiltrative surface to scenarios with a free drainage boundary condition. In this comparison, lower nitrogen concentrations and mass flux are observed at 6 ft in the scenarios with a water table at 6 ft illustrating the effect of increased denitrification due to increased soil moisture content in the capillary zone. The free drainage scenarios suggest decreasing concentrations beyond 6 ft, but the complete extent of the nitrogen plume in the soil is not captured within 6 ft of soil. Evaluation of the complete extent of the nitrogen plume would require a domain greater than 6 ft. Thus, future model simulations assuming free drainage can be assumed to conservatively estimate nitrogen transport and removal. Specifically, the model would over estimate the nitrogen concentrations suggesting less nitrogen removal.

While the maximum nitrogen concentration and mass flux reaching groundwater are lower for scenarios with greater depths to the water table, the extent (vertical and

horizontal) of nitrate nitrogen concentrations in the vadose zone increases with increasing water table depth. The increased nitrate nitrogen extent is attributed to the lower soil moisture content in the vadose zone as the water table depth increases. This means that shallow water tables (e.g., ~2 ft or greater) may enhance removal by increasing soil moisture content in the vadose zone provided that the loading rate is optimized to allow sufficient nitrification. When the water table is at 1 ft below the infiltrative surface, nitrification is limited because of the high water content.

3.1.3 Relative Effect of Distribution Configuration

Several factors are combined within the different distribution configurations: trenches vs. beds, equal vs unequal effluent distribution to the soil, and HLR. The interaction of these factors cannot be directly sorted out based on these limited Task D.7 HYDRUS-2D simulations because both soil texture and depth to groundwater also have a role in the overall nitrogen removal further complicating interpretation. However important information can still be gleaned from the model results with side-by-side visual inspection useful to qualitatively illustrate differences in performance.

The general trend of lower nitrate nitrogen and total nitrogen concentrations are observed for equally loaded configurations compared to unequally loaded configurations. While maximum nitrate nitrogen concentrations at the water table are higher for unequal loading scenarios (Table B.9), this does not appear to hold true for scenarios with a water table depth of 1 ft. The same general trend is observed for nitrate mass flux (equally loaded configurations < unequally loaded configurations). However, the total mass flux of total nitrogen at the water table is lower for equal distribution of effluent loading compared to unequal distribution of effluent loading for all comparable scenarios (Table B.10). Similar to the concentration and mass flux trends the estimated % of total nitrogen removed (both for concentration and mass flux) at the groundwater boundary was greater for equally loaded configurations compared to unequally loaded configurations, excluding scenarios with nitrified effluent and a 2ft water table (Table B.10).

Because equally loaded configurations relative to unequal configurations have the same mass loading, this observed trend suggest a benefit to the overall performance of an OWTS when the effluent loading is equalized. The higher HLR in the unequal loading configuration could result in a relatively higher moisture content limiting nitrification in some cases and reduced travel time in all cases limiting both nitrification and denitrification. However if the performance target for the OWTS is a lower nitrate concentration (but high ammonium) at a shallow water table, unequal loading may be preferred.

Trends comparing trench configurations to bed configurations are less pronounced. Generally lower total nitrogen concentrations are observed beneath beds with larger differences observed for sandy clay loam (compared to either less permeable sand or more permeable sand) and shallow water tables (compare both 6ft water table and free drainage to either 1ft or 2ft water tables). However, both nitrate concentrations and the % nitrogen removed (based on concentration) at the water table did not follow the same trend with lower concentrations or % removals observed sometimes beneath beds and other times beneath trenches. When comparing the total mass flux of either nitrate or total nitrogen, trenches have lower mass fluxes compared to beds with scenarios 15, 27, and 28 (all for sandy clay loam) as the only exceptions (see Table B.10). The estimated % of total nitrogen mass removed at the groundwater boundary was generally greater for trench configurations compared to bed configurations, excluding sandy clay loam scenarios (Table B.10).

Comparison of the % total mass flux removed normalizes the differences in loading rates between the distribution configurations. Taking the trench configuration in scenario #5 as an example, based on the hydraulic loading rate (2.67 cm/d) and total width of effluent application (3 times 1.83 ft or 5.5 ft), the total mass loading is 818.6 mg-N/ft•d. The total mass flux at the water table is 589.7 mg-N/ft•d (Table B.10) resulting in 28% total nitrogen mass removed. For the bed configuration in scenario #7, based on the hydraulic loading rate (1.68 cm/day) and total width of effluent application (13.1 ft), the total mass loading is 1225.2 mg-N/ft•d. The total mass flux at the water table is 983.93 mg-N/ft•d (Table B.10) resulting in only 20% total nitrogen mass removed and demonstrates the trench configuration outperforms the bed configuration.

As noted, several factors are combined within the different distribution configurations. Specifically, sandy clay loam configurations were loaded either ~19% less for trench configurations or ~42% less than bed configurations relative to the loading of less permeable sand or more permeable sand. Within a soil texture, trenches were loaded ~7% less than beds for sandy clay loam and ~33% less for less permeable sand or more permeable sand. However, the general trends still provides insight into how system implementation may affect performance depending on the area of concern (e.g., total mass flux of nitrogen to the enviroment vs. maximum nitrate concentration at depth below an OWTS). To assess the relative effect of the soil texture and distribution configuration on performance, a two-way analysis of variance was conducted. Results indicate that the distribution configuration was a more dominant factor on performance when the water table is shallow and that the soil texture becomes more dominant as the water table becomes deeper.

3.1.4 Relative Effect of Effluent Quality

The effect of effluent quality is described by increasing performance at the water table (i.e., higher removal or lower concentrations or lower mass fluxes) for nitrified effluent compared to STE. Lower maximum ammonium, nitrate, and total nitrogen concentrations were observed at the water table for scenarios with nitrified effluent applied to the soil compared to STE (Table B.11). The same is true for mass flux, where the total mass flux of ammonium, nitrate and total nitrogen to the groundwater is less for scenarios with nitrified effluent applied to the soil compared to STE (Table B.12).

This is not surprising given that the difference in the total nitrogen concentrations applied was half for nitrified effluent (15 mg-N/L as nitrate + 15 mg-N/L as ammonium = 30 mg-N/L as total nitrogen) compared to STE (0 mg-N/L as nitrate + 60 mg-N/L as ammonium = 60 mg-N/L as total nitrogen). To determine if the increased performance observed for nitrified effluent was solely due to the applied concentration, the relative difference between the performance measures was determined for nitrified effluent and STE for comparable scenarios (e.g., scenarios 22 and 49, scenarios 34 and 50, etc., See Table B.4). The performance measures used were the maximum nitrogen concentrations and total mass fluxes at the water table for nitrate nitrogen and total nitrogen. The estimated relative differences ranged from 55 to 99% suggesting that in some cases the increased performance was not only attributed to the lower concentrations applied. In general, there appeared to be less benefit of applying nitrified effluent to shallow water tables compared to deep water tables (55-62% relative difference in less permeable sands with a water table at 2 ft compared to 66-81% relative difference in less permeable sands with a water table at 6 ft) where nitrification is not a limiting factor. There also appeared to be a greater benefit to applying nitrified effluent to finer grained soils (99% relative difference for sandy clay loam and a water table at 6 ft; comparison of scenarios 26 to 57) again because nitrification could be limited at higher soil moisture contents for finer grained soils.

3.1.5 Summary

It is essential that all factors discussed above and the interaction among them is considered when looking at the performance of OWTS. Higher hydraulic loading rates increase steady state soil moisture content, which limits nitrification in some soil textures but enhances denitrification. A higher loading rate reduces travel times limiting both nitrification and denitrification. Soil moisture content and travel times differ by texture for a given loading rate. Capillary rise also differs by soil texture with increased soil moisture at the capillary zone enhancing denitrification. However, if the water table is too shallow (e.g., 1 ft), the capillary zone (>40 cm in fine textured soils) may be close to the infiltrative surface limiting nitrification. Performance benefits from nitrification before land application is greater for finer textured soils and high water table conditions. Relative com-

parisons of the simple tools developed based on HYDRUS-2D simulations demonstrates the effect of these factor on nitrogen removal under OWTS.

3.2 Corroboration of Simple Tools to Field Data

The HYDRUS-2D model was evaluated through corroboration with field data from two sites: GCREC and USF Lysimeter Station.

3.2.1 GCREC Corroboration

For the GCREC site, data from the Soil & Groundwater Facility Test Area 1 was used which represents a mound system receiving pressure dosed STE at 3.26 cm/d (0.8 gpd/ft^2). Soil in this area has been identified as Seffner fine sand. Because there were no data records for the Seffner series in the Florida Soil Characterization Data Retrieval System (University of Florida, 2007), soil properties and relevant model input parameters (θ_r, θ_s, α, and n) were set as equal to the less permeable sand. This also enabled comparison of the HYDRUS-2D outputs to the simple tools (scenario 17 for SE6 and scenario 29 for SE1-5) although the input concentrations were higher for the corroboration simulations. The average applied effluent quality was represented by 67.3 mg-N/L as ammonium + 0.22 mg-N/L as nitrate. In addition, two layers were added to represent the mound construction with 1ft of mound sand overlying the native soil (Seffner Fine Sand). This considerably improved model predictions. The water table varied over the six sampling events. A constant head boundary was set in HYDRUS 2D based on the measured water table depth to groundwater during the sampling event (Table 3.1).

Table 3.1
HYDRUS-2D Simulation Parameters Selected to Replicate GCREC Field Conditions

Sample Event	K_{sat} (cm/d)	Depth (ft)	HLR (cm/d)	θ_r	θ_s	α	n
mound sand	643.0	1.00	3.26	0.053	0.3747	0.035	3.18
1	352.6	5.58	3.26	0.017	0.3794	0.02	2.24
2	352.6	5.54	3.26	0.017	0.3794	0.02	2.24
3	352.6	3.40	3.26	0.017	0.3794	0.02	2.24
4	352.6	5.95	3.26	0.017	0.3794	0.02	2.24
5	352.6	6.59	3.26	0.017	0.3794	0.02	2.24
6	352.6	2.48	3.26	0.017	0.3794	0.02	2.24

For corroboration, the model output (maxiumum concentration) was compared to the observed nitrate nitrogen (ammonium nitrogen concentrations were below detection limits) for each of the 6 sampling events at the suction lysimeters located within the mini

mound at depths of 1 ft, 2 ft, and 3.5 ft below the infiltrative surface. The observed targets varied over the six sampling events (Table 3.2).

Table 3.2
Comparison of Field Observed GCREC Concentrations to HYDRUS-2D Corroboration Results[1]

Sample Event	Depth (ft)	Measured TN (mg-N/L)	Initial HYDRUS TN (mg-N/L)	Revised HYDRUS TN (mg-N/L)	Measured NO_3 (mg-N/L)	Final HYDRUS NO_3 (mg-N/L)
1	1	49.01	62.1	46.4	46	43.75
1	2	59.61	60.6	58.4	53	45.39
1	3.5	46.01	55.6	64.5	36	60.42
2	1	14.7	58.8	48.9	13	44.47
2	2	41.4	57.1	60.4	39	43.71
2	3.5	51.8	52.2	53.0	50	53.90
3	1	49.4	62.9	47.1	48	41.40
3	2	45.73	59.2	63.8	45	41.63
3	3.5	53.74	45.9	43.6	53	44.35
4	1	52.00	55.0	45.8	50	43.24
4	2	51.2	53.4	63.3	47	45.07
4	3.5	55.1	50.7	57.1	52	55.80
5	1	59.5	93.4	66.8	55	53.08
5	2	64.2	86.2	64.5	60	64.43
5	3.5	70.5	84	60.7	68	61.30
6	1	33.6	63.7	35.2	32	43.44
6	2	26.7	53.6	41.1	25	32.20
6	3.5	49.6	--[2]	--[2]	46	--[2]

[1] *Initial HYRDUS TN values were from the initial corroboration. Revised HYDRUS TN values include rainfall input but default nitrification rates. The corroboration targets for both the initial and revised HYDRUS runs were total nitrogen because ammonium was still predicted at depths greater than 1ft. Final HYDRUS values are as nitrate with the corroboration target as nitrate because all of the nitrogen below 1ft was in the form of nitrate.*

[2] *The 3.5ft suction lysimeter was below the water table during sampling event #6.*

Initial HYDRUS-2D corroboration runs were conducted using STE input concentrations equal to the STE field measured value at the time of sampling (i.e., six runs with different effluent input concentrations ranging from 60.5 to 89 mg-N/L). In addition, these initial HYDRUS 2D corroboration runs did not include rainfall inputs on the days preceding the sample event nor a layered system. HYDRUS-2D predictions were observed to be conservative (Table 3.2) compared to field data for the GCREC site. The average relative difference between GCREC field observations and HYDRUS-2D predictions were ~30% (excluding the 1 ft observation during SE2) and improved corroboration was

observed as the depth increased (with R^2 value at 3.5 ft equal to 0.9). Figure 3.1 illustrates the results from this initial corroboration run.

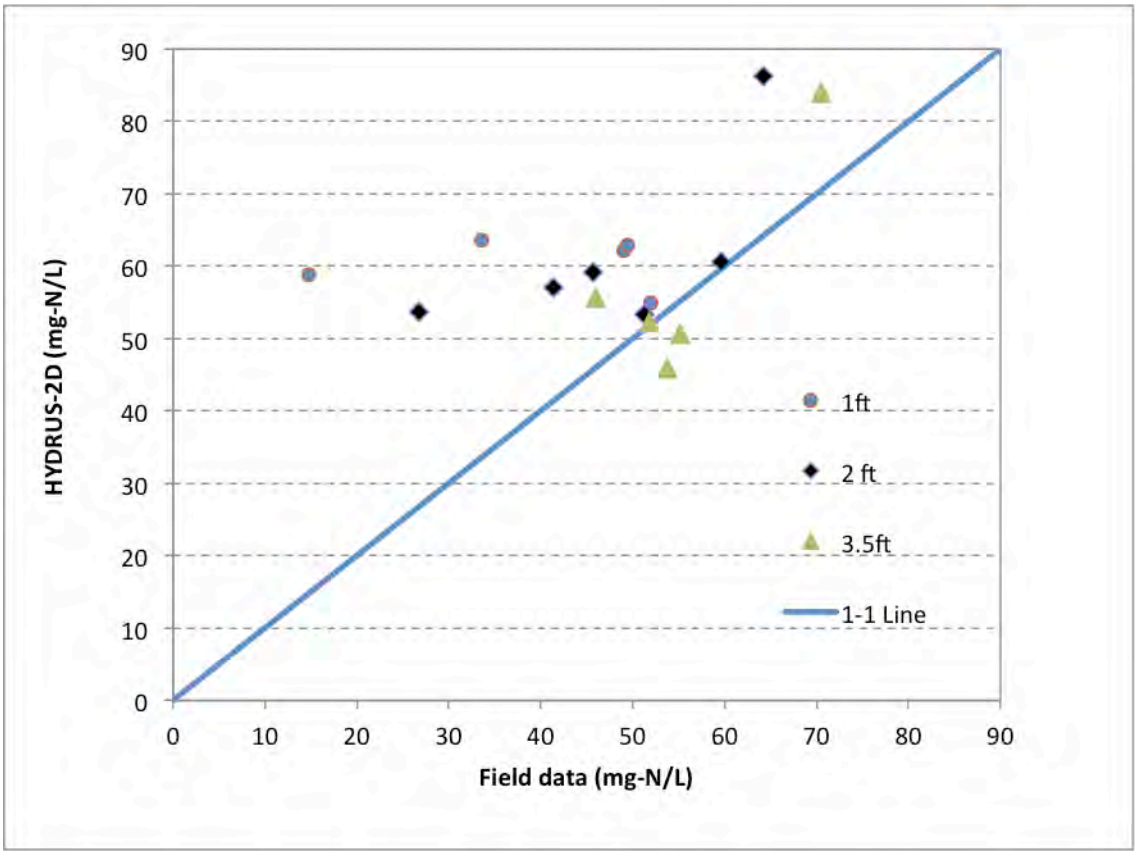

Figure 3.1
Initial HYDRUS-2D Corroboration Results for the GCREC S&GW Test Area 1 excluding Rainfall and with Measured STE Input Concentrations

The discrepancy between HYDRUS 2D predictions and observations was particularly high for some of the sampling events (SE2, SE4 and SE6) that had significant rainfall events on or few days prior to the sampling. In addition, the observed value at 1 ft for SE2 was exceptionally low (14 mg-N/L) compared to other observations and is considered to be an outlier. The observations demonstrated that precipitation had an effect and dilution was considered to be a factor that contributed to the low concentration in the field data, although other factors may have contributed to a relatively faster removal near the infiltrative surface. To evaluate corroboration improvement, HYDRUS-2D was rerun including precipitation input to better reflect actual field conditions, adding a mound sand layer, and using the average applied effluent quality. Figure 3.2 illustrates the corrobora-

tion results including precipitation while still using the default hydraulic parameter values for a less permeable sand shown in Table 3.2 and default values for nitrogen transformation (sorption, nitrification and denitrification). For these corroboration runs the average relative difference between GCREC field observations and HYDRUS 2D predictions was improved to 18%.

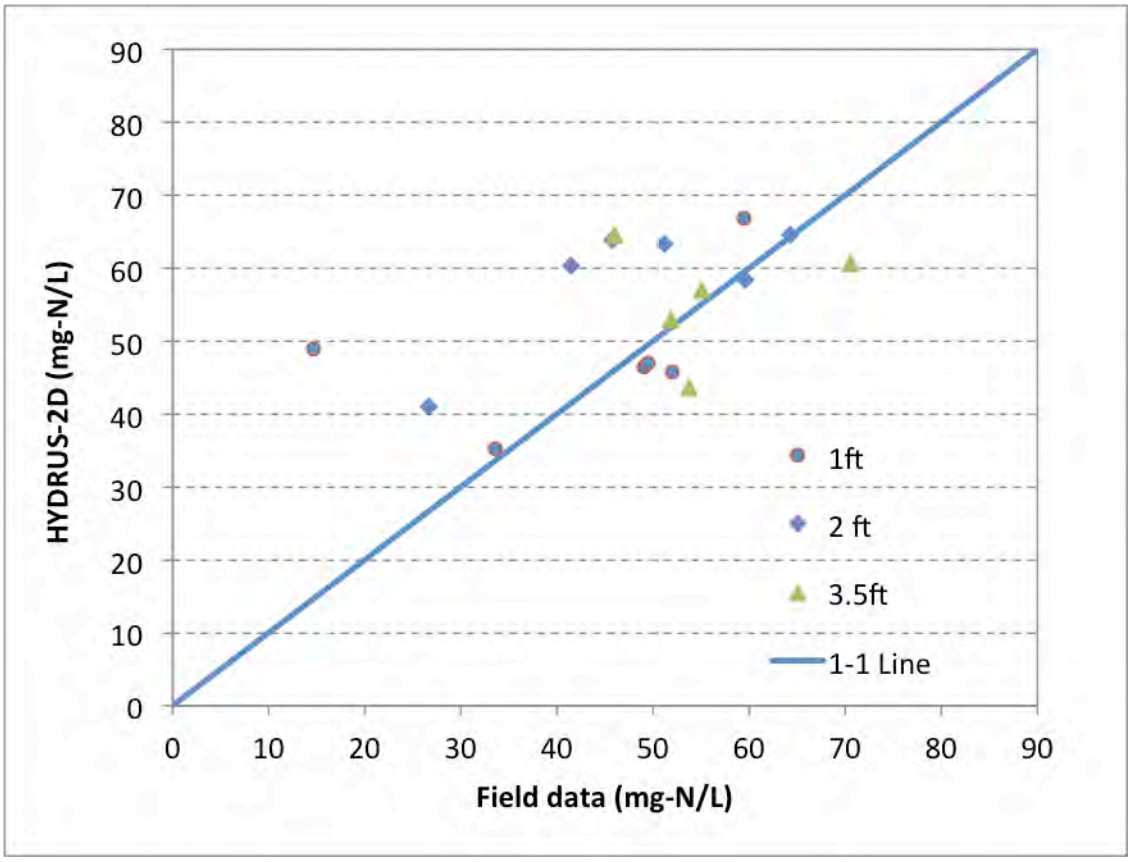

Figure 3.2
HYDRUS-2D Corroboration Results for the GCREC S&GW Test Area 1 including Rainfall during Sampling Events

One limitation observed for the HYDRUS model was that nitrification was relatively slower at higher loading rates compared to field data (or to STUMOD-FL, see Task D.9 deliverable), which resulted in relatively higher total nitrogen reaching the water table especially for a shallow water table. Ammonium nitrogen concentrations were below detection limits at all suction lysimeters in test area 1 for all the sampling events. This observation suggests complete nitrification in less than one foot of soil. However, HYDRUS-2D simulation results predicted ammonium at 1 and 2ft suggesting nitrification

was not as fast as it is observed in the field based on the default nitrogen transformation parameters used in the model.

Based on the ammonium results, further adjustment was made. The default nitrification rate used was a median rate of 56 mg-N/L/d. The range of reported nitrification rates is quite large, with a minimum value of 0.5 mg-N/L/d, a maximum value of 574 mg-N/L/d, and the median rate was 56 mg mg-N/L/d (McCray et al., 2010). The nitrification rate was adjusted to 200 mg-N/L/d which resulted in conversion of ammonium to nitrate within one foot as observed in the field. Ammonium concentrations ranged from 1.5 to 5 mg-N/L for all cases except for SE5. This modification further improved corroboration predictions as shown in Figure 3.3. The average relative difference between GCREC field observations and HYDRUS 2D predictions was 16% (excluding the 1ft observation during SE2).

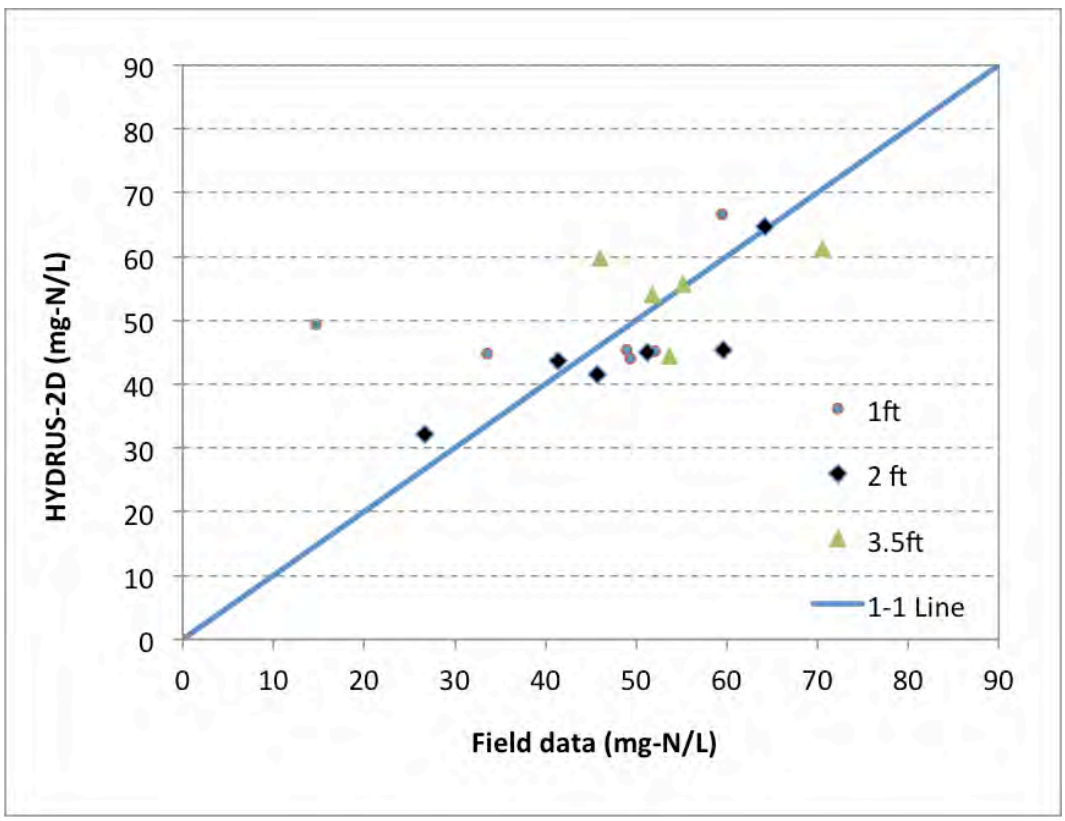

Figure 3.3
HYDRUS-2D Corroboration Results for Total Nitrogen at the GCREC S&GW Test Area 1 including Rainfall during Sampling Events and the Modified Nitrification Rate

Velocity was calculated from GCREC tracer tests and breakthrough curves developed at 1, 2 and 3.5 ft from the infiltrative surface. The time required for the tracer to reach a peak concentration was used as the travel time for each depth assuming all of the applied fluid infiltrates and the HLRs was 3.26 cm/d. The travel times for 1, 2 and 3.5 ft were 5.76, 6.75, and 10.72 days, respectively resulting in estimated velocities of 0.17, 0.30 and 0.19 ft/d for 1, 2 and 3.5 ft, respectively. The velocity calculated for the six HYDRUS-2D corroboration models (sampling events) did not differ much between the six model runs. The average velocities from the six runs were 0.27, 0.24 and 0.19 ft/d respectively for 1, 2 and 3.5 ft. These calculated average velocity are close to the velocity estimates from a tracer test particularly for the 2 ft and 3.5 ft depths.

Based on the observations from the GCREC site (Figures 3.2 and 3.3) the model captured the field data very well in some cases while in other cases the model either over or under predicted concentrations. Modifications to HYDRUS-2D parameterization made based on site specific observations achieved some improvement in corroboration. Specifically, for the GCREC, incorporation of rainfall, using an average ammonium input value based on the average measured STE concentration, incorporating a mound sand layer, and increasing the nitrification rate improved nitrate predictions with depth. The graphical outputs from the HYDRUS-2D initial corroboration and improved corroboration simulations are included in Appendix C (see Figures C.5 to C.10 and Figures C.19 to C.24).

The general trend for model output is a maximum nitrate concentration at shallow depths due to conversion of ammonium to nitrate via nitrification and then a gradual decrease in nitrate concentration with depth due to denitrification. The magnitude of denitrification depends on several factors including the denitrification rate, soil moisture content, soil temperature, and travel time. Field observations do not show such a consistent decrease in nitrate concentration with depth for a variety of reasons.

Model performance can always be improved through site specific calibration. The nitrification rate adjusted as a ‘soft calibration’ improved model performance by enabling faster nitrification and a better match between observed and predicted ammonium and nitrate nitrogen with depth. Although it is possible that general trends in model predictions can be captured using default values, site specific parameter values are needed to reduce errors in model predictions. Applying the new parameter values to other sites may not necessarily improve predictions at other sites and may introduce a bias that is poorly understood due to the limited data for corroboration. This was observed during corroboration at the USF site where a different set of parameter values were required to improve

HYDRUS-2D predictions. For example, GCREC parameters used for the USF corroboration did not improve model predictions compared to the observed USF field data further suggesting the site specific nature of best fit parameter values. Yet, outputs from generalized default values can still be used to assess the relative differences between scenarios of site and operating conditions to get an understanding of the relative change in behaviors with changing inputs and site conditions.

3.2.2 USF Lysimeter Station Corroboration

At the USF Lysimeter Station, corroboration was evaluated using three sets of parameter values (Table 3.3): 1) generalized more permeable sand, 2) Candler fine sand, and 3) parameters based on site specific soil characteristics measured at the lysimeter station. Soil at the lysimeter station was identified as Candler fine sand, which is generally characterized by 97.3% sand, 1.4% silt, 1.4% clay, a saturated hydraulic conductivity of 890.4 cm/d, and a bulk density of 1.50 g/cm^3 (University of Florida, 2007). Parameter estimation is described in Section 2.1 for the generalized more permeable sand (see Table 2.4) and the Candler fine sand (see Table 2.3). Site specific soil characteristics were obtained from the project report (Ayres Associates 1993). Following the approach described in Section 2.1, the relevant parameters (θ_r, θ_s, α, and n) were estimated specific to the soil measurements reported for lysimeter station. Soil moisture was not measured at 15bar suction so θ_r was set to equal moisture content measured at 345 cm suction (the maximum suction measured). Operational data and field observations were obtained from the project report (Ayres Associates 1993). The applied effluent quality was represented by 40.5 mg-N/L as ammonium + 0.04 mg-N/L as nitrate delivered to the soil at two HLRs, 3.06 and 6.12 cm/d (0.75 and 1.5 gpd/ft^2).

Table 3.3
HYDRUS-2D Simulation Parameters Selected to Replicate USF Lysimeter Station Field Conditions

Run ID[1]	K_{sat} (cm/d)	Depth (ft)	HLR (cm/d)	θ_r	θ_s	α	n
1	670.8	2, 4	3.06	0.013	0.3874	0.024	2.52
2	670.8	2, 4	6.12	0.013	0.3874	0.024	2.52
3	890.4	2, 4	3.06	0.0079	0.3856	0.023	3.57
4	890.4	2, 4	6.12	0.0079	0.3856	0.023	3.57
5	633.4	2, 4	3.06	0.0368	0.3978	0.017	6.24
6	633.4	2, 4	6.12	0.0368	0.3978	0.017	6.24

[1] *Parameters for runs 1 and 2 are based on more permeable sand (see Section 2.1). Parameters for runs 3 and 4 are based on generalized Candler fine sand (see Table 2.3, Section 2.1). Parameters for runs 5 and 6 are based on site specific soil characteristics measured at the USF Lysimeter Station (Ayres Associates, 1993).*

This approach evaluates improvements to corroboration as the data used for modeling is refined. First using generalized more permeable sand parameters provides insight into how the simple tools in Appendix B relate to a site that would be most similar to the more permeable sand. Second, using the generalized Candler fine sand data provides insight into how using readily available data would improve the model predictions relative to the simple tools in Appendix B. Finally, the site specific data provides insight into further model prediction improvements relative to the simple tools in Appendix B, but at the cost of conducting field characterization.

Initial corroboration involved comparison of the model output (maxiumum concentration) to average observed nitrate nitrogen concentrations screened to exclude sampling events that occurred within two days of a measured rain event. This assumption was supported by a two-way ANOVA that indicated that the majority of the variability (57%, α = 0.01) in the unscreened data was attributed to rain and assumed that there was no difference between samples due to collection method (ceramic suction lysimeter or stainless steel pan). In addition because only TKN and nitrate were measured, it was assumed that ammonium concentrations were equal to TKN (47.2 mg-N/L). This is a conservative assumption as some fraction of the TKN would have been organic nitrogen. This approach resulted in an overly conservative estimate by under predicting nitrogen removal by up to ~50% (Table 3.4 and Figure 3.4).

Table 3.4
Comparison of USF Field Observations to Candler Fine Sand HYDRUS-2D Corroboration Results[1]

Sample Event	HLR	Depth (ft)	Measured NO_3 (mg-N/L)	Initial HYDRUS NO_3 (mg-N/L)	Revised HYDRUS NO_3 (mg-N/L)	Final HYDRUS NO_3 (mg-N/L)
Averaged	3.06	2	27.5	46.1	--	--
Averaged	3.06	4	29.0	45.1	--	--
Averaged	6.12	2	18.0	26.5	--	--
Averaged	6.12	4	26.0	36.4	--	--
12/21/92	3.06	2	29.3	--	33.7	28.4
12/21/92	3.06	4	17.0	--	29.2	19.1
12/21/92	6.12	2	30.7	--	38.6	37.1
12/21/92	6.12	4	26.7	--	37.1	34.1
1/20/93	3.06	2	29.0	--	26.7	22.4
1/20/93	3.06	4	18.5	--	25.2	16.9
1/20/93	6.12	2	33.5	--	36.0	34.5
1/20/93	6.12	4	27.5	--	32.5	29.8

[1] *Initial HYDRUS results are from the initial corroboration. Revised HYDRUS results are with the modified nitrification rate, but default denitrification rate. Final HYDRUS results are from adjusted runs with modified nitrification and denitrification rates.*

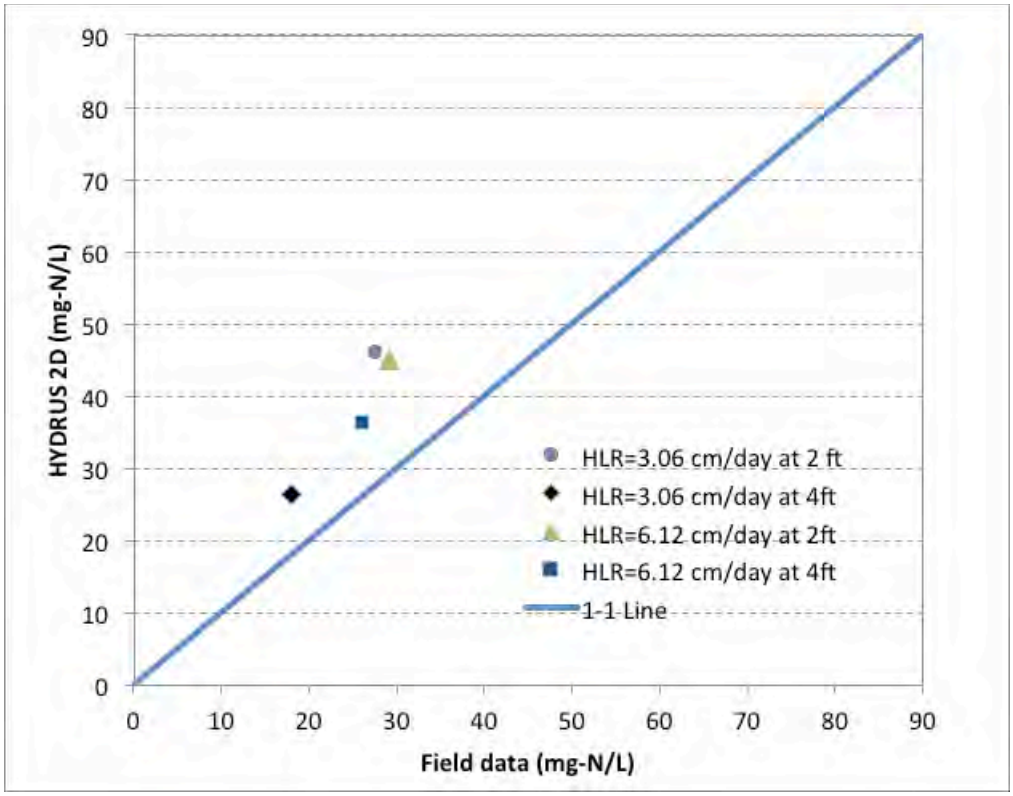

Figure 3.4
Initial HYDRUS-2D Nitrate Nitrogen Corroboration Results for the USF Lysimeter Station using Averaged Field Observations and Higher Effluent Input

To improve corroboration, the model output was compared to the average observed nitrate nitrogen concentrations (triplicate samples) on two sampling dates; 12/21/1992 pan sample and 1/20/1993 lysimeter sample. The December sample had 11 dry days prior to the sampling date (11 days with no rainfall) and the second sample had 4 dry days. In addition, the input ammonium concentration was lowered to 40.5 mg-N/L to better reflect field measurements and a 2ft water table was added to reflect the constant head boundary maintained during field testing. Finally, similar to the GCREC corroboration, precipitation was added as a variable input. A 'soft calibration' was again necessary to better match field observations.

At first median default nitrification and denitrification rates were used (56 mg-N/L/d and 2.58 mg-N/L/d, respectively), but this resulted in over prediction of nitrogen concentrations at all soil depths for all set of conditions and hydraulic parameter sets shown in Table 3.3. Because nitrification was slower in HYDRUS-2D simulations than demonstrated by field observations, the nitrification rate was adjusted to 300 mg-N/L/d to match field

observations. Reported denitrification rates for 100% WFP ranged from 0.033 to 127 mg-N/L/d with a median rate of mg-N/L/d (McCray et al., 2010). Using median default denitrification rates still over predict nitrate concentration 90% of the time although the nitrification rate was adjusted to reflect field data on ammonium concentration (Table 3.5). The R^2 values were also relatively low ranging from 0.3 to 0.45. The model particularly over predicted nitrogen concentrations at the lower hydraulic loading rate and 4 ft water table conditions. For the GCREC site, modification to the nitrification rate was sufficient to improve model predictions. Unlike the GCREC model, the USF Lysimeter Station model consistently over predicted concentrations even with adjusted nitrification rate. Thus, denitrification rate was also adjusted to 5.5 mg-N/L/d to better match field observations. This difference in soft calibration between the GCREC and USF lysimeter station models shows that parameter values have to be adjusted for each site to get a better fit to field data.

Table 3.5
Comparison of USF Field Observations to Revised Final HYDRUS-2D Corroboration Results

Sample Event	HLR	Depth (ft)	Measured NO_3 (mg-N/L)	More Permeable Sand HYDRUS NO_3 (mg-N/L)	Candler Fine Sand HYDRUS NO_3 (mg-N/L)	USF Site Specific HYDRUS NO_3 (mg-N/L)
12/21/92	3.06	2	29.3	27.5	28.4	19.8
12/21/92	3.06	4	17.0	15.3	19.1	11.5
12/21/92	6.12	2	30.7	37.0	37.1	35.2
12/21/92	6.12	4	26.7	32.8	34.1	31.5
1/20/93	3.06	2	29.0	22.4	22.4	19.2
1/20/93	3.06	4	18.5	15.4	16.9	12.1
1/20/93	6.12	2	33.5	32.3	34.5	28.1
1/20/93	6.12	4	27.5	30.5	29.8	29.8

With the incorporation of rainfall and adjusted nitrification and denitrification rates, the model predictions matched field observations relatively well (Figures 3.5, 3.6, and 3.7). The R^2 values improved to 0.68 to 0.54. The relative % difference between field observations and HYDRUS 2D predictions was also further reduced to <25%. The model produced a better fit at a depth of 4 ft compared to 2 ft.

A tracer test conducted at the USF Lysimeter Station estimated travel times of 3 to 4 days (Ayres Associates, 1993). However, in some cases the control test cells had longer travel times compared to test cells receiving STE and in some cases travel times at the higher HLR were longer compared to the lower HLR making interpretation difficult. Velocities calculated from the tracer data were: 0.67 ft/d for HLR of 3.06 cm/d at a 2ft depth, 1.00 ft/d for HLR of 3.06 cm/d at a 4ft depth, 0.61 ft/d for HLR of 6.12 cm/d at a 2ft depth, and 1.21 ft/d for HLR of 6.12 cm/d at a 4ft depth. Alternatively, assuming all

the applied water infiltrates, the velocity can be roughly estimated as HLR divided by porosity. This approach estimates velocities closer to the HYDRUS-2D predictions than the tracer test estimates (i.e., 3.06*0.0328/(0.38) = 0.264 ft/d or 0.53 ft/day for HLR=6.12 cm/d).

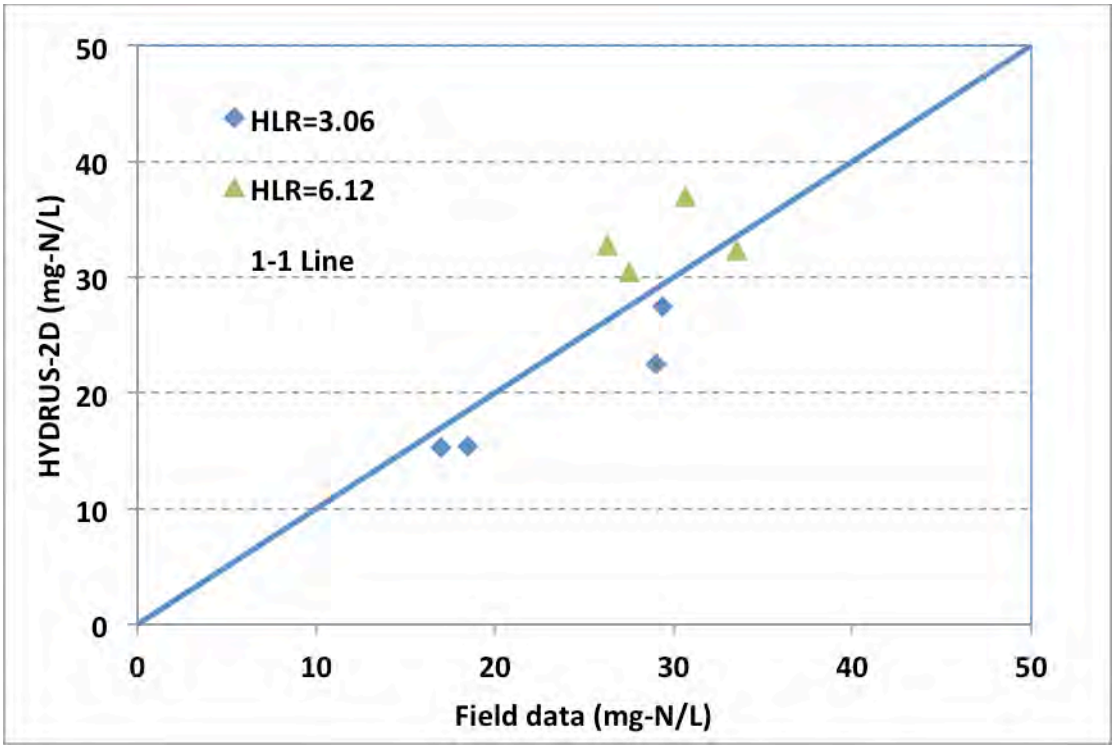

Figure 3.5
Adjusted HYDRUS-2D Corroboration Results for the USF Lysimeter Station using Parameters Representative of Generalized More Permeable Sand

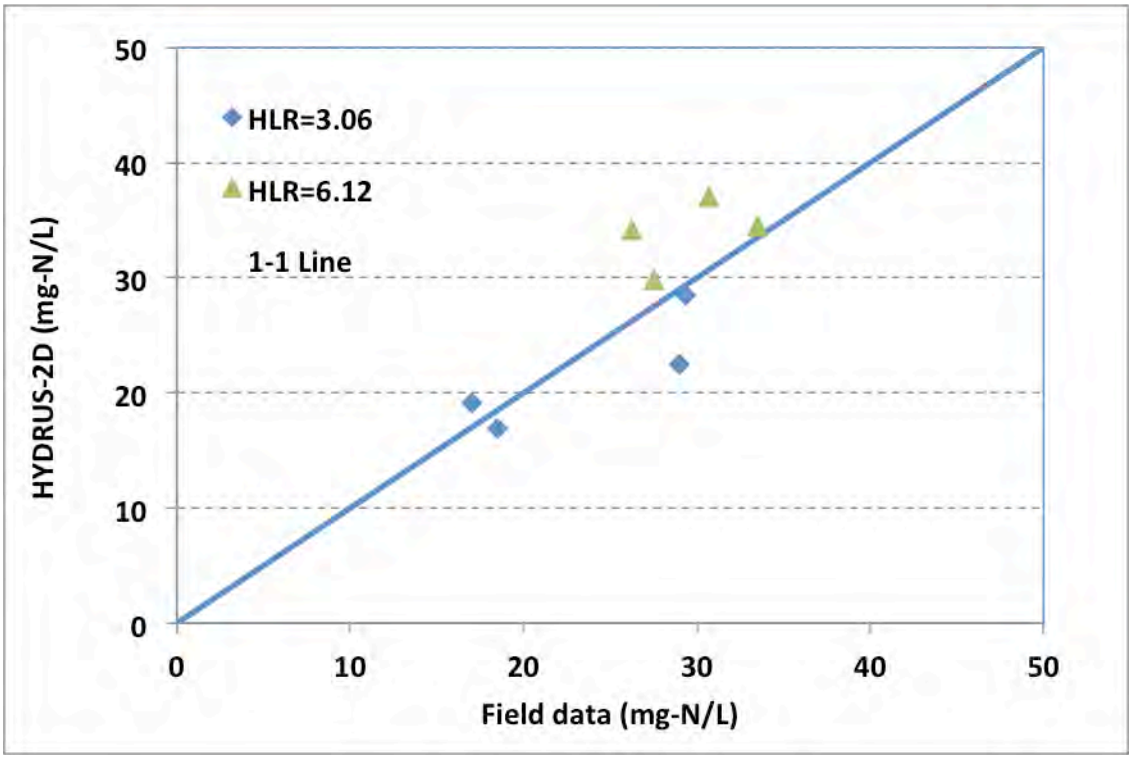

Figure 3.6
Adjusted HYDRUS-2D Corroboration Results for the USF Lysimeter Station using Parameters Representative of Generalized Candler Fine Sand

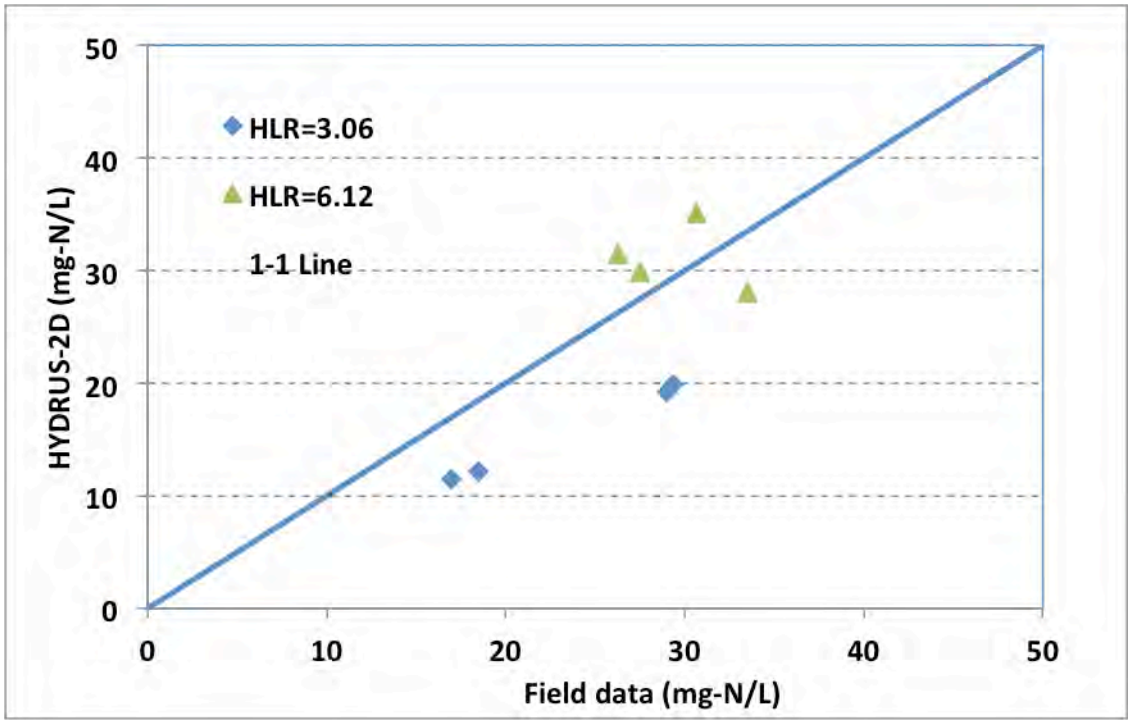

Figure 3.7
Adjusted HYDRUS-2D Corroboration Results for the USF Lysimeter Station using Parameters Determined from Site Specific Soil Characteristics

It is interesting to note that the corroboration fits did not improve significantly as more specific parameters were used. Specifically, the R^2 values for the generalized more permeable sand (Figure 3.5), the generalized Candler fine sand (Figure 3.6) and the site specific soil (Figure 3.7) were 0.68, 0.64, and 0.54, respectively. Similarly, the relative difference between field observations and HYDRUS 2D predictions decreased for the generalized more permeable sand or generalized Candler fine sand compared to the site specific soil (14% for more permeable sand and Candler fine sand, 24% for USF site specific). The relatively worse model fits using site specific data is most likely attributed to the estimation of van Genuchten fitting parameters using field measurements that did not include soil moisture at suctions > 345cm. Model performance could be improved through site specific calibration, but as shown when using the calibrated parameters from the GCREC for the lysimeter facility the overall performance of the model at a different site is not necessarily improved.

It was observed that the percent nitrogen removal decreased with increasing hydraulic loading rate for both the HYDRUS-2D runs and field observations. This could be attributed to the increased velocity/reduced travel time at higher loading rates. Furthermore, reduction in removal efficiency with increasing hydraulic loading rate was not as

large in the field observation compared to the reduction obtained from the HYDRUS-2D runs. This suggests that under field conditions, there are additional factors that compensate for the effect of reduced travel times due to increased hydraulic loading rate that are not captured in the model. For instance, an increased carbon loading as a result of increasing hydraulic loading may compensate for reduced travel time. In sufficient field observations limits the ability to further speculate or modify the model.

Comparison of the simulation results using Candler fine sand parameters (Figures C.1 and C.2) to the simulation results using the generalized more permeable sand parameters (Figures C.3 and C.4) suggests that the generalized Candler fine sand parameters represent a relatively coarser sand producing lower moisture contents. The difference in moisture content is not that high and is not expected to cause a difference in nitrification. However, ammonium penetrated deeper into the soil profile in the run with Candler fine sand parameters (coarser soil) which could be attributed to faster percolation (relatively higher velocities or lower residence times). This means that nitrate concentrations were lower at shallow depths for the Candler fine sand relative to the generalized more permeable sand. The effect of soil texture was consistent regardless of the HLR (3.06 or 6.12 cm/day). Although the nitrogen profiles from the simulation results based on site specific parameters (Figures C.11 thorugh C.18) are not directly comparable (due to incorporation of rainfall, adjusted nitrification and denitrification rates, different ammonium input concentrations, and different sample event observations), the moisture profile suggest that the site is more coarse than the generalized more permeable sand, but less coarse than the Candler fine sand.

Alternatively, by comparing runs within a soil texture the effect of the HLR can be seen to result in ammonium penetrating deeper when the HLR is higher (6.12 cm/d compared to 3.06 cm/d) (Figure C.1 vs. C.2; Figure C.3 vs C.4; Figure C.11 vs C.13; Figure C.12 vs C.14; Figure C.15 vs C.17; and Figure C.16 vs C.18). This effect is observed for both soil textures and is again attributed to higher velocities (reduced retention times) at the higher HLR resulting in lower nitrate concentrations at shallower depths. Although the model outputs for these corroboration runs illustrate different behaviors (e.g., soil moisture, velocity, effect of soil texture), the simulated outputs were not significantly different in regards to nitrogen removal at the water table.

3.2.3 Summary

In summary, corroboration of HYDRUS-2D varied, but model predictions were intuitive considering factors that are expected to influence removal (HLR, effluent concentration, soil texture, etc.). Corroboration simulation results were closer to field observations as the depth increased. It may be that very shallow domains (e.g., 1 ft or less) are not generally well represented by HYDRUS.

Model performance can always be improved through site specific calibration. Applying the new parameter values to other sites may not necessarily improve predictions as was observed during corroboration at the USF site based on soft calibration parameter values from the GCREC corroboration.

The Task D.7 simple tools presented here as developed by HYDRUS-2D are useful and accurate for the goal of illustrating subsurface behaviors of OWTS as influenced by operating and environmental conditions. Even without rigorus calibration, these Task D.7 simple tools can be used to assess the overall impact of scenarios involving site and operational conditions to gain a good understanding of the effect these various factors have on nitrogen reduction. In other words, the soft calibrated model provided simple tools useful to answering "what if" scenarios providing insight about the relative impact of common input parameters and operational conditions.

Section 4.0
Summary

Simple tools were developed in Task D.7 to illustrate subsurface behaviors such that if key operating conditions change, a general understanding of the expected change to OWTS performance can be gained. HYDRUS-2D was used to simulate operating conditions for a range of typical OWTS operating conditions in Florida. The approach used was based on a modified factorial design to highlight treatment performance as effected by soil texture, depth to the water table, distribution configuration, and effluent quality.

Increased performance at the water table (i.e., higher removal or lower concentrations or lower mass fluxes) was generally observed as the soil texture becomes finer (more permeable sand → less permeable sand → sandy clay loam) and the depth to the water table increased. Several factors are combined within the different distribution configurations: trenches vs. beds, equal vs unequal effluent distribution to the soil, and HLR. The interaction of the factors combined within the distribution configuration precludes robust analysis, but trenches appear to perform better than beds and OWTS with equal distribution of effluent loading appear to perform better than OWTS with unequal distribution of effluent loading. Finally, increased performance at the water table was observed for nitrified effluent compared to STE with less apparent benefit for shallow water tables and sands.

HYDRUS-2D was corroborated to two field studies and although this corroboration varied, model predictions were intuitive and are generally conservative estimates by under predicting nitrogen removal.

Section 5.0
References

Ayres Associates. 1993. The Capability of Fine Sandy Soil for Septic Tank Effluent: A Field Investigation at an In-Situ Lysimeter Facility in Florida. Prepared for State of Florida, Dept. of Health and Rehabilitative Services.

Beach, D.N. and J.E. McCray. 2003. Numerical modeling of unsaturated flow in wastewater soil absorption systems. Ground Water Monitoring Remediation 23 (2):64-72.

Beal, C.D., D.W. Rassam, E.A. Gardner, G. Kirchhof, and N.W. Menzies. 2008. Influence of Hydraulic Loading and Effluent Flux on Surface Surcharging in Soil Absorption Systems. Journal of Hydrologic Engineering 13 (8):681:692.

Bumgarner, J.R. and J.E. McCray. 2007. Estimating biozone hydraulic conductivity in wastewater soil-infiltration systems using inverse numerical modeling. Water Research 41(11):2349-2360.

Doyle, S., J.E. McCray, K.S. Lowe, G.D. Thyne. 2005. Modeling Phosphorus Reaction and Transport at an Experimental Onsite Wastewater Site. Proc. NOWRA 15th Annual Technical Education & Exposition Conference.

Finch, S.D., D.E. Radcliffe, and L.T. West. 2008. Modeling trench sidewall and bottom flow in on-site wastewater systems. Journal of Hydrologic Engineering 13(8):693-701.

Greenacre, Michael. 2008. STA254, Stanford University. www.econ.upf.edu. Universitat Pompeu Fabra, Barcelona, Spain.

Heatwole, K.K., J.E. McCray. 2007. Modeling Potential Vadose-Zone Transport of Nitrogen from Onsite Wastewater Systems at the Development Scale. J. Contaminant Hydrology, 91:184-201.

Jury, W.A. and R. Horton. 2004. Soil Physics. 6th ed. Wiley.

Lowe, K., M. Tucholke, J. Tomaras, K. Conn, C. Hoppe, J. Drewes, J. McCray, and J. Munakata-Marr. 2009. Influent Constituent Characteristics of the Modern Waste Stream from Single Sources: Final Report. Project No. 04-DEC-1. Prepared for WERF, Alexandria, VA by CSM, Golden CO.

Maag, M. and F.P. Vinther. 1996. Nitrous oxide emission by nitrification and denitrification in different soil types and at different soil moisture contents and temperatures. Applied Soil Ecology 4(1):5-14.

McCray, J.E., D.N. Huntzinger, S.M. Van Cuyk, R.L. Siegrist. 2000. Mathematical Modeling of Unsaturated Flow and Transport in Soil-Based Wastewater Treatment Systems. Proc. WEFTEC 2000, 73rd Annual Conference and Exhibition, WEF.

McCray, J., M. Geza, K. Lowe, T. Boving, D. Radcliffe, M. Tucholke, A. Wunsch, S. Roberts, J. Amador, J. Atoyan, J. Drewes, D. Kalen, G. Loomis. 2010. Quantitative Tools to Determine the Expected Performance of Wastewater Soil Treatment Units. Final Reports and Tools: Guidance Manual, User's Guide, Visual Graphics, STUMOD, and NCALC. WERF, DEC1R06. PDF available at: www.werf.org

MINITAB 2000. Release 13, User's Guide.

Park, P.J., J. Manjourides, and M. Pagano 2009. A permutation test for determining significance of clusters with applications to spatial and gene expression data. Computational Statistics and Data Analysis. NIH Public Access. 53(12): 4290-4300.

Radcliffe, D.E., L.T. West, and J. Singer. 2005. Gravel effect on wastewater infiltration from septic system trenches. Soil Science Society of America Journal 69:1217-1224.

Radcliffe, D.E., and L.T. West. 2009. Design hydraulic loading rates for onsite wastewater systems. Vadose Zone Journal 8(1):1-11.

Šimůnek, J., M. Sejna, and M.T. van Genuchten. 1999. The HYDRUS-2D Software Package for Simulating Two-dimensional Movement of Water, Heat, and Multiple Solutes in Variably Saturated Media. Version 2.0. Agricultural Research Service, U.S. Department of Agriculture, Riverside, CA.

Tucholke, M.B., J.E. McCray, G.D. Thyne, and R.M. Waskom. 2007. Variability in denitrification rates: Literature review and analysis. Proceedings of the National Onsite

Wastewater Recycling Association 16th Annual Technical Education & Exposition Conference, in Baltimore, MD. NOWRA, Santa Cruz, CA.

University of Florida. 2007. Florida Soil Characterization Data Retrieval System. Department of Soil and Water Science. http://soils.ifas.ufl.edu/flsoils/databaseintro

Zedah, L.A. 1965. Fuzzy Sets. Information and Control, 8:338-353.

Appendix A: Soil Texture Prevalence in Florida

Florida encompasses about 34.5 million acres of land, out of which approximately 4.8 million acres (14%) is considered urban land and 29.5 million acres soil. Of the 420 reported soil series, sand, loamy sand and sandy loam cover 75% of all land area and muck soils cover about 10% (http://dlis.dos.state.fl.us/library/flcollection/landWater.cfm and www.soilsurvey.org). Figure A.1 depicts the distribution of all land in Florida.

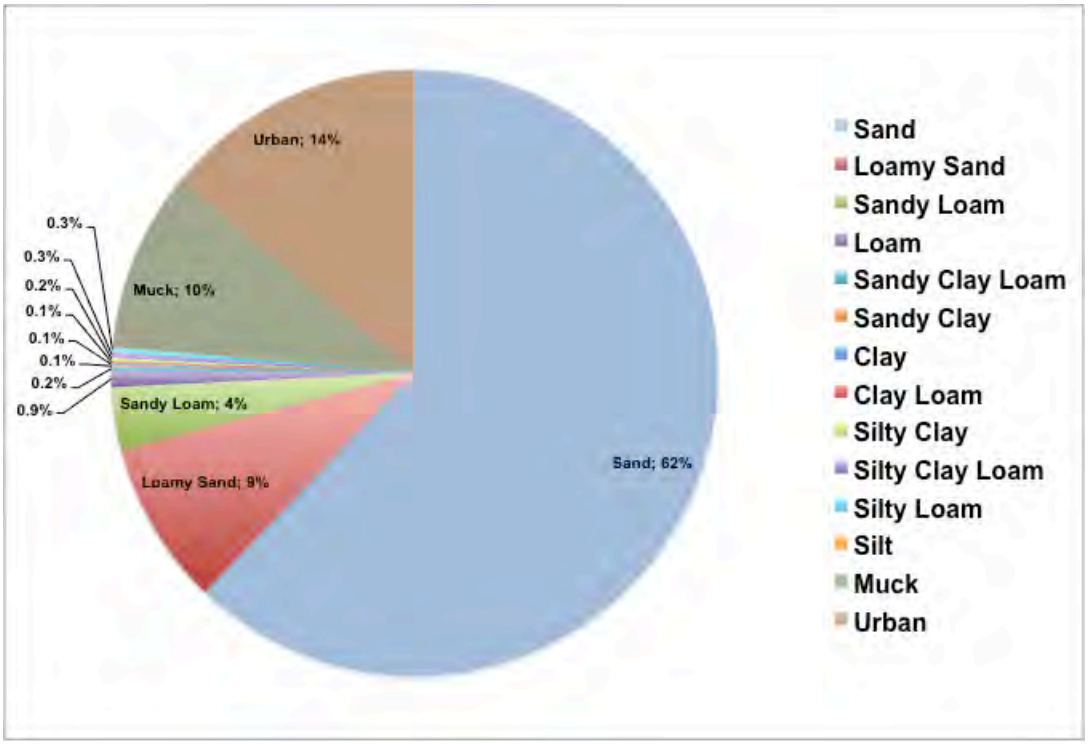

Figure A.1
Extent of Soil Textures, Muck, and Urban Land in Florida
(by acreage of total land area)

Excluding urban lands or mucky soils, there are 333 soil series that cover 26 million acres for further analysis potentially relevant to OWTS. Of this "useable" land area (i.e., 333 soil series), sandy soils cover 81%, with loamy sands and sandy loams 11% and 4.4% respectively (Table A.1). It is interesting to note that the top ten most prevalent soils series (by acreage) encompass 28% of the useable land, the top twenty series encompass 43%, the top thirty cover 54%, and the top fifty cover 69% of all usable land. In

other words, 15% of the soil series predominate nearly 70% of the useable land area. Again, the top thirty soils are primarily sand (26 soil series with 3 loamy sands and 1 sandy loam) as are the top fifty soils (44 sands, and 5 loamy sands & 1 sandy loams).

Table A.1
Summary of Soil Texture Distribution in Florida[1]

Soil Texture	Frequency[2]	Acreage	Estimated % of "Usable Land"
Sand	191	21,478,470	81%
Loamy Sand	56	3,012,799	11%
Sandy Loam	50	1,161,877	4.4%
Loam	12	299,256	1.1%
Sandy Clay Loam	4	69,312	0.3%
Sandy Clay	1	22,516	0.1%
Clay	5	37,161	0.1%
Clay Loam	4	45,687	0.2%
Silty Clay	1	58,756	0.2%
Silty Clay Loam	5	100,302	0.5%
Silty Loam	4	95,731	0.4%
Silt	0	0	0.0%

1 Applies to land areas only, excluding urban areas and mucks. Compiled from the Cooperative Soil Survey (www.soilsurvey.org).

2 Number of soil series identified/listed for the given soil texture.

For each soil series with reported data, the median values of % sand, silt and clay fractions were calculated, and compared to the USDA soil textural triangle, excluding sand (Figure A.2). As expected, the soil textural classification did not always overlay with the median calculated values of %sand, %silt, and %clay.

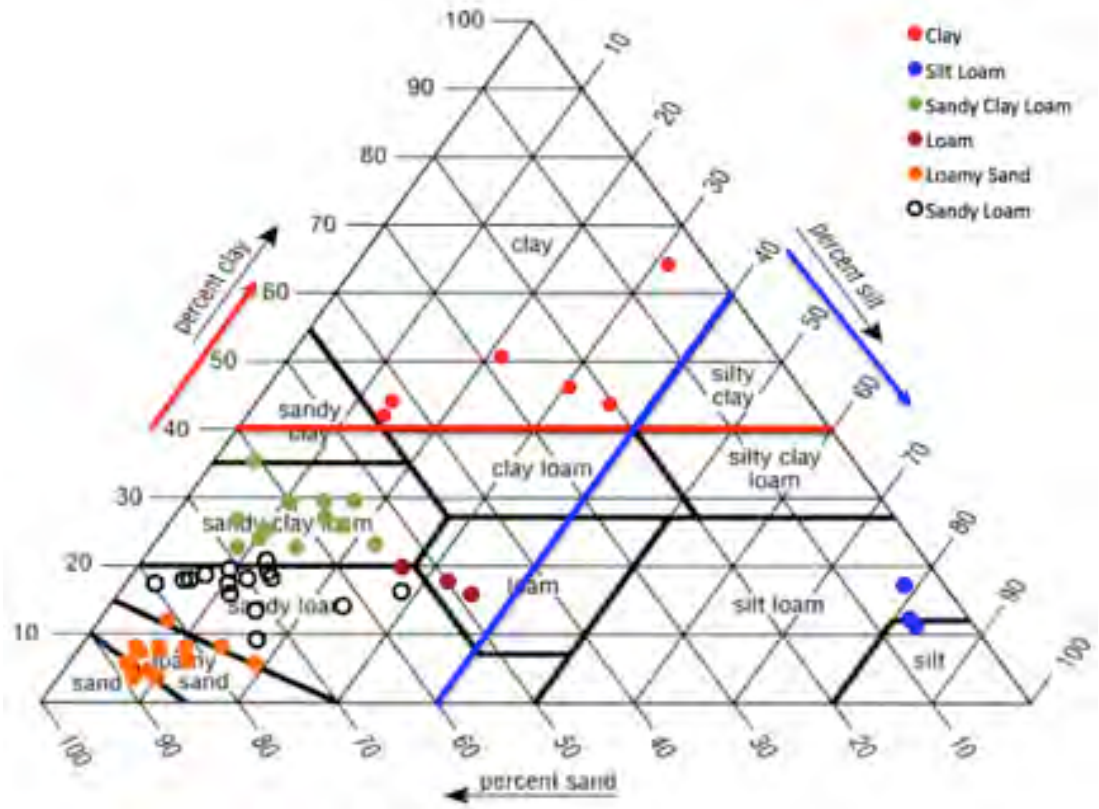

Figure A.2
Illustration of the distribution of Florida soil series, excluding sand
(Legend reflects the defined textural class for the series as listed by the USDA Cooperative Soil Survey. Symbols on the graph reflect the calculated median % sand/silt/clay fraction.)

Table A.2
Minimum Sum of Squares (SSQ) as Determined using Solver when Estimating van Genuchten Parameters.

Soil Series	α (1/cm)	n	SSQ
Adamsville	0.025	2.92	21.56
Albany	0.020	2.25	10.19
Alpin	0.023	2.65	17.94
Apopka	0.034	2.11	13.26
Arredondo	0.021	2.42	23.21
Astatula	0.030	2.96	18.39
Basinger	0.020	2.63	28.26
Blanton	0.023	2.43	30.48
Bonifay	0.032	1.80	8.45
Candler	0.023	3.57	33.45
Eau Gallie	0.017	2.08	11.28
Felda	0.015	2.29	3.84
Floridana	0.015	1.58	43.90
Holopaw	0.017	2.23	15.90
Immokalee	0.026	2.34	35.22
Lake	0.030	2.52	21.12
Lakeland	0.037	2.38	21.68
Leon	0.026	2.02	17.64
Malabar	0.021	2.43	18.21
Millhopper	0.026	2.41	21.75
Myakka	0.022	2.00	18.39
Oldsmar	0.030	2.06	24.96
Ortega	0.024	3.56	42.86
Otela	0.016	2.96	15.65
Paola	0.041	2.68	18.04
Pineda	0.017	2.49	6.83
Placid	0.021	1.76	12.94
Plummer	0.017	2.34	9.34
Pomello	0.022	2.80	27.74
Pomona	0.021	1.92	7.50
Riviera	0.017	2.42	22.55
Rutledge	0.016	1.97	8.17
Sapelo	0.019	2.06	13.87
Smyrna	0.021	2.25	21.27
Sparr	0.023	2.32	9.20
St Lucie	0.060	2.84	23.63
Tavares	0.024	2.97	25.72
Troup	0.037	1.90	12.29
Wabasso	0.019	1.90	11.45
Zolfo	0.019	4.21	19.29

Table A.2
Minimum Sum of Squares (SSQ) as Determined using Solver when Estimating van Genuchten Parameters (cont.).

Soil Series	α (1/cm)	n	SSQ
More Permeable Sand	0.024	2.52	21.25
Less Permeable Sand	0.020	2.24	11.02
Sandy clay loam	0.009	1.84	43.49

Table A.3
Summary of Sand Series Groupings based on the Principal Component Analysis Described in Section 2.1.

Soil Series ID	Soil Series	Grouping
1	Adamsville	more permeable sand
2	Albany	less permeable sand
3	Alpin	less permeable sand
4	Apopka	more permeable sand
5	Arredondo	less permeable sand
6	Astatula	more permeable sand
7	Basinger	more permeable sand
8	Blanton	less permeable sand
9	Bonifay	less permeable sand
10	Candler	more permeable sand
11	Eau Gallie	more permeable sand
12	Felda	less permeable sand
13	Floridana	less permeable sand
14	Holopaw	less permeable sand
15	Immokalee	more permeable sand
16	Lake	more permeable sand
17	Lakeland	more permeable sand
18	Leon	more permeable sand
19	Malabar	more permeable sand
20	Millhopper	more permeable sand
21	Myakka	more permeable sand
22	Oldsmar	more permeable sand
23	Ortega	more permeable sand
24	Otela	less permeable sand
25	Paola	more permeable sand
26	Pineda	more permeable sand
27	Placid	less permeable sand
28	Plummer	less permeable sand
29	Pomello	more permeable sand
30	Pomona	less permeable sand

Table A.3
Summary of Sand Series Groupings based on the Principal Component Analysis Described in Section 2.1 (cont.).

Soil Series ID	Soil Series	Grouping
31	Riviera	less permeable sand
32	Rutledge	less permeable sand
33	Sapelo	less permeable sand
34	Smyrna	more permeable sand
35	Sparr	less permeable sand
36	St Lucie	more permeable sand
37	Tavares	more permeable sand
38	Troup	less permeable sand
39	Wabasso	less permeable sand
40	Zolfo	more permeable sand

Appendix B:
Simple Tools Prepared using Hydrus-2D

Table B.1
Summary of Simulations that are Comparable to Illustrate Behaviors due to Soil Texture

Simulation ID	Distribution Configuration	Effluent Composition[1]	Water Table Depth
1, 5, 9	Trenches, equal dist	STE	1 ft below IS
2, 6, 10	Trenches, unequal dist	STE	1 ft below IS
3, 7, 11	Bed, equal dist	STE	1 ft below IS
4, 8, 12	Bed, unequal dist	STE	1 ft below IS
13, 17, 21	Trenches, equal dist	STE	2 ft below IS
14, 18, 22	Trenches, unequal dist	STE	2 ft below IS
15, 19, 23	Bed, equal dist	STE	2 ft below IS
16, 20, 24	Bed, unequal dist	STE	2 ft below IS
25, 29, 33	Trenches, equal dist	STE	6 ft below IS
26, 30, 34	Trenches, unequal dist	STE	6 ft below IS
27, 31, 35	Bed, equal dist	STE	6 ft below IS
28, 32, 36	Bed, unequal dist	STE	6 ft below IS
37, 41, 45	Trenches, equal dist	STE	free drainage
38, 42, 46	Trenches, unequal dist	STE	free drainage
39, 43, 47	Bed, equal dist	STE	free drainage
40, 44, 48	Bed, unequal dist	STE	free drainage
49, 51	Trenches, unequal dist	NE	2 ft below IS
50, 52	Trenches, unequal dist	NE	6 ft below IS
53, 55	Bed, unequal dist	NE	2 ft below IS
54, 56	Bed, unequal dist	NE	6 ft below IS

[1] *Effluent representative of septic tank effluent (STE) as 60 mg-N/L NH_4 + 0 mg-N/L NO_3; effluent representative of nitrified effluent (NE) as 15 mg-N/L NH_4 + 15 mg-N/L NO_3*

Table B.2
Summary of Simulations that are Comparable to Illustrate Behaviors due to Water Table Depth

Simulation ID	Distribution Configuration	Soil Texture	Effluent Composition[1]
1, 13, 25, 37	Trenches, equal dist	sandy clay loam	STE
2, 14, 26, 38	Trenches, unequal dist	sandy clay loam	STE
3, 15, 27, 39	Bed, equal dist	sandy clay loam	STE
4, 16, 28, 40	Bed, unequal dist	sandy clay loam	STE
5, 17, 29, 41	Trenches, equal dist	less permeable sand	STE
6, 18, 30, 42	Trenches, unequal dist	less permeable sand	STE
7, 19, 31, 43	Bed, equal dist	less permeable sand	STE
8, 20, 32, 44	Bed, unequal dist	less permeable sand	STE
9, 21, 33, 45	Trenches, equal dist	more permeable sand	STE
10, 22, 34, 46	Trenches, unequal dist	more permeable sand	STE
11, 23, 35, 47	Bed, equal dist	more permeable sand	STE
12, 24, 36, 48	Bed, unequal dist	more permeable sand	STE
49, 50	Trenches, unequal dist	sandy clay loam	NE
51, 52	Trenches, unequal dist	less permeable sand	NE
53, 54	Bed, unequal dist	sandy clay loam	NE
55, 56	Bed, unequal dist	less permeable sand	NE
58, 59	Trenches, unequal dist	layered soil textures	NE

1 *Effluent representative of septic tank effluent (STE) as 60 mg-N/L NH_4 + 0 mg-N/L NO_3; effluent representative of nitrified effluent (NE) as 15 mg-N/L NH_4 + 15 mg-N/L NO_3*

Table B.3
Summary of Simulations that are Comparable to Illustrate Behaviors due to Distribution Configuration

Simulation ID	Soil Texture	Effluent Composition[1]	Water Table Depth
1, 2, 3, 4	sandy clay loam	STE	1 ft below IS
5, 6, 7, 8	less permeable sand	STE	1 ft below IS
9, 10, 11, 12	more permeable sand	STE	1 ft below IS
13, 14, 15, 16	sandy clay loam	STE	2 ft below IS
17, 18, 19, 20	less permeable sand	STE	2 ft below IS
21, 22, 23, 24	more permeable sand	STE	2 ft below IS
25, 26, 27, 28	sandy clay loam	STE	6 ft below IS
29, 30, 31, 32	less permeable sand	STE	6 ft below IS
33, 34, 35, 36	more permeable sand	STE	6 ft below IS
37, 38, 39, 40	sandy clay loam	STE	free drainage
41, 42, 43, 44	less permeable sand	STE	free drainage
45, 46, 47, 48	more permeable sand	STE	free drainage
49, 53	sandy clay loam	NE	2 ft below IS
50, 54	less permeable sand	NE	6 ft below IS
51, 55	sandy clay loam	NE	2 ft below IS
52, 56	less permeable sand	NE	6 ft below IS

[1] *Effluent representative of septic tank effluent (STE) as 60 mg-N/L NH_4 + 0 mg-N/L NO_3; effluent representative of nitrified effluent (NE) as 15 mg-N/L NH_4 + 15 mg-N/L NO_3*

Table B.4
Summary of Simulations that are Comparable to Illustrate Behaviors due to Effluent Composition

Simulation ID	Distribution Configuration	Soil Texture	Water Table Depth
14, 49	Trenches, unequal dist	sandy clay loam	2 ft below IS
16, 53	Bed, unequal dist	sandy clay loam	2 ft below IS
18, 51	Trenches, unequal dist	less permeable sand	2 ft below IS
20, 55	Bed, unequal dist	less permeable sand	2 ft below IS
26, 50	Trenches, unequal dist	sandy clay loam	6 ft below IS
28, 54	Bed, unequal dist	sandy clay loam	6 ft below IS
30, 52	Trenches, unequal dist	less permeable sand	6 ft below IS
32, 56	Bed, unequal dist	less permeable sand	6 ft below IS
34, 57	Trenches, unequal dist	more permeable sand	6 ft below IS

Table B.5
Maximum Nitrogen Concentrations at the Water Table for Simulations that are Comparable to Illustrate Behaviors due to Soil Texture

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Conc (mg-N/L)	NO_3 Conc (mg-N/L)	TN Conc (mg-N/L)	Est %TN Removed
1	T-E	SCL	STE	1	38.4	14.5	53.0	12
5		LPS			11.5	40.8	52.3	13
9		MPS			4.1	47.8	52.0	13
2	T-UE	SCL	STE	1	51.2	6.8	58.0	3
6		LPS			36.	20.8	57.0	5
10		MPS			30.4	26.4	56.8	5
3	B-E	SCL	STE	1	10.4	31.0	41.3	31
7		LPS			1.2	48.7	49.9	17
11		MPS			0.1	49.7	49.8	17
4	B-UE	SCL	STE	1	35.0	16.9	51.9	13
8		LPS			26.8	28.7	55.5	7
12		MPS			18.3	37.0	55.3	8
13	T-E	SCL	STE	2	0.0	34.9	34.9	42
17		LPS			0.0	43.5	43.5	27
21		MPS			0.0	45.4	45.4	24
14	T-UE	SCL	STE	2	14.6	32.5	47.0	22
18		LPS			0.0	51.9	51.9	13
22		MPS			0.0	52.8	52.8	12
15	B-E	SCL	STE	2	0.0	23.7	23.7	61
19		LPS			0.0	42.3	42.3	30
23		MPS			0.0	44.1	44.1	27
16	B-UE	SCL	STE	2	0.1	40.7	40.8	32
20		LPS			0.0	50.8	50.8	15
24		MPS			0.0	51.7	51.7	14
25	T-E	SCL	STE	6	0.0	0.0	0.0	100
29		LPS			0.0	24.0	24.0	60
33		MPS			0.0	31.6	31.6	47
26	T-UE	SCL	STE	6	0.0	5.9	5.9	90
30		LPS			0.0	36.5	36.5	39
34		MPS			0.0	42.4	42.4	29
27	B-E	SCL	STE	6	0.0	0.0	0.0	100
31		LPS			0.0	33.1	33.1	45
35		MPS			0.0	39.1	39.1	35

Table B.5 (cont.)
Maximum Nitrogen Concentrations at the Water Table for Simulations that are Comparable to Illustrate Behaviors due to Soil Texture

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Conc (mg-N/L)	NO_3 Conc (mg-N/L)	TN Conc (mg-N/L)	Est %TN Removed
28	B-UE	SCL	STE	6	0.0	3.4	3.4	94
32		LPS			0.0	42.3	42.3	30
36		MPS			0.0	46.6	46.6	22
37	T-E	SCL	STE	FD	0.0	12.2	12.2	80
41		LPS			0.0	48.0	48.0	20
45		MPS			0.0	53.3	53.3	11
38	T-UE	SCL	STE	FD	0.0	25.3	25.3	58
42		LPS			0.0	51.6	51.6	14
46		MPS			0.0	55.3	55.3	8
39	B-E	SCL	STE	FD	0.0	9.6	9.6	84
43		LPS			0.0	49.7	49.7	17
47		MPS			0.0	53.8	53.8	10
40	B-UE	SCL	STE	FD	0.0	21.2	21.2	65
44		LPS			0.0	52.4	52.4	13
48		MPS			0.0	55.7	55.7	7
51	T-UE	LPS	NE	2	0.0	22.6	22.6	25
49		MPS			0.0	23.5	23.5	22
52	T-UE	LPS	NE	6	0.0	9.7	9.7	68
50		MPS			0.0	14.4	14.4	52
55	B-UE	LPS	NE	2	0.0	21.8	21.8	28
53		MPS			0.0	22.4	22.4	25
56	B-UE	LPS	NE	6	0.0	14.2	14.2	53
54		MPS			0.0	17.6	17.6	41

[1] *Distribution Configuration: T-E, trench, equal; T-UE, trench, unequal; B-E, bed, equal; B-UE, bed, unequal.*

[2] *Soil Texture: SCL, sandy clay loam; LPS, less permeable sand; MPS, more permeable sand.*

[3] *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*

[4] *Depth to water table below the infiltrative surface. FD = free drainage.*

Table B.6
Total Nitrogen Mass Flux (mg-N/ft·d) at the Water Table for Simulations that are Comparable to Illustrate Behaviors due to Soil Texture

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Mass Flux	NO_3 Mass Flux	TN Mass Flux	Est %TN Removed
1	T-E	SCL	STE	1	266.8	173.4	440.2	34
5		LPS			69.9	519.3	589.2	28
9		MPS			21.2	613.9	635.1	22
2	T-UE	SCL	STE	1	386.5	140.2	526.7	21
6		LPS			256.4	404.2	660.6	19
10		MPS			193.2	465.0	658.2	20
3	B-E	SCL	STE	1	94.0	351.0	445.1	38
7		LPS			20.0	963.9	983.9	20
11		MPS			1.6	981.9	983.5	20
4	B-UE	SCL	STE	1	277.1	252.5	529.6	26
8		LPS			337.3	725.3	1062.6	13
12		MPS			214.5	842.1	1056.6	14
13	T-E	SCL	STE	2	0.0	250.2	250.2	62
17		LPS			0.0	447.3	447.3	45
21		MPS			0.0	479.5	479.5	41
14	T-UE	SCL	STE	2	45.0	301.7	346.7	48
18		LPS			0.0	547.3	547.3	33
22		MPS			0.0	571.2	571.2	30
15	B-E	SCL	STE	2	0.0	228.2	228.2	68
19		LPS			0.0	787.5	787.5	36
23		MPS			0.0	830.0	830.0	32
16	B-UE	SCL	STE	2	0.4	362.6	363.0	49
20		LPS			0.0	910.1	910.1	26
24		MPS			0.0	938.3	938.3	24
25	T-E	SCL	STE	6	0.0	0.1	0.1	100
29		LPS			0.0	200.3	200.3	76
33		MPS			0.0	313.0	313.0	62
26	T-UE	SCL	STE	6	0.0	17.3	17.3	97
30		LPS			0.0	322.7	322.7	61
34		MPS			0.0	417.7	417.7	49

Table B.6 (cont.)
Total Nitrogen Mass Flux (mg-N/ft·d) at the Water Table for Simulations that are Comparable to Illustrate Behaviors due to Soil Texture

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Mass Flux	NO_3 Mass Flux	TN Mass Flux	Est %TN Removed
27	B-E	SCL	STE	6	0.0	0.1	0.1	100
31		LPS			0.0	520.1	520.1	58
35		MPS			0.0	654.1	654.1	47
28	B-UE	SCL	STE	6	0.0	12.5	12.5	98
32		LPS			0.0	653.9	653.9	47
36		MPS			0.0	766.7	766.7	38
37	T-E	SCL	STE	FD	0.0	61.7	61.7	91
41		LPS			0.0	580.6	580.6	29
45		MPS			0.0	682.6	682.6	17
38	T-UE	SCL	STE	FD	0.0	138.7	138.7	79
42		LPS			0.0	621.3	621.3	24
46		MPS			0.0	706.0	706.0	14
39	B-E	SCL	STE	FD	0.0	71.9	71.9	90
43		LPS			0.0	957.0	957.0	22
47		MPS			0.0	1069.8	1069.8	13
40	B-UE	SCL	STE	FD	0.0	147.2	147.2	79
44		LPS			0.0	1005.5	1005.5	18
48		MPS			0.0	1100.3	1100.3	10
51	T-UE	LPS	NE	2	0.0	208.0	208.0	49
49		MPS			0.0	225.5	225.5	45
52	T-UE	LPS	NE	6	0.0	62.1	62.1	85
50		MPS			0.0	112.6	112.6	73
55	B-UE	LPS	NE	2	0.0	356.1	356.1	42
53		MPS			0.0	371.4	371.4	39
56	B-UE	LPS	NE	6	0.0	179.5	179.5	71
54		MPS			0.0	247.7	247.7	60

[1] *Distribution Configuration: T-E, trench, equal; T-UE, trench, unequal; B-E, bed, equal; B-UE, bed, unequal.*

[2] *Soil Texture: SCL, sandy clay loam; LPS, less permeable sand; MPS, more permeable sand.*

[3] *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*

[4] *Depth to water table below the infiltrative surface. FD = free drainage.*

All fluxes are in mg-N per foot (length) of trench per day.

Table B.7
Maximum Nitrogen Concentrations at the Water Table for Simulations that are Comparable to Illustrate Behaviors due to Water Table Depth

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Conc (mg-N/L)	NO_3 Conc (mg-N/L)	TN Conc (mg-N/L)	Est %TN Removed
1	T-E	SCL	STE	1	38.4	14.5	53.0	12
13				2	0.0	34.9	34.9	42
25				6	0.0	0.0	0.0	100
37				FD	0.0	12.2	12.2	80
2	T-UE	SCL	STE	1	51.2	6.8	58.0	3
14				2	14.6	32.5	47.0	22
26				6	0.0	5.9	5.9	90
38				FD	0.0	25.3	25.3	58
3	B-E	SCL	STE	1	10.4	31.0	41.3	31
15				2	0.0	23.7	23.7	61
27				6	0.0	0.0	0.0	100
39				FD	0.0	9.6	9.6	84
4	B-UE	SCL	STE	1	35.0	16.9	51.9	13
16				2	0.1	40.7	40.8	32
28				6	0.0	3.4	3.4	94
40				FD	0.0	21.2	21.2	65
5	T-E	LPS	STE	1	11.5	40.8	52.3	13
17				2	0.0	43.5	43.5	27
29				6	0.0	24.0	24.0	60
41				FD	0.0	48.0	48.0	20
6	T-UE	LPS	STE	1	36.2	20.8	57.0	5
18				2	0.0	51.9	51.9	13
30				6	0.0	36.5	36.5	39
42				FD	0.0	51.6	51.6	14
7	B-E	LPS	STE	1	1.2	48.7	49.9	17
19				2	0.0	42.3	42.3	30
31				6	0.0	33.1	33.1	45
43				FD	0.0	49.7	49.7	17
8	B-UE	LPS	STE	1	26.8	28.7	55.5	7
20				2	0.0	50.8	50.8	15
32				6	0.0	42.3	42.3	30
44				FD	0.0	52.4	52.4	13

Table B.7 (cont.)
Maximum Nitrogen Concentrations at the Water Table for Simulations that are Comparable to Illustrate Behaviors due to Water Table Depth

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Conc (mg-N/L)	NO_3 Conc (mg-N/L)	TN Conc (mg-N/L)	Est %TN Removed
9	T-E	MPS	STE	1	4.1	47.8	52.0	13
21				2	0.0	45.4	45.4	24
33				6	0.0	31.6	31.6	47
45				FD	0.0	53.3	53.3	11
10	T-UE	MPS	STE	1	30.4	26.4	56.8	5
22				2	0.0	52.8	52.8	12
34				6	0.0	42.4	42.4	29
46				FD	0.0	55.3	55.3	8
11	B-E	MPS	STE	1	0.1	49.7	49.8	17
23				2	0.0	44.1	44.1	27
35				6	0.0	39.1	39.1	35
47				FD	0.0	53.8	53.8	10
12	B-UE	MPS	STE	1	18.3	37.0	55.3	8
24				2	0.0	51.7	51.7	14
36				6	0.0	46.6	46.6	22
48				FD	0.0	55.7	55.7	7
49	T-UE	MPS	NE	2	0.0	23.5	23.5	22
50				6	0.0	14.4	14.4	52
51	T-UE	LPS	NE	2	0.0	22.6	22.6	25
52				6	0.0	9.7	9.7	68
53	B-E	MPS	NE	2	0.0	22.4	22.4	25
54				6	0.0	17.6	17.6	41
55	B-UE	LPS	NE	2	0.0	21.8	21.8	28
56				6	0.0	14.2	14.2	53
58	T-UE	layered	STE	2	13.7	33.0	46.7	22
59				6	0.0	6.5	6.5	89

[1] *Distribution Configuration: T-E, trench, equal; T-UE, trench, unequal; B-E, bed, equal; B-UE, bed, unequal.*

[2] *Soil Texture: SCL, sandy clay loam; LPS, less permeable sand; MPS, more permeable sand.*

[3] *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*

[4] *Depth to water table below the infiltrative surface. FD = free drainage.*

Table B.8
Total Nitrogen Mass Flux (mg-N/ft·d) at the Water Table for Simulations that are Comparable to Illustrate Behaviors due to Water Table Depth

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Mass Flux	NO_3 Mass Flux	TN Mass Flux	Est %TN Removed
1	T-E	SCL	STE	1	266.8	173.4	440.2	34
13				2	0.0	250.2	250.2	62
25				6	0.0	0.1	0.1	100
37				FD	0.0	61.7	61.7	91
2	T-UE	SCL	STE	1	386.5	140.2	526.7	21
14				2	45.0	301.7	346.7	48
26				6	0.0	17.3	17.3	97
38				FD	0.0	138.7	138.7	79
3	B-E	SCL	STE	1	94.0	351.0	445.1	38
15				2	0.0	228.2	228.2	68
27				6	0.0	0.1	0.1	100
39				FD	0.0	71.9	71.9	90
4	B-UE	SCL	STE	1	277.1	252.5	529.6	26
16				2	0.4	362.6	363.0	49
28				6	0.0	12.5	12.5	98
40				FD	0.0	147.2	147.2	79
5	T-E	LPS	STE	1	69.9	519.3	589.2	28
17				2	0.0	447.3	447.3	45
29				6	0.0	200.3	200.3	76
41				FD	0.0	580.6	580.6	29
6	T-UE	LPS	STE	1	256.4	404.2	660.6	19
18				2	0.0	547.3	547.3	33
30				6	0.0	322.7	322.7	61
42				FD	0.0	621.3	621.3	24
7	B-E	LPS	STE	1	20.0	963.9	983.9	20
19				2	0.0	787.5	787.5	36
31				6	0.0	520.1	520.1	58
43				FD	0.0	957.0	957.0	22
8	B-UE	LPS	STE	1	337.3	725.3	1062.6	13
20				2	0.0	910.1	910.1	26
32				6	0.0	653.9	653.9	47
44				FD	0.0	1005.5	1005.5	18

Table B.8 (cont.)
Total Nitrogen Mass Flux (mg-N/ft·d) at the Water Table for Simulations that are Comparable to Illustrate Behaviors due to Water Table Depth

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Mass Flux	NO_3 Mass Flux	TN Mass Flux	Est %TN Removed
9	T-E	MPS	STE	1	21.2	613.9	635.1	22
21				2	0.0	479.5	479.5	41
33				6	0.0	313.0	313.0	62
45				FD	0.0	682.6	682.6	17
10	T-UE	MPS	STE	1	193.2	465.0	658.2	20
22				2	0.0	571.2	571.2	30
34				6	0.0	417.7	417.7	49
46				FD	0.0	706.0	706.0	14
11	B-E	MPS	STE	1	1.6	981.9	983.5	20
23				2	0.0	830.0	830.0	32
35				6	0.0	654.1	654.1	47
47				FD	0.0	1069.8	1069.8	13
12	B-UE	MPS	STE	1	214.5	842.1	1056.6	14
24				2	0.0	938.3	938.3	24
36				6	0.0	766.7	766.7	38
48				FD	0.0	1100.3	1100.3	10
49	T-UE	MPS	NE	2	0.0	225.5	225.5	45
50				6	0.0	112.6	112.6	73
51	T-UE	LPS	NE	2	0.0	208.0	208.0	49
52				6	0.0	62.1	62.1	85
53	B-E	MPS	NE	2	0.0	371.4	371.4	39
54				6	0.0	247.7	247.7	60
55	B-UE	LPS	NE	2	0.0	356.1	356.1	42
56				6	0.0	179.5	179.5	71
58	T-UE	layered	STE	2	39.4	294.7	334.1	59
59				6	0.0	19.6	19.6	98

[1] *Distribution Configuration: T-E, trench, equal; T-UE, trench, unequal; B-E, bed, equal; B-UE, bed, unequal.*

[2] *Soil Texture: SCL, sandy clay loam; LPS, less permeable sand; MPS, more permeable sand.*

[3] *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*

[4] *Depth to water table below the infiltrative surface. FD = free drainage.*

All fluxes are in mg-N per foot (length) of trench per day.

Table B.9
Maximum Nitrogen Concentrations at the Water Table for Simulations that are Comparable to Illustrate Behaviors due to Distribution Configuration

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Conc (mg-N/L)	NO_3 Conc (mg-N/L)	TN Conc (mg-N/L)	Est %TN Removed
1	T-E	SCL	STE	1	38.4	14.5	53.0	12
2	T-UE				51.2	6.8	58.0	3
3	B-E				10.4	31.0	41.3	31
4	B-UE				35.0	16.9	51.9	13
5	T-E	LPS	STE	1	11.5	40.8	52.3	13
6	T-UE				36.2	20.8	57.0	5
7	B-E				1.2	48.7	49.9	17
8	B-UE				26.8	28.8	55.5	7
9	T-E	MPS	STE	1	4.1	47.8	52.0	13
10	T-UE				30.4	26.4	56.8	5
11	B-E				0.1	49.7	49.8	17
12	B-UE				18.3	37.0	55.3	8
13	T-E	SCL	STE	2	0.0	34.9	34.9	42
14	T-UE				14.6	32.5	47.0	22
15	B-E				0.0	23.7	23.7	61
16	B-UE				0.1	40.7	40.8	32
17	T-E	LPS	STE	2	0.0	43.5	43.5	27
18	T-UE				0.0	51.9	51.9	13
19	B-E				0.0	42.3	42.3	30
20	B-UE				0.0	50.8	50.8	15
21	T-E	MPS	STE	2	0.0	45.4	45.4	24
22	T-UE				0.0	52.8	52.8	12
23	B-E				0.0	44.0	44.1	27
24	B-UE				0.0	51.7	51.7	14
25	T-E	SCL	STE	6	0.0	0.0	0.0	100
26	T-UE				0.0	5.9	5.9	90
27	B-E				0.0	0.0	0.0	100
28	B-UE				0.0	3.4	3.4	94

Table B.9 (cont.)
Maximum Nitrogen Concentrations at the Water Table for Simulations that are Comparable to Illustrate Behaviors due to Distribution Configuration

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Conc (mg-N/L)	NO_3 Conc (mg-N/L)	TN Conc (mg-N/L)	Est %TN Removed
29	T-E	LPS	STE	6	0.0	24.0	24.0	60
30	T-UE				0.0	36.5	36.5	39
31	B-E				0.0	33.0	33.1	45
32	B-UE				0.0	42.3	42.3	30
33	T-E	MPS	STE	6	0.0	31.6	31.6	47
34	T-UE				0.0	42.4	42.4	29
35	B-E				0.0	39.1	39.1	35
36	B-UE				0.0	46.6	46.6	22
37	T-E	SCL	STE	FD	0.0	12.2	12.2	80
38	T-UE				0.0	25.3	25.3	58
39	B-E				0.0	9.6	9.6	54
40	B-UE				0.0	21.2	21.2	65
41	T-E	LPS	STE	FD	0.0	48.0	48.0	20
42	T-UE				0.0	51.6	51.6	14
43	B-E				0.0	49.7	49.7	17
44	B-UE				0.0	52.4	52.4	13
45	T-E	MPS	STE	FD	0.0	53.3	53.3	11
46	T-UE				0.0	55.3	55.3	8
47	B-E				0.0	53.8	53.8	10
48	B-UE				0.0	55.7	55.7	7
49	T-UE	MPS	NE	2	0.0	23.5	23.5	61
53	B-UE				0.0	22.4	22.4	63
50	T-UE	MPS	NE	6	0.0	14.4	14.4	76
54	B-UE				0.0	17.6	17.6	71
51	T-UE	LPS	NE	2	0.0	22.6	22.6	62
55	B-UE				0.0	21.8	21.8	64
52	T-UE	LPS	NE	6	0.0	9.7	9.7	84
56	B-UE				0.0	14.2	14.2	76

[1] *Distribution Configuration: T-E, trench, equal; T-UE, trench, unequal; B-E, bed, equal; B-UE, bed, unequal. Note, different hydraulic loading rates apply to each configuration.*

[2] *Soil Texture: SCL, sandy clay loam; LPS, less permeable sand; MPS, more permeable sand.*

[3] *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*

[4] *Depth to water table below the infiltrative surface. FD = free drainage.*

Table B.10
Total Nitrogen Mass Flux (mg-N/ft·d) at the Water Table for Simulations that are Comparable to Illustrate Behaviors due to Distribution Configuration

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Mass Flux	NO_3 Mass Flux	TN Mass Flux	Est %TN Removed
1	T-E	SCL	STE	1	266.8	173.4	440.2	34
2	T-UE				386.5	140.2	526.7	21
3	B-E				94.0	351.1	445.1	38
4	B-UE				277.1	252.5	529.6	26
5	T-E	LPS	STE	1	69.9	519.3	589.2	28
6	T-UE				256.4	404.2	660.6	19
7	B-E				20.0	963.9	983.9	20
8	B-UE				337.3	725.3	1062.6	13
9	T-E	MPS	STE	1	21.2	613.9	635.1	22
10	T-UE				193.2	465.0	658.2	20
11	B-E				1.6	981.9	983.5	20
12	B-UE				214.5	842.1	1056.6	14
13	T-E	SCL	STE	2	0.0	250.2	250.2	62
14	T-UE				45.0	301.7	346.7	48
15	B-E				0.0	228.2	228.2	68
16	B-UE				0.4	362.6	363.0	49
17	T-E	LPS	STE	2	0.0	447.3	447.3	45
18	T-UE				0.0	547.3	547.4	33
19	B-E				0.0	787.5	787.5	36
20	B-UE				0.0	910.1	910.1	26
21	T-E	MPS	STE	2	0.0	479.5	479.5	41
22	T-UE				0.0	571.2	571.2	30
23	B-E				0.0	830.0	830.0	32
24	B-UE				0.0	938.3	938.3	24
25	T-E	SCL	STE	6	0.0	0.1	0.1	100
26	T-UE				0.0	17.3	17.3	97
27	B-E				0.0	0.1	0.1	100
28	B-UE				0.0	12.5	12.5	98
29	T-E	LPS	STE	6	0.0	200.3	200.3	76
30	T-UE				0.0	322.7	322.7	61
31	B-E				0.0	520.1	520.1	58
32	B-UE				0.0	653.9	653.9	47

Table B.10 (cont.)
Total Nitrogen Mass Flux (mg-N/ft·d) at the Water Table for Simulations that are Comparable to Illustrate Behaviors due to Distribution Configuration

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Mass Flux	NO_3 Mass Flux	TN Mass Flux	Est %TN Removed
33	T-E	MPS	STE	6	0.00	313.0	313.0	62
34	T-UE				0.00	417.7	417.7	49
35	B-E				0.00	654.1	654.1	47
36	B-UE				0.00	766.7	766.7	38
37	T-E	SCL	STE	FD	0.00	61.7	61.7	91
38	T-UE				0.00	138.7	138.7	79
39	B-E				0.00	71.9	71.9	90
40	B-UE				0.00	147.2	147.2	79
41	T-E	LPS	STE	FD	0.00	580.6	580.6	29
42	T-UE				0.00	621.3	621.3	24
43	B-E				0.00	957.0	957.0	22
44	B-UE				0.00	1005.5	1005.5	18
45	T-E	MPS	STE	FD	0.00	682.6	682.6	17
46	T-UE				0.00	706.0	706.0	14
47	B-E				0.00	1069.8	1069.8	13
48	B-UE				0.00	1100.3	1100.3	10
49	T-UE	MPS	NE	2	0.00	225.5	225.5	45
53	B-UE				0.00	371.4	371.4	39
50	T-UE	MPS	NE	6	0.00	112.6	112.6	73
54	B-UE				0.00	247.7	247.7	60
51	T-UE	LPS	NE	2	0.00	208.0	208.0	49
55	B-UE				0.00	356.1	356.1	42
52	T-UE	LPS	NE	6	0.00	62.1	62.1	85
56	B-UE				0.00	179.5	179.5	71

[1] *Distribution Configuration: T-E, trench, equal; T-UE, trench, unequal; B-E, bed, equal; B-UE, bed, unequal. Note, different hydraulic loading rates apply to each configuration.*

[2] *Soil Texture: SCL, sandy clay loam; LPS, less permeable sand; MPS, more permeable sand.*

[3] *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*

[4] *Depth to water table below the infiltrative surface. FD = free drainage.*

All fluxes are in mg-N per foot (length) of trench per day.

Table B.11
Maximum Nitrogen Concentrations at the Water Table for Simulations that are Comparable to Illustrate Behaviors due to Effluent Composition

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Conc (mg-N/L)	NO_3 Conc (mg-N/L)	TN Conc (mg-N/L)	Est %TN Removed
18	T-UE	LPS	STE	2	0.0	51.9	51.9	13
51			NE		0.0	22.6	22.6	25
20	B-UE	LPS	STE	2	0.0	50.8	50.8	15
55			NE		0.0	21.8	21.8	28
22	T-UE	MPS	STE	2	0.0	52.8	52.8	12
49			NE		0.0	23.5	23.5	22
24	B-UE	MPS	STE	2	0.0	51.7	51.7	14
53			NE		0.0	22.4	22.4	25
26	T-UE	SCL	STE	6	0.0	5.9	5.9	90
57			NE		0.0	0.0	0.0	100
30	T-UE	LPS	STE	6	0.0	36.5	36.5	39
52			NE		0.0	9.7	9.7	68
32	B-UE	LPS	STE	6	0.0	42.3	42.3	30
56			NE		0.0	14.2	14.2	53
34	T-UE	MPS	STE	6	0.0	42.4	42.4	29
50			NE		0.0	14.4	14.4	52
36	B-UE	MPS	STE	6	0.0	46.6	46.6	22
54			NE		0.0	17.6	17.6	41

[1] *Distribution Configuration: T-E, trench, equal; T-UE, trench, unequal; B-E, bed, equal; B-UE, bed, unequal.*

[2] *Soil Texture: SCL, sandy clay loam; LPS, less permeable sand; MPS, more permeable sand.*

[3] *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*

[4] *Depth to water table below the infiltrative surface.*

Table B.12
Total Nitrogen Mass Flux (mg-N/ft·d) at the Water Table for Simulations that are Comparable to Illustrate Behaviors due to Effluent Composition

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Mass Flux	NO_3 Mass Flux	TN Mass Flux	Est %TN Removed
18	T-UE	LPS	STE	2	0.0	547.3	547.3	33
51			NE		0.0	208.0	208.0	49
20	B-UE	LPS	STE	2	0.0	910.1	910.1	26
55			NE		0.0	356.1	356.1	42
22	T-UE	MPS	STE	2	0.0	571.2	571.2	30
49			NE		0.0	225.5	225.5	45
24	B-UE	MPS	STE	2	0.0	938.3	938.3	24
53			NE		0.0	371.4	371.4	39
26	T-UE	SCL	STE	6	0.0	17.3	17.3	97
57			NE		0.0	0.1	0.1	100
30	T-UE	LPS	STE	6	0.0	322.7	322.7	61
52			NE		0.0	62.1	62.1	85
32	B-UE	LPS	STE	6	0.0	653.9	653.9	47
56			NE		0.0	179.5	179.5	71
34	T-UE	MPS	STE	6	0.0	417.7	417.7	49
50			NE		0.0	112.6	112.6	73
36	B-UE	MPS	STE	6	0.0	766.7	766.7	38
54			NE		0.0	247.7	247.7	60

[1] *Distribution Configuration: T-E, trench, equal; T-UE, trench, unequal; B-E, bed, equal; B-UE, bed, unequal.*

[2] *Soil Texture: SCL, sandy clay loam; LPS, less permeable sand; MPS, more permeable sand.*

[3] *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*

[4] *Depth to water table below the infiltrative surface.*

All fluxes are in mg-N per foot (length) of trench per day.

Table B.13
Maximum Nitrogen Concentrations at the Water Table for Simulations that are not Comparable to Other Simulations

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Conc (mg-N/L)	NO_3 Conc (mg-N/L)	TN Conc (mg-N/L)	Est %TN Removed
57	T-UE	SCL	NE	6	0.0	0.0	0.0	100
58	T-UE	0-2' LPS 2-4' SCL	STE	2	13.7	33.0	46.7	22
59	T-UE	0-2' LPS 2-4' SCL	STE	6	0.0	6.5	6.5	89
60	T-UE	0-4' LPS 4-8' SCL	STE	6	0.0	19.8	19.8	67
61	T-UE	0-5' LPS 5-8' SCL	STE	6	0.0	26.2	26.2	56
62	T-UE	0-4' MPS 4-8' SCL	STE	6	0.0	21.5	21.5	64
63	T-UE	0-5' MPS 5-8' SCL	STE	6	0.0	29.8	29.8	50
64	T-UE	0-4' SCL 4-8' LPS	STE	6	0.0	33.8	33.8	44

[1] *Distribution Configuration: T-E, trench, equal; T-UE, trench, unequal; B-E, bed, equal; B-UE, bed, unequal.*

[2] *Soil Texture: SCL, sandy clay loam; LPS, less permeable sand; MPS, more permeable sand. See Table 1.1 for detailed layer thicknesses and hydraulic loading rates.*

[3] *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*

[4] *Depth to water table below the infiltrative surface. Note, layer depths are relative to ground surface.*

Table B.14
Total Nitrogen Mass Flux (mg-N/ft·d) at the Water Table for Simulations that are not Comparable to Other Simulations

ID	Dist. Config.[1]	Soil Texture[2]	Eff. Comp.[3]	Water Table Depth[4] (ft)	NH_4 Mass Flux	NO_3 Mass Flux	TN Mass Flux	Est %TN Removed
57	T-UE	SCL	NE	6	0.0	0.1	0.1	100
58	T-UE	0-2' LPS 2-4' SCL	STE	2	39.4	294.7	334.1	59
59	T-UE	0-2' LPS 2-4' SCL	STE	6	0.0	19.6	19.6	98
60	T-UE	0-4' LPS 4-8' SCL	STE	6	0.0	121.1	121.1	85
61	T-UE	0-5' LPS 5-8' SCL	STE	6	0.0	195.0	195.0	76
62	T-UE	0-4' MPS 4-8' SCL	STE	6	0.0	144.4	144.4	82
63	T-UE	0-5' MPS 5-8' SCL	STE	6	0.0	242.4	242.4	70
64	T-UE	0-4' SCL 4-8' LPS	STE	6	0.0	257.0	257.0	69

[1] *Distribution Configuration: T-E, trench, equal; T-UE, trench, unequal; B-E, bed, equal; B-UE, bed, unequal.*

[2] *Soil Texture: SCL, sandy clay loam; LPS, less permeable sand; MPS, more permeable sand. See Table 1.1 for detailed layer thicknesses and hydraulic loading rates.*

[3] *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*

[4] *Depth to water table below the infiltrative surface. Note, layer depths are relative to ground surface.*

All fluxes are in mg-N per foot (length) of trench per day.

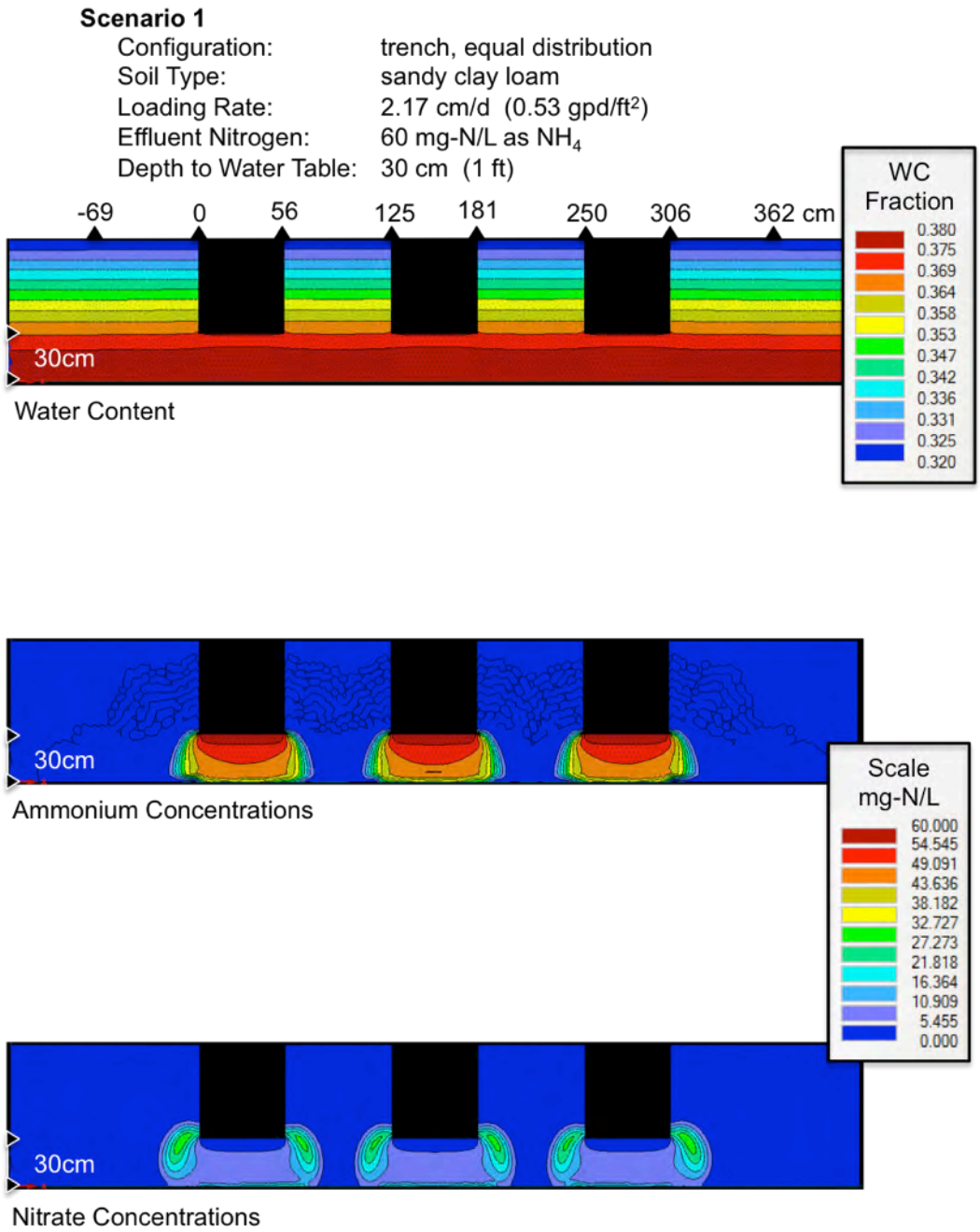

Figure B.1
Scenario 1

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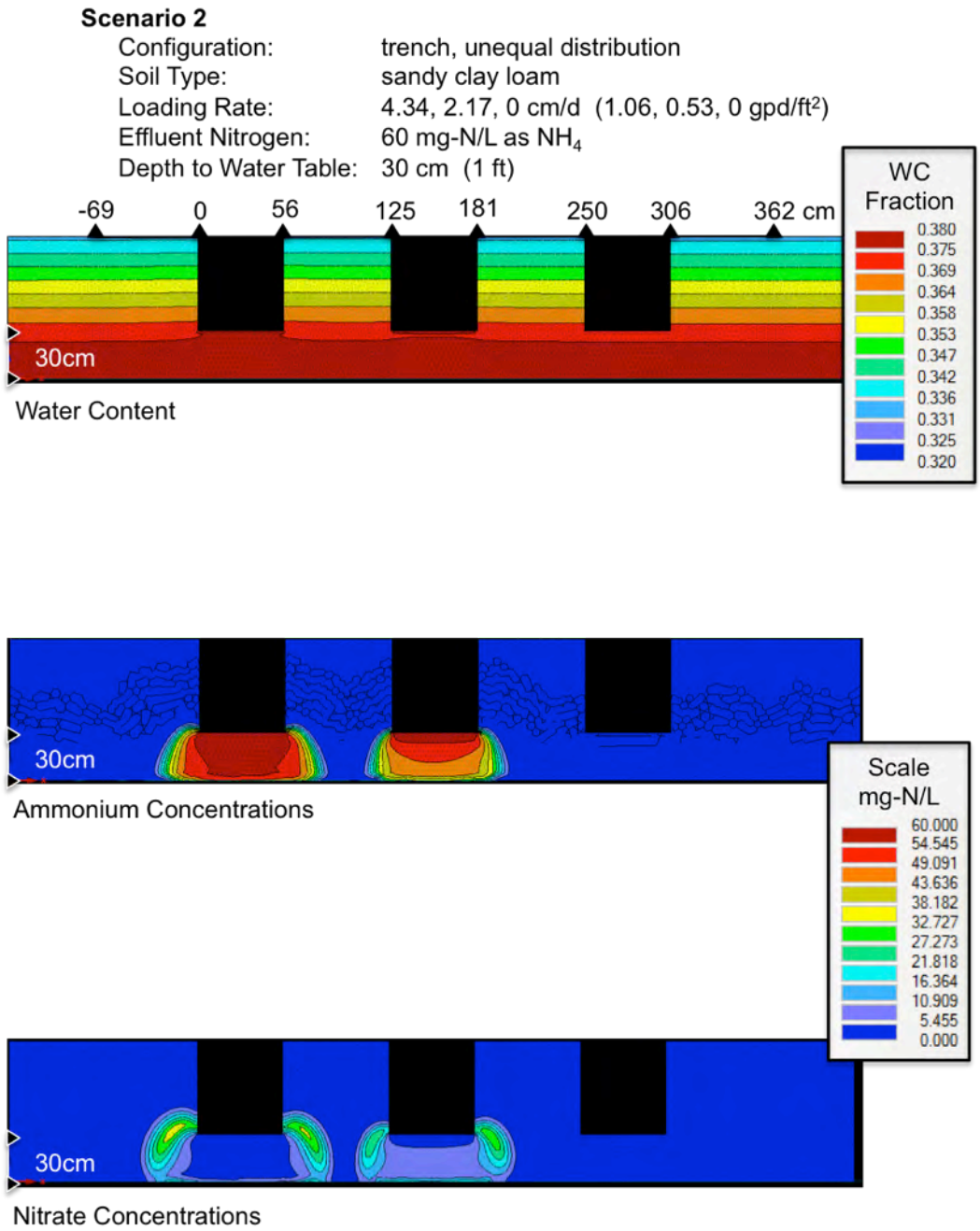

Figure B.2
Scenario 2

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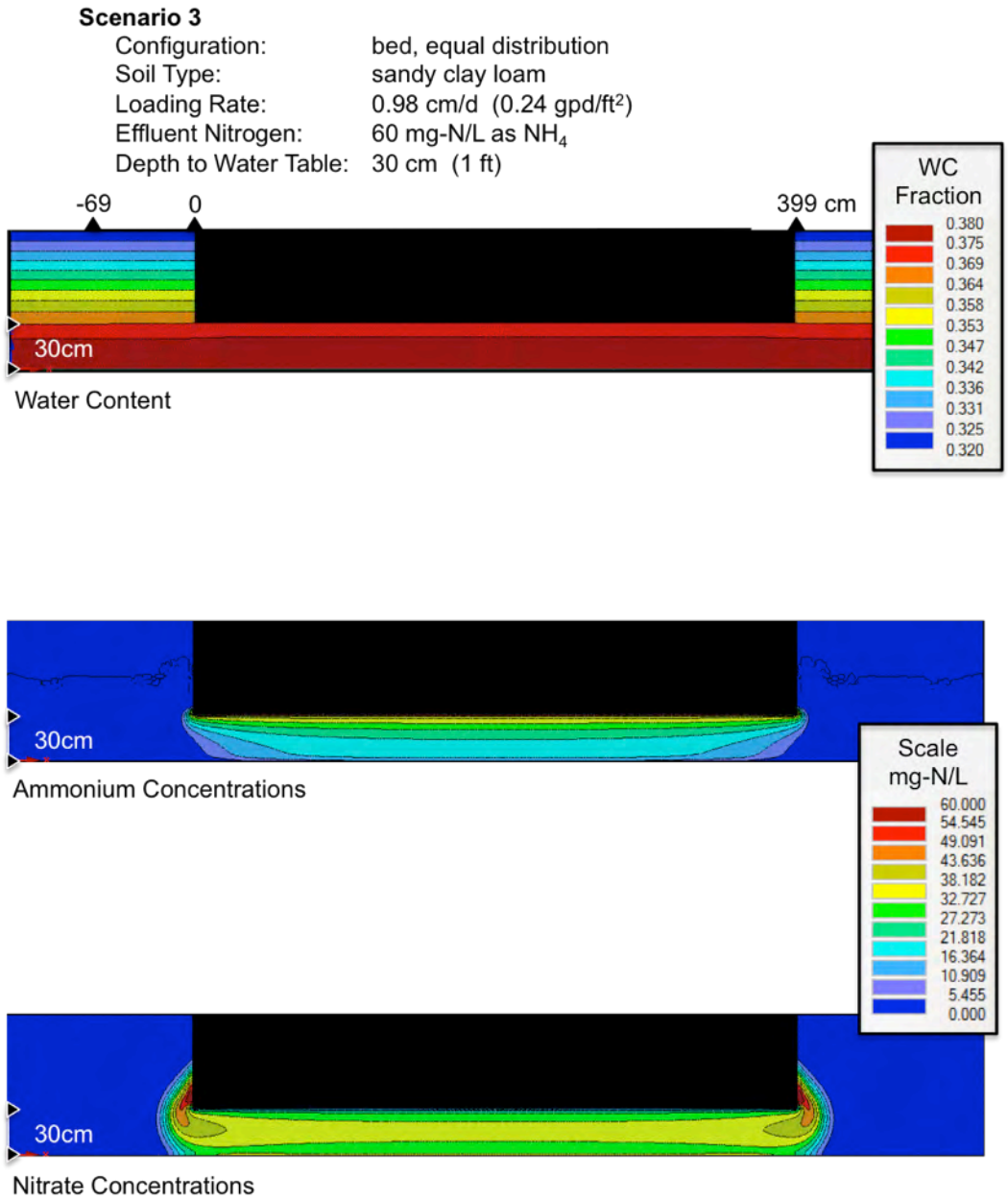

Figure B.3
Scenario 3

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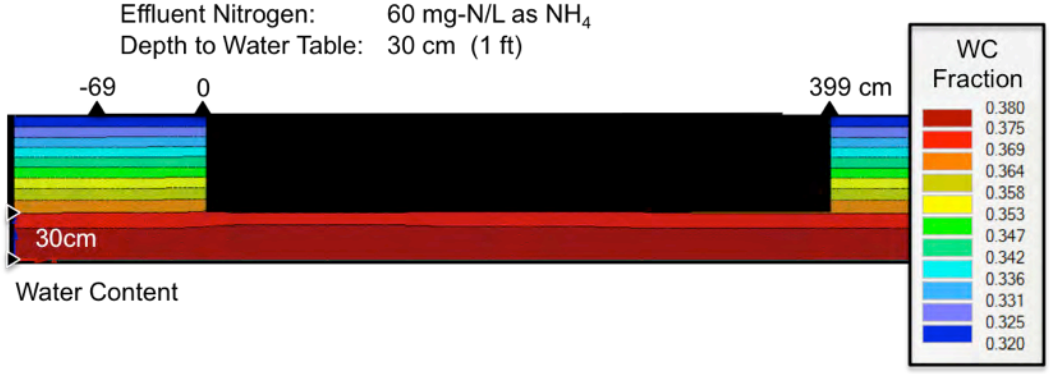
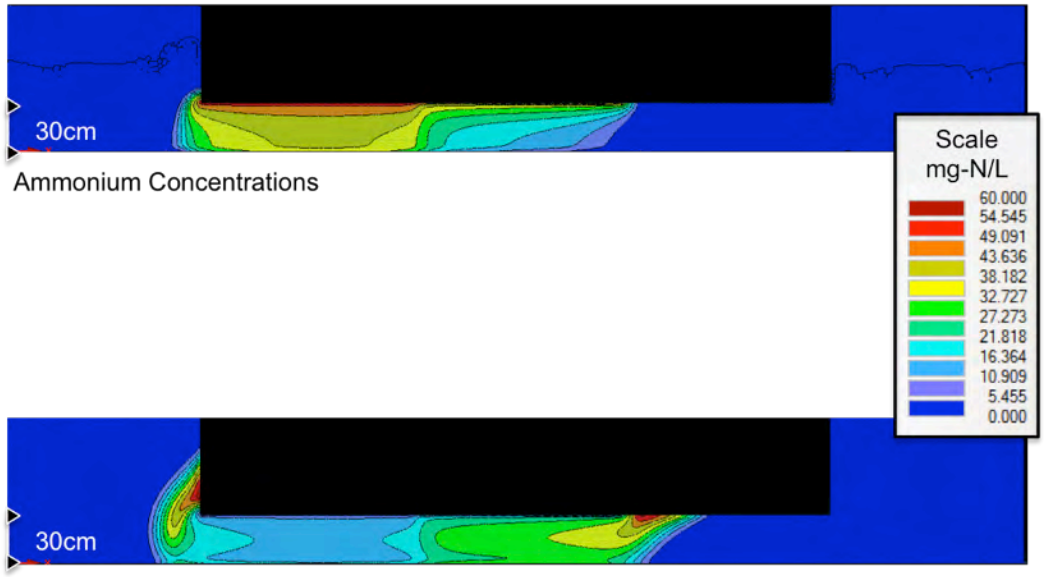
Scenario 4

Configuration:	bed, unequal distribution
Soil Type:	sandy clay loam
Loading Rate:	1.97, 0.98, 0 cm/d (0.48, 0.24, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	30 cm (1 ft)



Water Content



Ammonium Concentrations

Nitrate Concentrations

Figure B.4
Scenario 4

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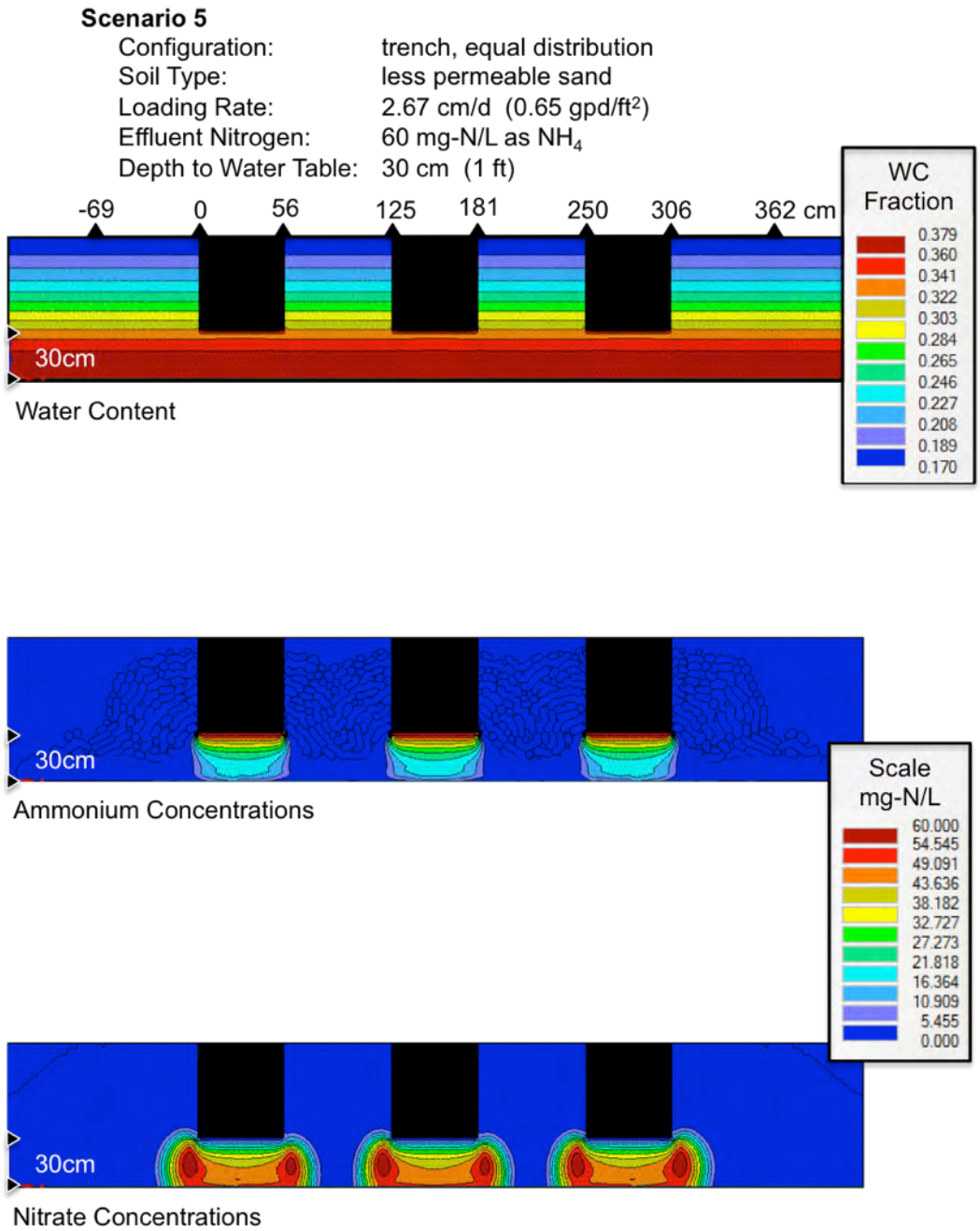

Figure B.5
Scenario 5

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Scenario 6

Configuration:	trench, unequal distribution
Soil Type:	less permeable sand
Loading Rate:	5.35, 2.67, 0 cm/d (1.31, 0.65, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	30 cm (1 ft)

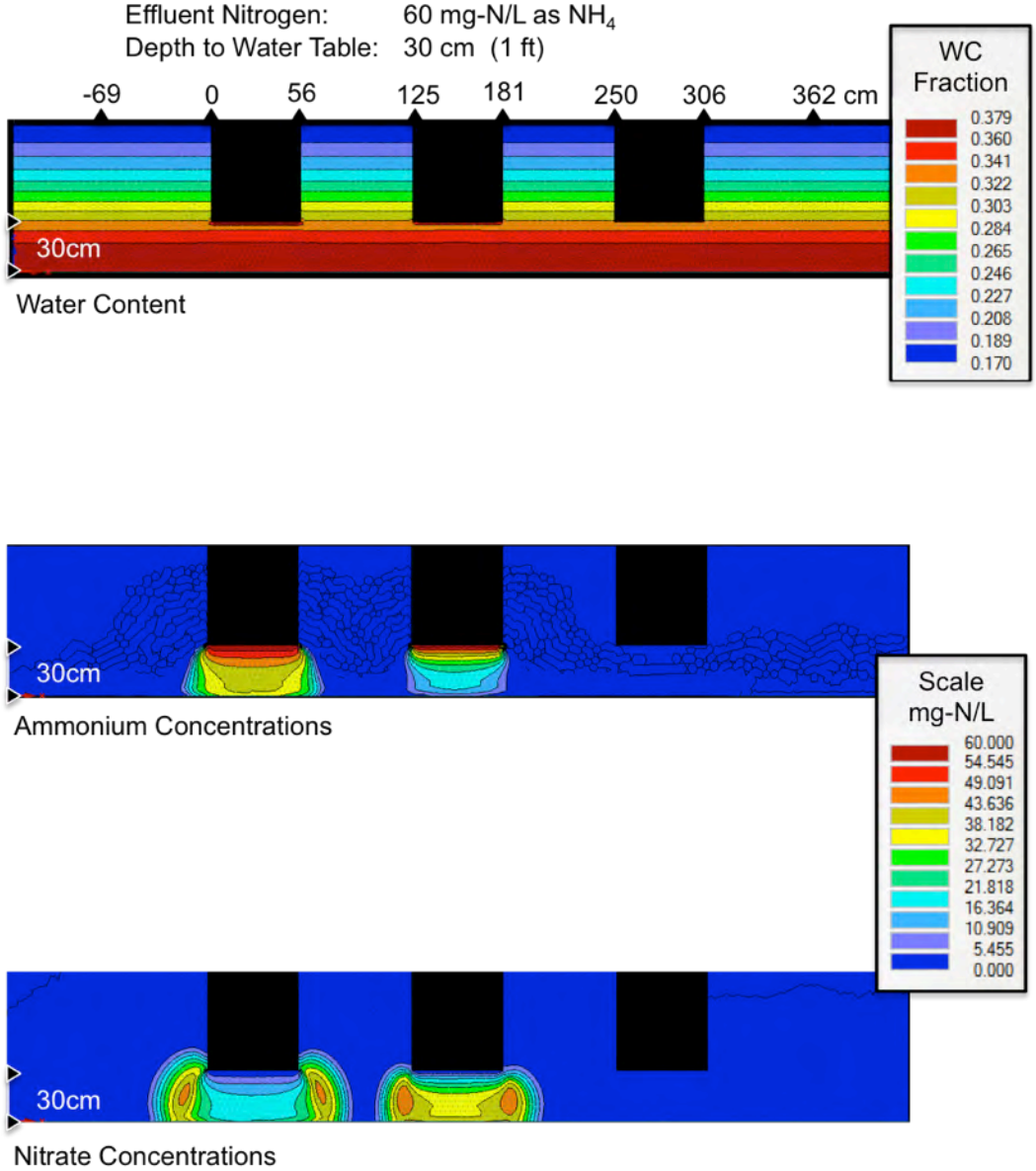
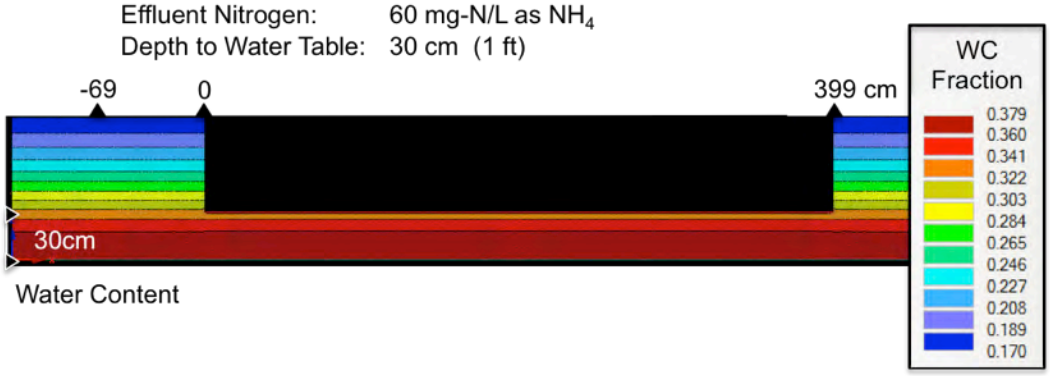


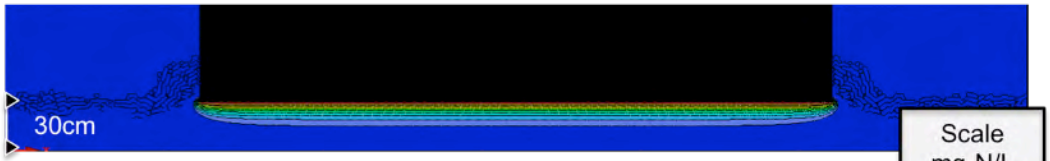
Figure B.6
Scenario 6

Scenario 7

Configuration:	bed, equal distribution
Soil Type:	less permeable sand
Loading Rate:	1.68 cm/d (0.41 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	30 cm (1 ft)



Water Content



Ammonium Concentrations

Nitrate Concentrations

Figure B.7
Scenario 7

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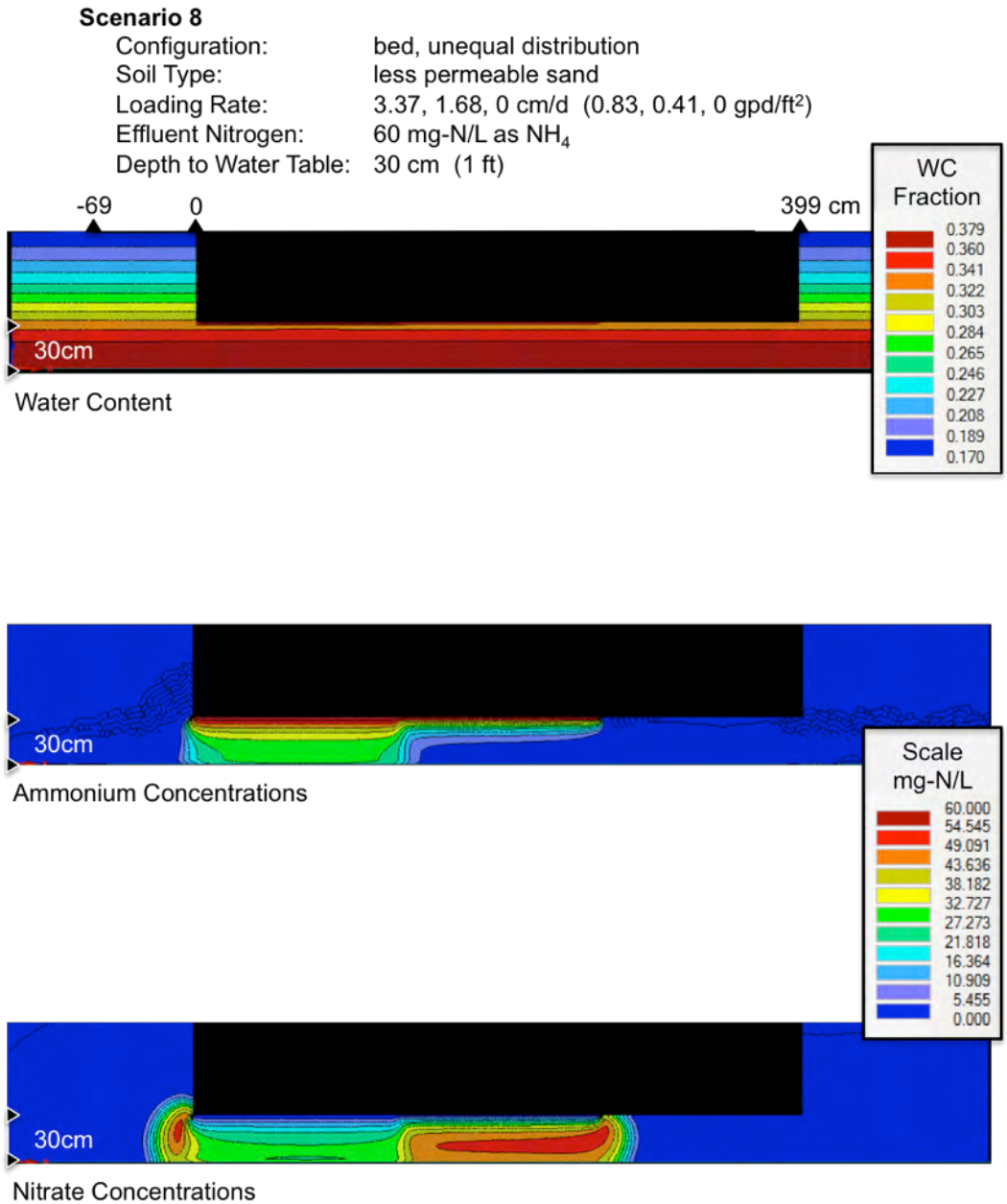

Figure B.8
Scenario 8

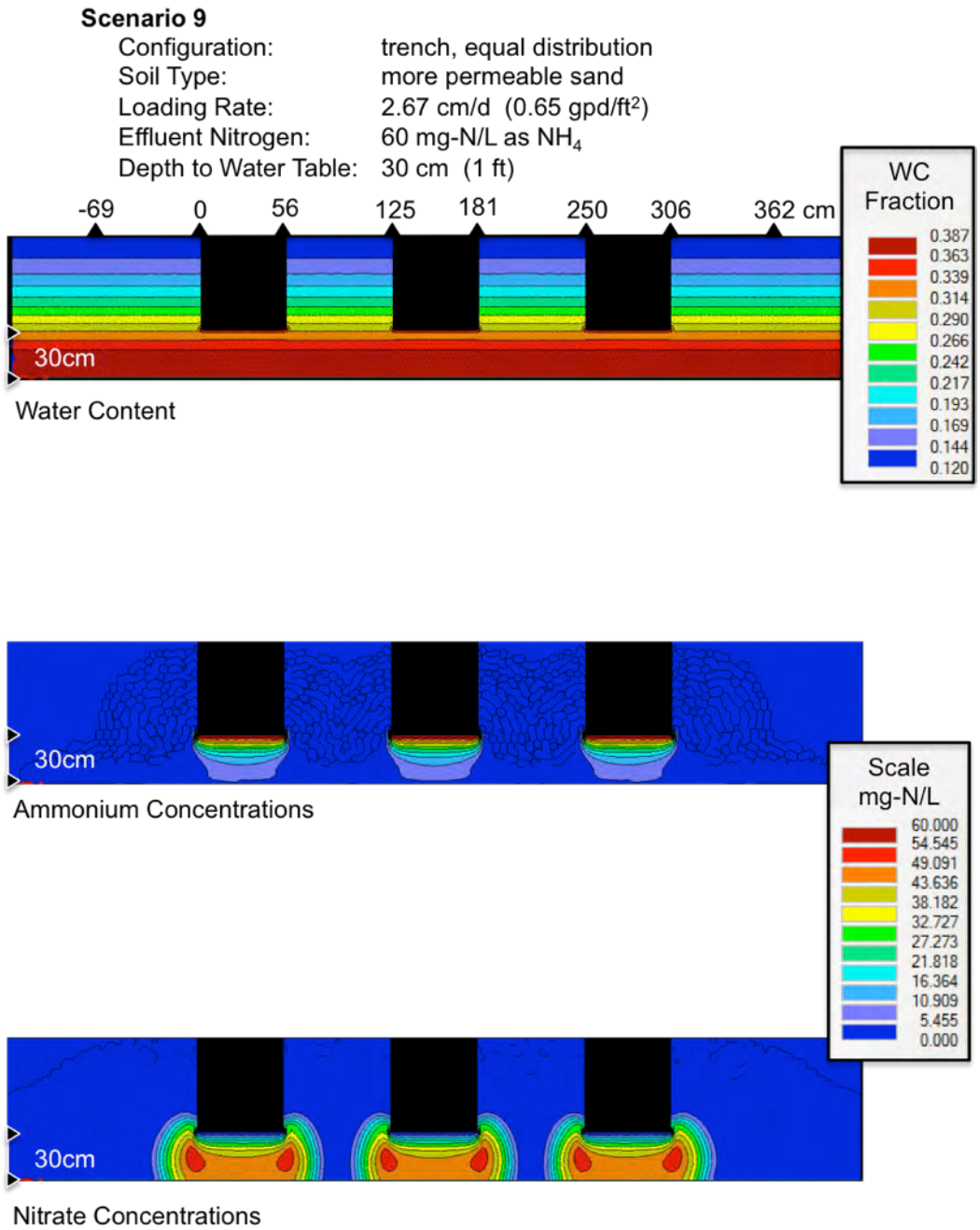

Figure B.9
Scenario 9

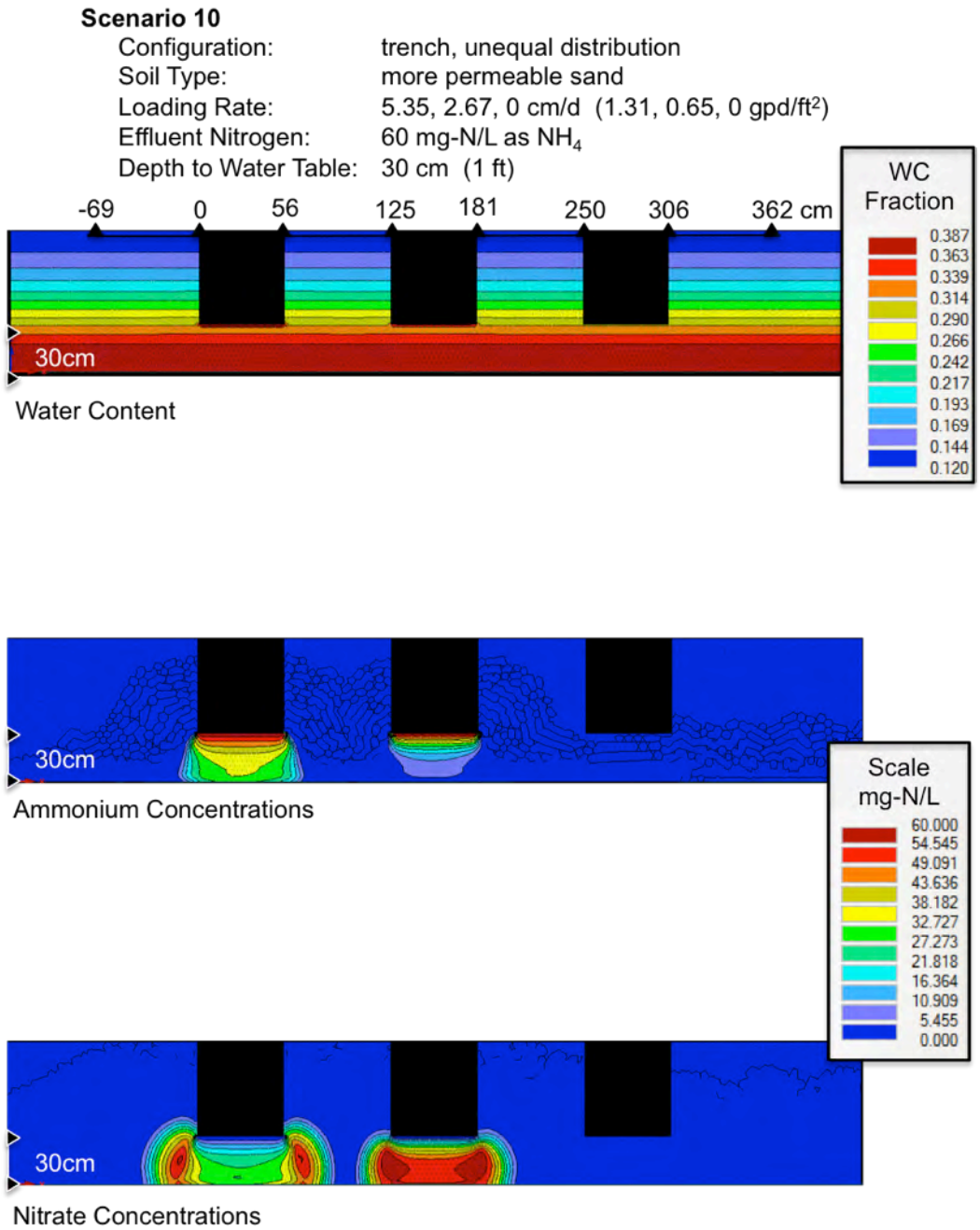

Figure B.10
Scenario 10

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Scenario 11

Configuration:	bed, equal distribution
Soil Type:	more permeable sand
Loading Rate:	1.68 cm/d (0.41 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	30 cm (1 ft)

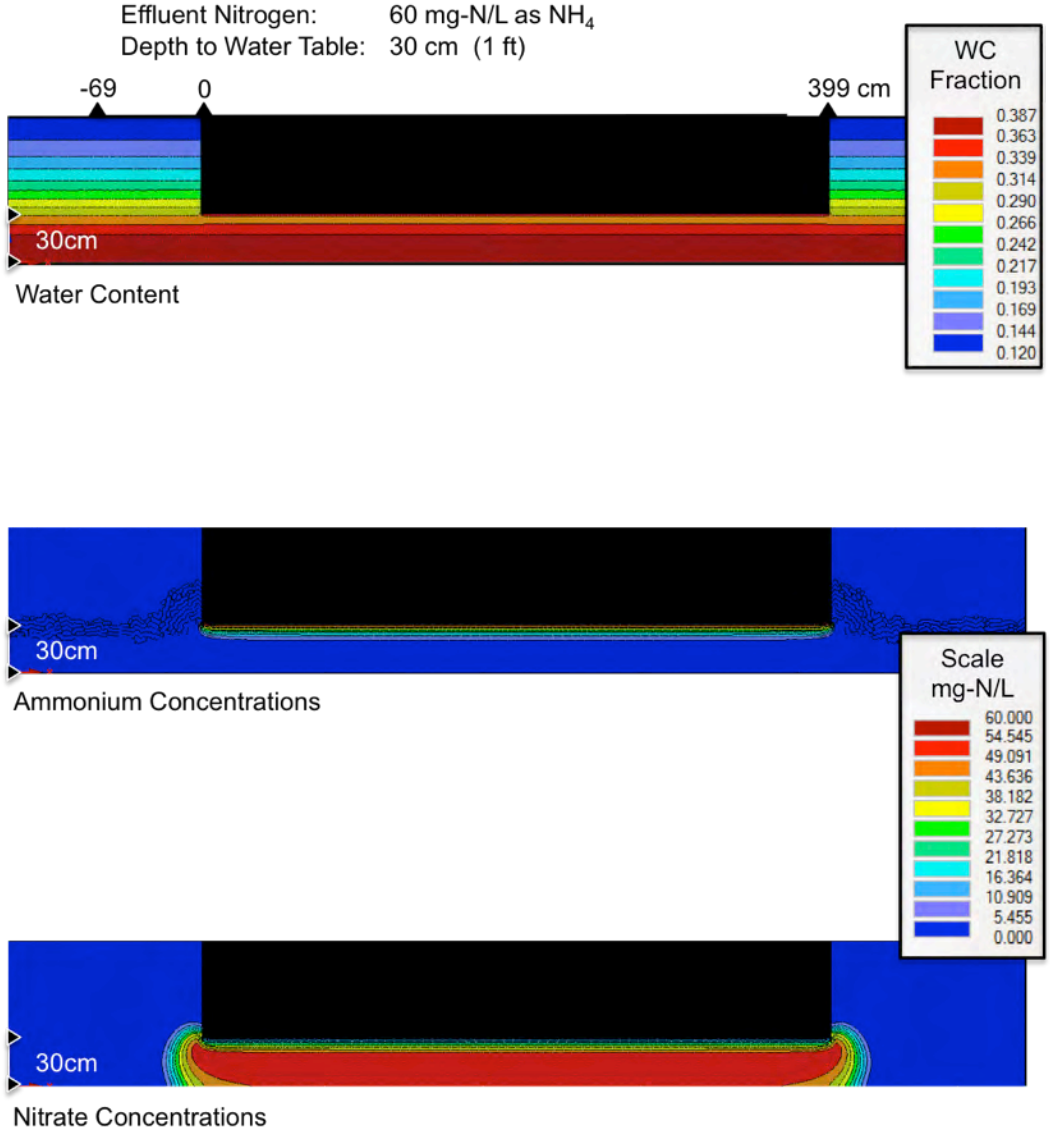

Figure B.11
Scenario 11

Scenario 12

Configuration:	bed, unequal distribution
Soil Type:	more permeable sand
Loading Rate:	3.37, 1.68, 0 cm/d (0.83, 0.41, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	30 cm (1 ft)

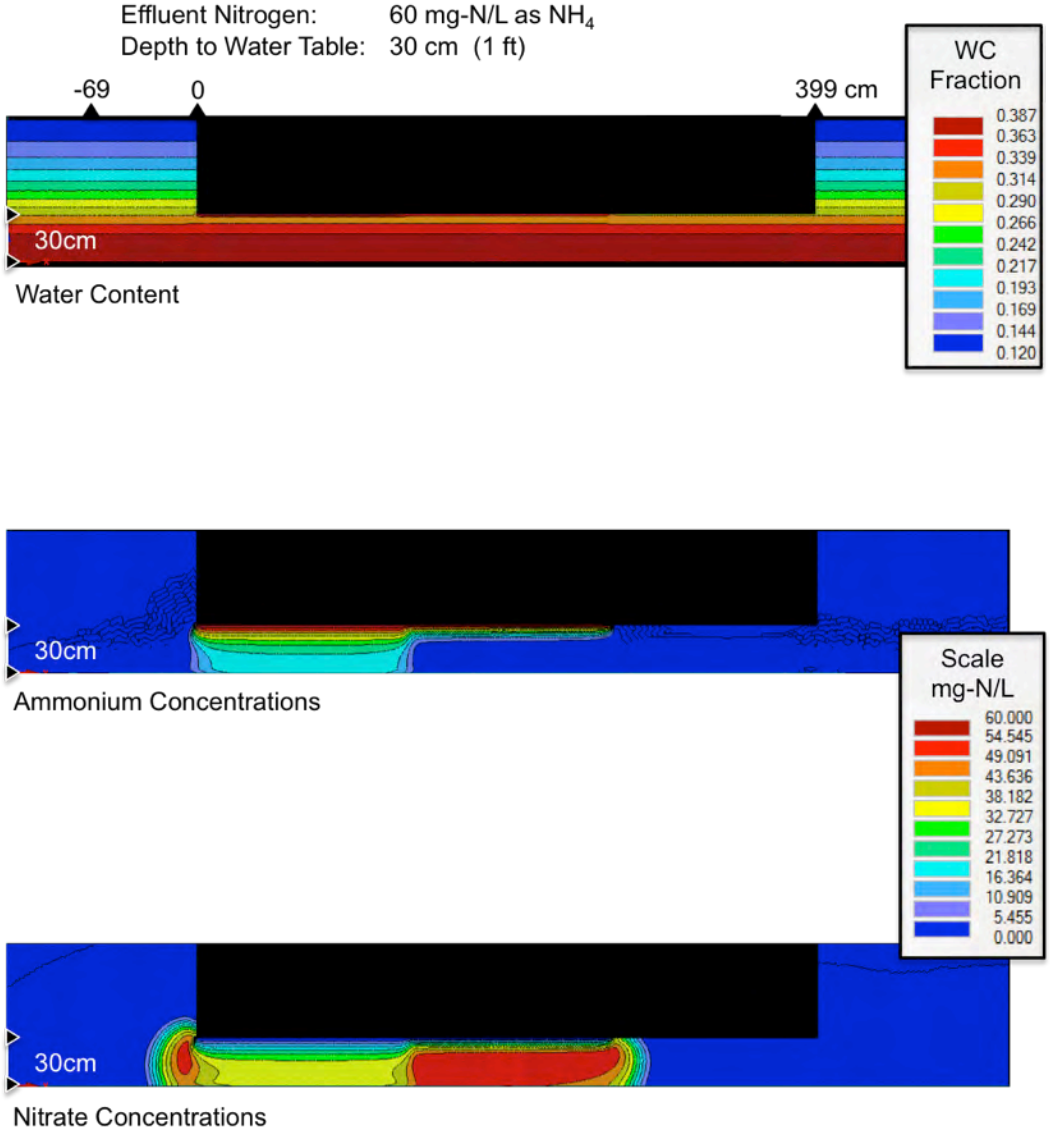

Figure B.12
Scenario 12

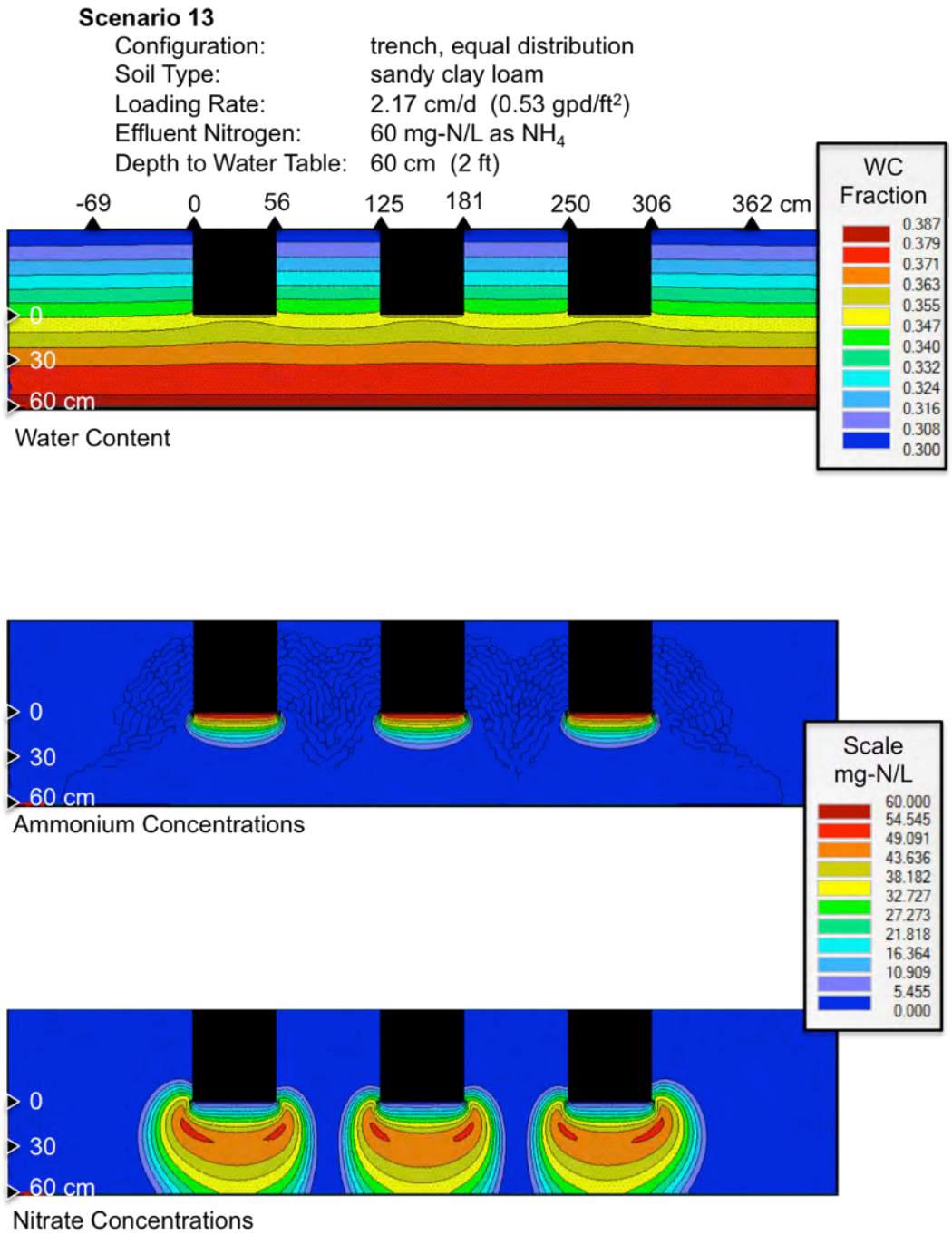

Figure B.13
Scenario 13

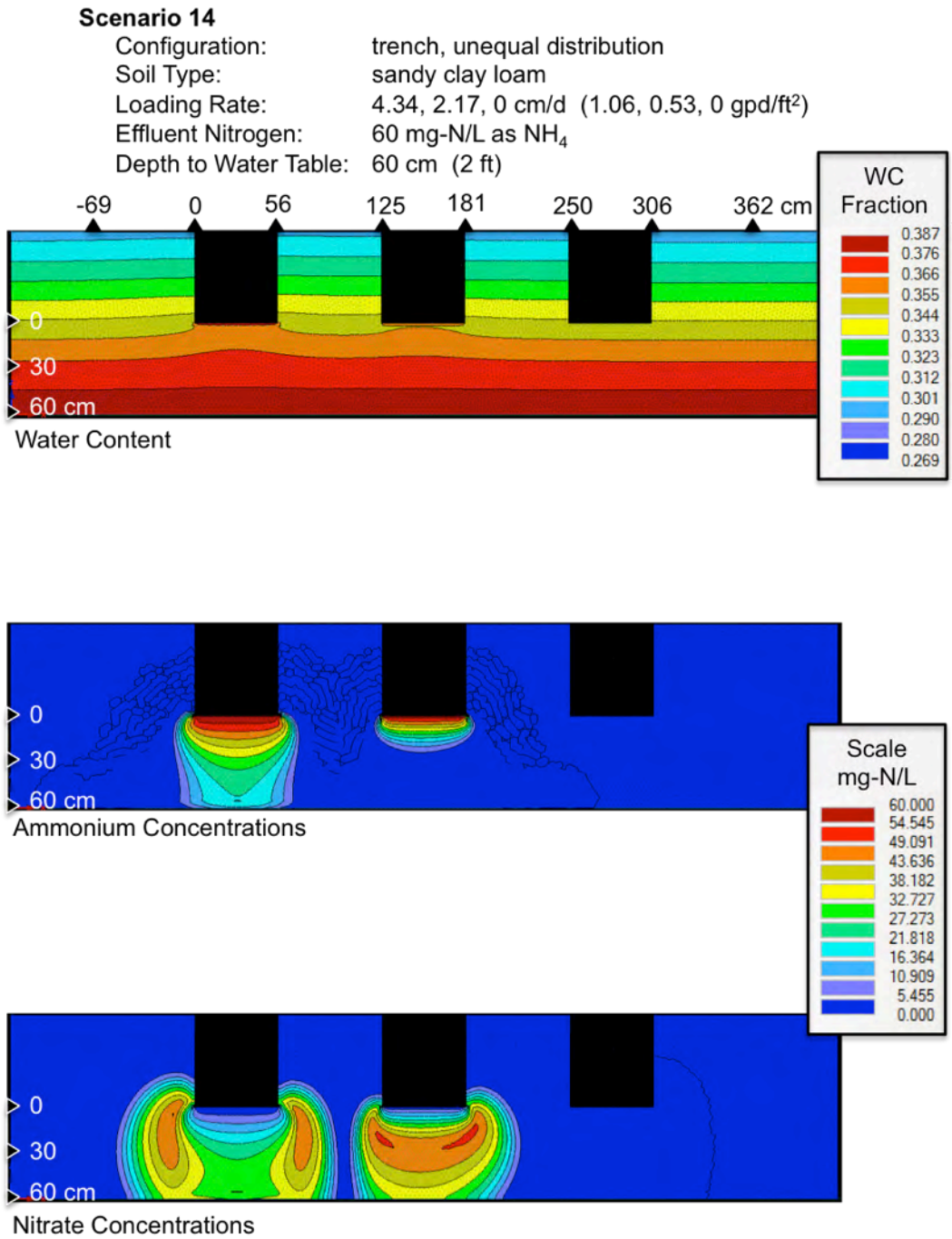

Figure B.14
Scenario 14

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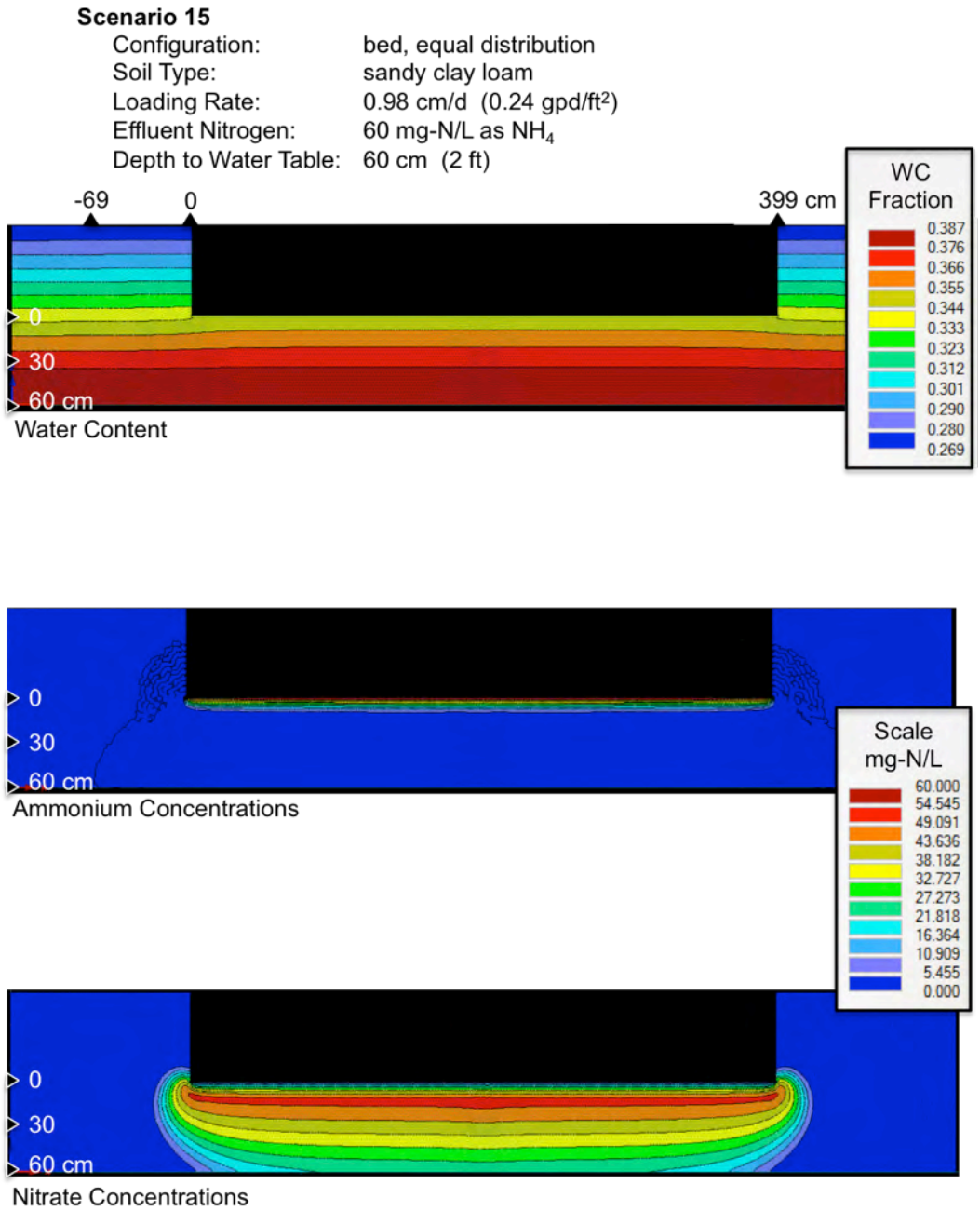

Figure B.15
Scenario 15

Scenario 16

Configuration:	bed, unequal distribution
Soil Type:	sandy clay loam
Loading Rate:	1.97, 0.98, 0 cm/d (0.48, 0.24, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	60 cm (2 ft)

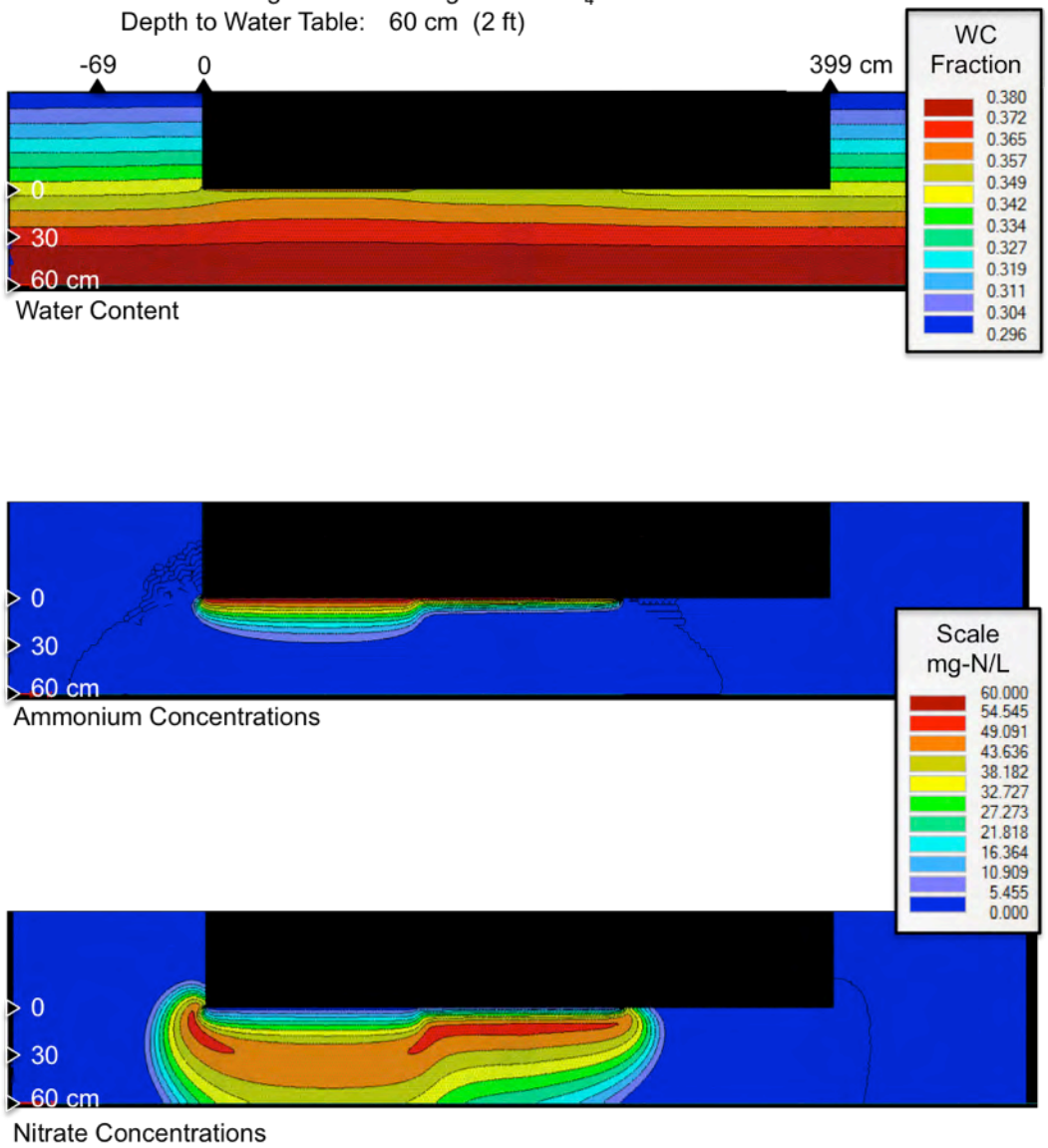

Figure B.16
Scenario 16

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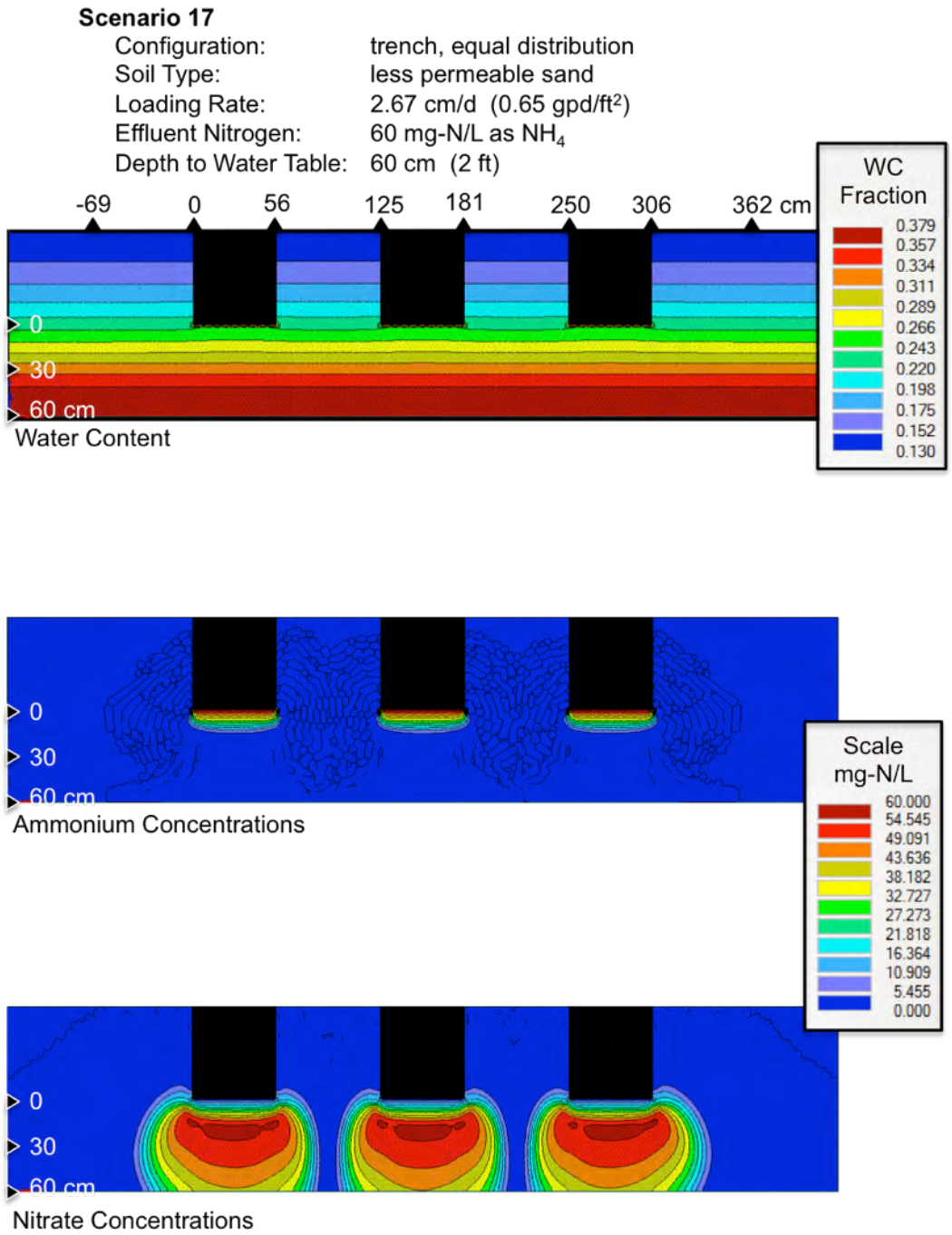


Figure B.17
Scenario 17

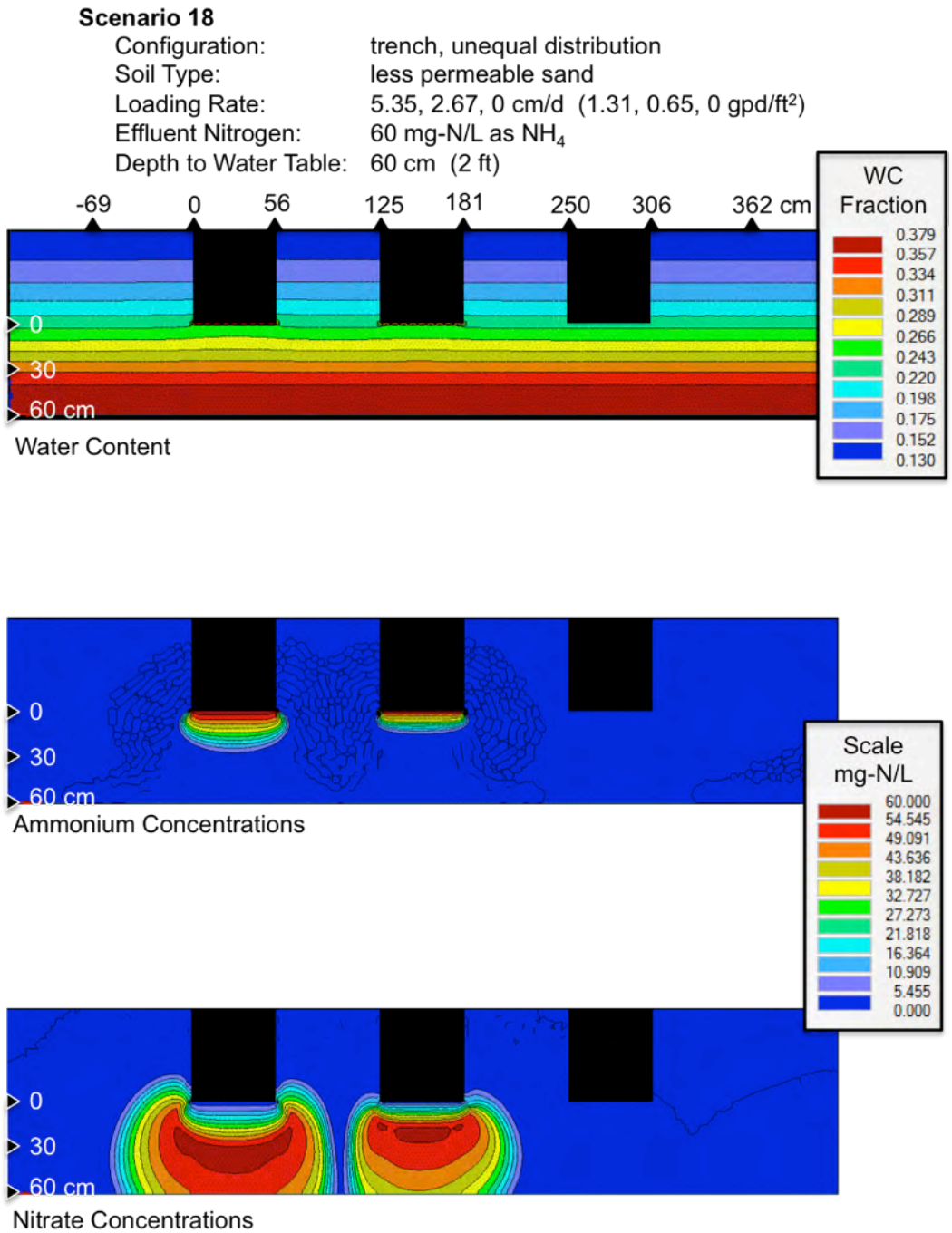


Figure B.18
Scenario 18

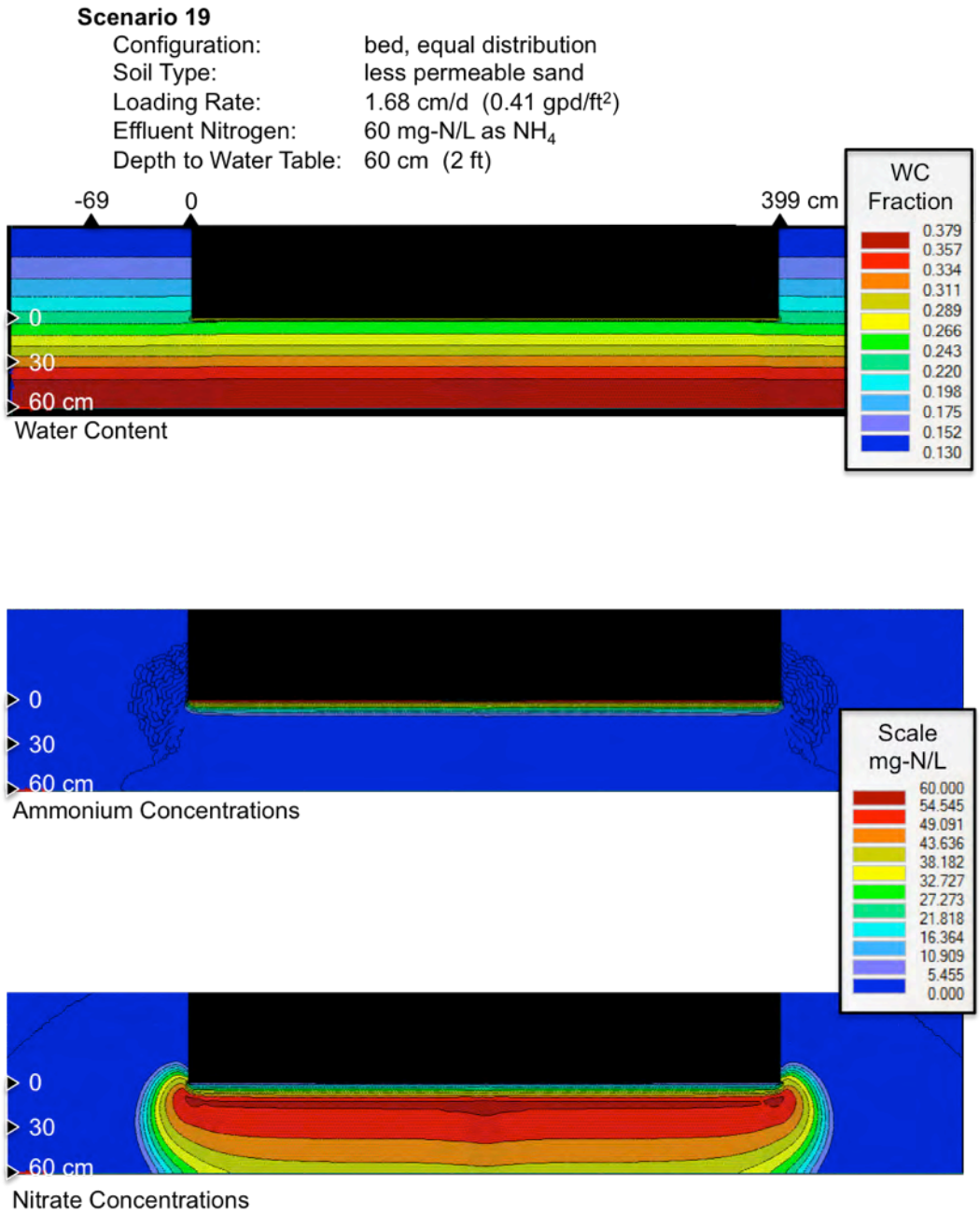


Figure B.19
Scenario 19

Scenario 20

Configuration:	bed, unequal distribution
Soil Type:	less permeable sand
Loading Rate:	3.37, 1.68, 0 cm/d (0.83, 0.41, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	60 cm (2 ft)

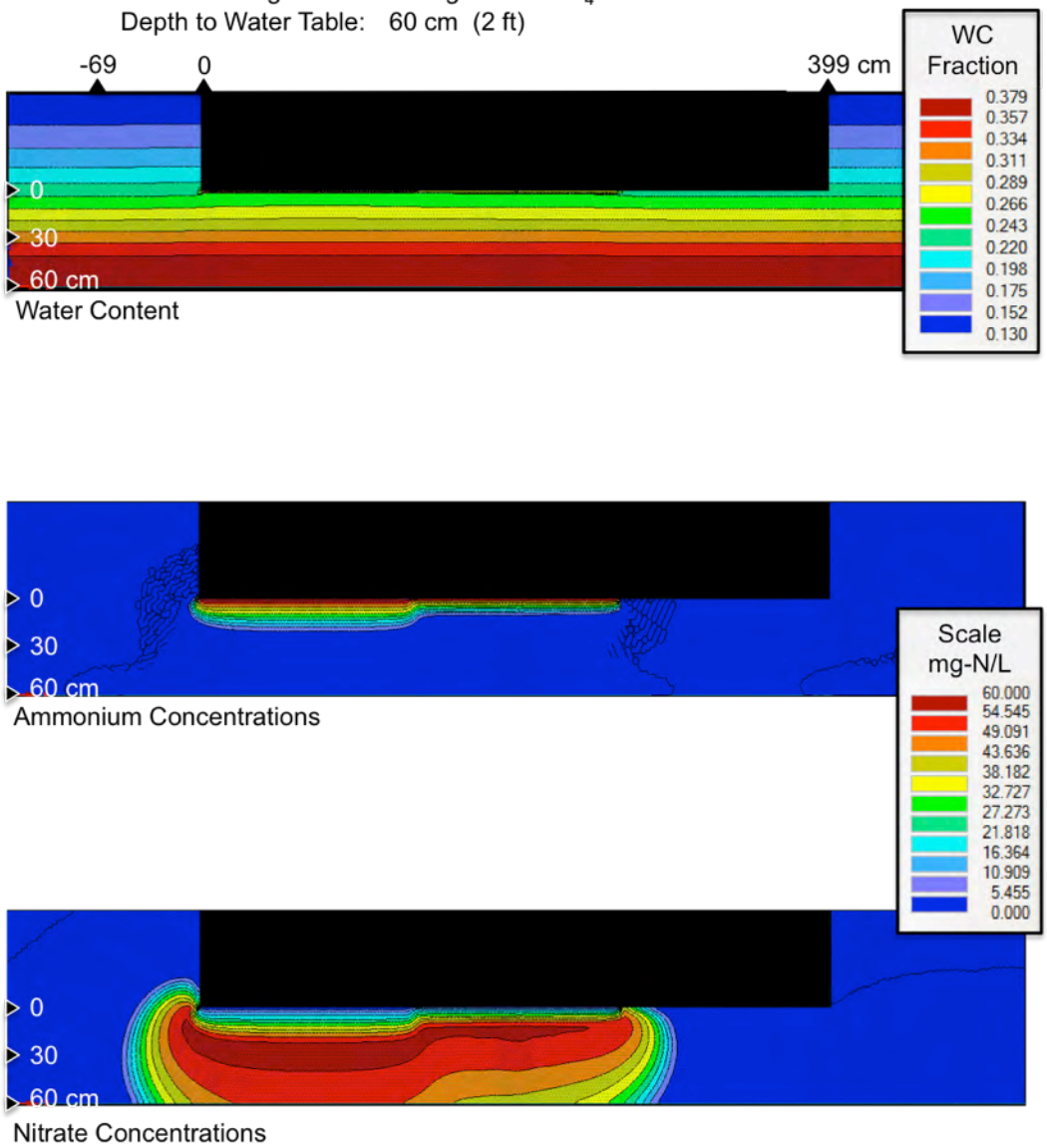


Figure B.20
Scenario 20

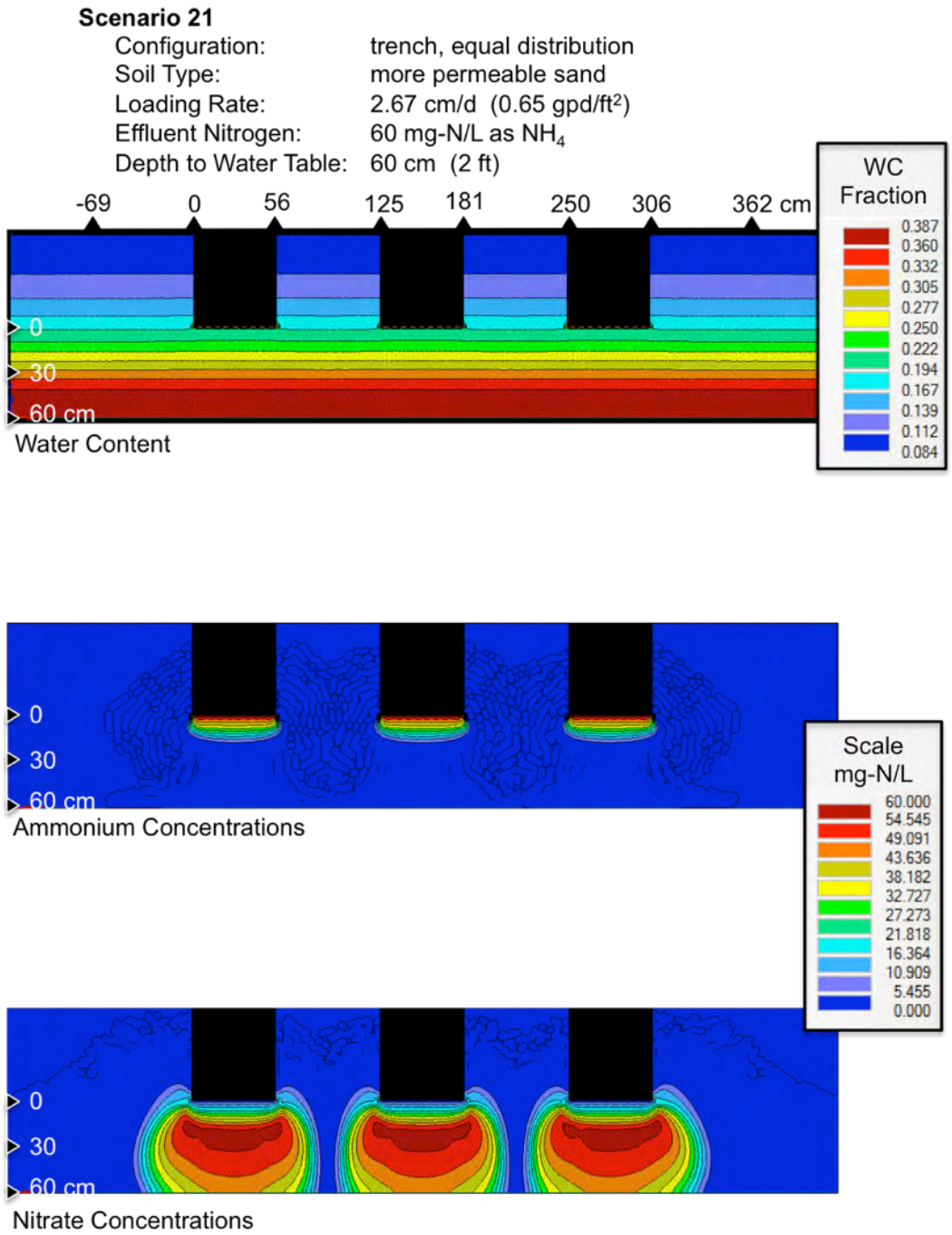


Figure B.21
Scenario 21

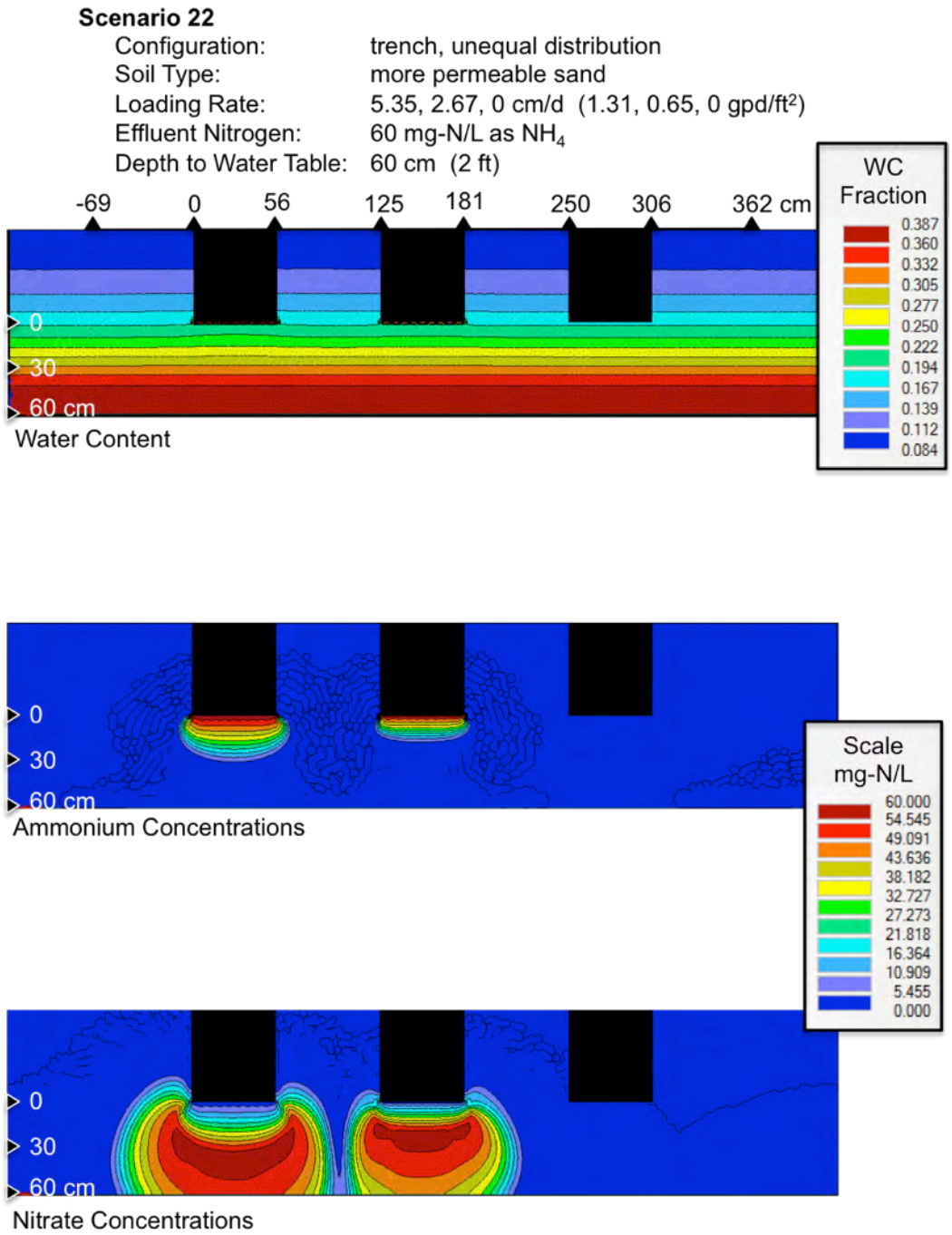


Figure B.22
Scenario 22

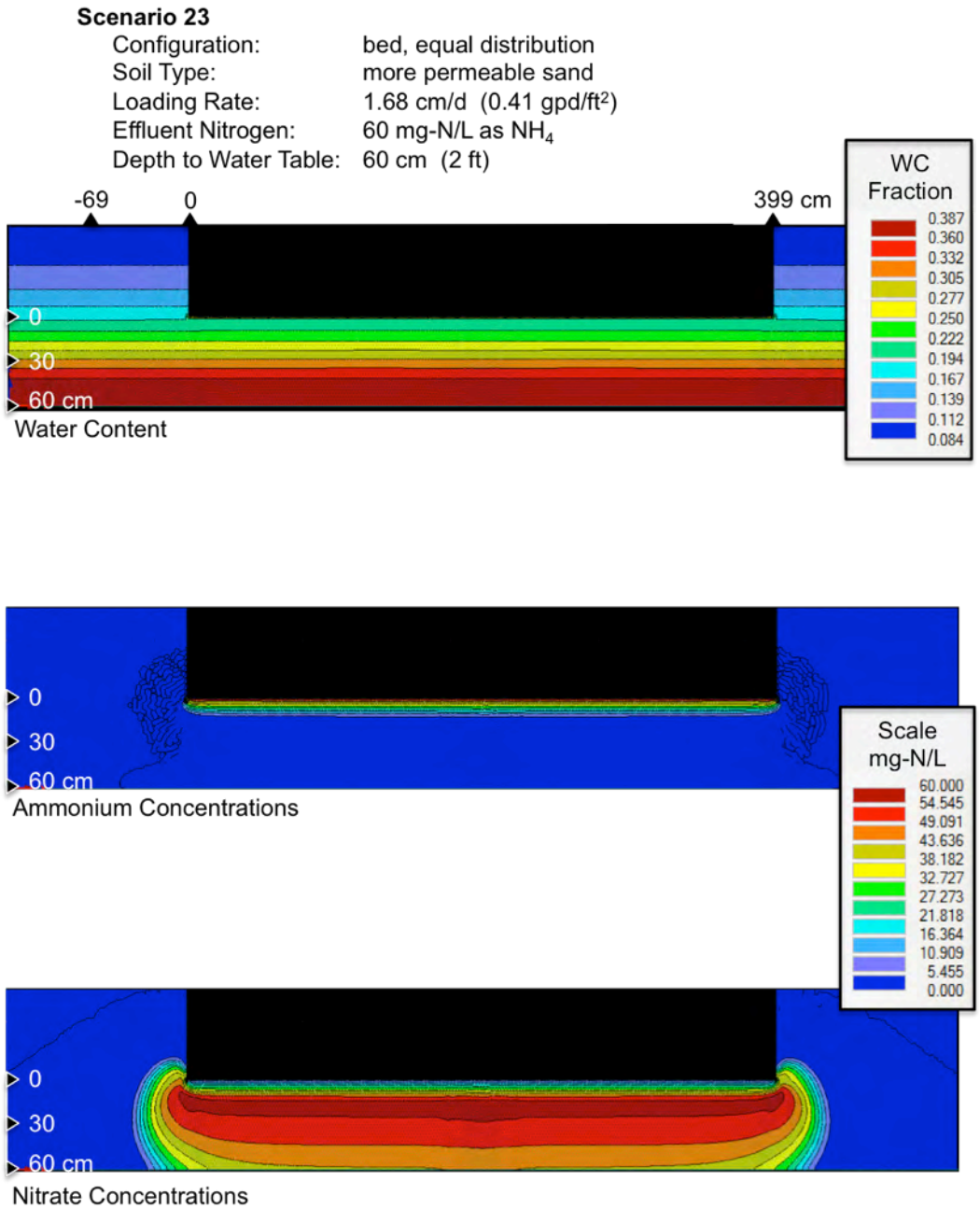
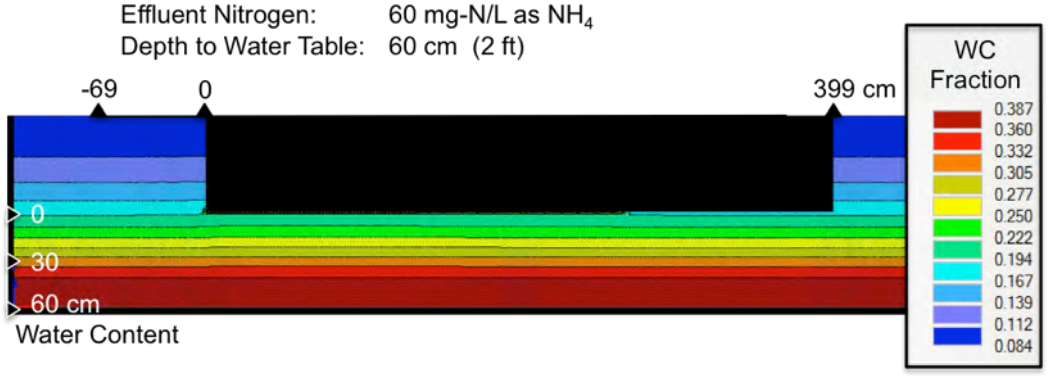
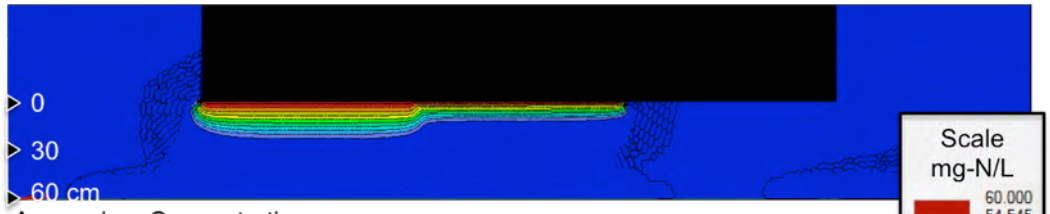


Figure B.23
Scenario 23

Scenario 24

Configuration:	bed, unequal distribution
Soil Type:	more permeable sand
Loading Rate:	3.37, 1.68, 0 cm/d (0.83, 0.41, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	60 cm (2 ft)





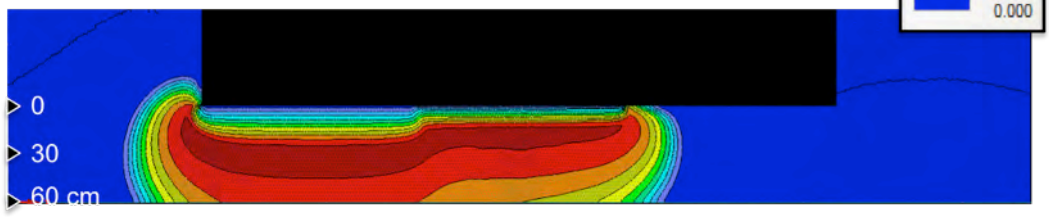


Figure B.24
Scenario 24

Scenario 25

Configuration:	trench, equal distribution
Soil Type:	sandy clay loam
Loading Rate:	2.17 cm/d (0.53 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6ft)

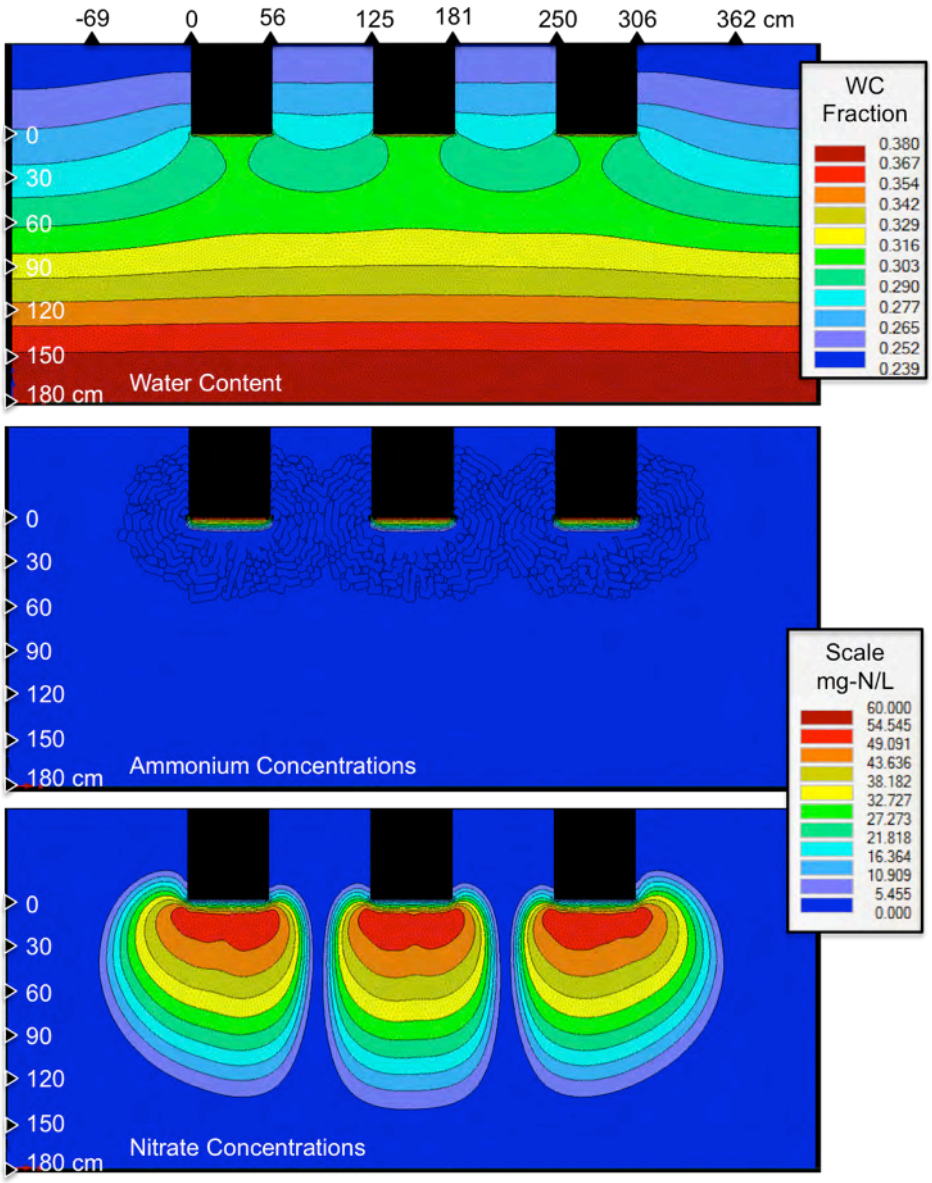


Figure B.25
Scenario 25

Scenario 26

Configuration:	trench, unequal distribution
Soil Type:	sandy clay loam
Loading Rate:	4.34, 2.17, 0 cm/d (1.06, 0.53, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6ft)

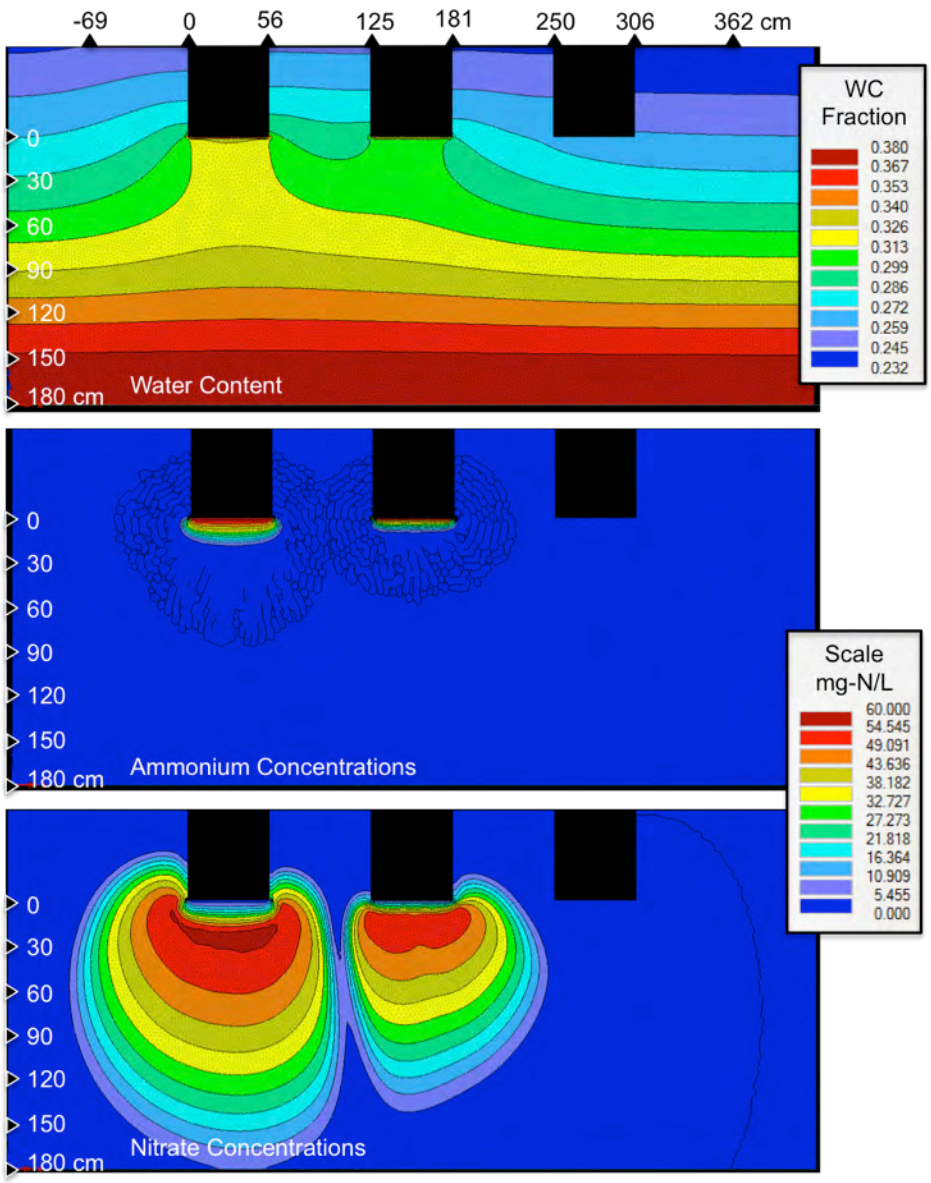


Figure B.26
Scenario 26

Scenario 27

Configuration:	bed, equal distribution
Soil Type:	sandy clay loam
Loading Rate:	0.98 cm/d (0.24 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6ft)

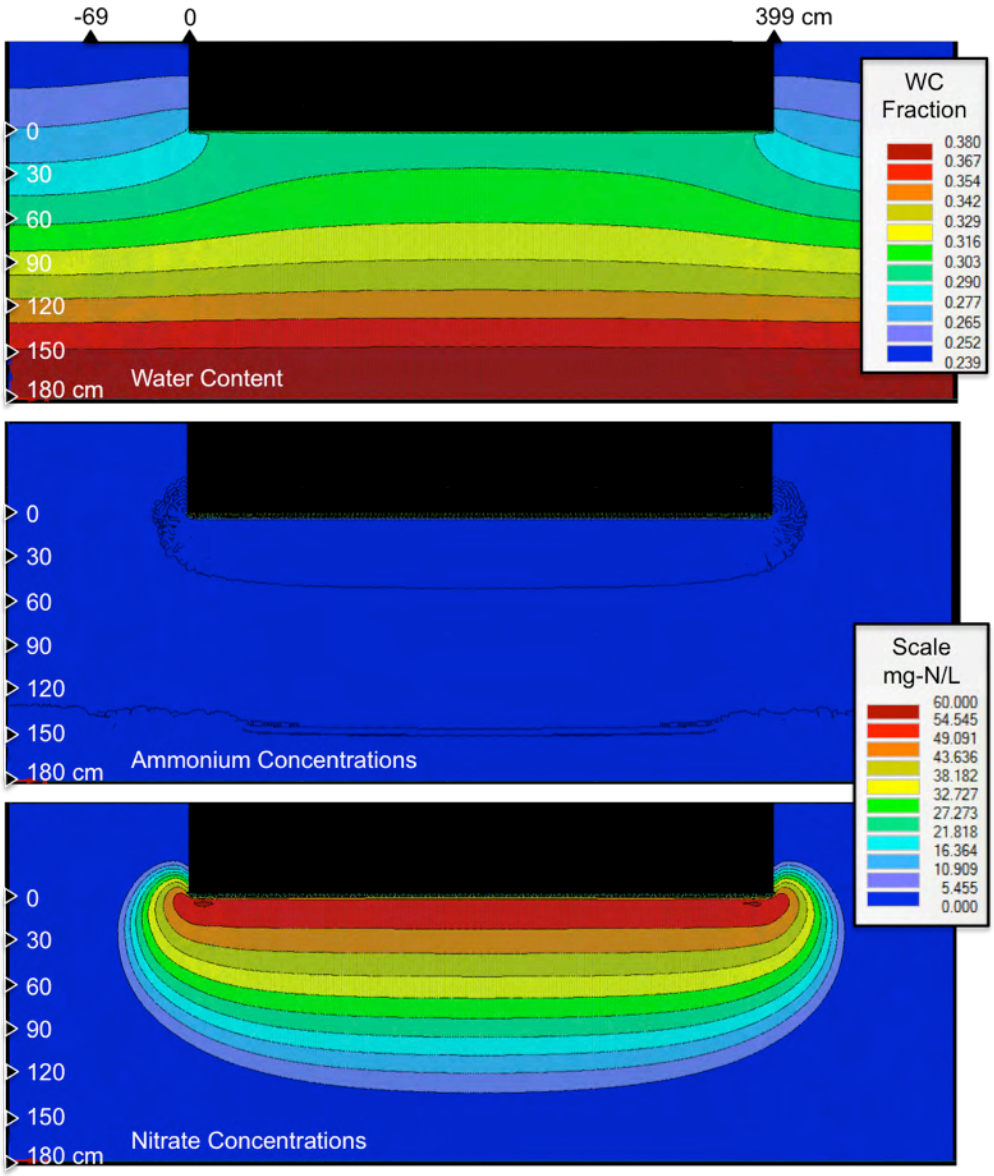


Figure B.27
Scenario 27

Scenario 28

Configuration:	bed, unequal distribution
Soil Type:	sandy clay loam
Loading Rate:	1.97, 0.98, 0 cm/d (0.48, 0.24, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft)

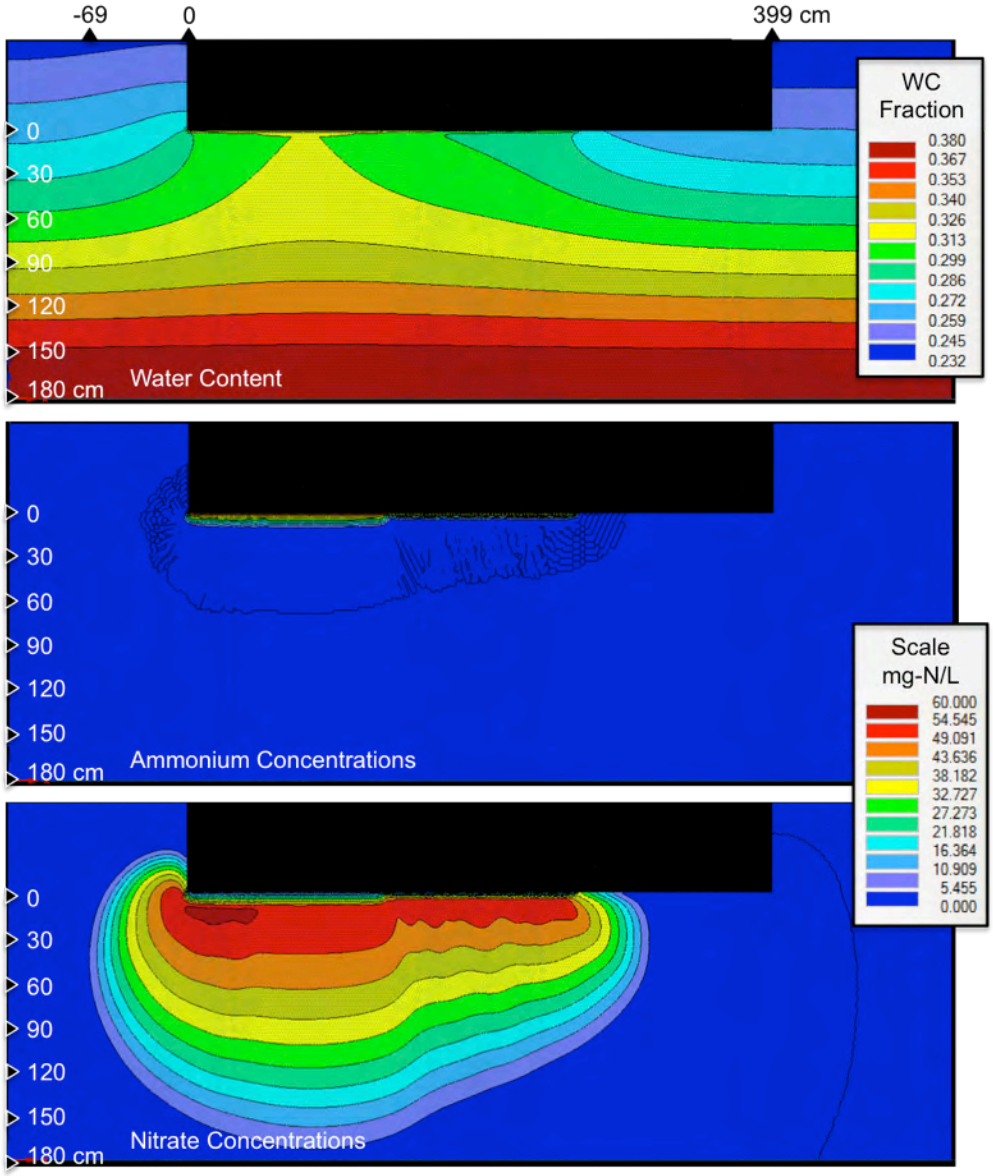


Figure B.28
Scenario 28

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Scenario 29

Configuration:	trench, equal distribution
Soil Type:	less permeable sand
Loading Rate:	2.67 cm/d (0.65 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft)

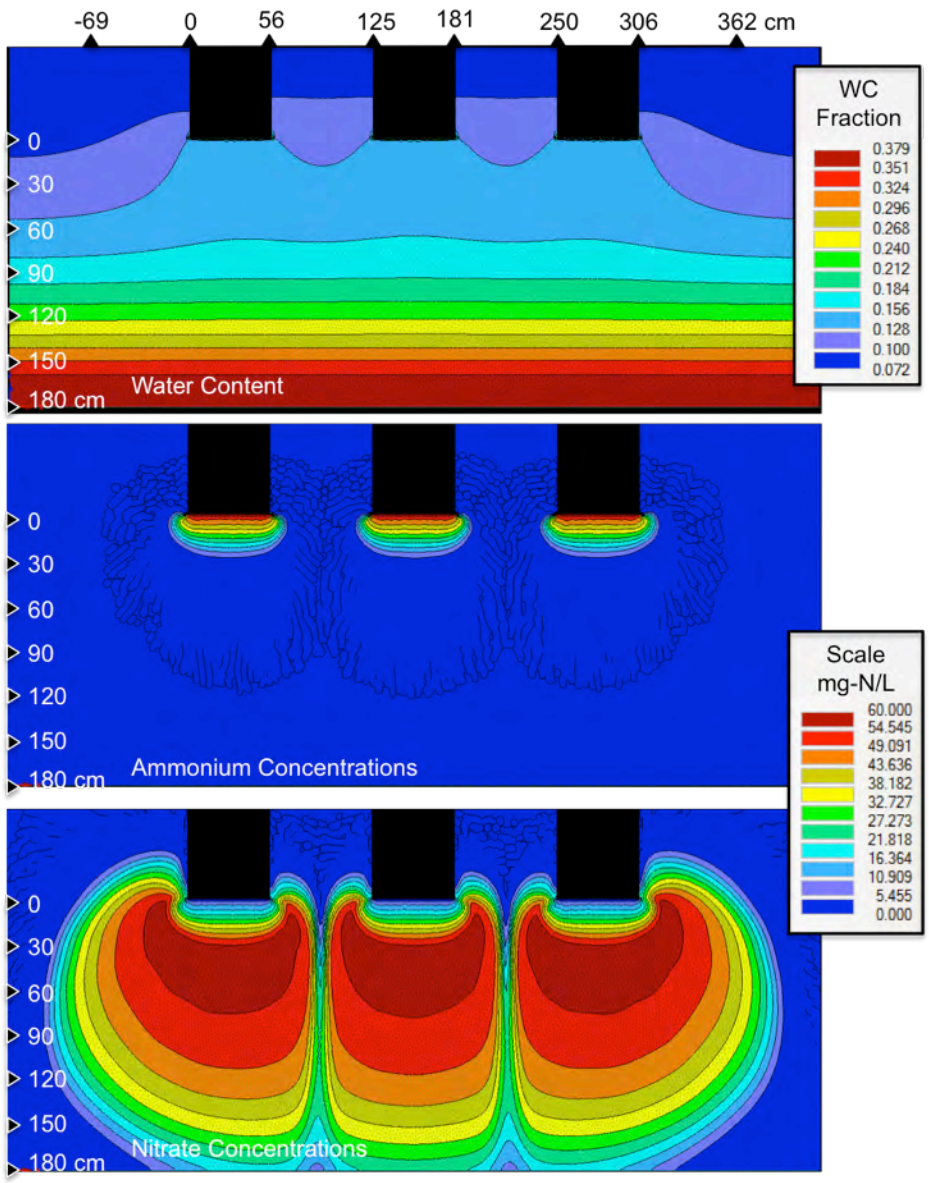

Figure B.29
Scenario 29

Scenario 30

Configuration:	trench, unequal distribution
Soil Type:	less permeable sand
Loading Rate:	5.35, 2.67, 0 cm/d (1.31, 0.65, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft)

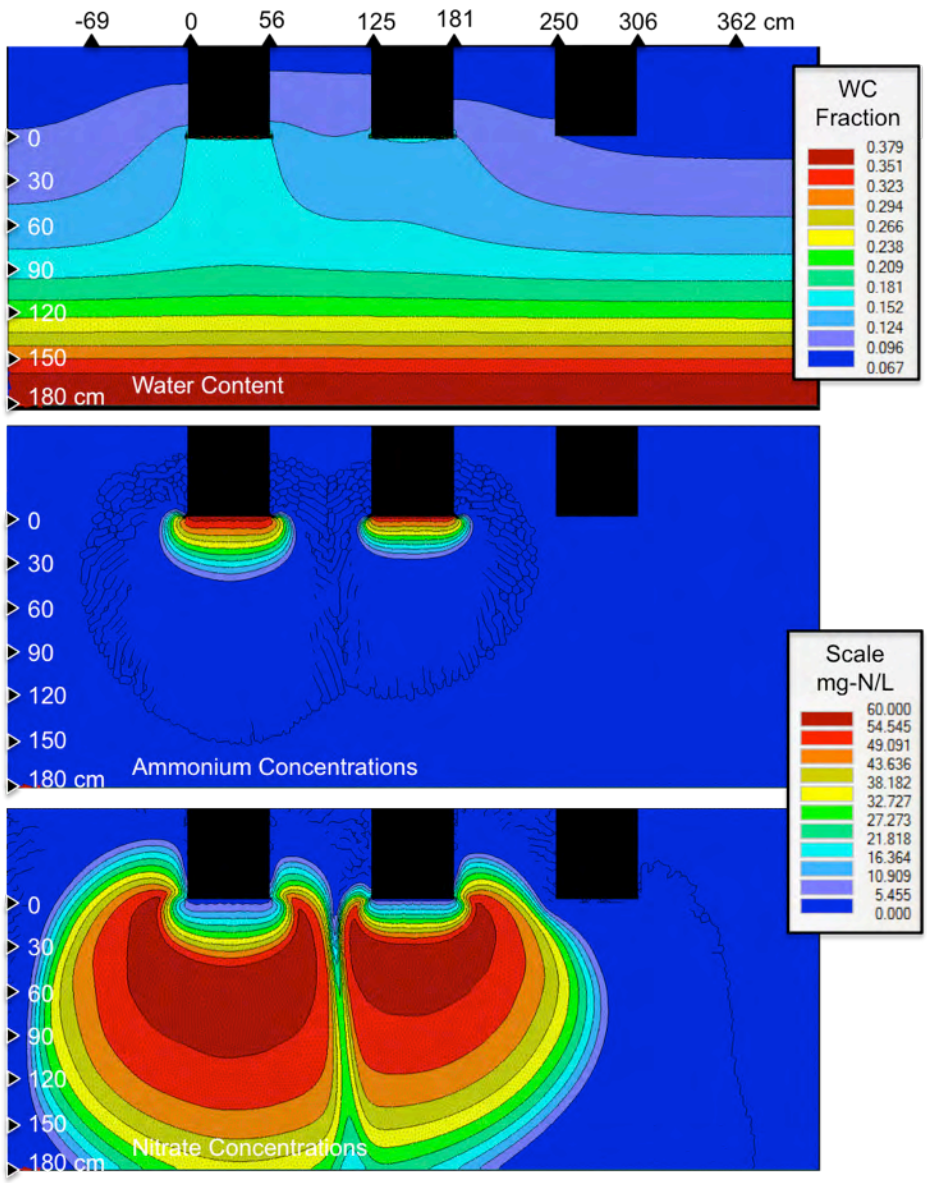

Figure B.30
Scenario 30

Scenario 31

Configuration:	bed, equal distribution
Soil Type:	less permeable sand
Loading Rate:	1.68 cm/d (0.41 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft)

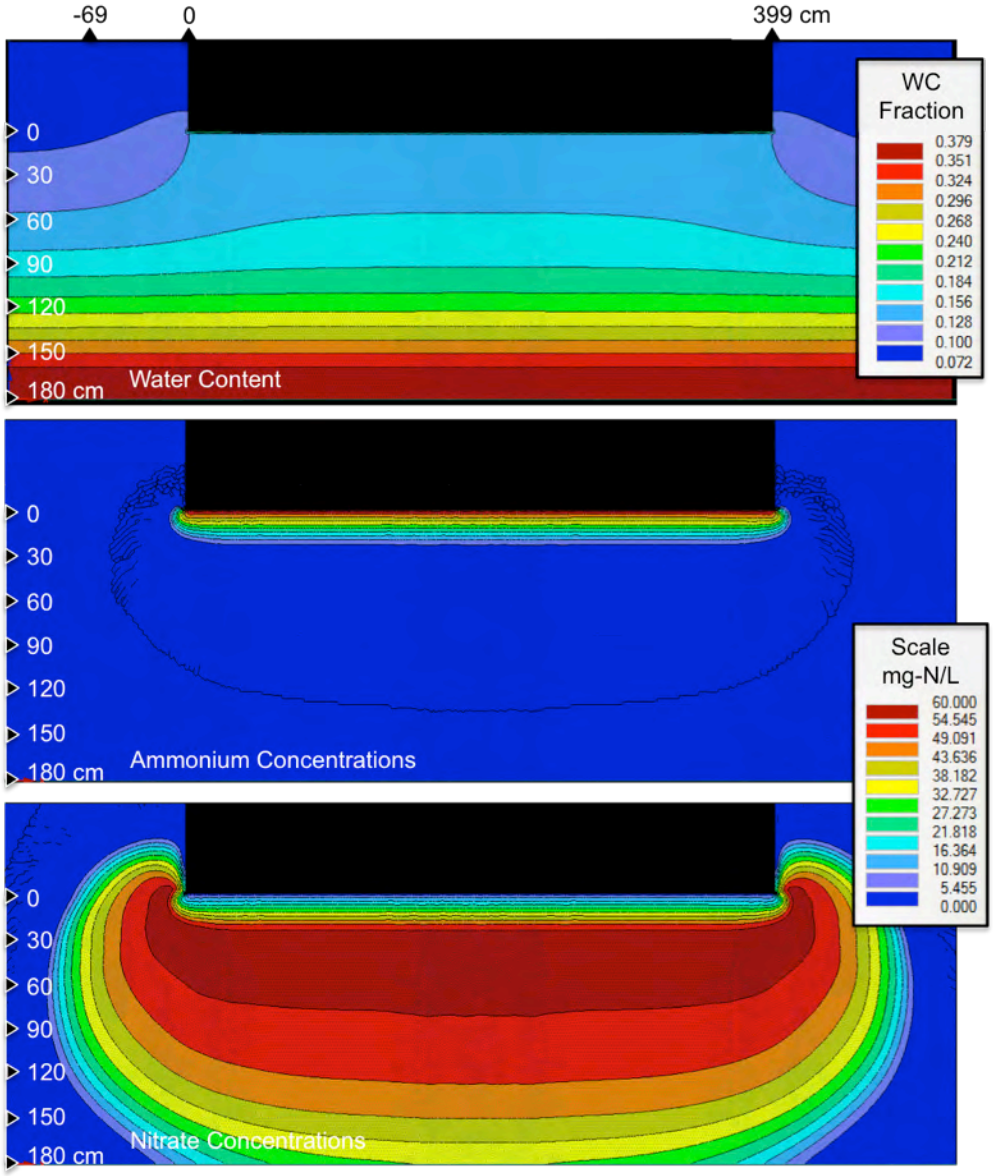

Figure B.31
Scenario 31

Scenario 32

Configuration:	bed, unequal distribution
Soil Type:	less permeable sand
Loading Rate:	3.37, 1.68, 0 cm/d (0.83, 0.41, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft)

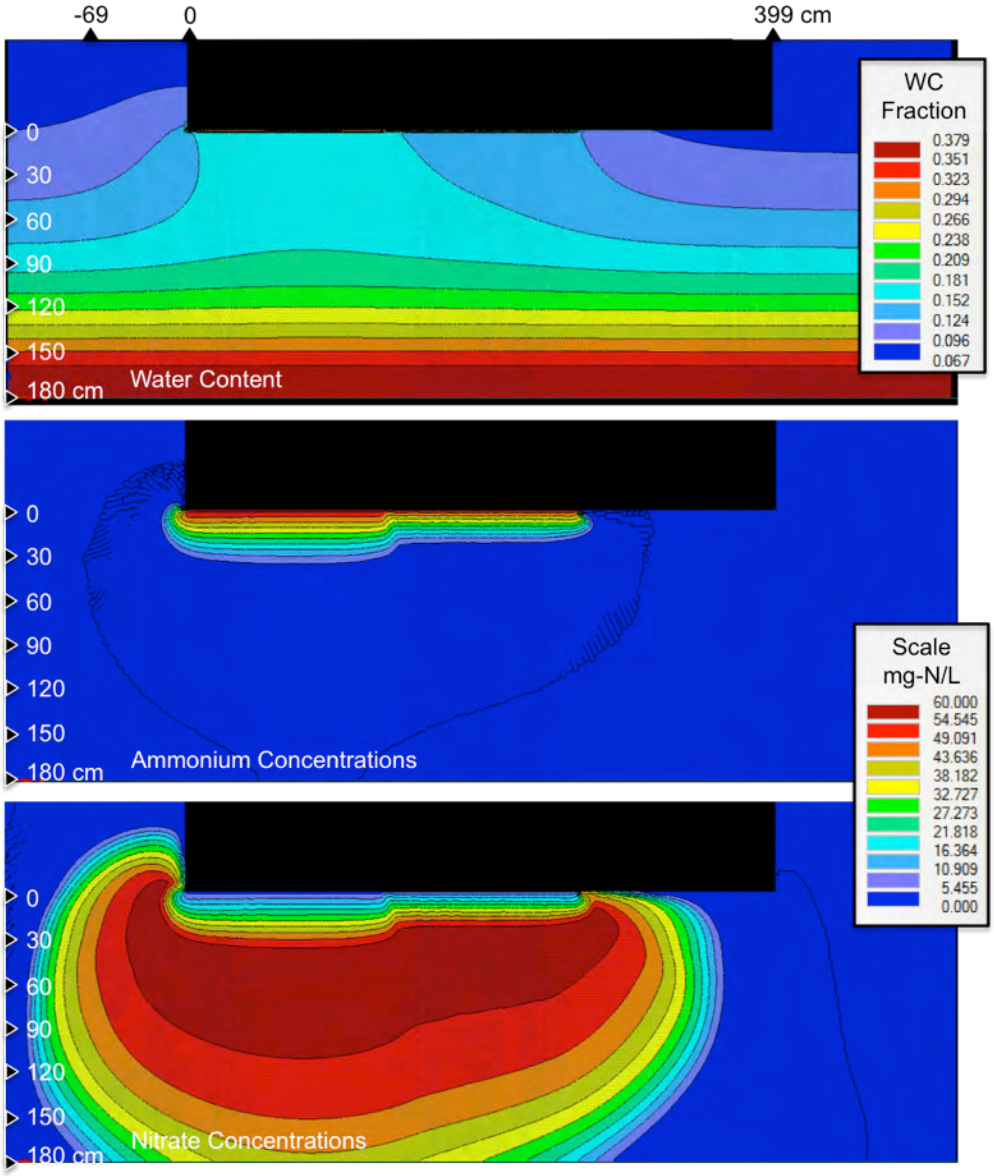

Figure B.32
Scenario 32

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Scenario 33

Configuration:	trench, equal distribution
Soil Type:	more permeable sand
Loading Rate:	2.67 cm/d (0.65 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft)

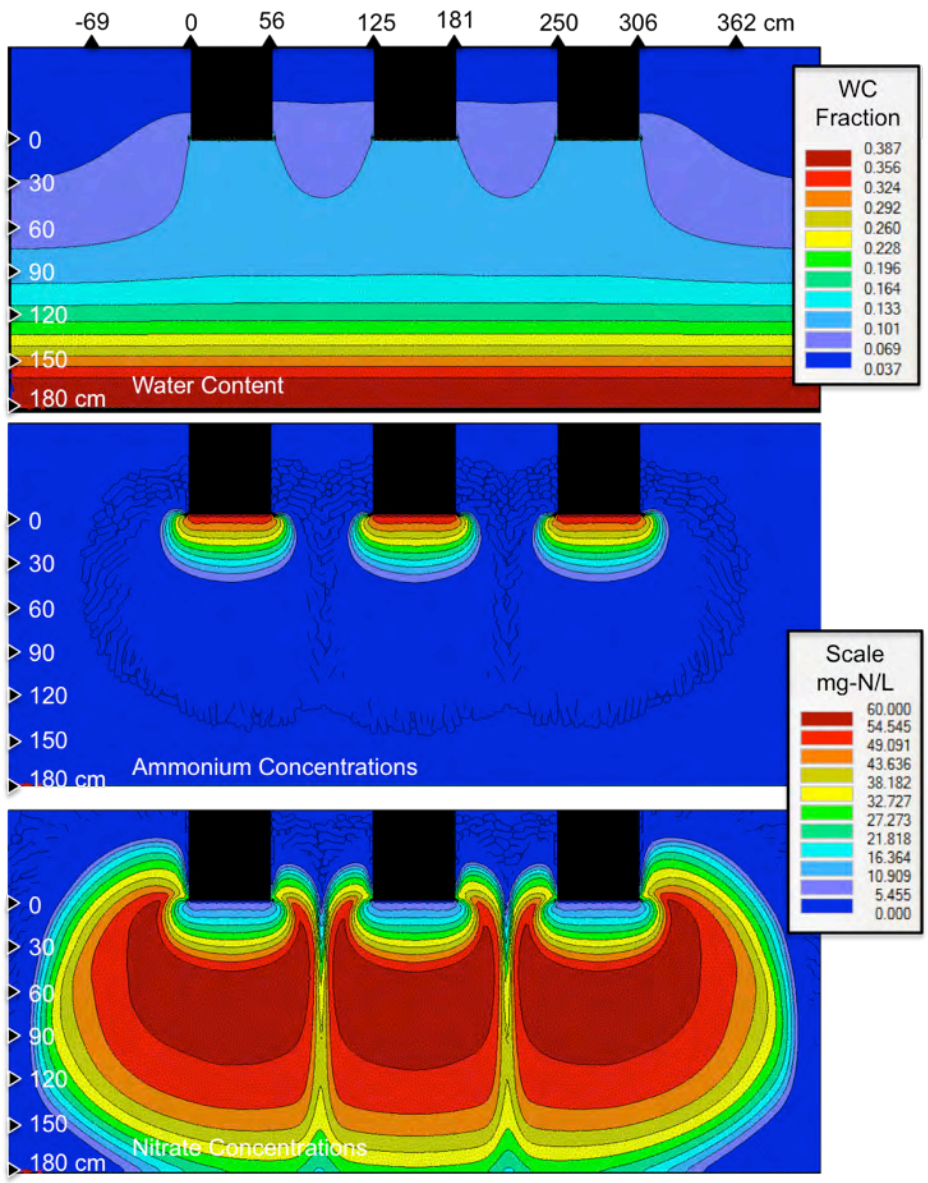

Figure B.33
Scenario 33

Scenario 34

Configuration:	trench, unequal distribution
Soil Type:	more permeable sand
Loading Rate:	5.35, 2.67, 0 cm/d (1.31, 0.65, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft)

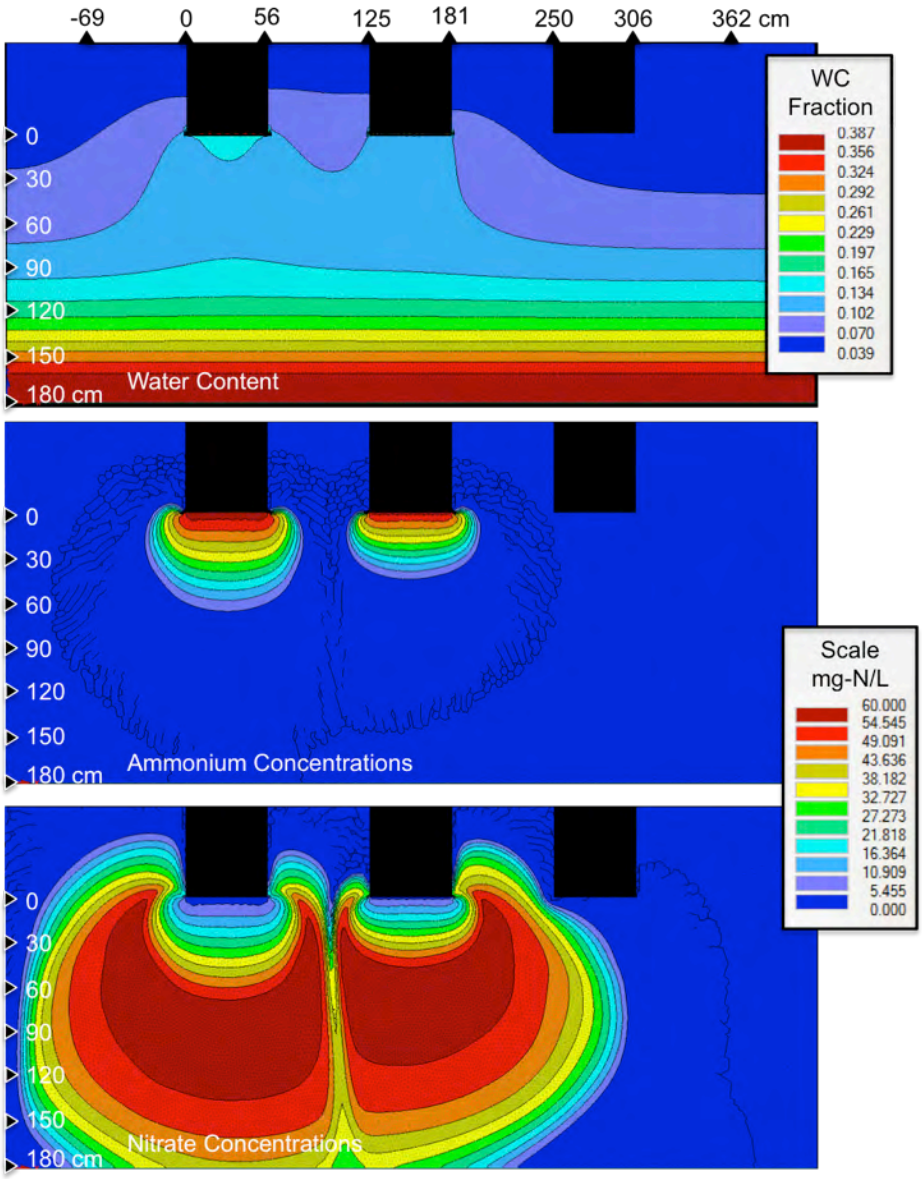

Figure B.34
Scenario 34

Scenario 35

Configuration:	bed, equal distribution
Soil Type:	more permeable sand
Loading Rate:	1.68 cm/d (0.41 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft)

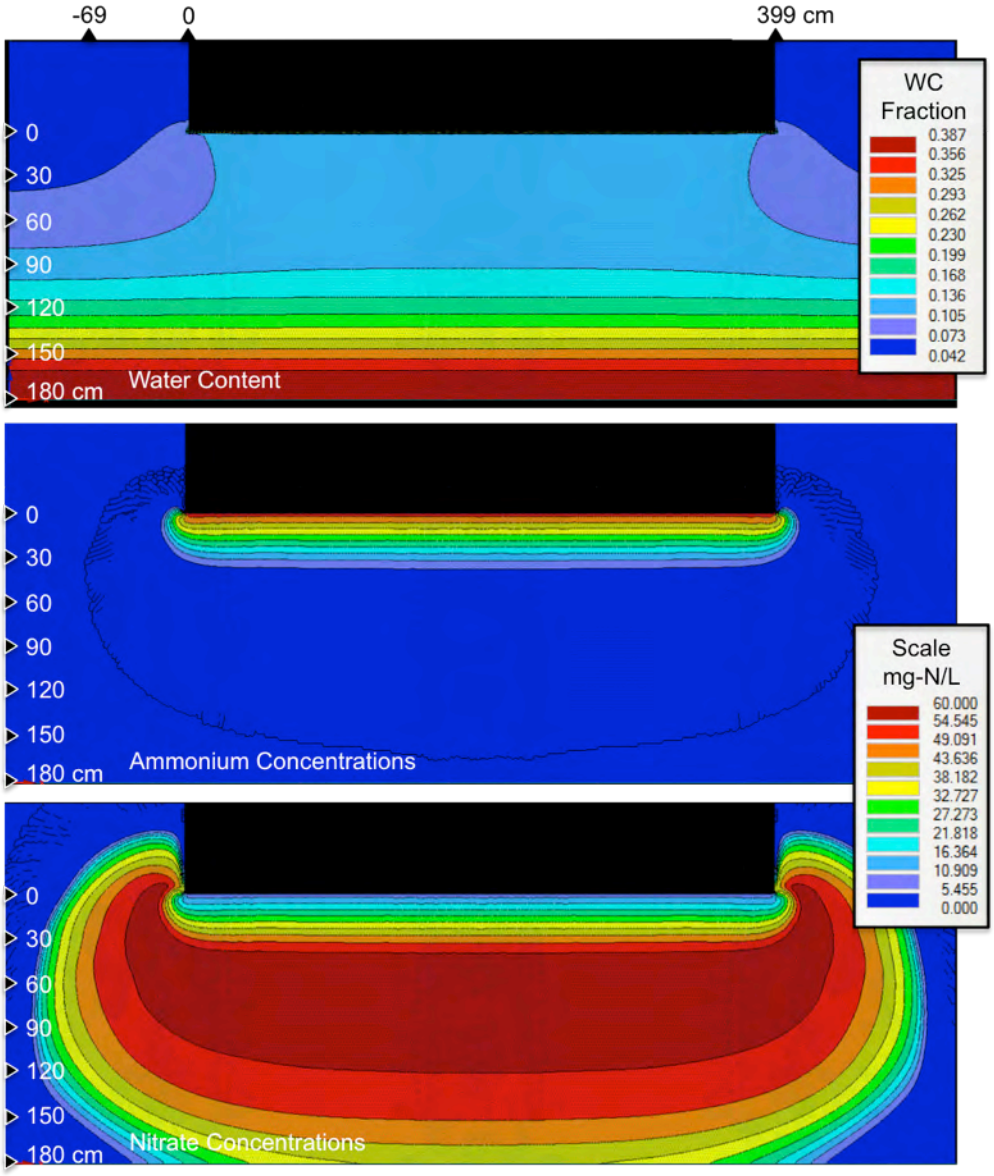

Figure B.35
Scenario 35

Scenario 36

Configuration:	bed, unequal distribution
Soil Type:	more permeable sand
Loading Rate:	3.37, 1.68, 0 cm/d (0.83, 0.41, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft)

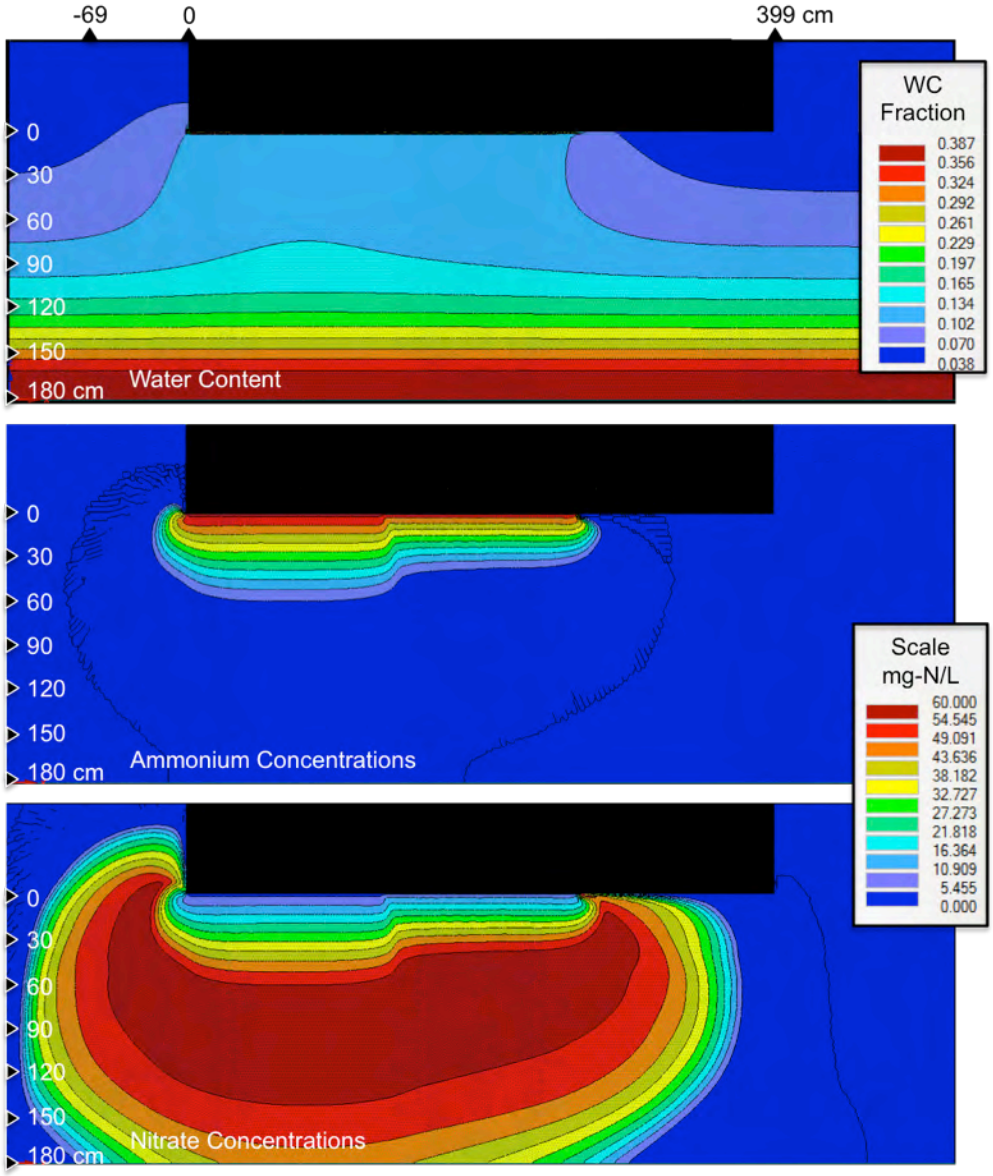

Figure B.36
Scenario 36

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Scenario 37

Configuration:	trench, equal distribution
Soil Type:	sandy clay loam
Loading Rate:	2.17 cm/d (0.53 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	free drainage

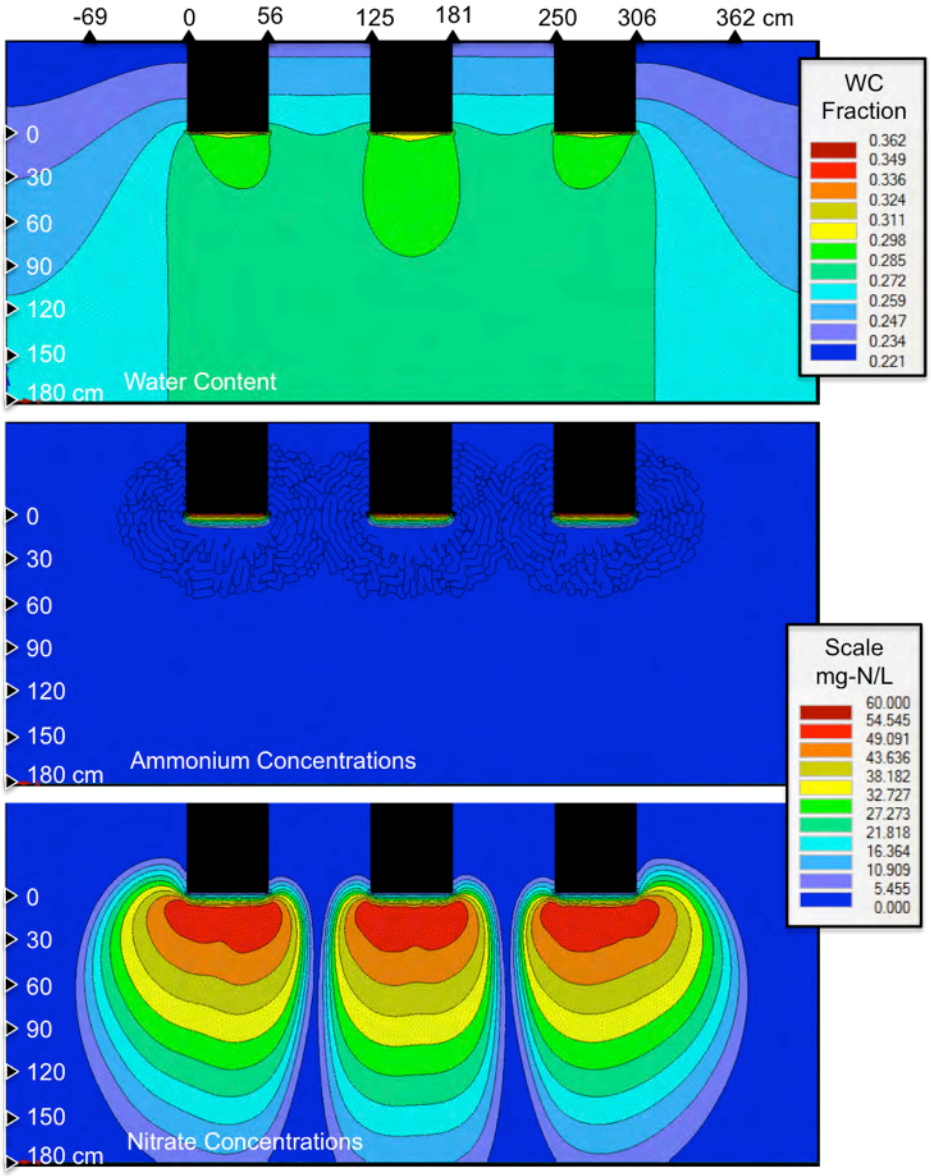

Figure B.37
Scenario 37

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Scenario 38

Configuration:	trench, unequal distribution
Soil Type:	sandy clay loam
Loading Rate:	4.34, 2.17, 0 cm/d (1.06, 0.53, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	free drainage

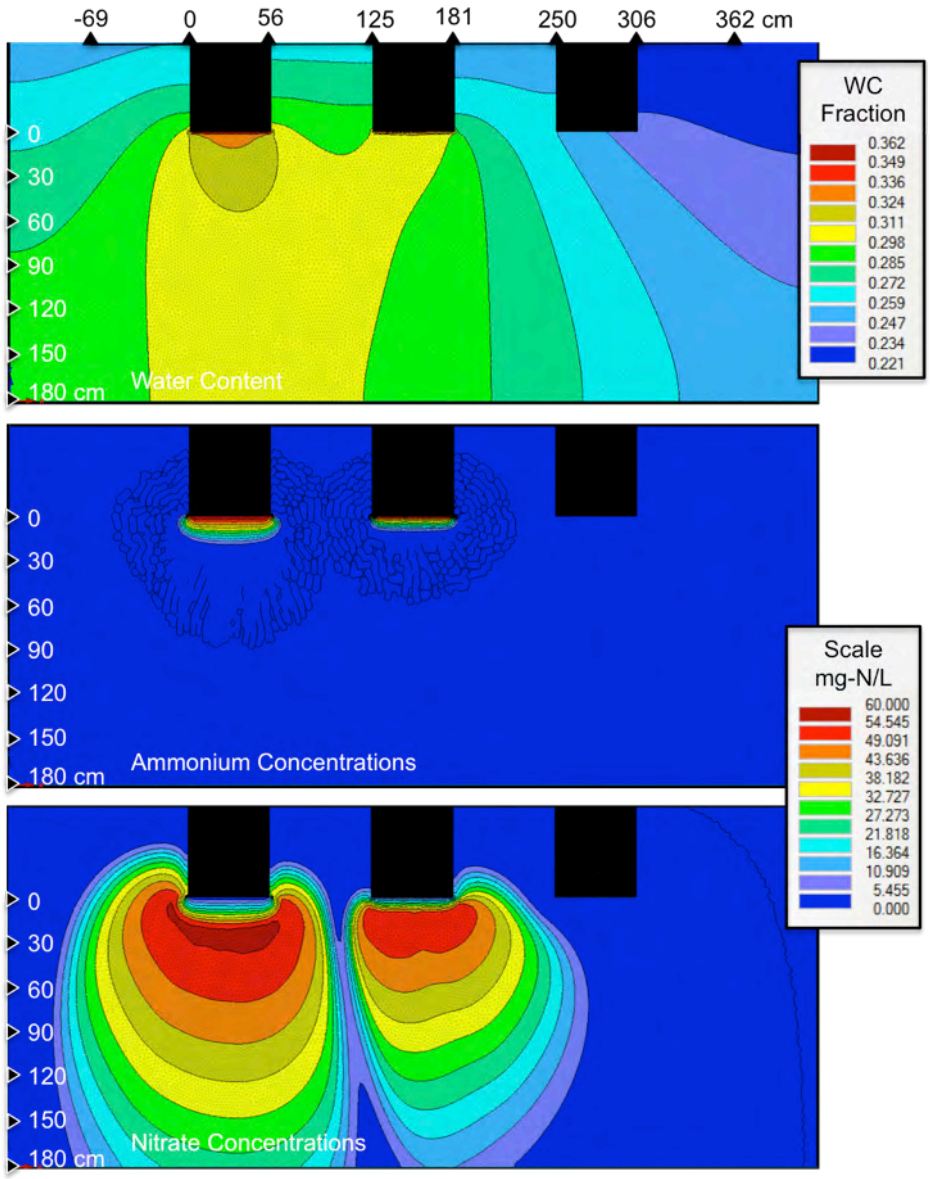

Figure B.38
Scenario 38

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Scenario 39

Configuration:	bed, equal distribution
Soil Type:	sandy clay loam
Loading Rate:	0.98 cm/d (0.24 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	free drainage

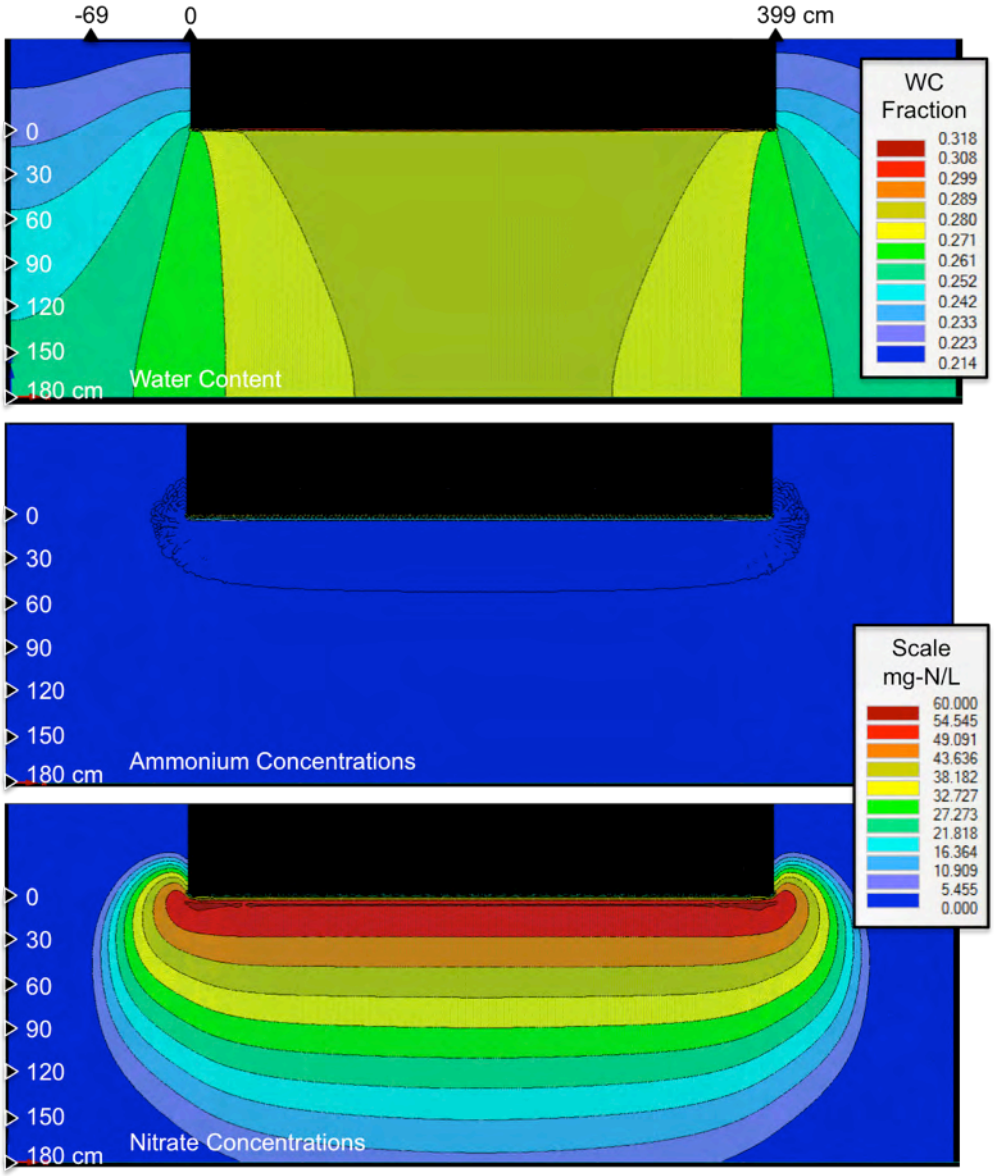

Figure B.39
Scenario 39

Scenario 40

Configuration:	bed, unequal distribution
Soil Type:	sandy clay loam
Loading Rate:	1.97, 0.98, 0 cm/d (0.48, 0.24, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	free drainage

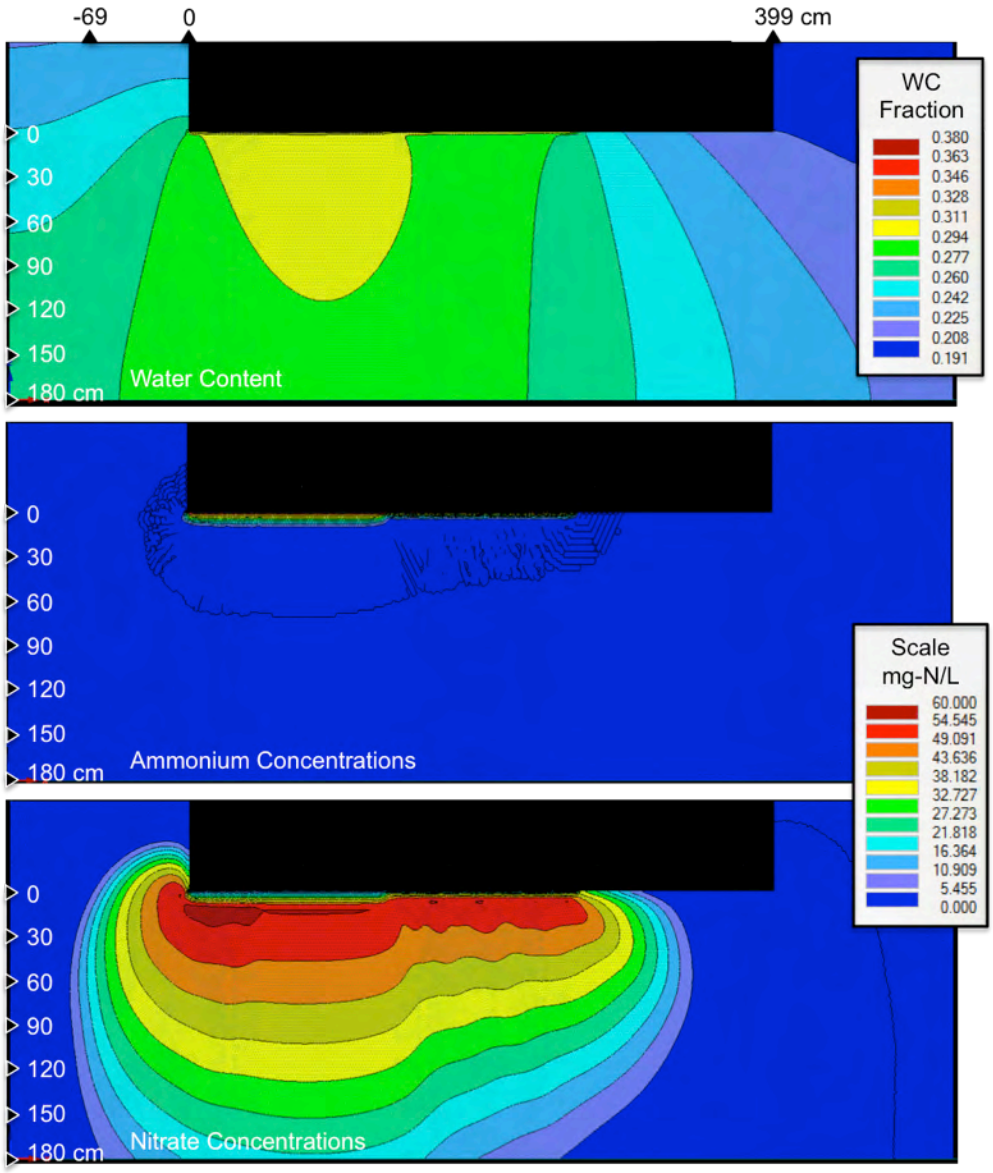

Figure B.40
Scenario 40

Scenario 41

Configuration:	trench, equal distribution
Soil Type:	less permeable sand
Loading Rate:	2.67 cm/d (0.65 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	free drainage

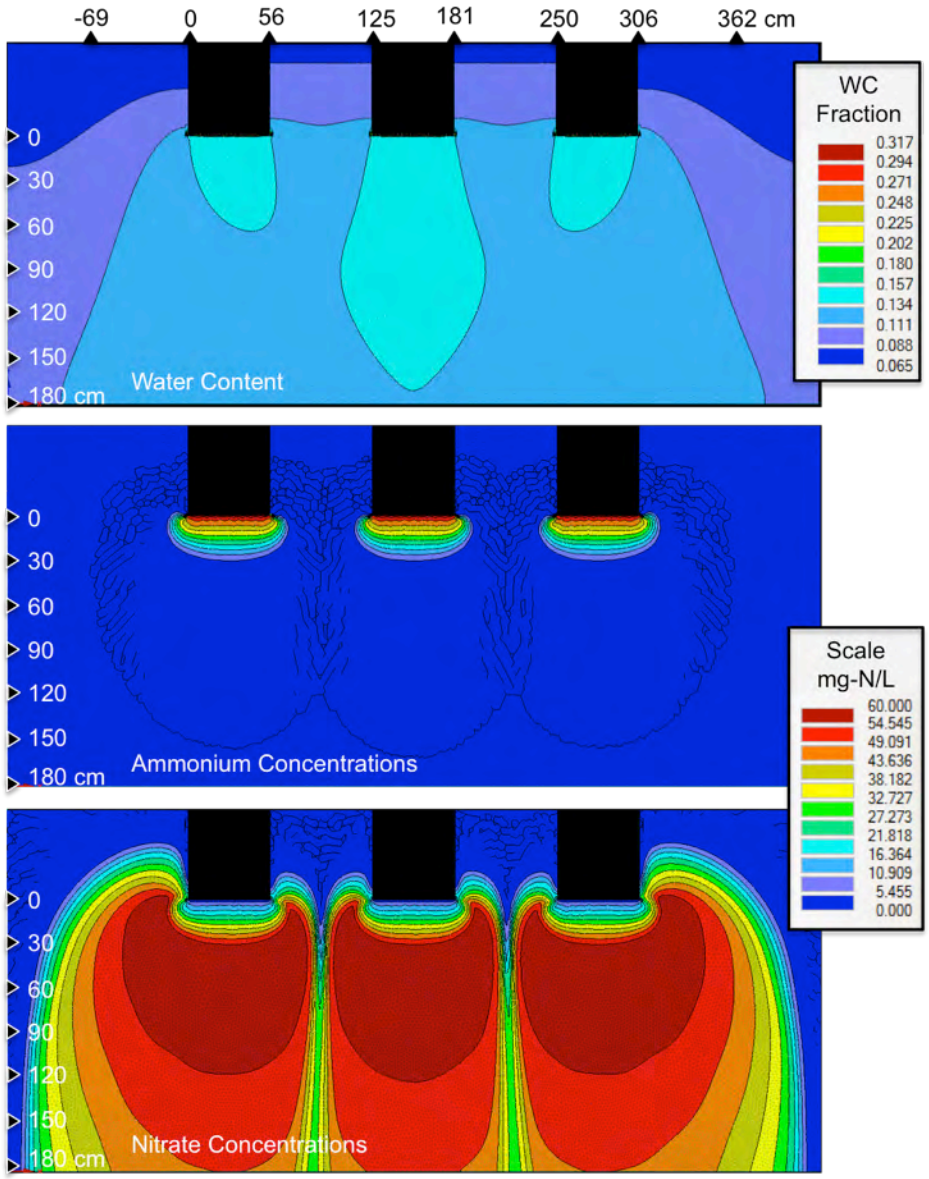

Figure B.41
Scenario 41

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Scenario 42

Configuration:	trench, unequal distribution
Soil Type:	less permeable sand
Loading Rate:	5.35, 2.67, 0 cm/d (1.31, 0.65, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	free drainage

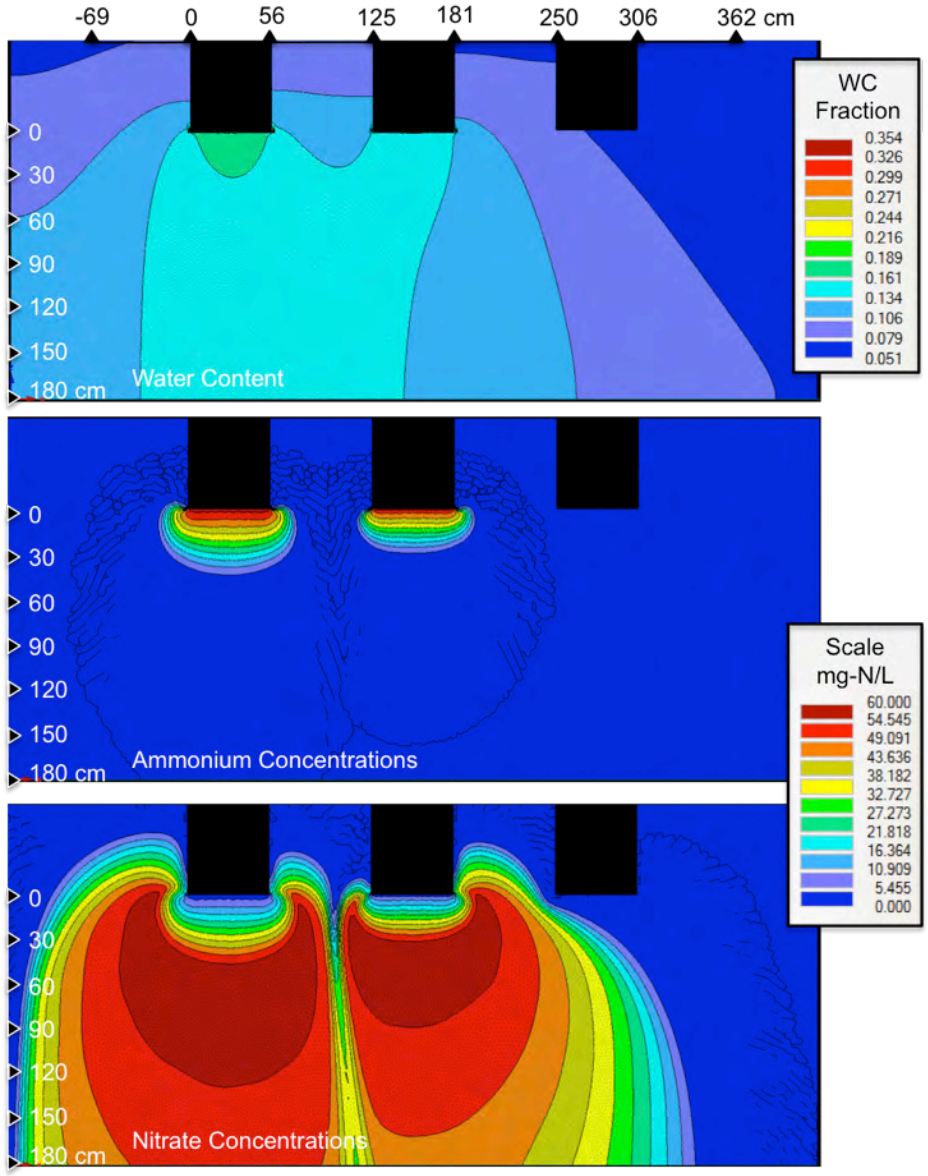

Figure B.42
Scenario 42

Scenario 43

Configuration:	bed, equal distribution
Soil Type:	less permeable sand
Loading Rate:	1.68 cm/d (0.41 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	free drainage

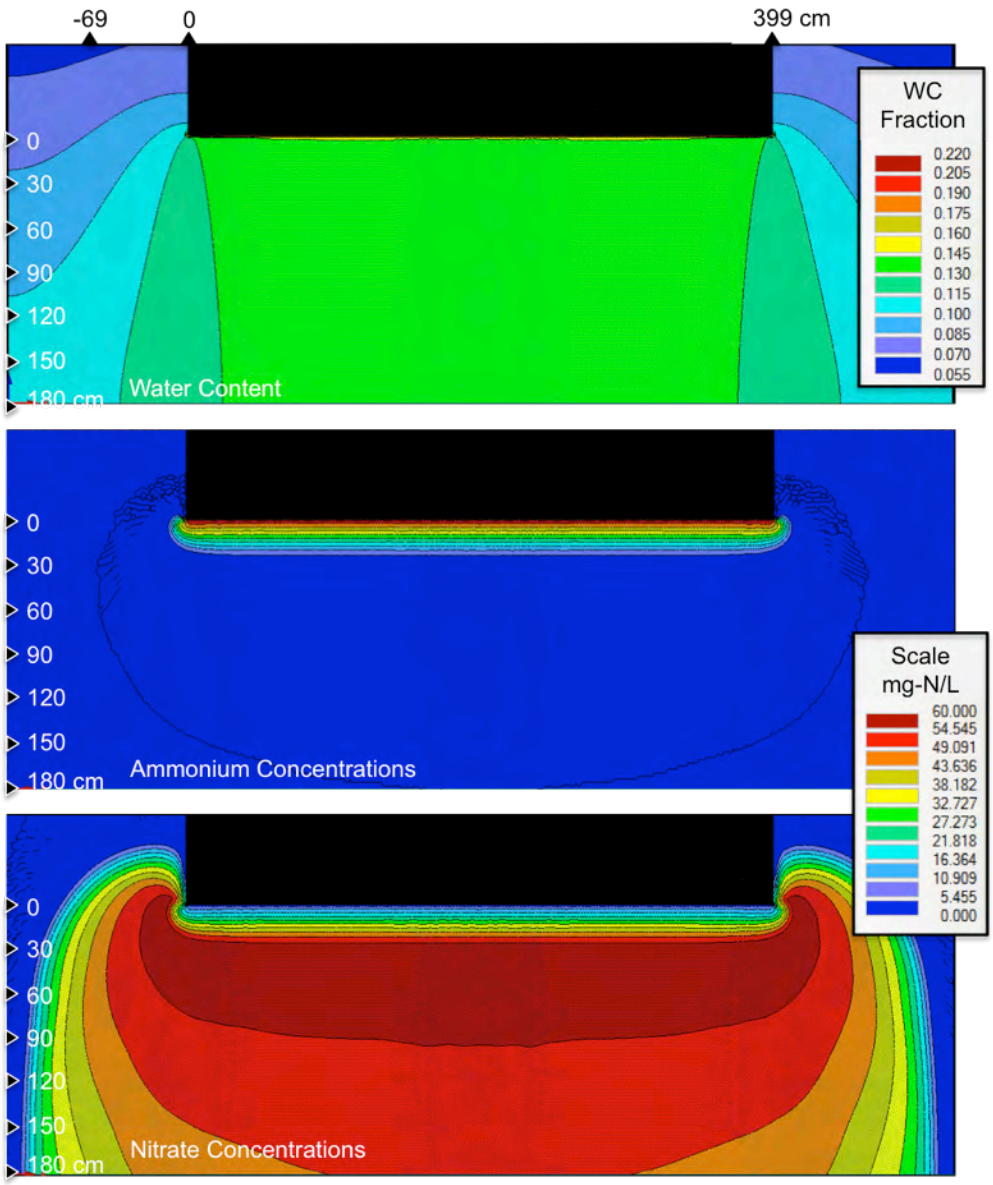

Figure B.43
Scenario 43

Scenario 44

Configuration:	bed, unequal distribution
Soil Type:	less permeable sand
Loading Rate:	3.37, 1.68, 0 cm/d (0.83, 0.41, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	free drainage

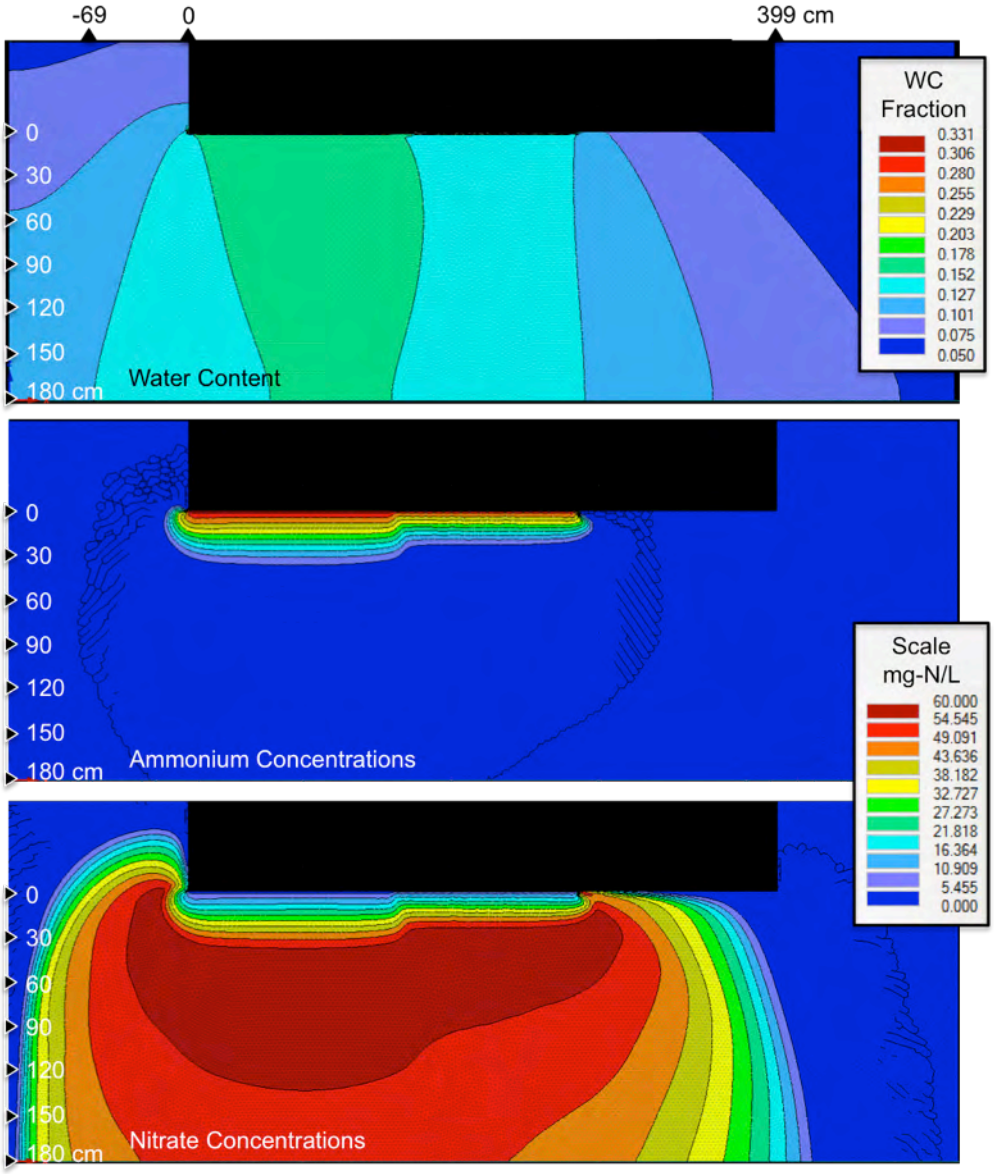

Figure B.44
Scenario 44

Scenario 45

Configuration:	trench, equal distribution
Soil Type:	more permeable sand
Loading Rate:	2.67 cm/d (0.65 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	free drainage

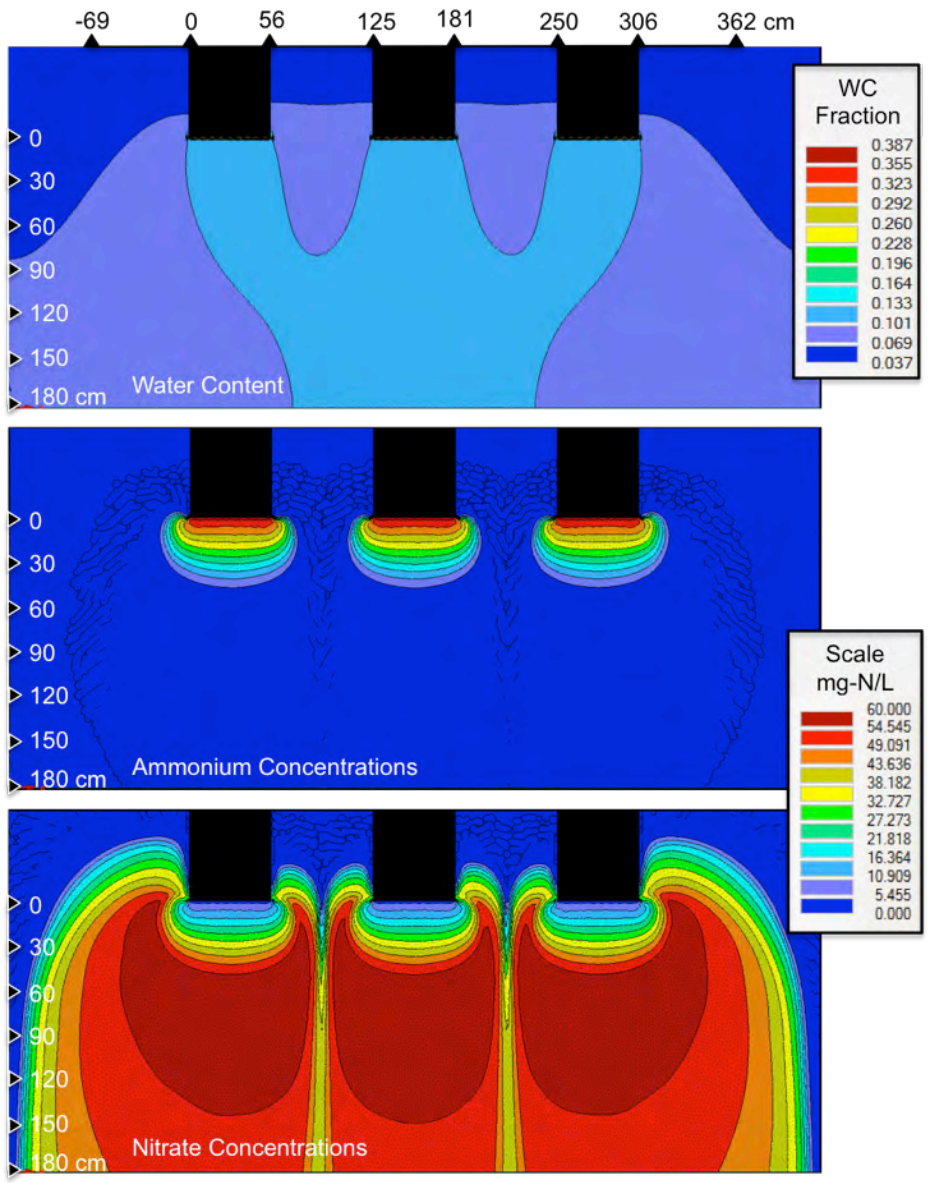

Figure B.45
Scenario 45

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Scenario 46

Configuration:	trench, unequal distribution
Soil Type:	more permeable sand
Loading Rate:	5.35, 2.67, 0 cm/d (1.31, 0.65, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	free drainage

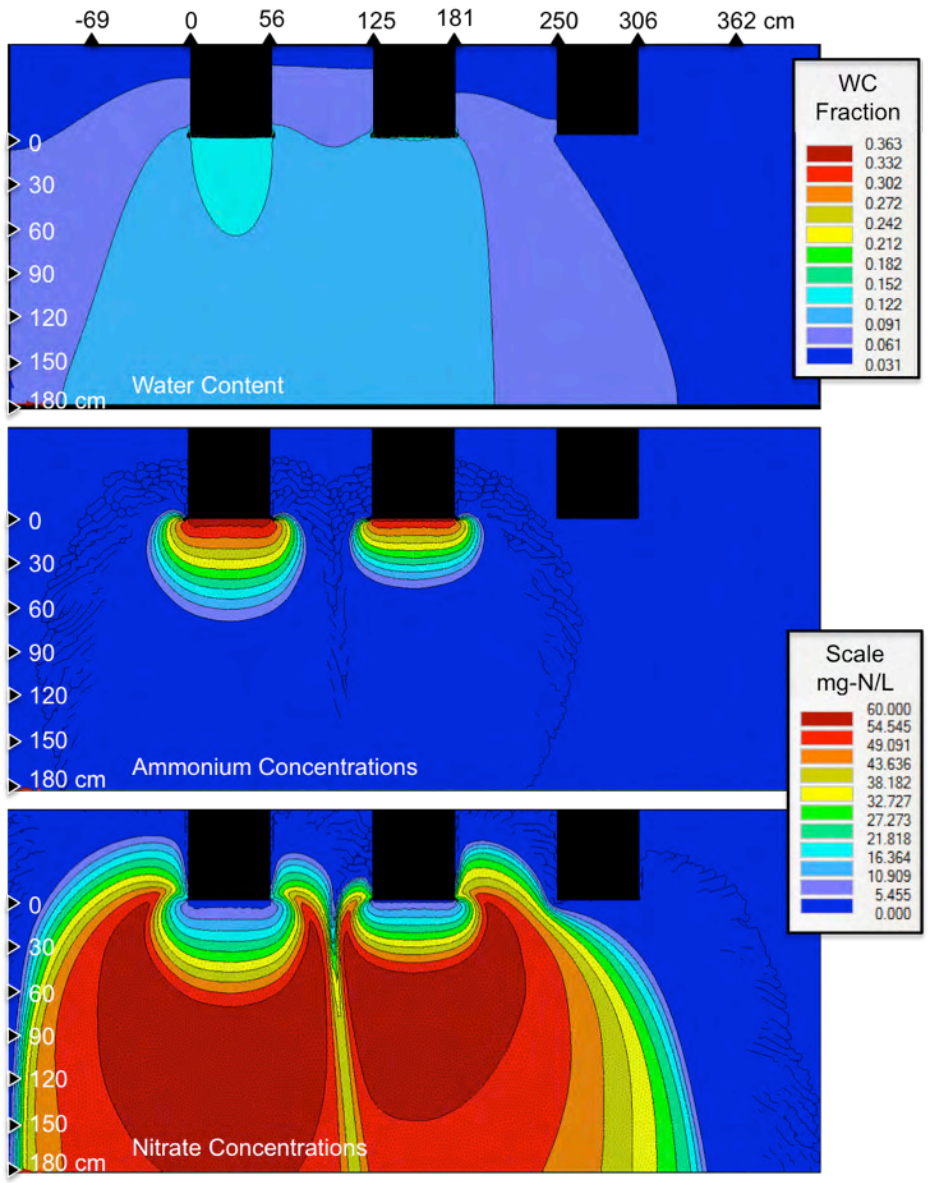

Figure B.46
Scenario 46

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Scenario 47

Configuration:	bed, equal distribution
Soil Type:	more permeable sand
Loading Rate:	1.68 cm/d (0.41 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	free drainage

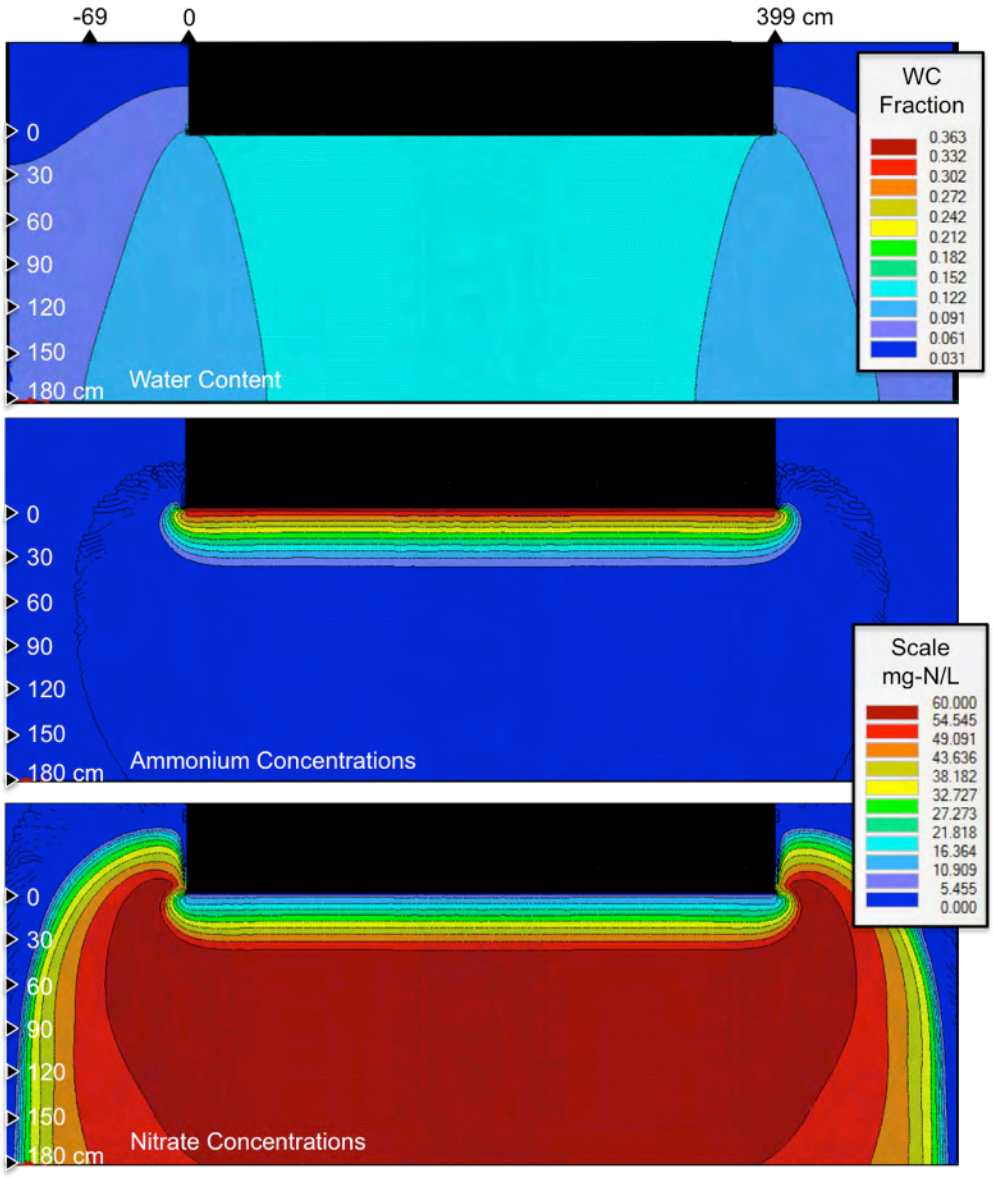


Figure B.47
Scenario 47

Scenario 48

Configuration:	bed, unequal distribution
Soil Type:	more permeable sand
Loading Rate:	3.37, 1.68, 0 cm/d (0.83, 0.41, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	free drainage

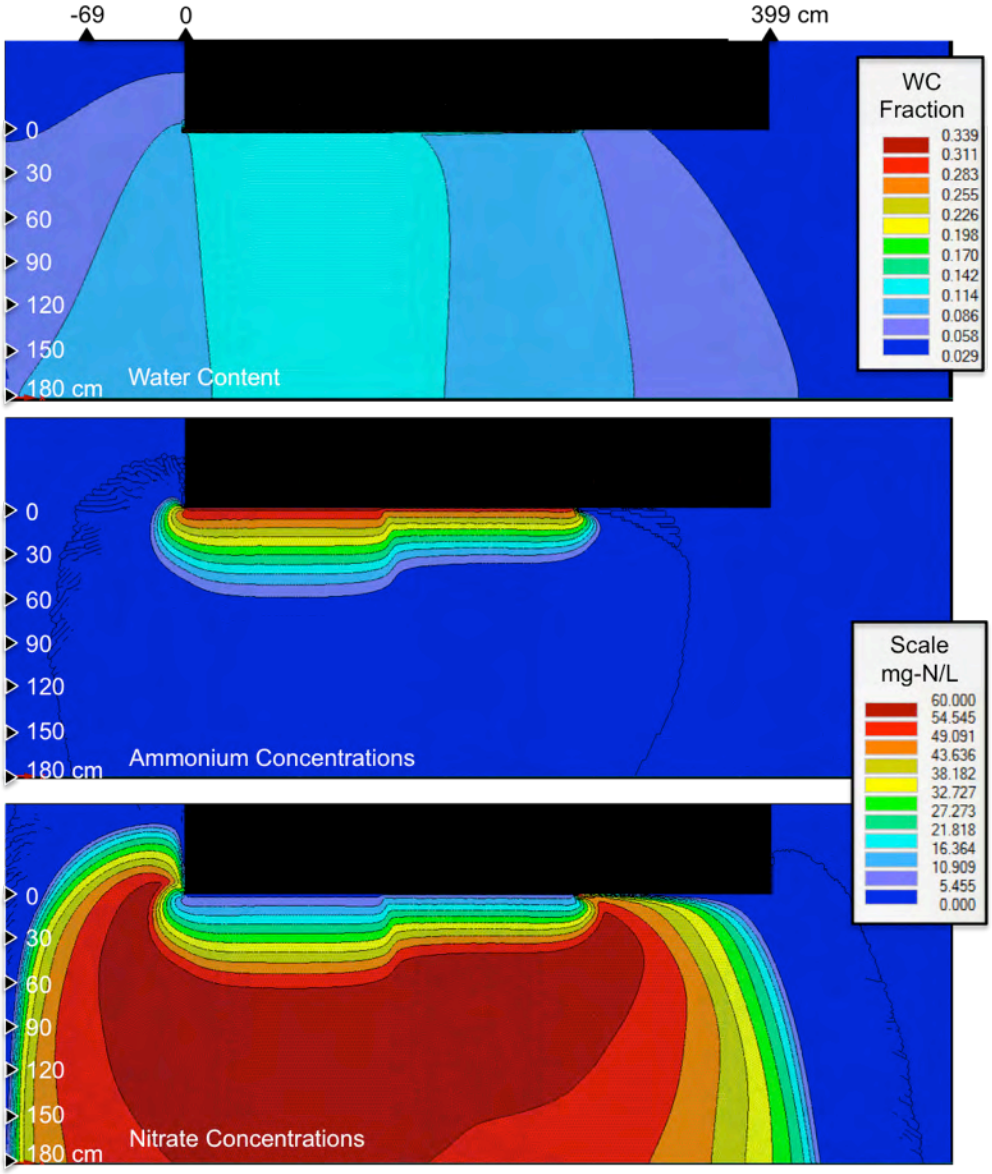
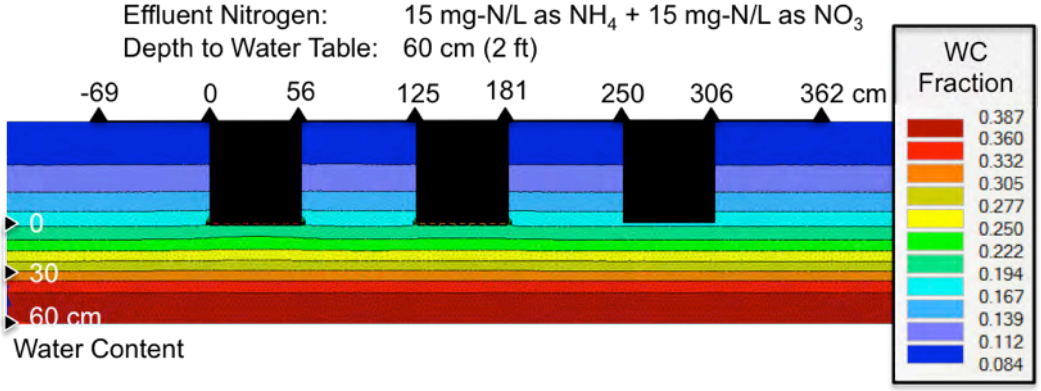


Figure B.48
Scenario 48

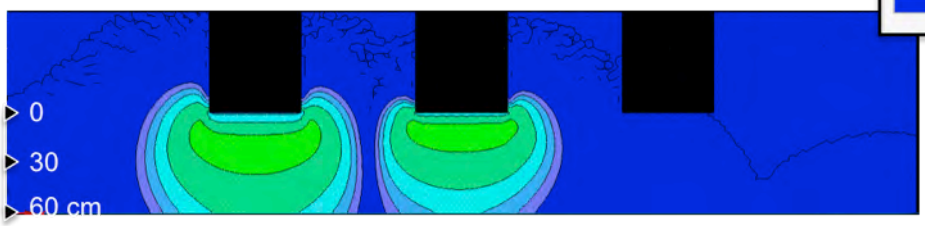
Scenario 49

Configuration: trench, unequal distribution
Soil Type: more permeable sand
Loading Rate: 5.35, 2.67, 0 cm/d (1.31, 0.65, 0 gpd/ft^2)
Effluent Nitrogen: 15 mg-N/L as NH_4 + 15 mg-N/L as NO_3
Depth to Water Table: 60 cm (2 ft)



Water Content

Ammonium Concentrations



Nitrate Concentrations

Figure B.49
Scenario 49

Scenario 50

Configuration:	trench, unequal distribution
Soil Type:	more permeable sand
Loading Rate:	5.35, 2.67, 0 cm/d (1.31, 0.65, 0 gpd/ft^2)
Effluent Nitrogen:	15 mg-N/L as NH_4 + 15 mg-N/L as NO_3
Depth to Water Table:	183 cm (6 ft)

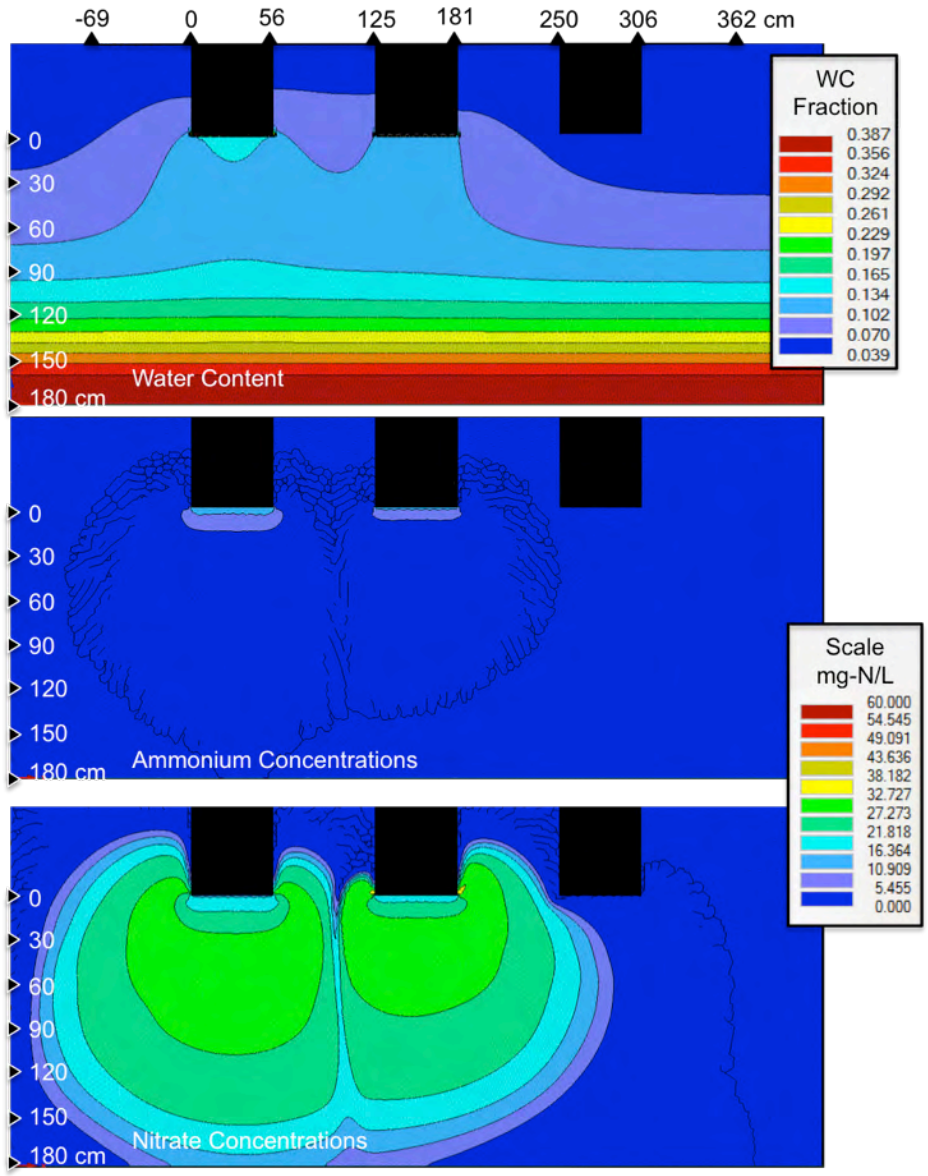


Figure B.50
Scenario 50

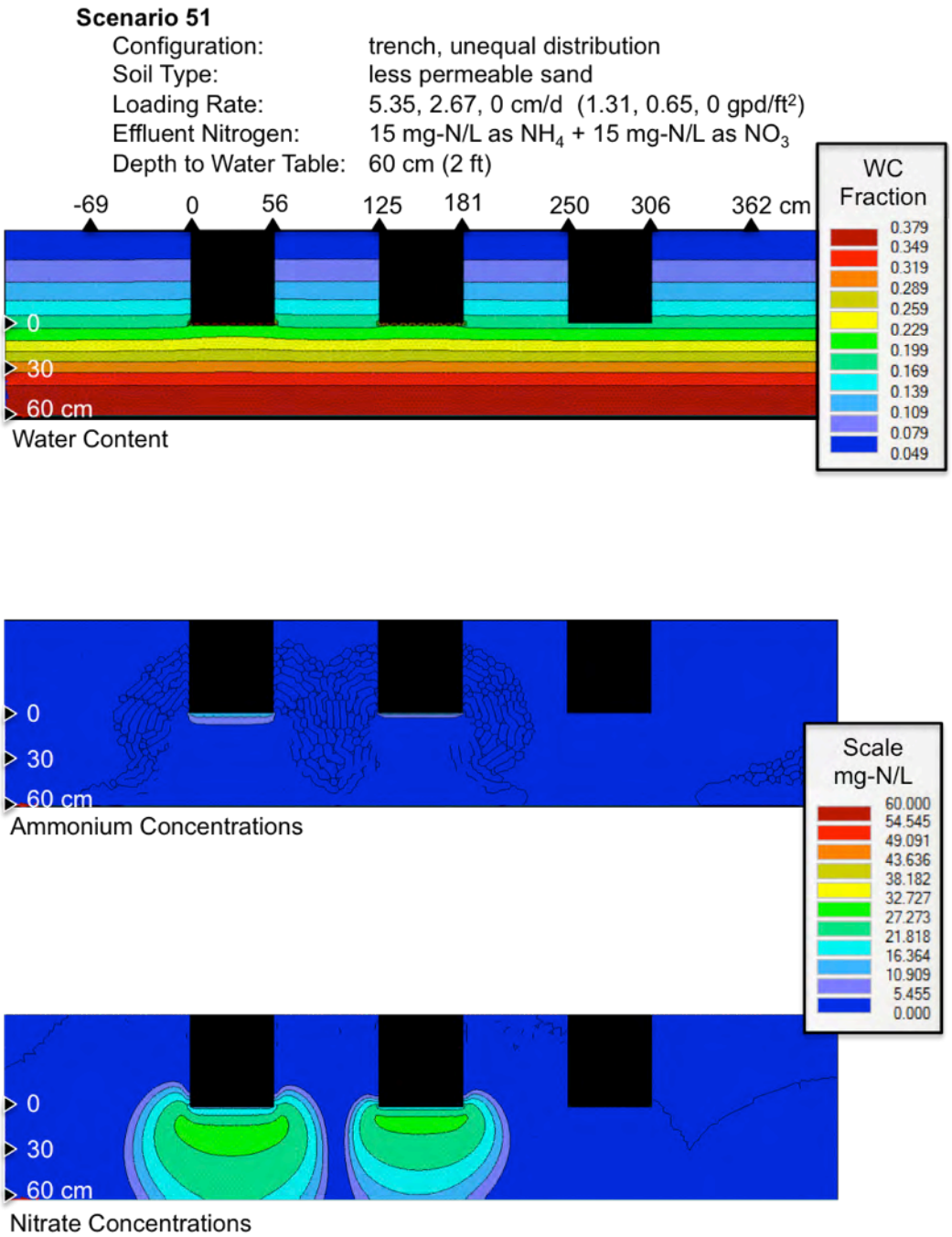


Figure B.51
Scenario 51

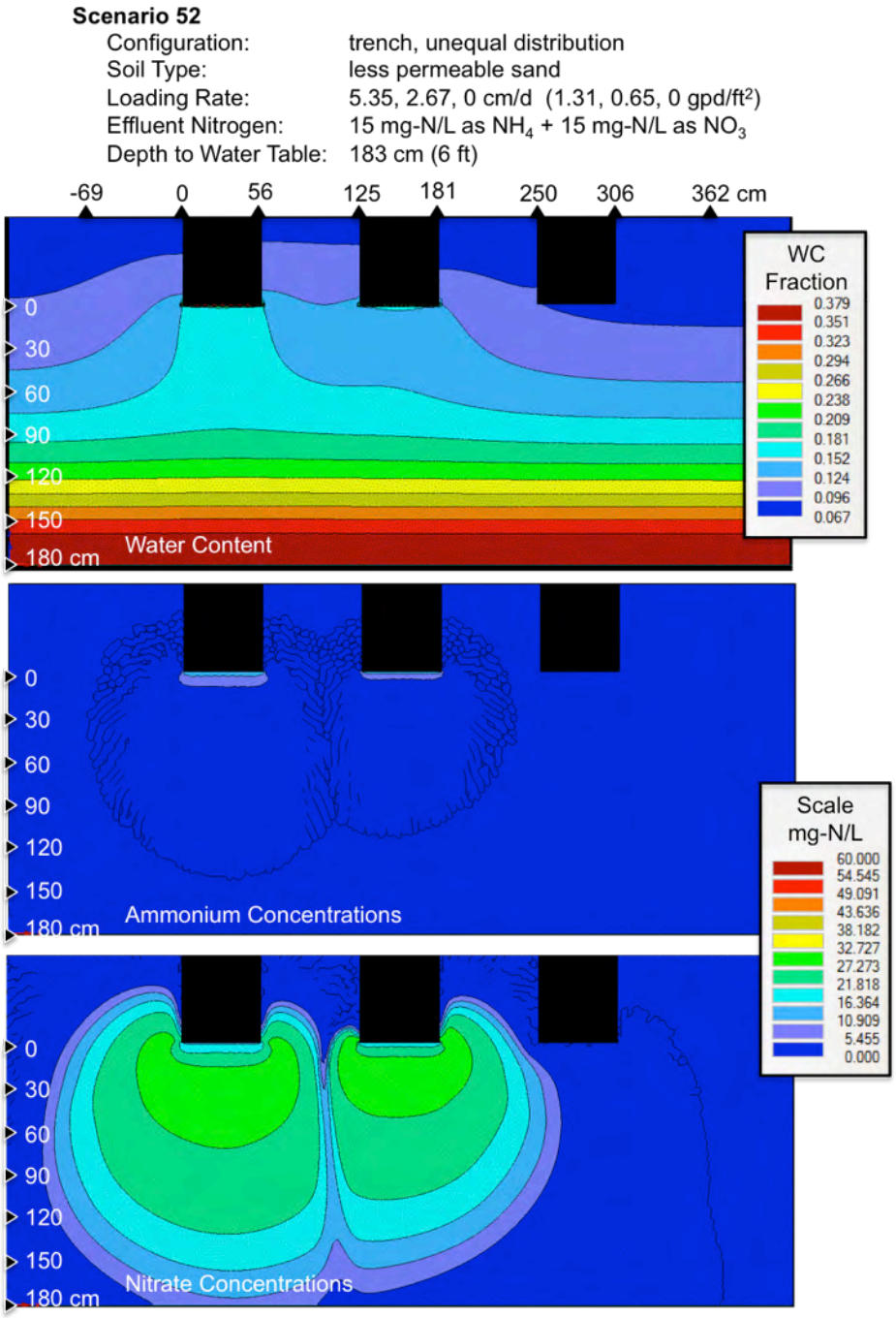
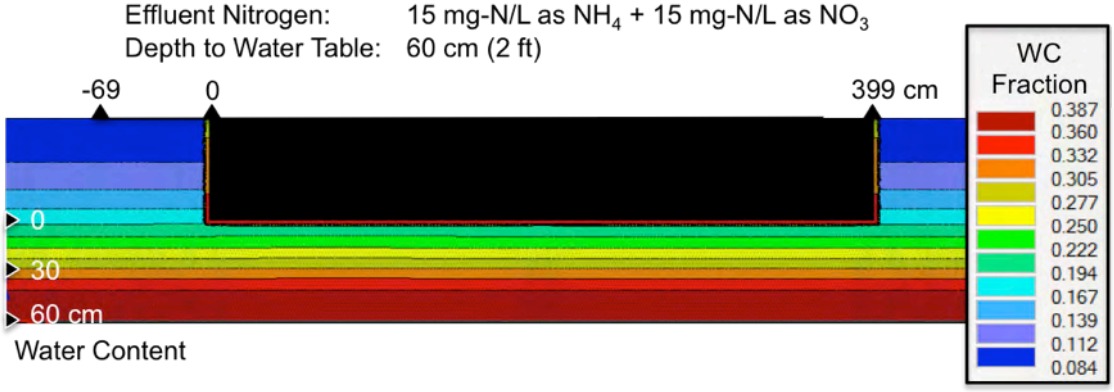


Figure B.52
Scenario 52

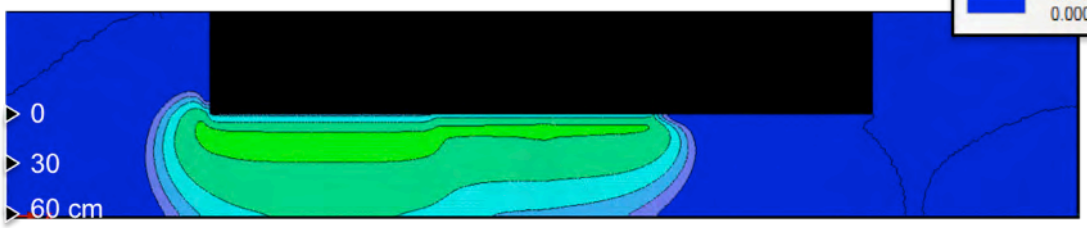
Scenario 53

Configuration:	bed, unequal distribution
Soil Type:	more permeable sand
Loading Rate:	3.37, 1.68, 0 cm/d (0.83, 0.41, 0 gpd/ft^2)
Effluent Nitrogen:	15 mg-N/L as NH_4 + 15 mg-N/L as NO_3
Depth to Water Table:	60 cm (2 ft)



Water Content

Ammonium Concentrations



Nitrate Concentrations

Figure B.53
Scenario 53

Scenario 54

Configuration:	bed, unequal distribution
Soil Type:	more permeable sand
Loading Rate:	3.37, 1.68, 0 cm/d (0.83, 0.41, 0 gpd/ft^2)
Effluent Nitrogen:	15 mg-N/L as NH_4 + 15 mg-N/L as NO_3
Depth to Water Table:	183 cm (6 ft)

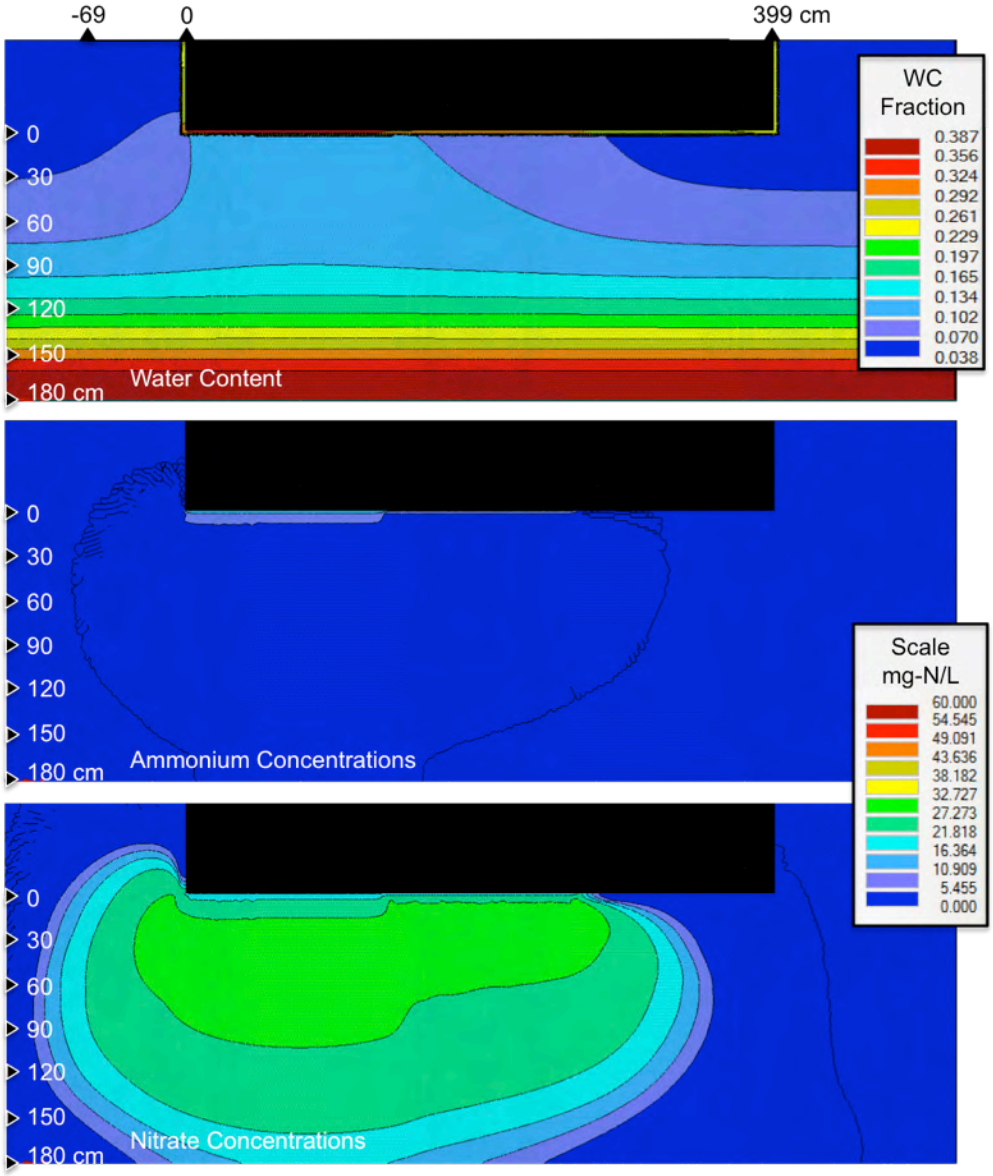


Figure B.54
Scenario 54

Scenario 55

Configuration:	bed, unequal distribution
Soil Type:	less permeable sand
Loading Rate:	3.37, 1.68, 0 cm/d (0.83, 0.41, 0 gpd/ft^2)
Effluent Nitrogen:	15 mg-N/L as NH_4 + 15 mg-N/L as NO_3
Depth to Water Table:	60 cm (2 ft)

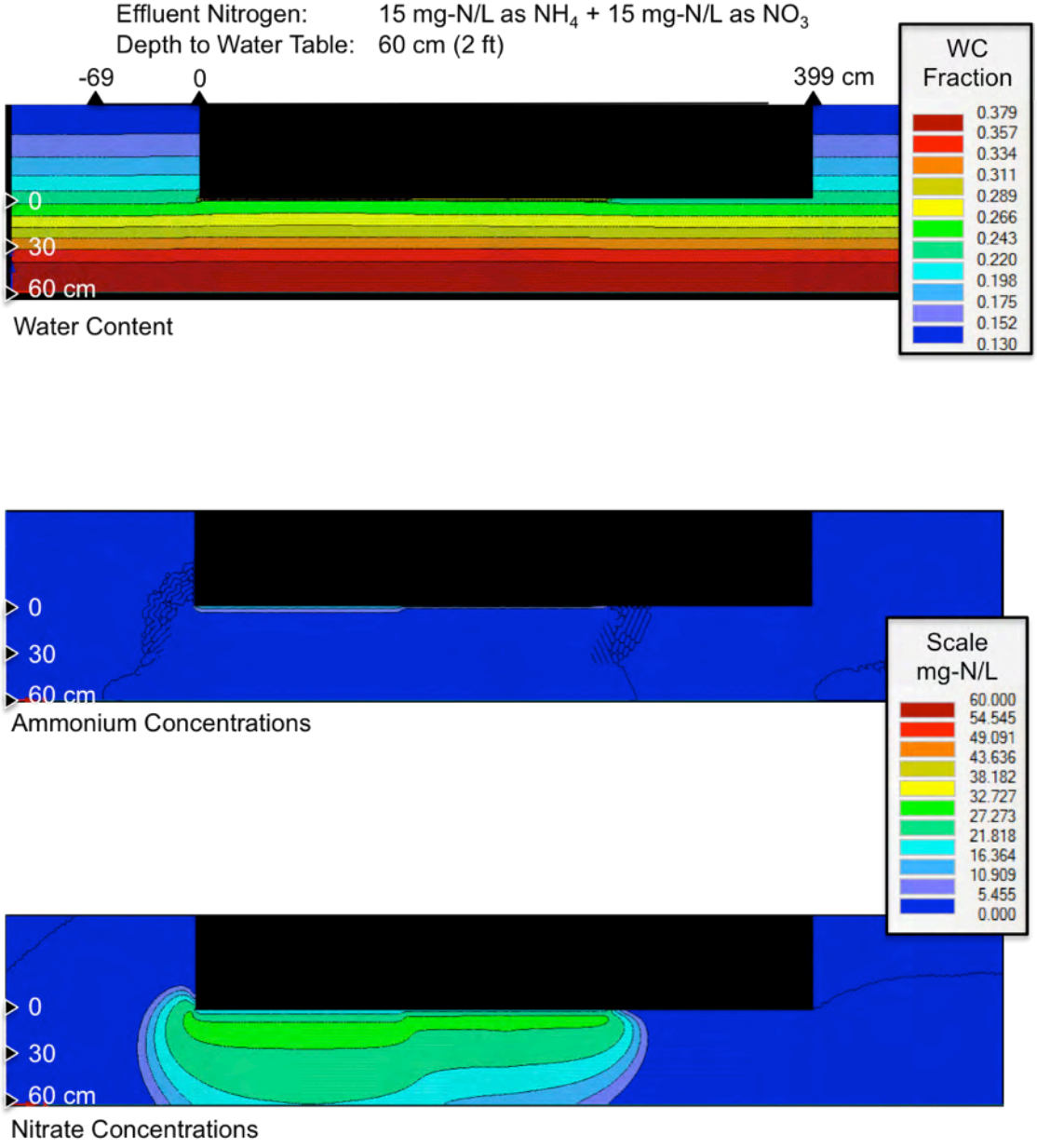


Figure B.55
Scenario 55

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Scenario 56

Configuration:	bed, unequal distribution
Soil Type:	less permeable sand
Loading Rate:	3.37, 1.68, 0 cm/d (0.83, 0.41, 0 gpd/ft^2)
Effluent Nitrogen:	15 mg-N/L as NH_4 + 15 mg-N/L as NO_3
Depth to Water Table:	183 cm (6 ft)

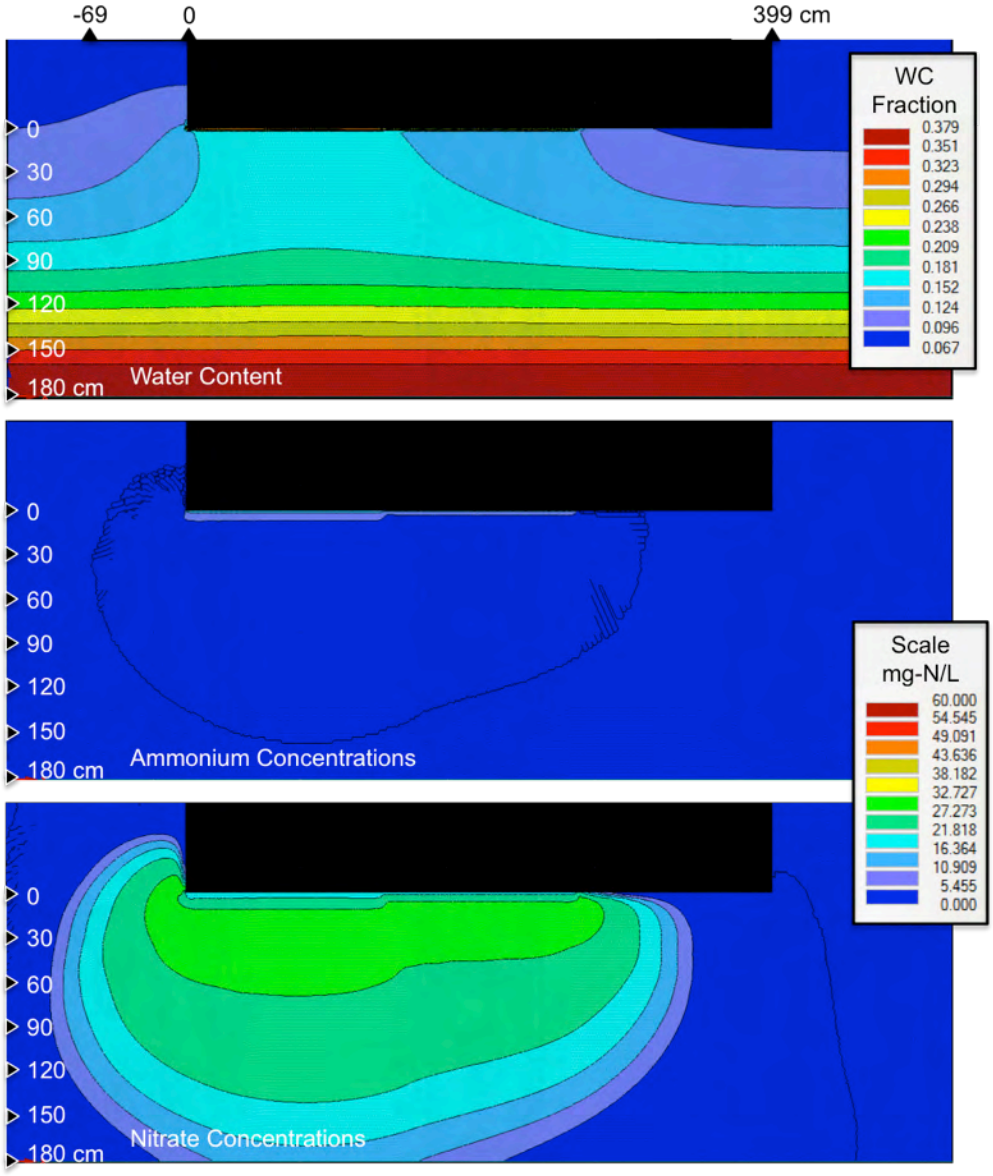

Figure B.56
Scenario 56

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Scenario 57

Configuration:	trench, unequal distribution
Soil Type:	sandy clay loam
Loading Rate:	4.34, 2.17, 0 cm/d (1.06, 0.53, 0 gpd/ft^2)
Effluent Nitrogen:	15 mg-N/L as NH_4 + 15 mg-N/L as NO_3
Depth to Water Table:	183 cm (6 ft)

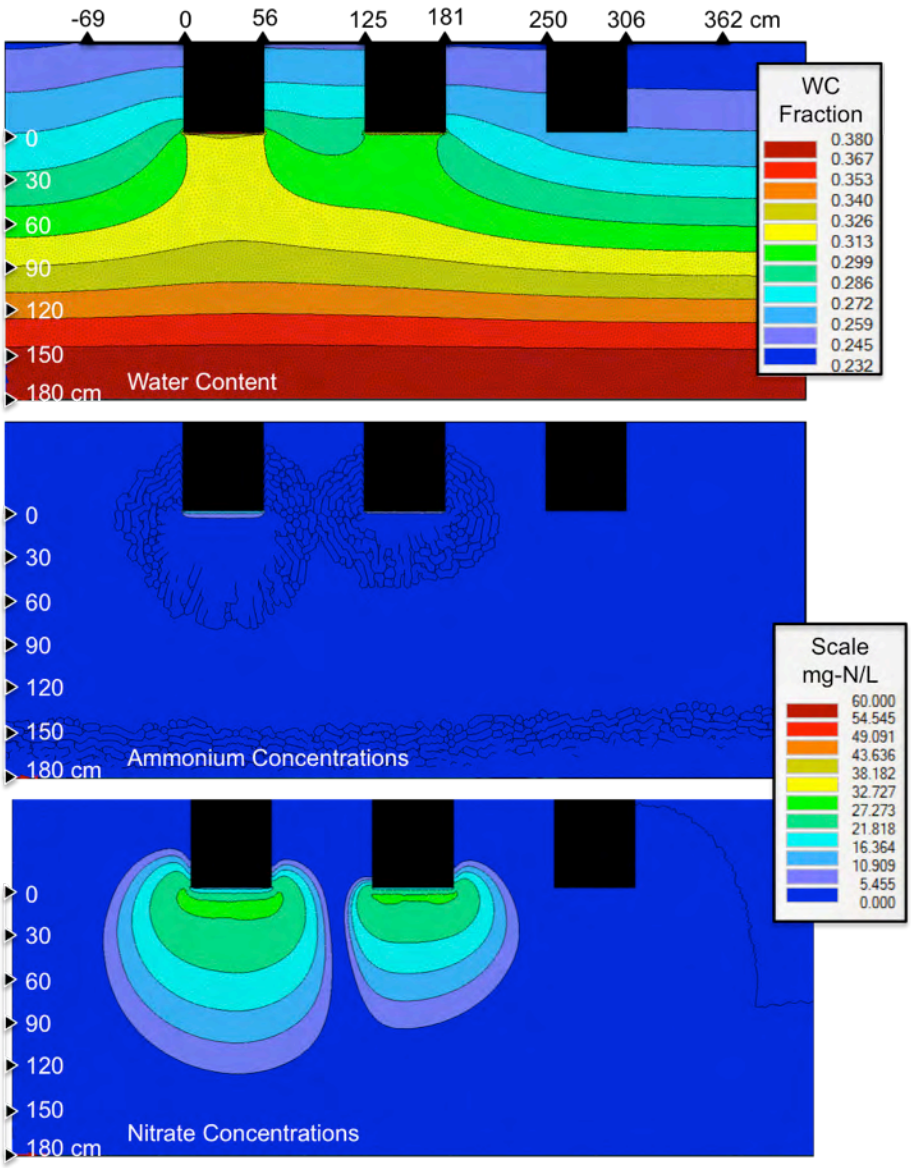

Figure B.57
Scenario 57

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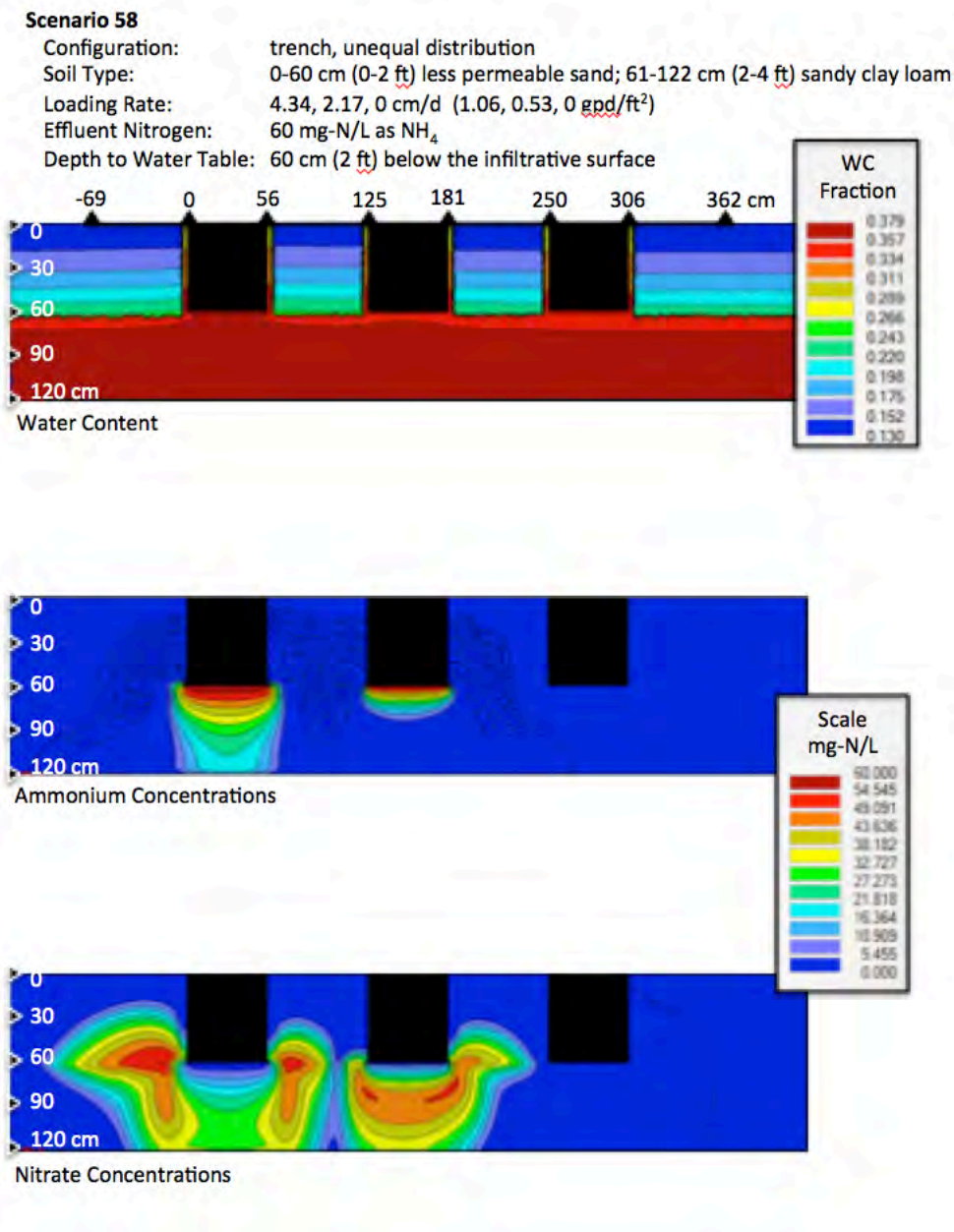

Figure B.58
Scenario 58

Scenario 59

Configuration:	trench, unequal distribution
Soil Type:	0-61 cm (0-2ft) less permeable sand; 61-244 cm (2-8 ft) sandy clay loam
Loading Rate:	4.34, 2.17, 0 cm/d (1.06, 0.53, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft) below the infiltrative surface

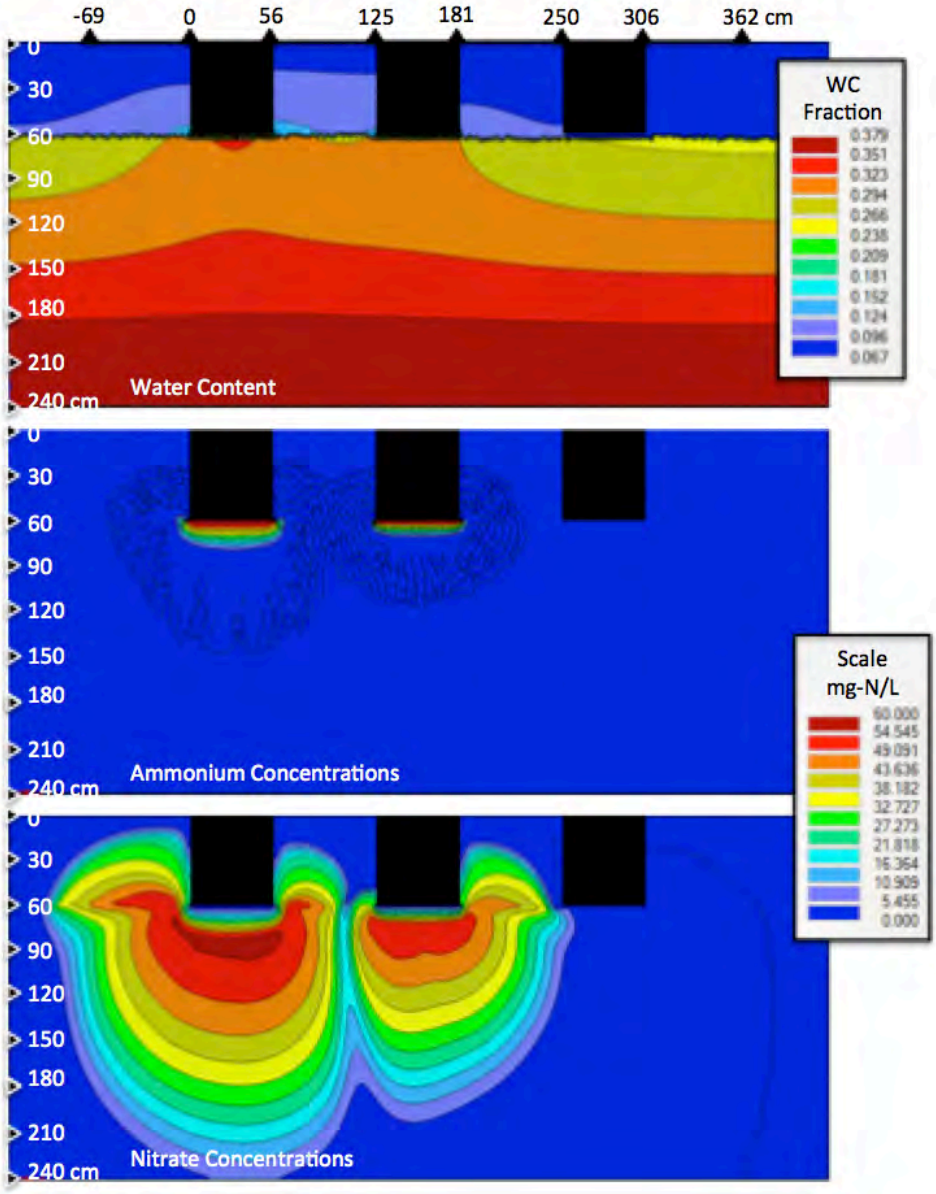

Figure B.59
Scenario 59

Scenario 60

Configuration:	trench, unequal distribution
Soil Type:	0-122 cm (0-4 ft) less permeable sand; 122-244 cm (4-8 ft) sandy clay loam
Loading Rate:	5.35, 2.67, 0 cm/d (1.31, 0.65, 0 gpd/ft²)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft) below the infiltrative surface

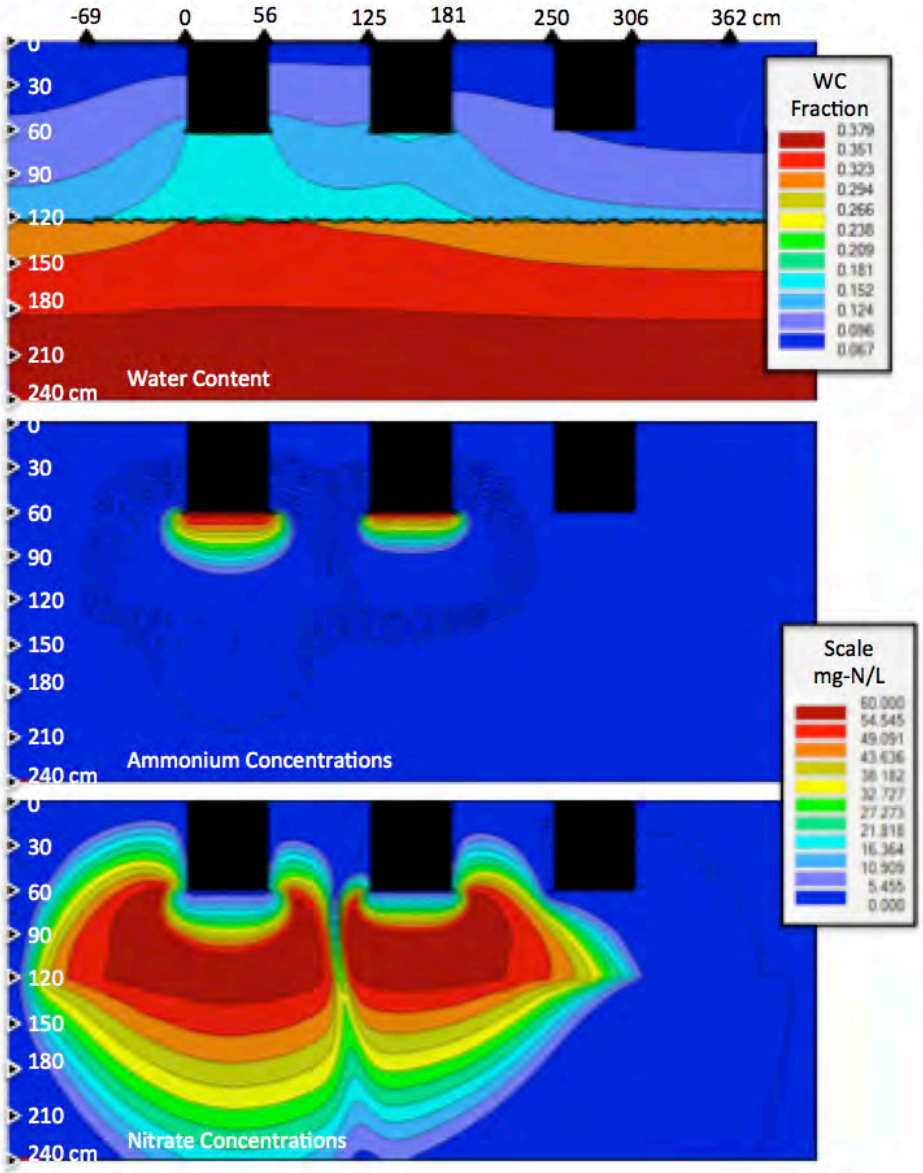

Figure B.60
Scenario 60

Scenario 61

Configuration:	trench, unequal distribution
Soil Type:	0-160 cm (0-5.25 ft) less permeable sand; 160-244 cm (5.25-8 ft) sandy clay loam
Loading Rate:	5.35, 2.67, 0 cm/d (1.31, 0.65, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft) below the infiltrative surface

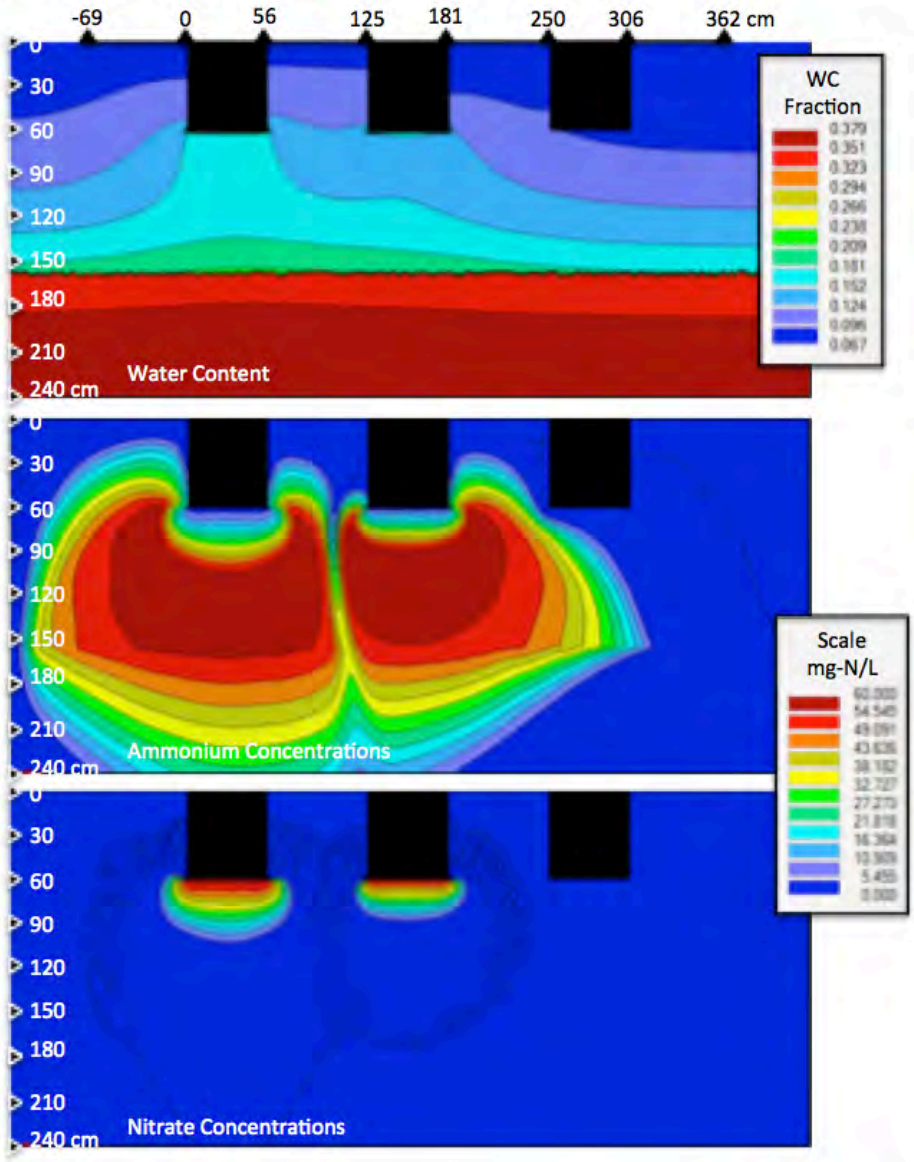

Figure B.61
Scenario 61

Scenario 62

Configuration:	trench, unequal distribution
Soil Type:	0-122 cm (0-4 ft) more permeable sand; 122-244 cm (4-8 ft) sandy clay loam
Loading Rate:	5.35, 2.67, 0 cm/d (1.31, 0.65, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft) below the infiltrative surface

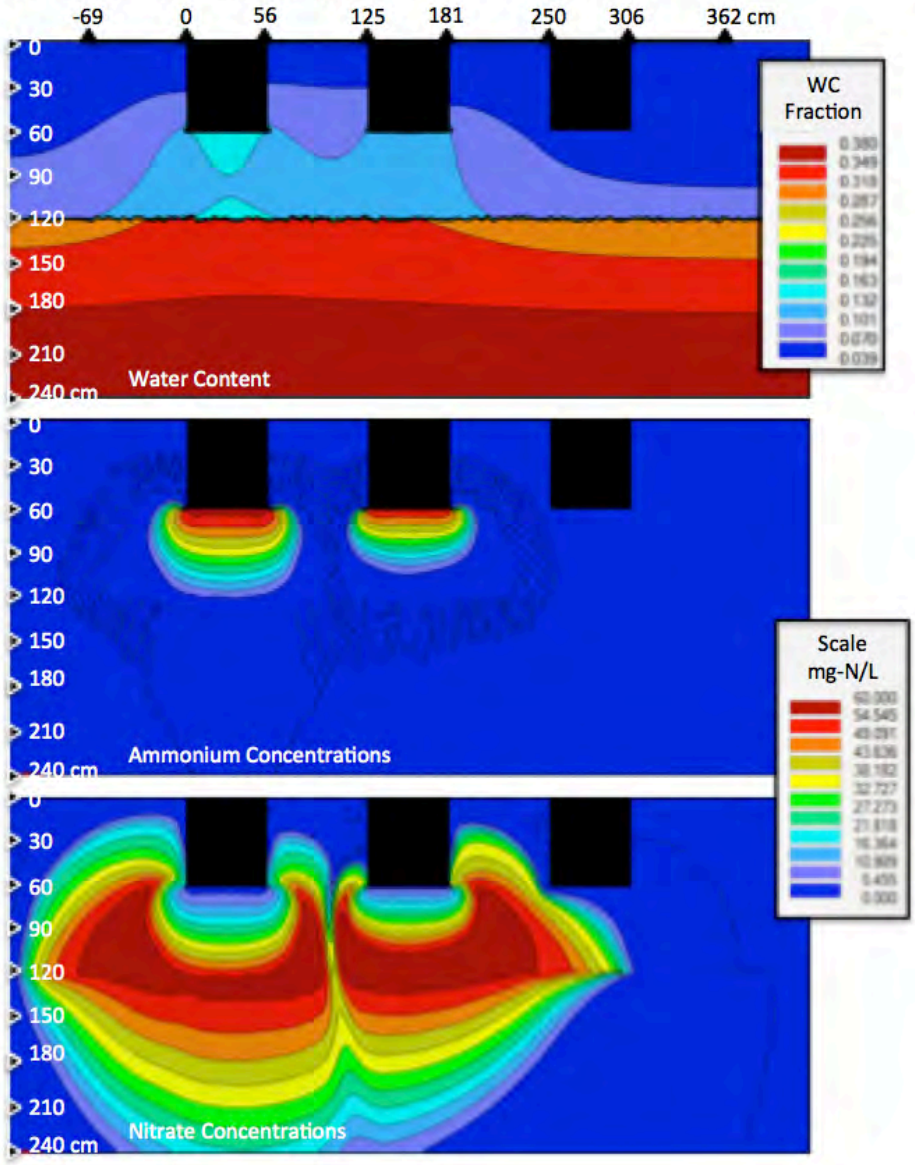

Figure B.62
Scenario 62

Scenario 63

Configuration:	trench, unequal distribution
Soil Type:	0-160 cm (0-5.25 ft more permeable sand; 160-244 cm (5.25-8 ft) sandy clay loam
Loading Rate:	5.35, 2.67, 0 cm/d (1.31, 0.65, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft) below the infiltrative surface

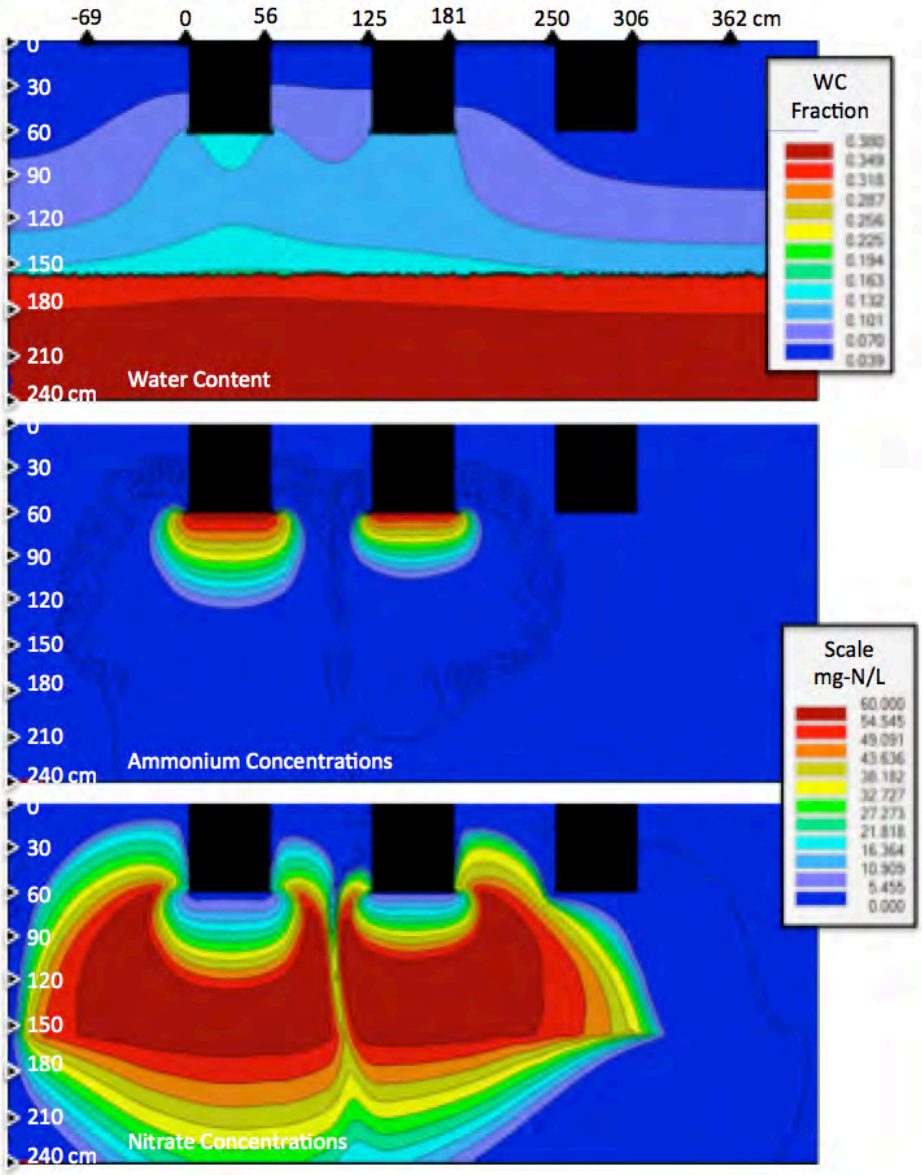

Figure B.63
Scenario 63

Scenario 64

Configuration:	trench, unequal distribution
Soil Type:	0-122 cm (0-4 ft) sandy clay loam; 122-244 cm (4-8 ft)) less permeable sand
Loading Rate:	5.35, 2.67, 0 cm/d (1.31, 0.65, 0 gpd/ft^2)
Effluent Nitrogen:	60 mg-N/L as NH_4
Depth to Water Table:	183 cm (6 ft) below the infiltrative surface

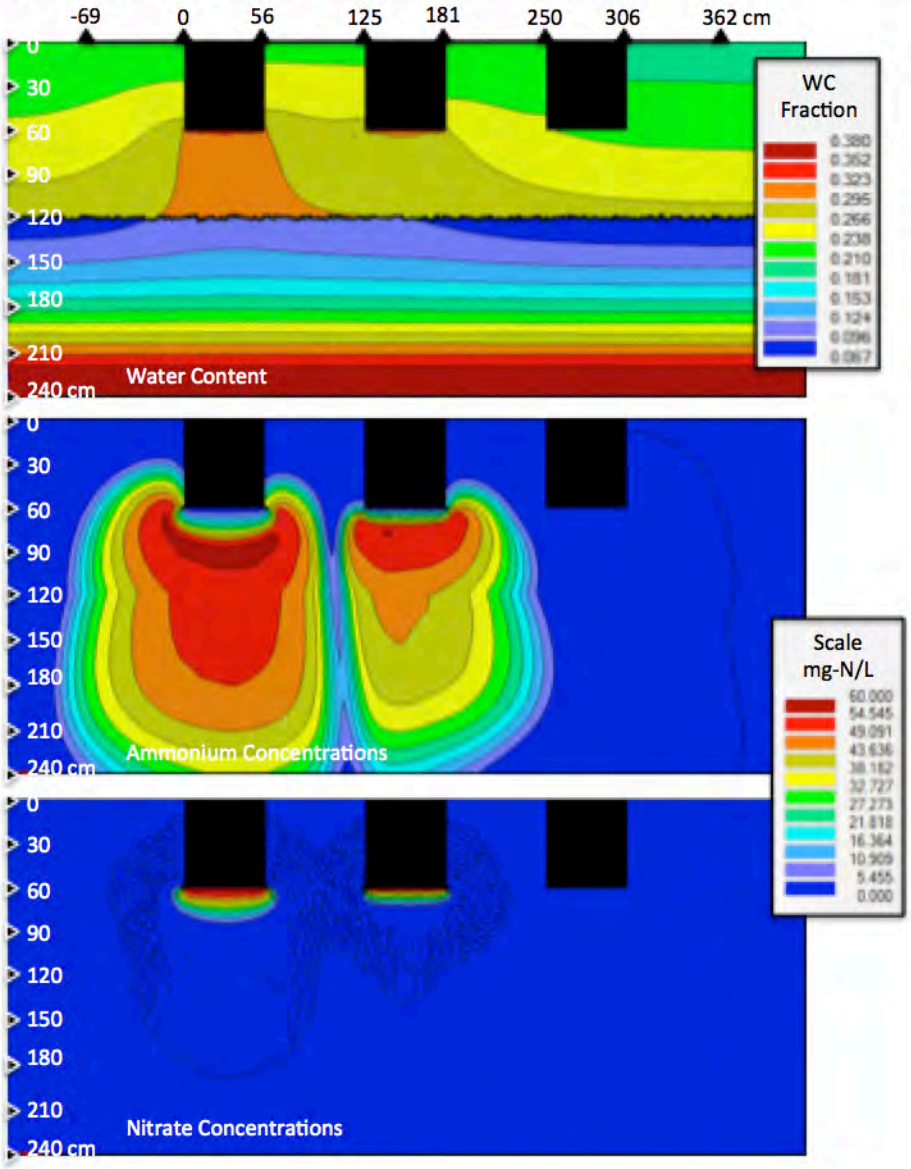

Figure B.64
Scenario 64

Appendix C: HYDRUS-2D Corroboration Results for USF Lysimeter Station and GCREC Field Sites

Task D-7 simple tools were corroborated to available field data from the USF Lysimeter Station and the University of Florida Gulf Coast Research and Education Center (GCREC). In each case the input concentration reflects the STE concentration at the time of sampling and the domain size (depth) reflects the water table depth at the time of sampling. The simulation parameters are provided in Tables 3.1 and 3.2. HYDRUS-2D modeling results (water content, ammonium and nitrate) are presented here. Figures C.1 - C.10 are from the initial corroboration (e.g., no rainfall, default nitrification and denitrification rates) as described in Section 3.2 and provided in the previous report version. Figures C.11 - C.24 are from the revised corroboration runs described in Section 3.2 (e.g., include rainfall, soft calibrated nitrification and denitrification rates).

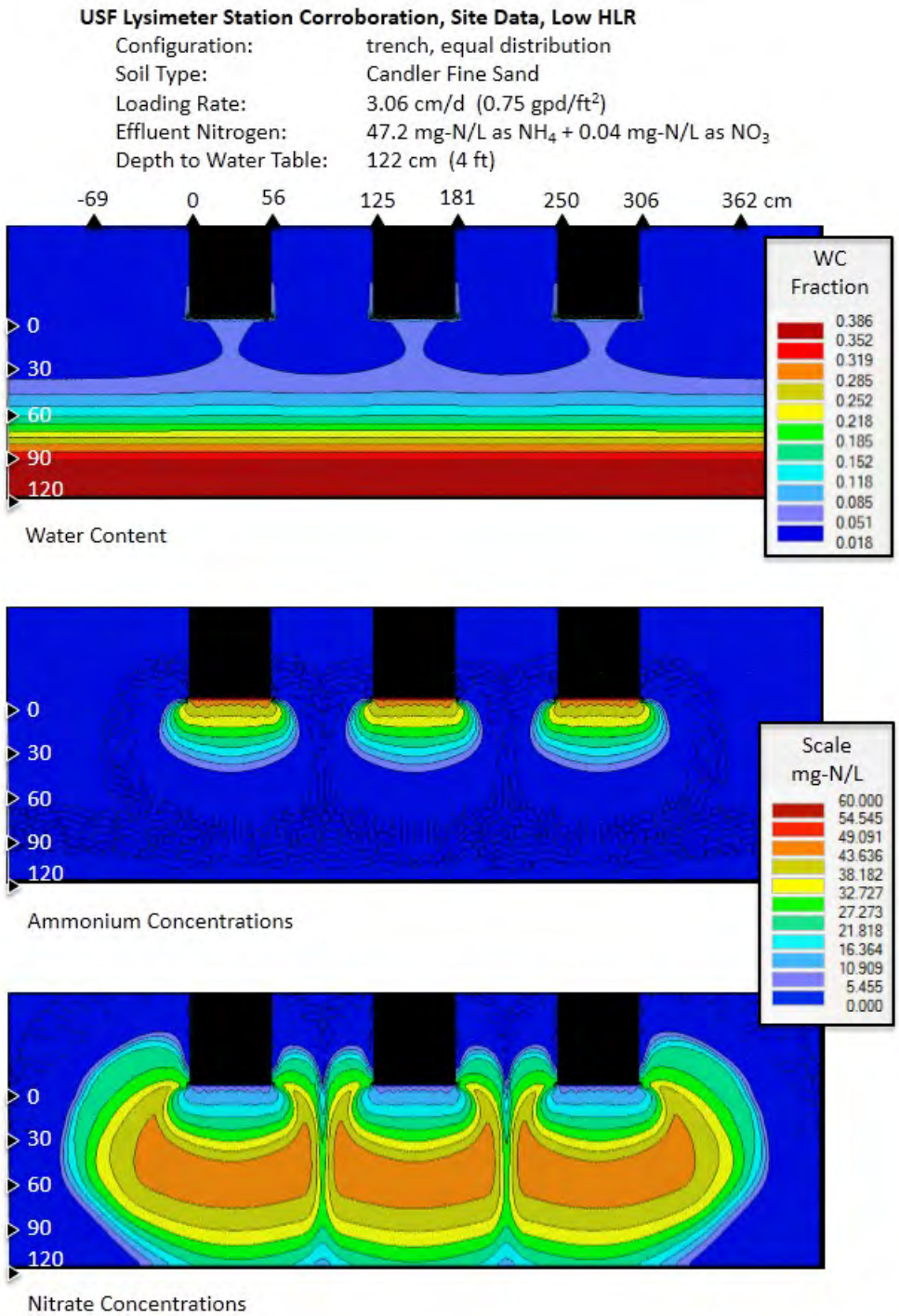

Figure C.1
USF Lysimeter Station Initial Corroboration, Site Date, Low HLR
(no rainfall, default nitrification and denitrification rates)

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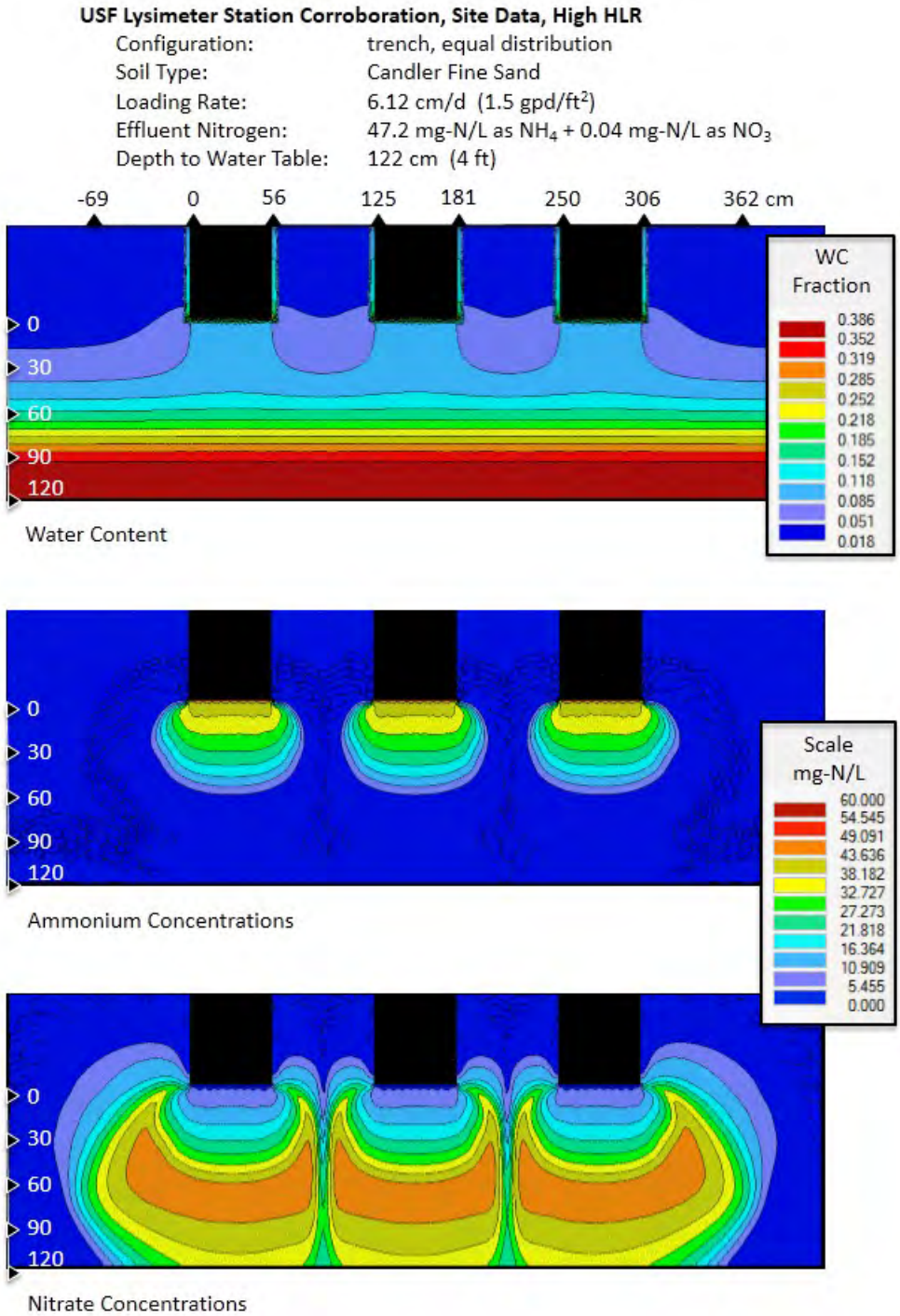

Figure C.2
USF Lysimeter Station Initial Corroboration, Site Date, High HLR
(no rainfall, default nitrification and denitrification rates)

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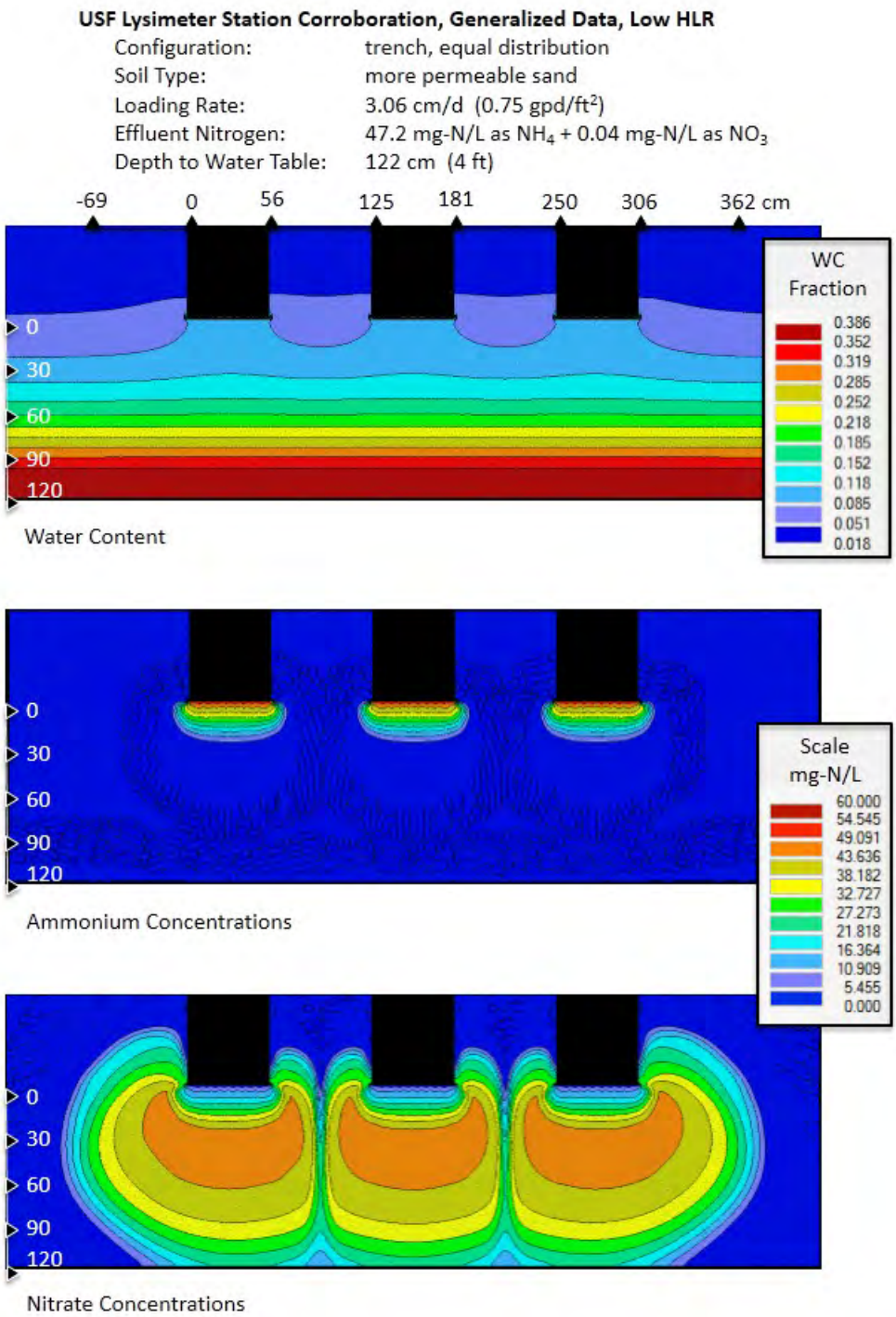

Figure C.3
USF Lysimeter Station Initial Corroboration, Generalized Date, Low HLR
(no rainfall, default nitrification and denitrification rates)

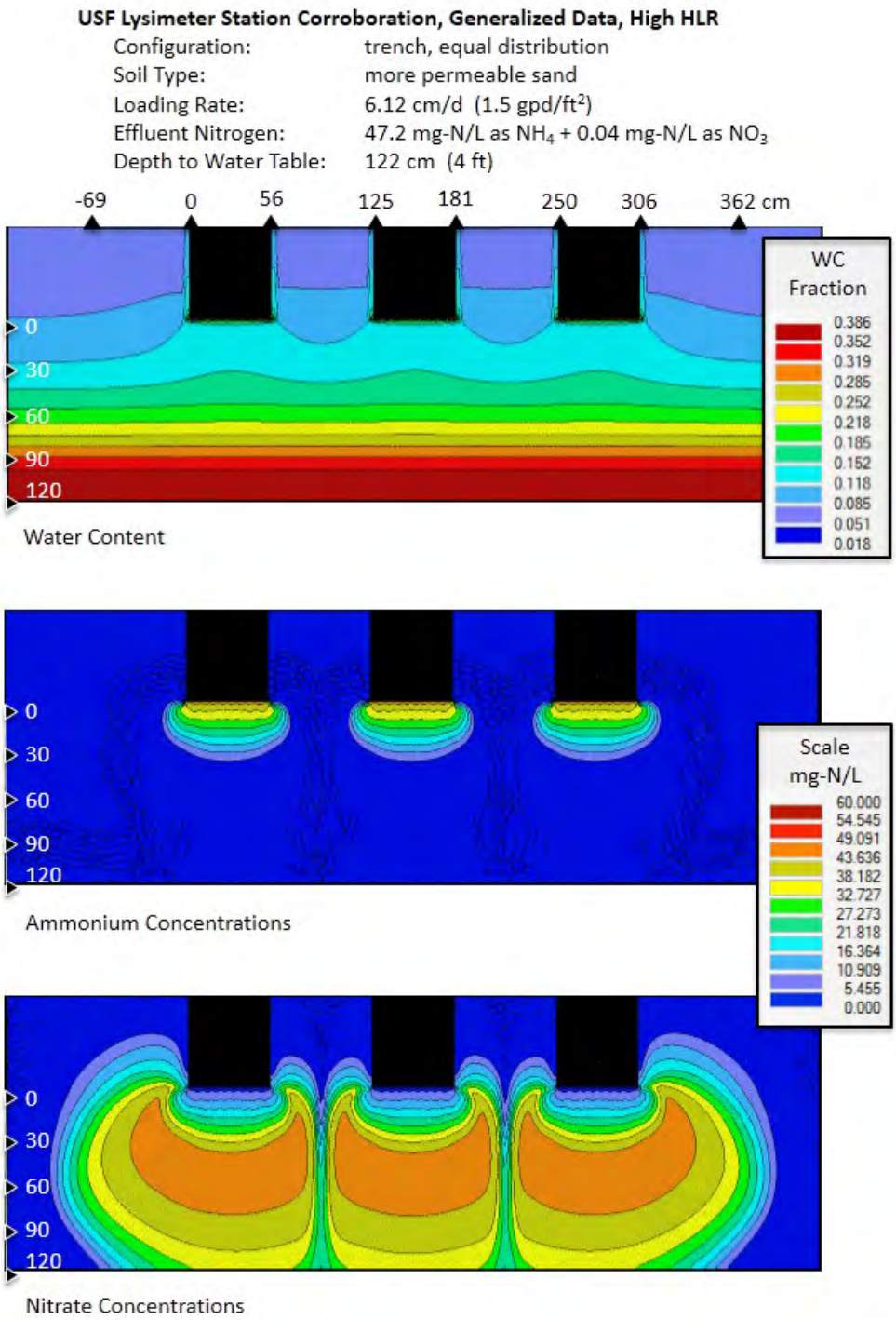

Figure C.4
USF Lysimeter Station Initial Corroboration, Generalized Date, High HLR
(no rainfall, default nitrification and denitrification rates)

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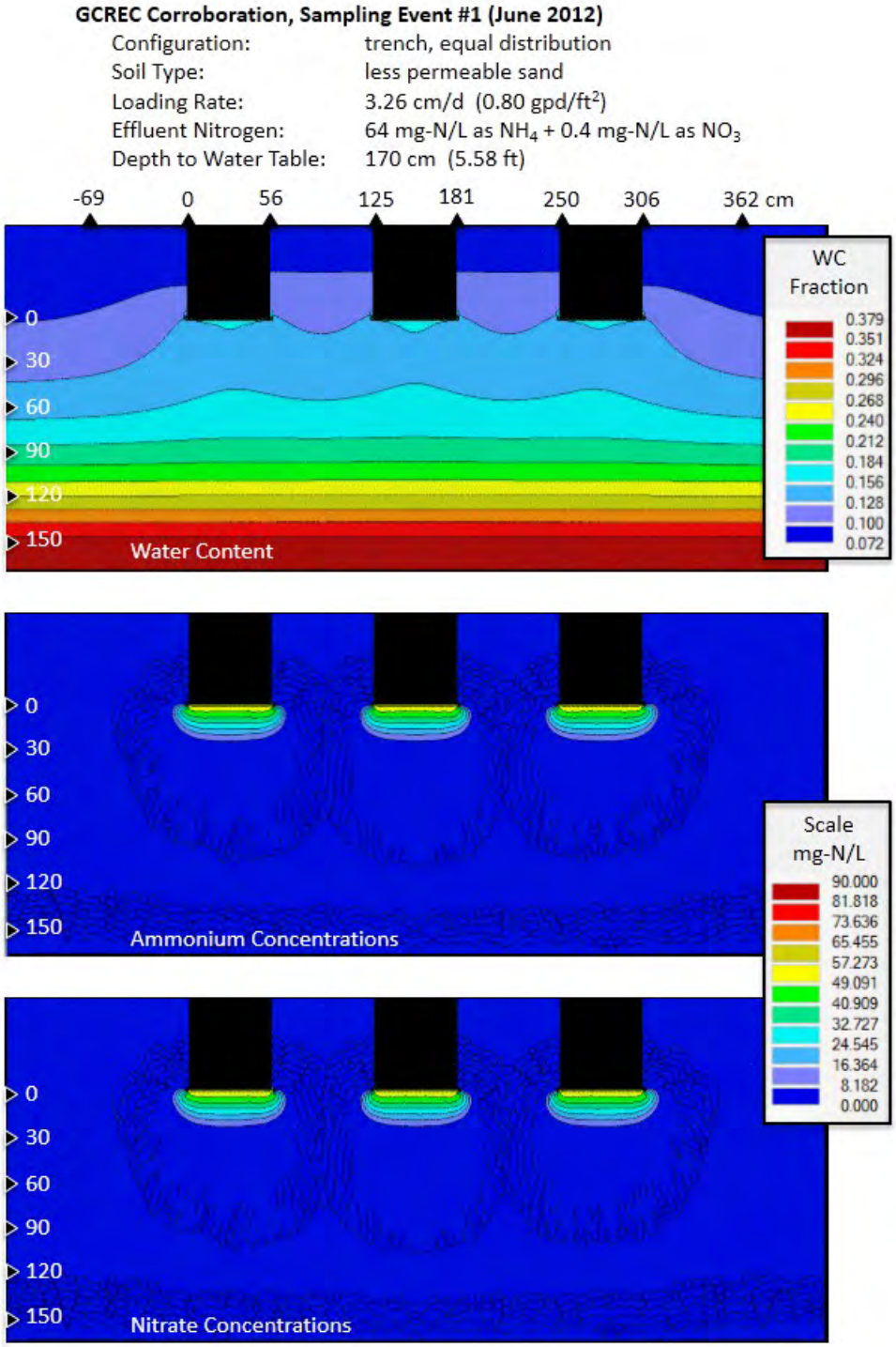

Figure C.5
GCREC Initial Corroboration, Sampling Event #1 (June 2012)
(no rainfall, variable ammonium inputs, default nitrification rate)

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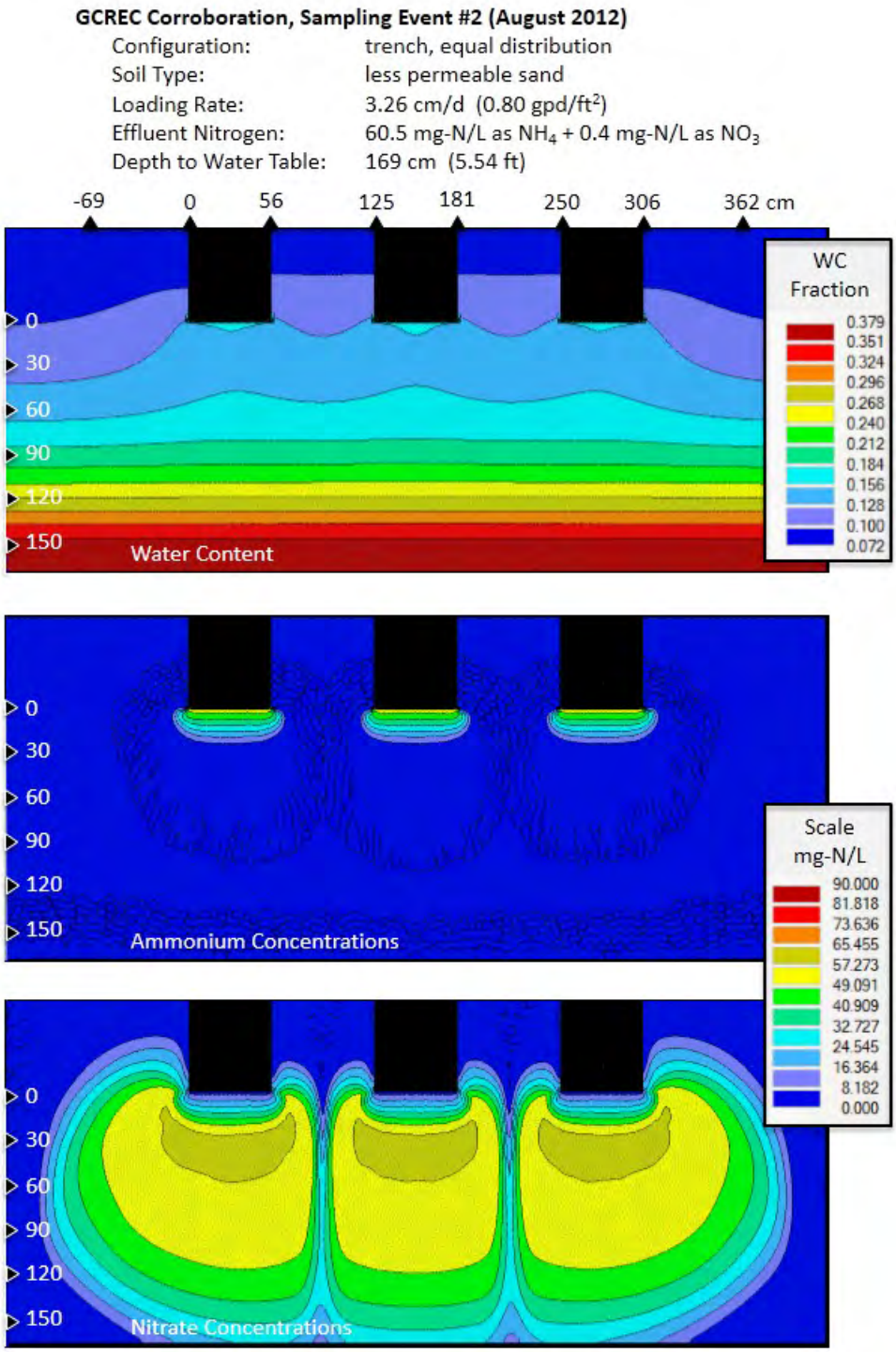

Figure C.6
GCREC Initial Corroboration, Sampling Event #2 (August 2012)
(no rainfall, variable ammonium inputs, default nitrification rate)

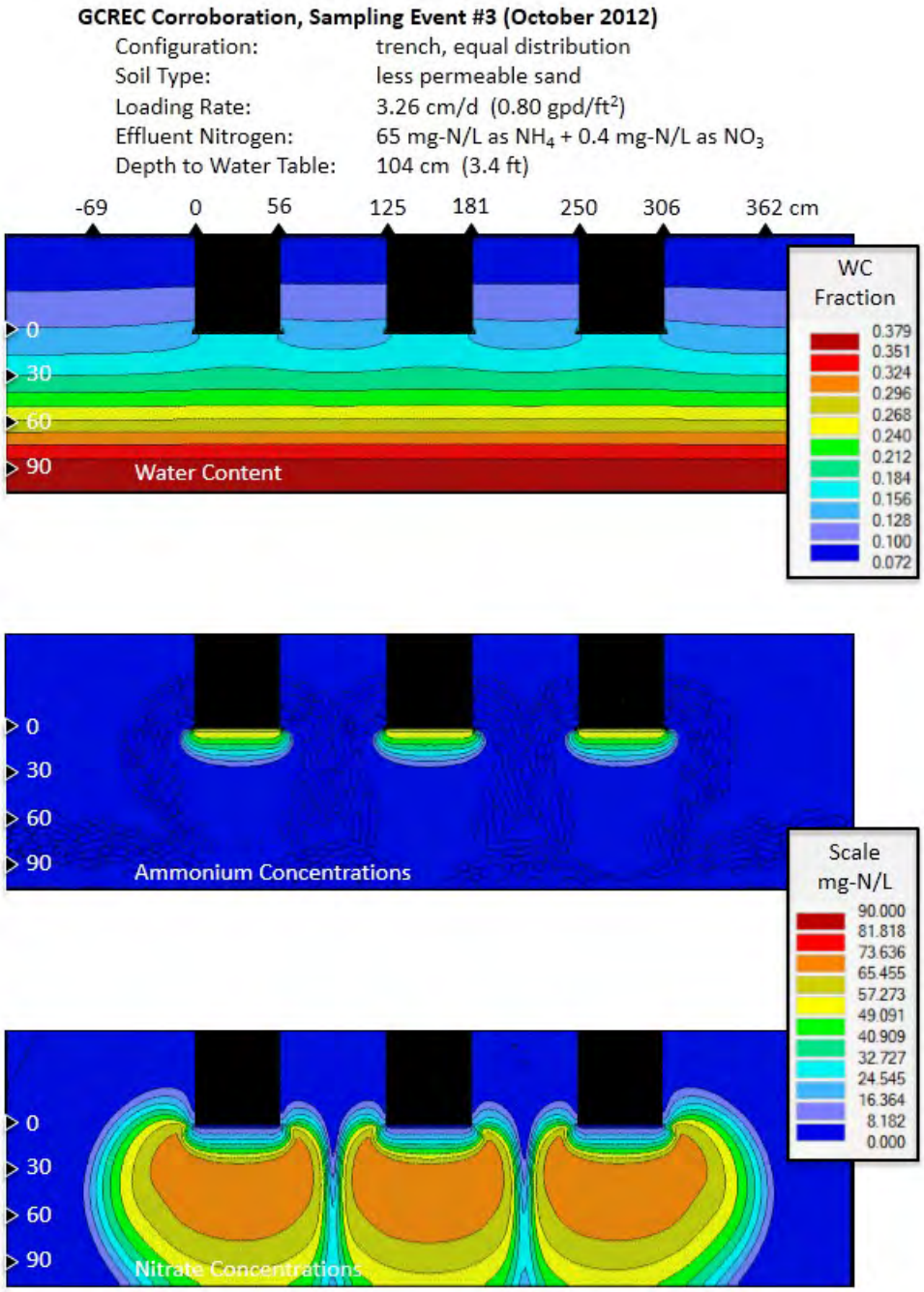

Figure C.7
GCREC Initial Corroboration, Sampling Event #3 (October 2012)
(no rainfall, variable ammonium inputs, default nitrification rate)

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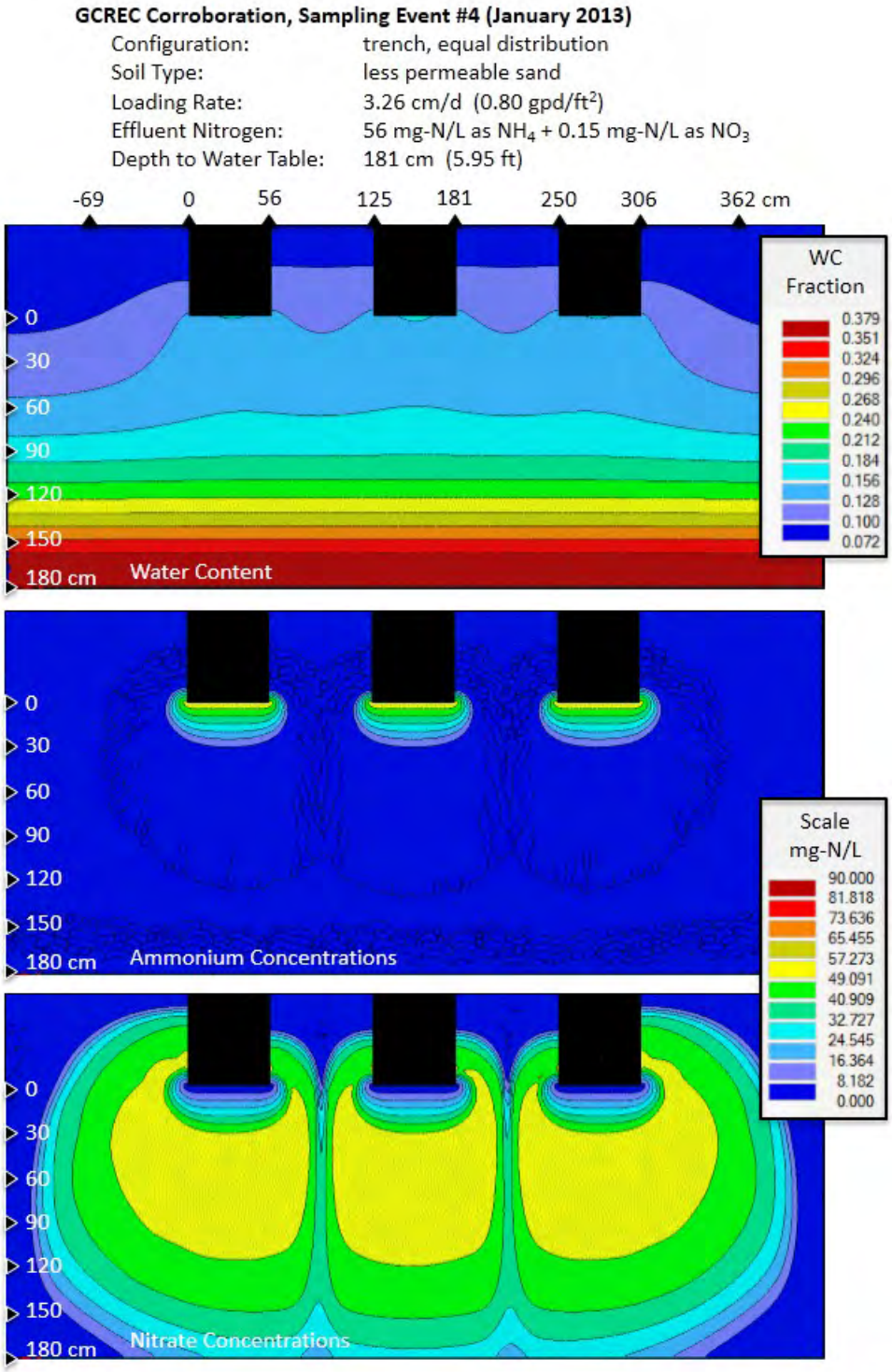

Figure C.8
GCREC Initial Corroboration, Sampling Event #4 (January 2013)
(no rainfall, variable ammonium inputs, default nitrification rate)

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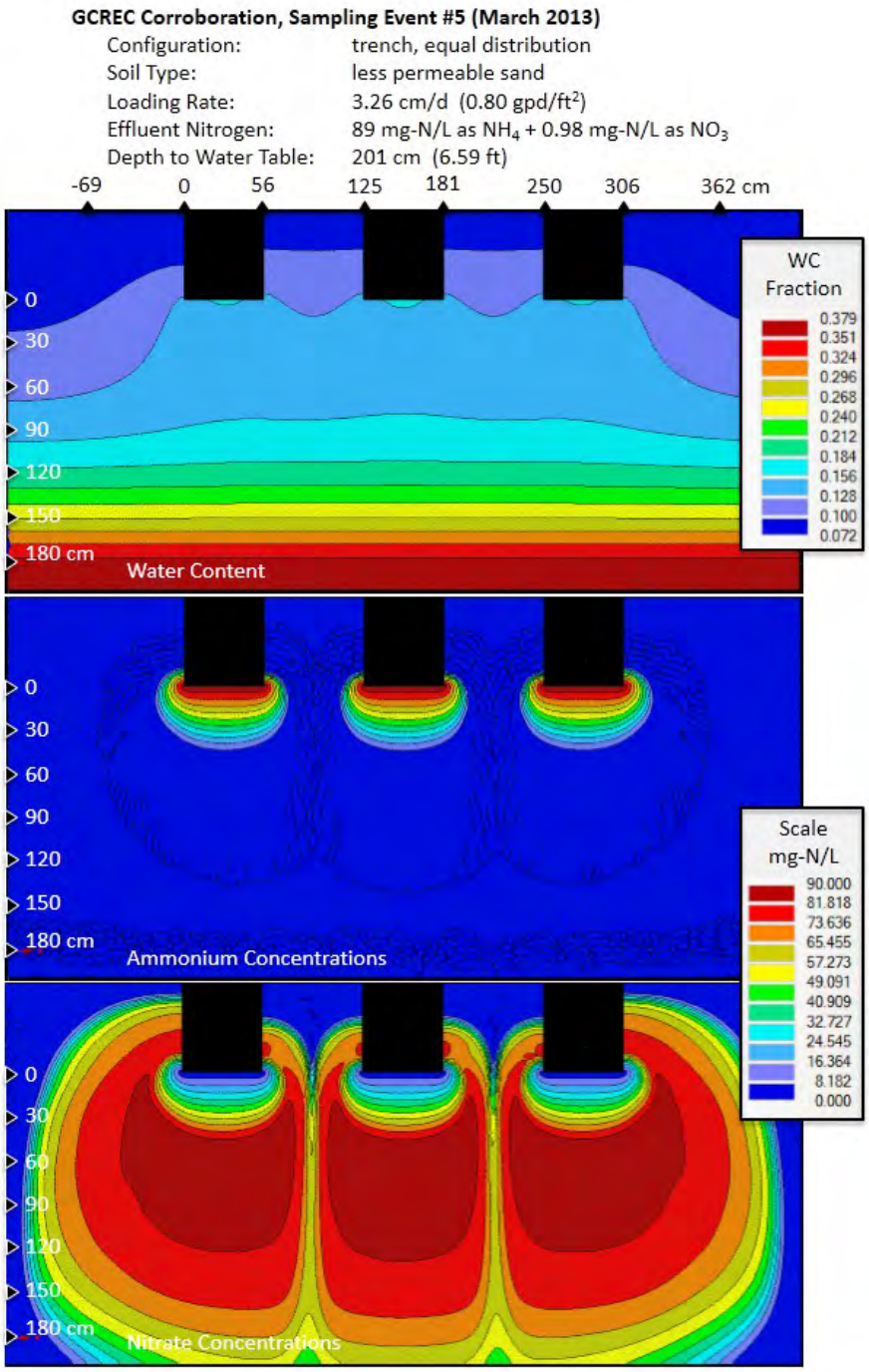

Figure C.9
GCREC Initial Corroboration, Sampling Event #5 (March 2013)
(no rainfall, variable ammonium inputs, default nitrification rate)

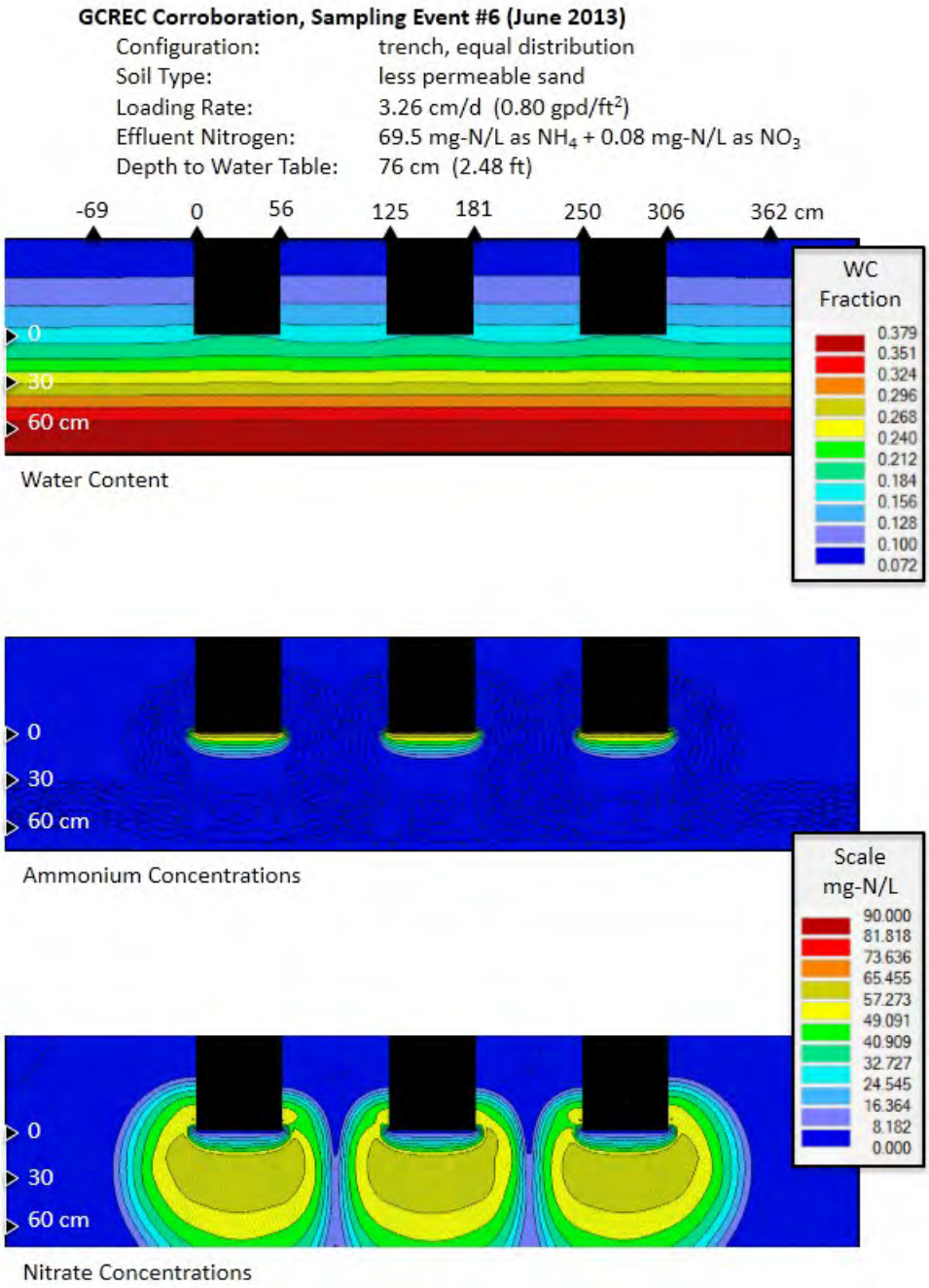

Figure C.10
GCREC Initial Corroboration, Sampling Event #6 (June 2013)
(no rainfall, variable ammonium inputs, default nitrification rate)

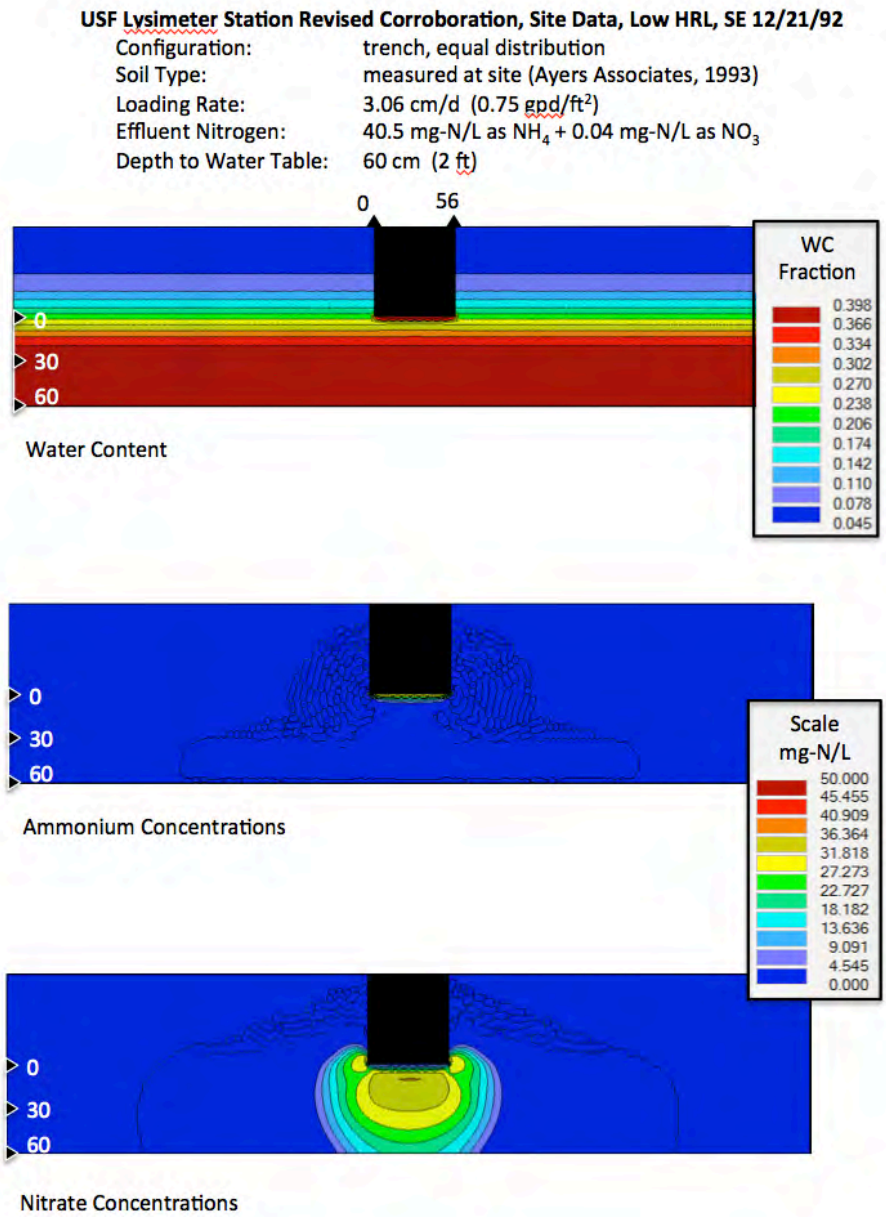

Figure C.11
USF Lysimeter Station Revised Corroboration, Site Date, Low HLR, SE 12/21/92
(rainfall, modified nitrification and denitrification rates)

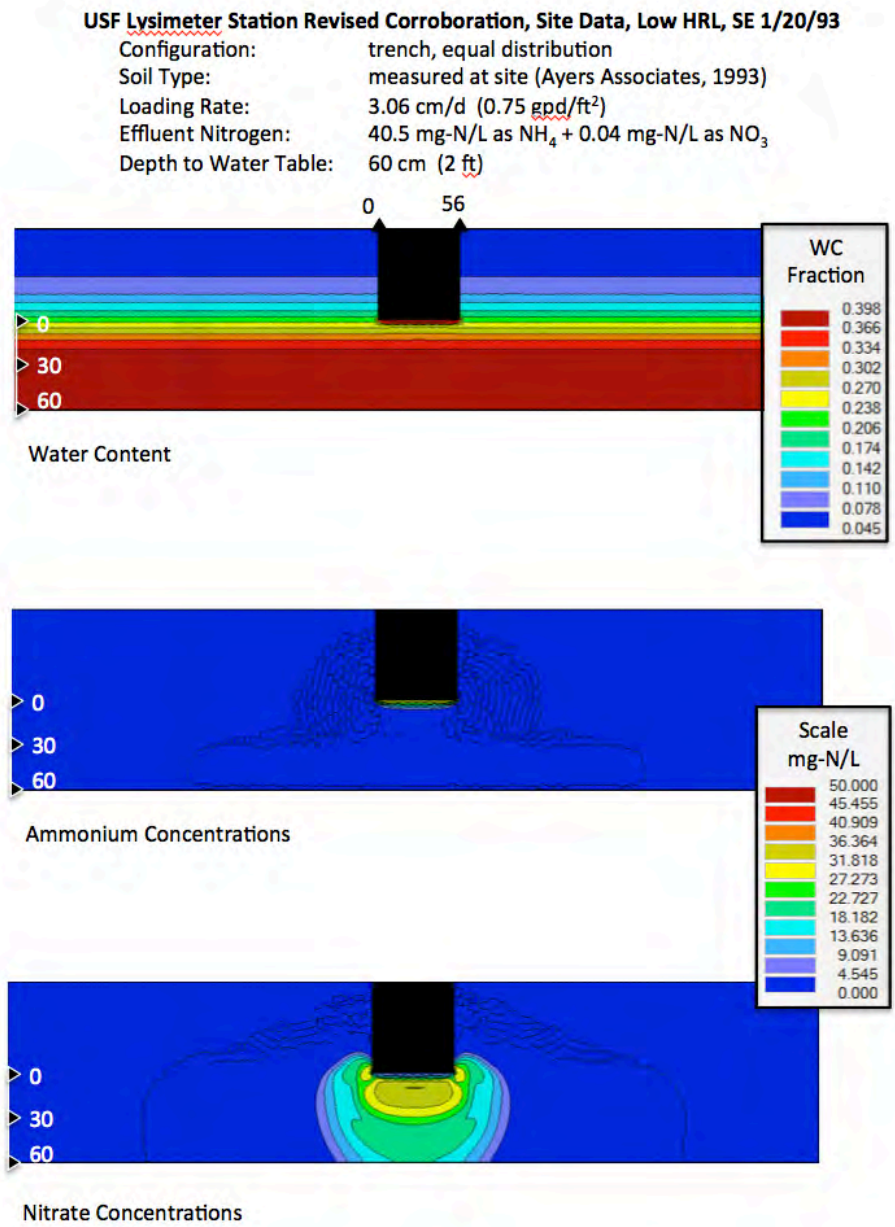

Figure C.12
USF Lysimeter Station Revised Corroboration, Site Date, Low HLR, SE 1/20/93
(rainfall, modified nitrification and denitrification rates)

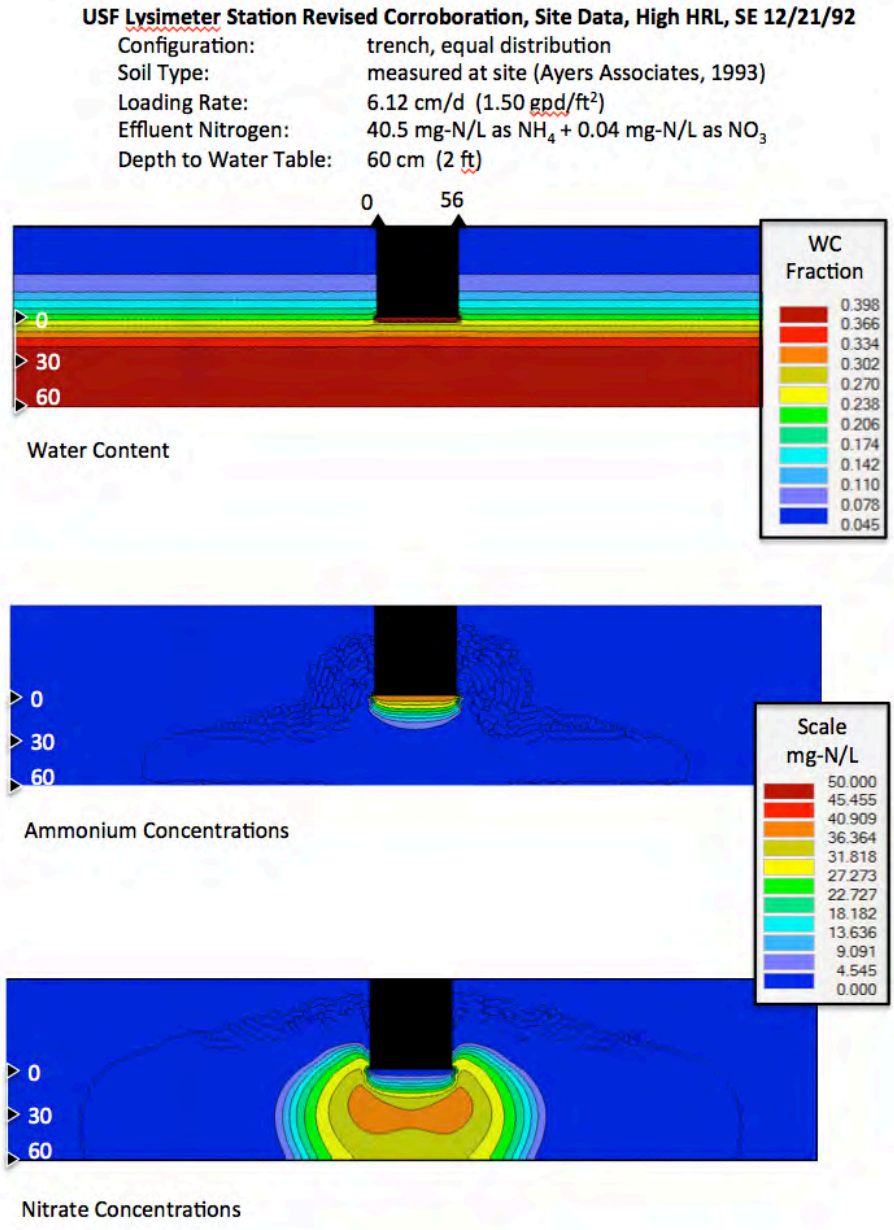

Figure C.13
USF Lysimeter Station Revised Corroboration, Site Date, High HLR, SE 12/21/92
(rainfall, modified nitrification and denitrification rates)

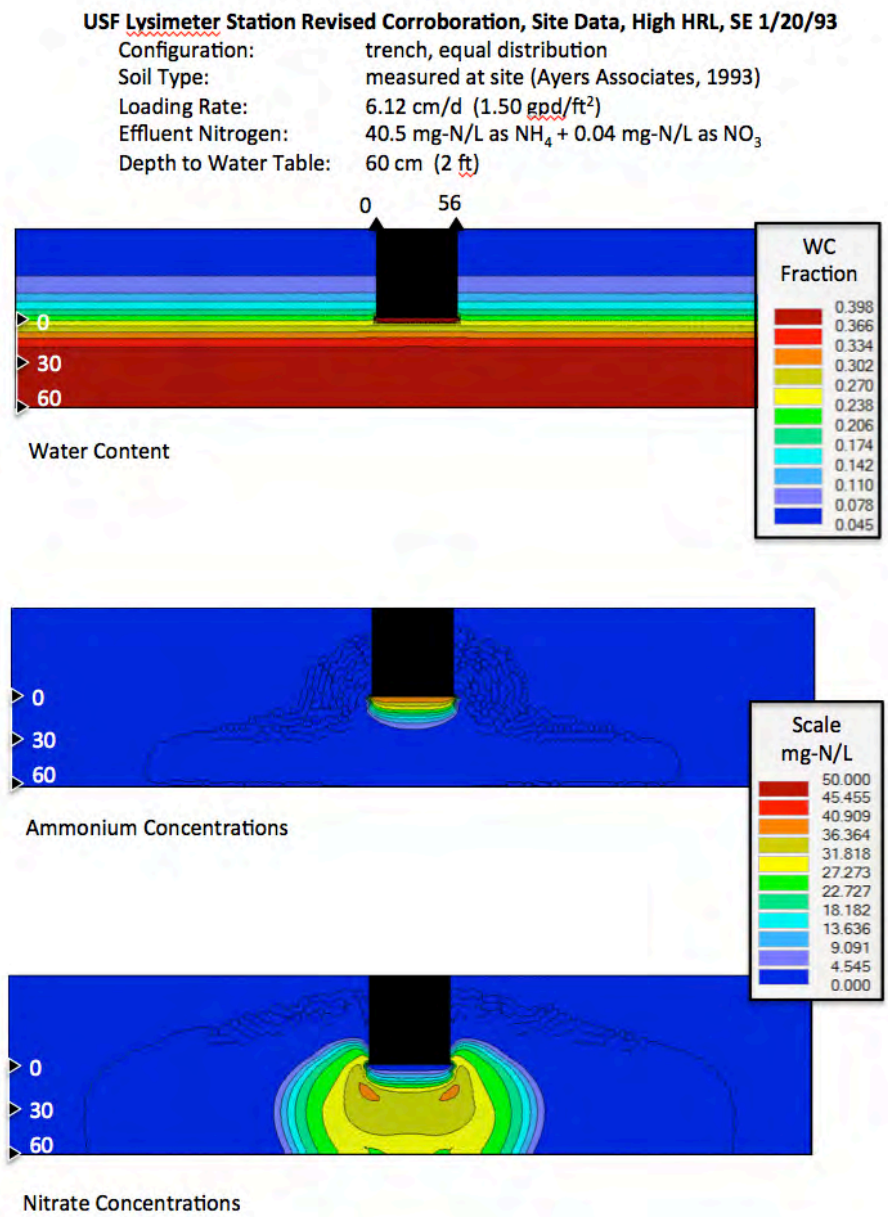

Figure C.14
USF Lysimeter Station Revised Corroboration, Site Date, High HLR, SE 1/20/93
(rainfall, modified nitrification and denitrification rates)

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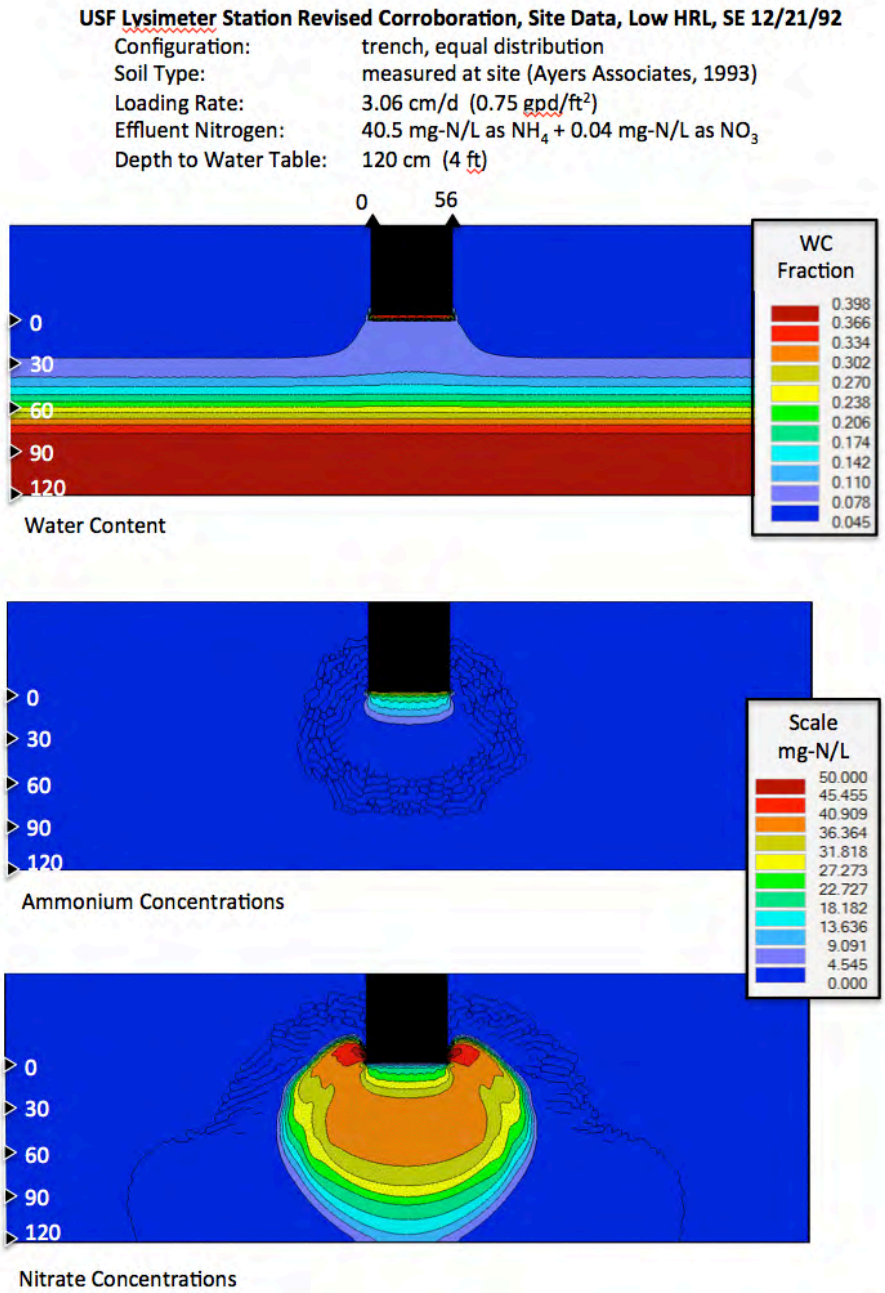

Figure C.15
USF Lysimeter Station Revised Corroboration, Site Date, Low HLR, SE 12/21/92
(rainfall, modified nitrification and denitrification rates)

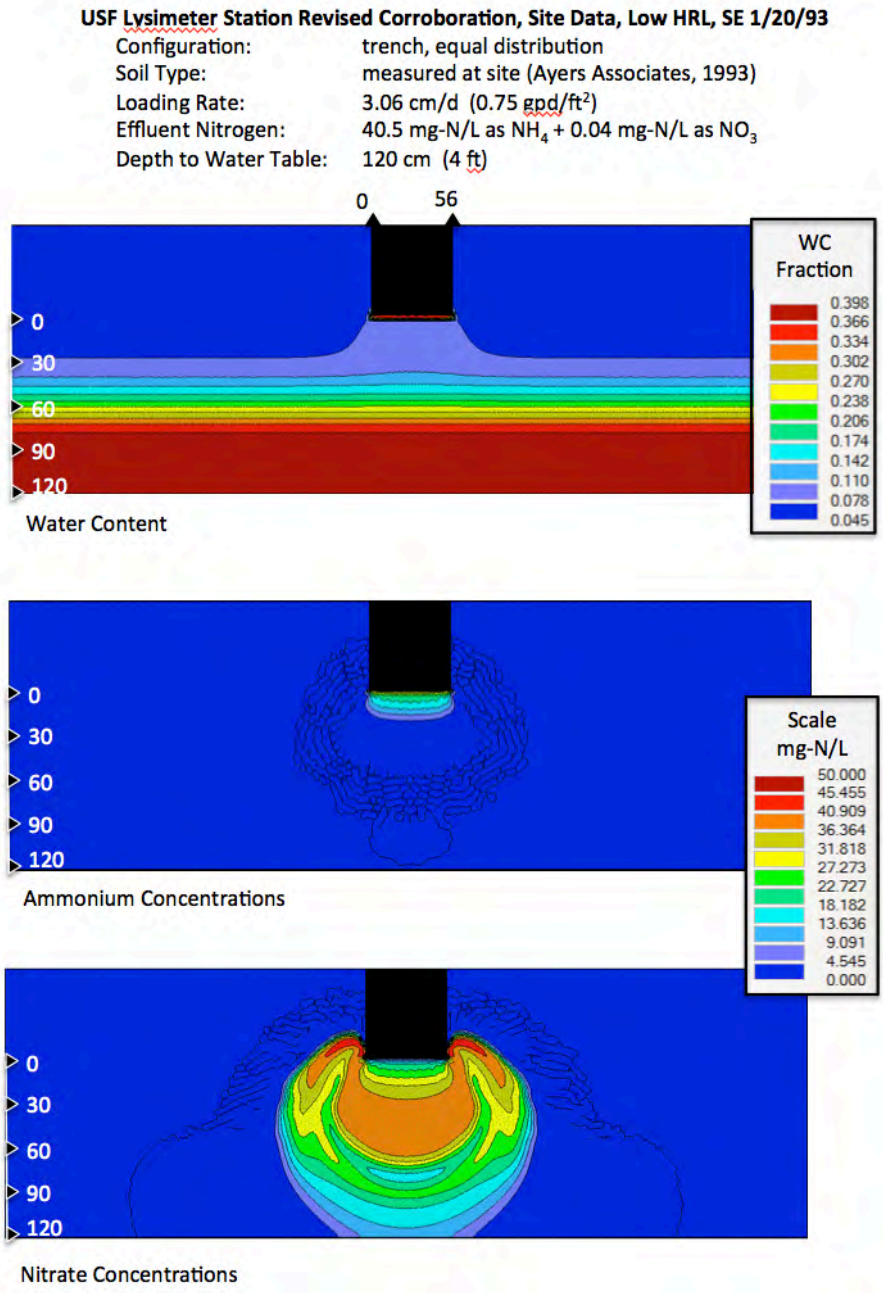

Figure C.16
USF Lysimeter Station Revised Corroboration, Site Date, Low HLR, SE 1/20/93
(rainfall, modified nitrification and denitrification rates)

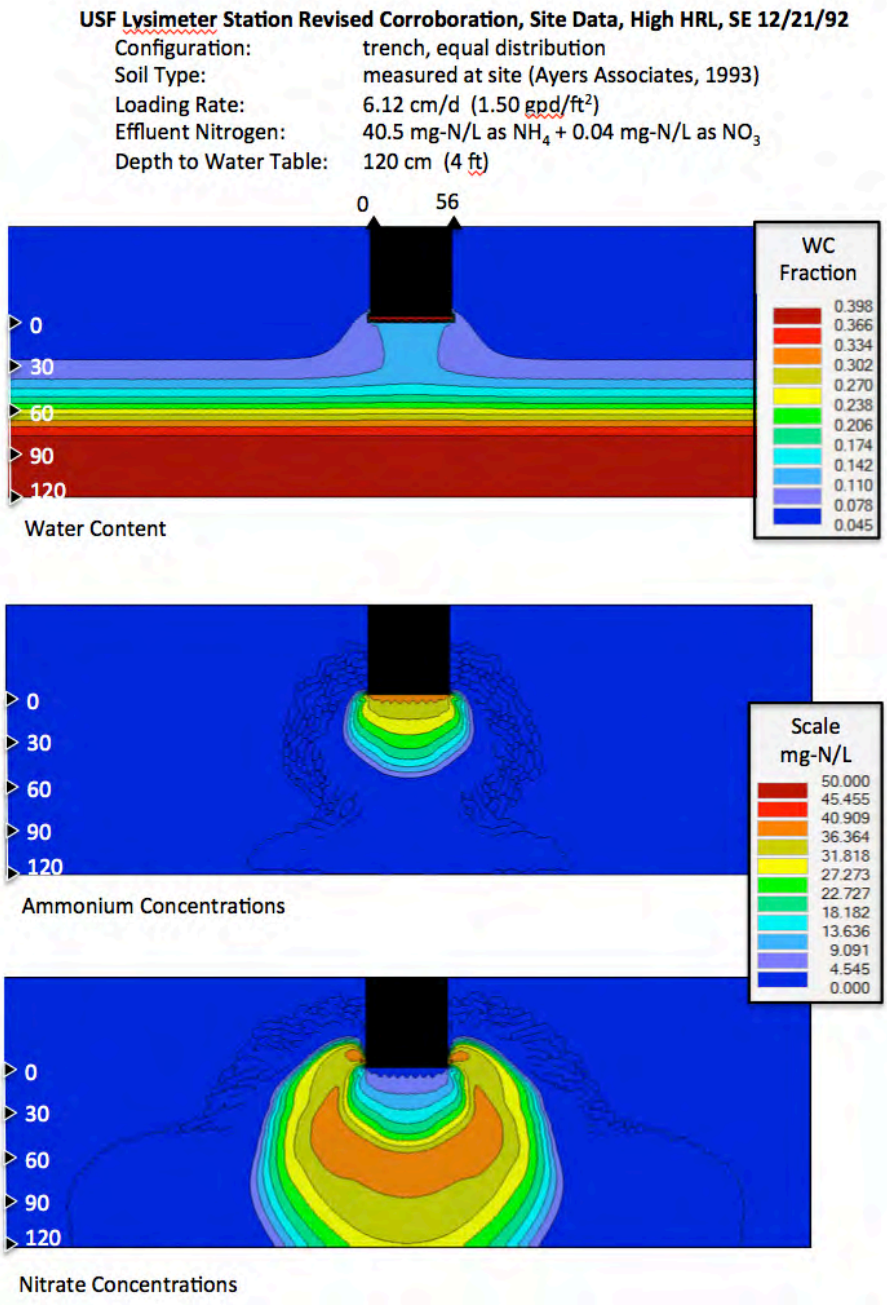

Figure C.17
USF Lysimeter Station Revised Corroboration, Site Date, High HLR, SE 12/21/92
(rainfall, modified nitrification and denitrification rates)

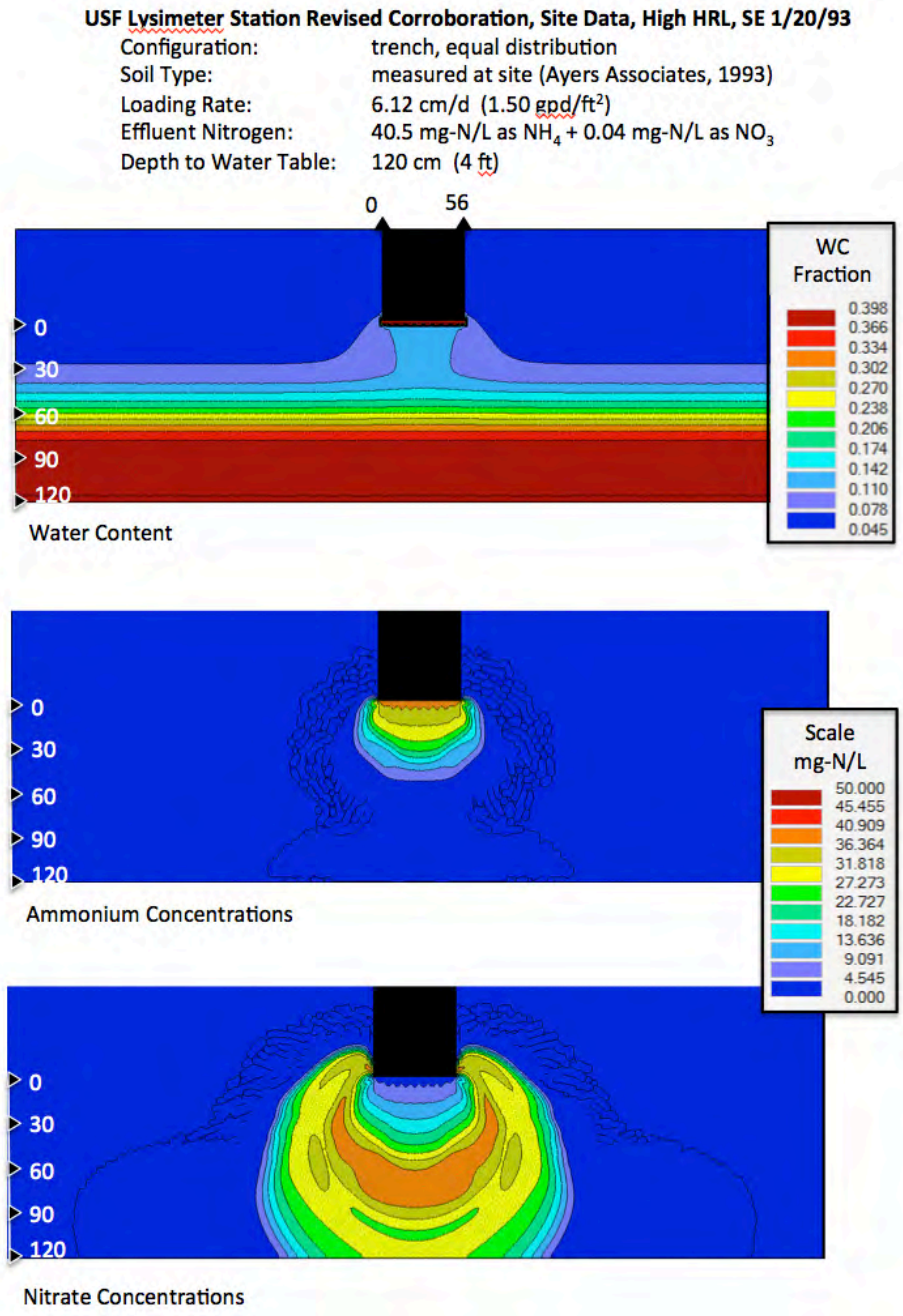

Figure C.18
USF Lysimeter Station Revised Corroboration, Site Date, High HLR, SE 1/20/93
(rainfall, modified nitrification and denitrification rates)

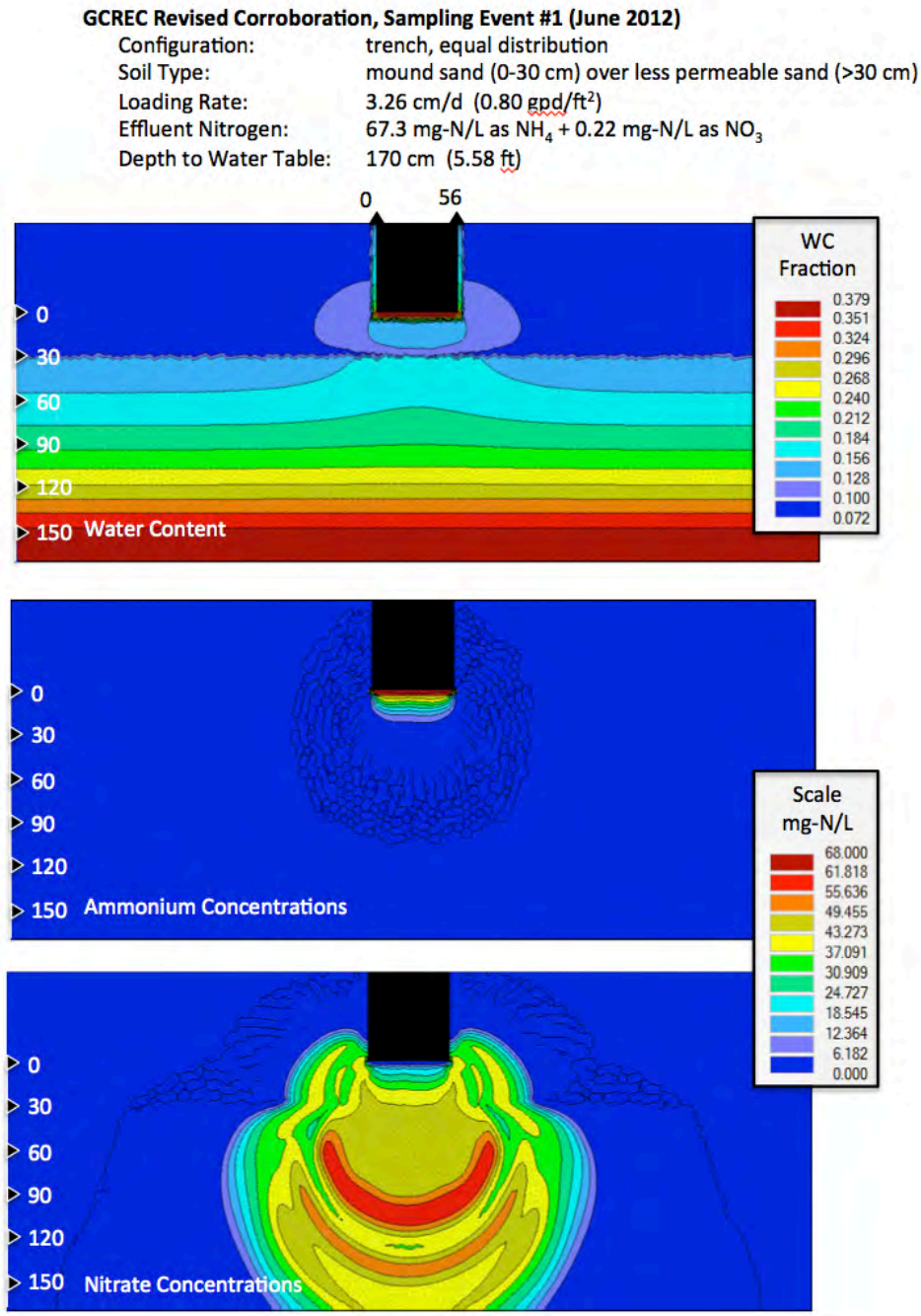

Figure C.19
GCREC Revised Corroboration, Sampling Event #1 (June 2012)
(rainfall, averaged ammonium input, layers, modified nitrification rate)

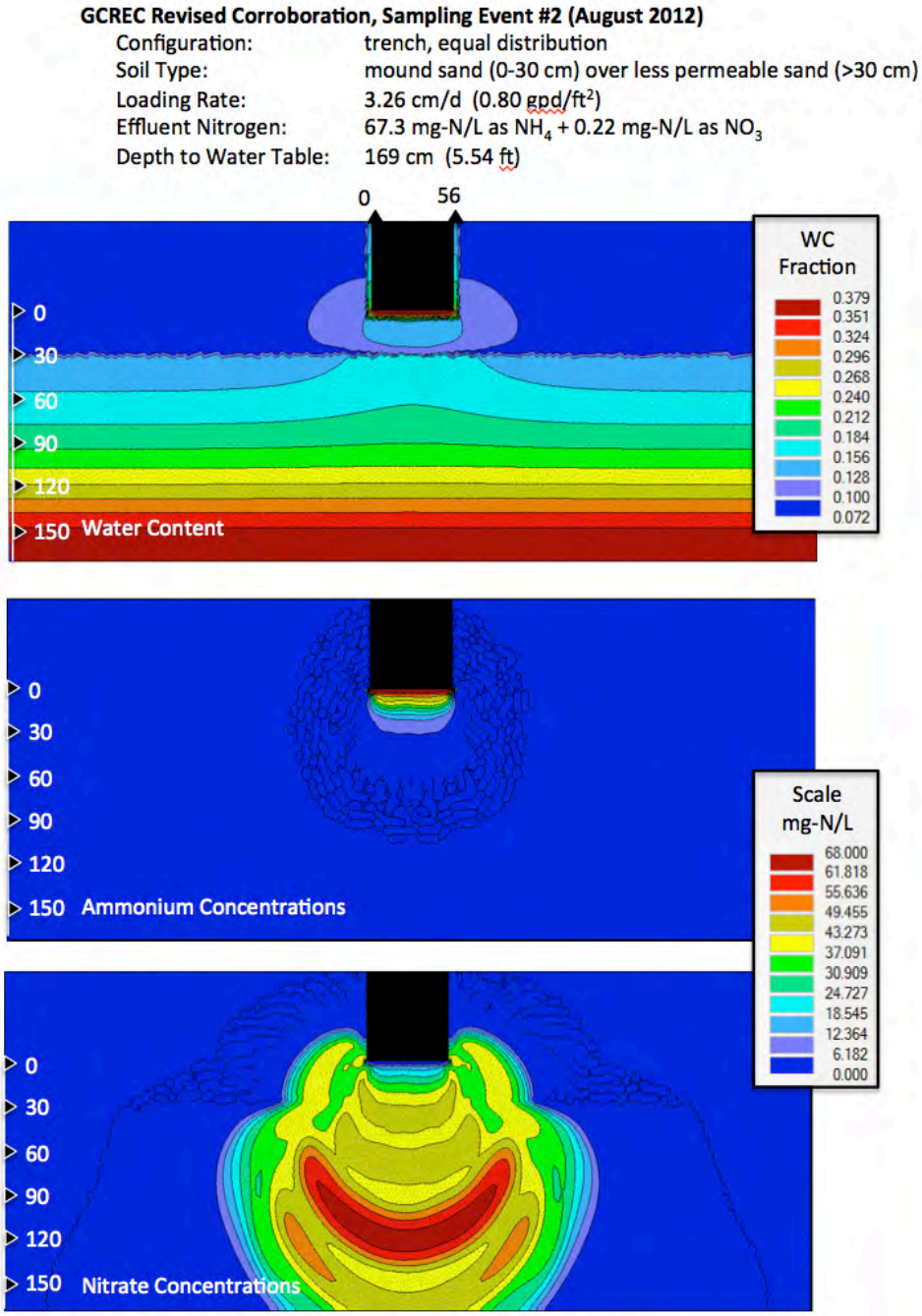

Figure C.20
GCREC Revised Corroboration, Sampling Event #2 (August 2012)
(rainfall, averaged ammonium input, layers, modified nitrification rate)

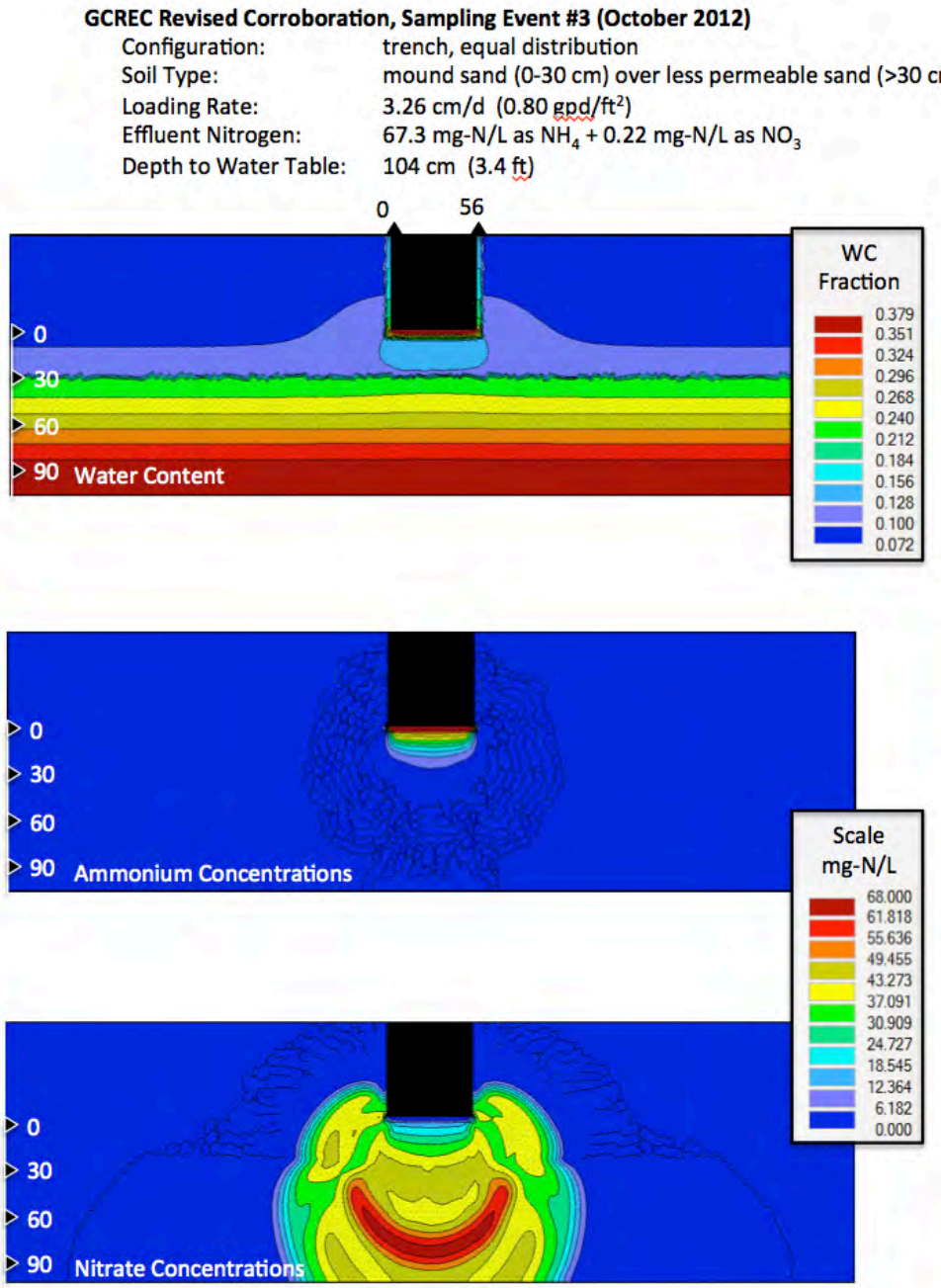

Figure C.21
GCREC Revised Corroboration, Sampling Event #3 (October 2012)
(rainfall, averaged ammonium input, layers, modified nitrification rate)

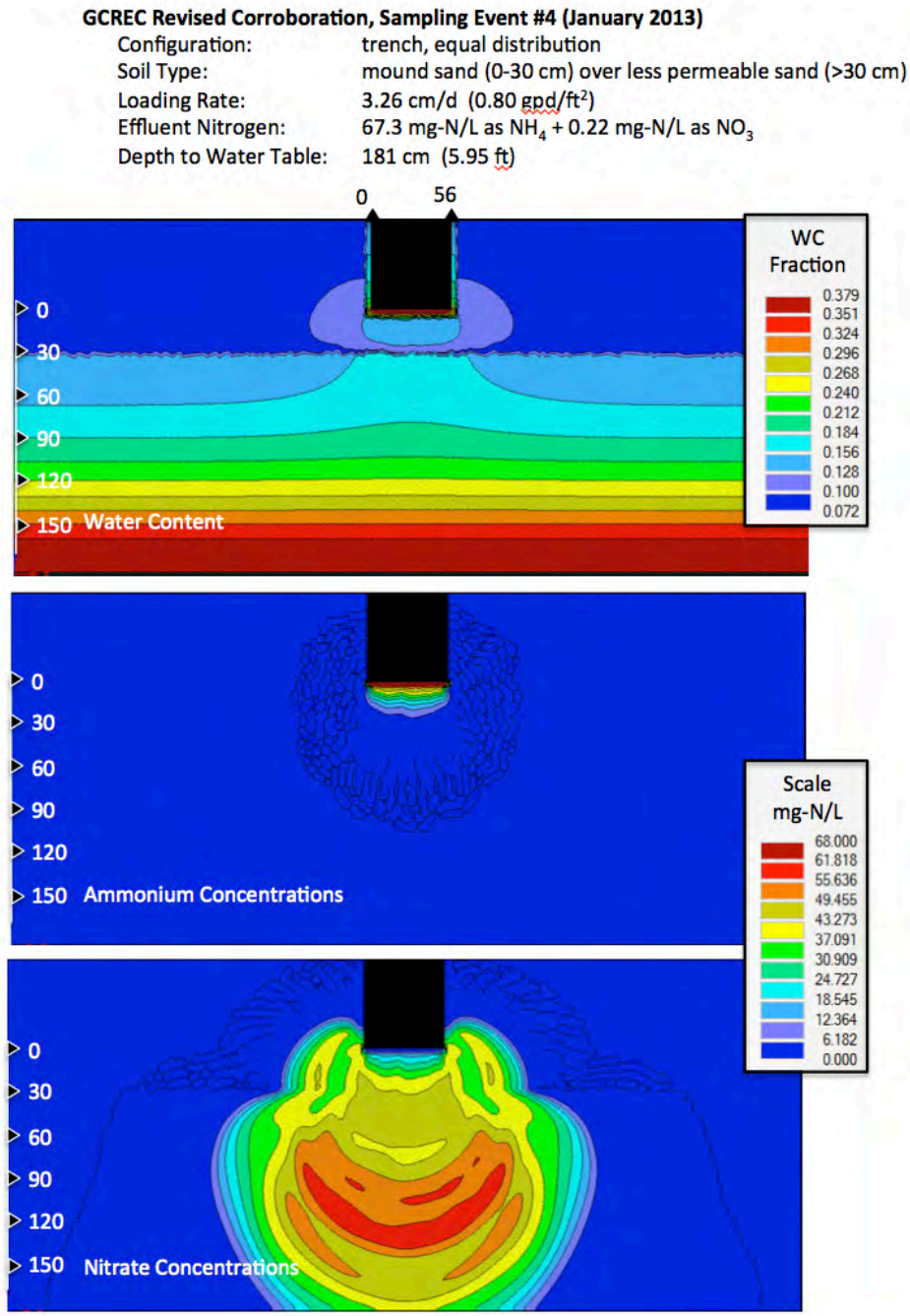

Figure C.22
GCREC Revised Corroboration, Sampling Event #4 (January 2013)
(rainfall, averaged ammonium input, layers, modified nitrification rate)

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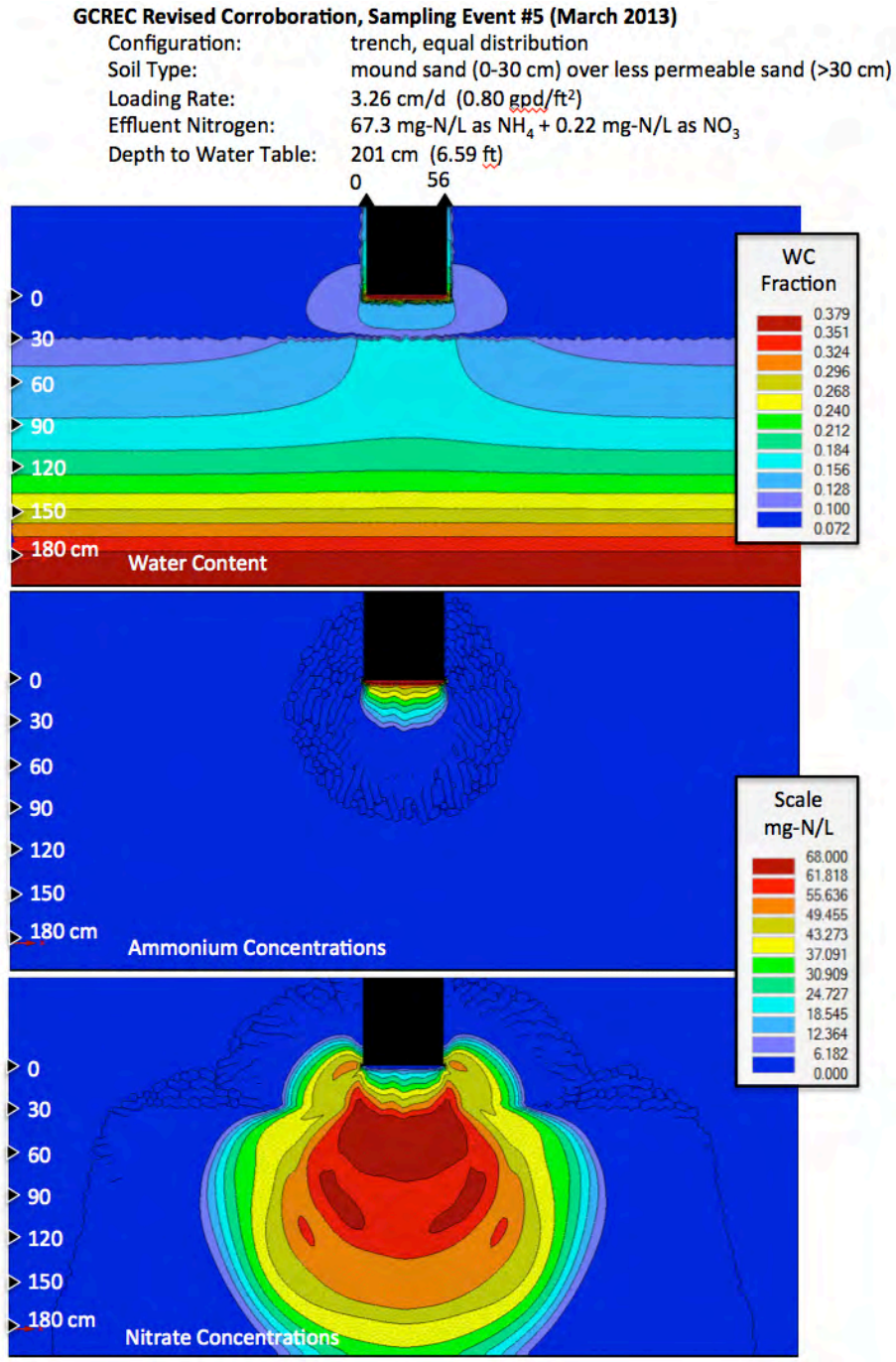

Figure C.23
GCREC Revised Corroboration, Sampling Event #5 (March 2013)
(rainfall, averaged ammonium input, layers, modified nitrification rate)

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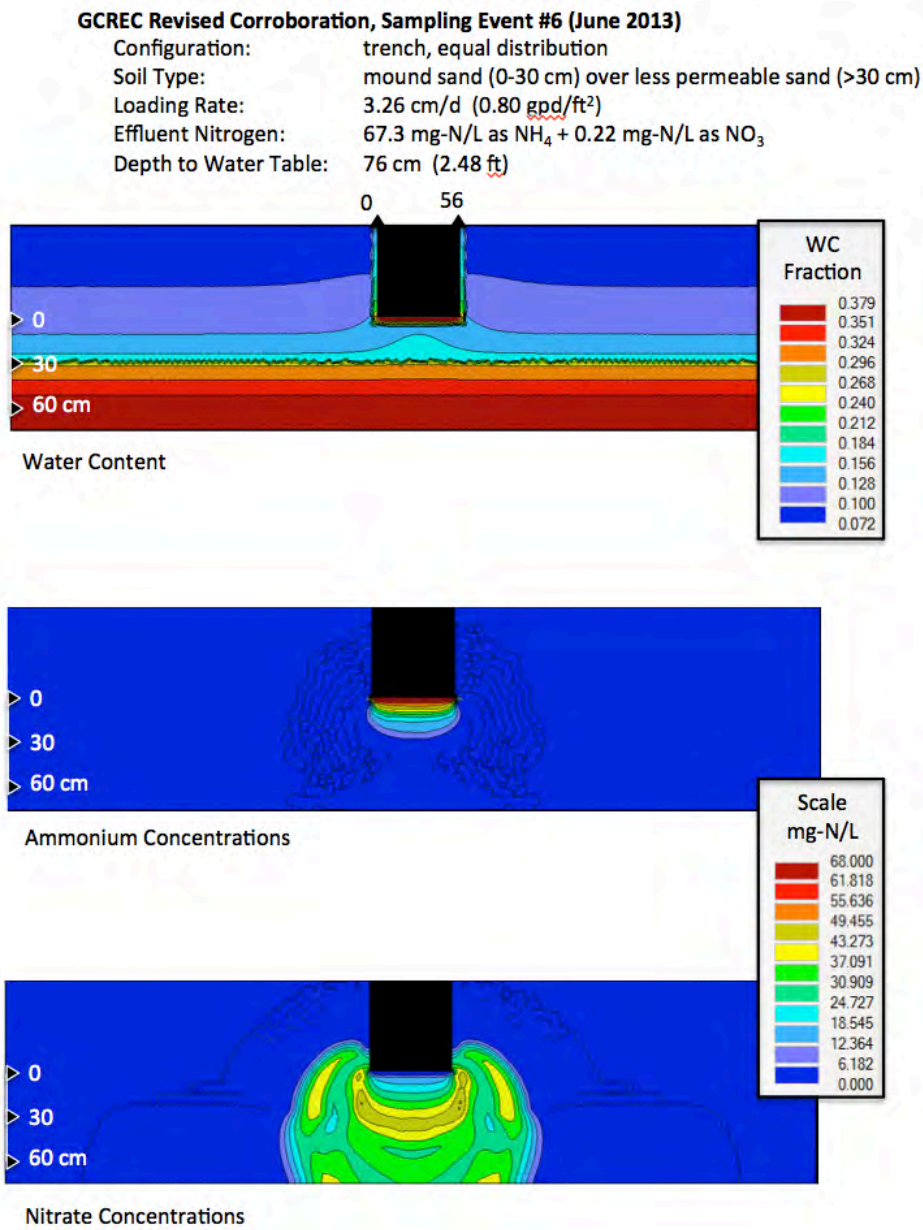

Figure C.24
GCREC Revised Corroboration, Sampling Event #6 (June 2013)
(rainfall, averaged ammonium input, layers, modified nitrification rate)

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