



Nutrient Tracking Tool (NTT) Technical Report

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INTRODUCTION

This report documents the development and evaluation of the Nutrient Tracking Tool (NTT), a web-based tool used to evaluate nutrient and sediment losses from crop and pasture land. NTT was developed to evaluate conservation practices for US farms using the Agricultural Policy Environment eXtender Model (APEX) (Williams et al., 2000). NTT uses farm field specific topography, soil, weather, and agronomic management data sources. The tool was designed such that comparisons of multiple conservation management alternatives can be evaluated as part of a single conservation planning assessment in order to efficiently arrive at the best management practice choices for a specific field and farm. NTT is a valuable tool for evaluating the impact of various conservation practices the water quality and quantity, as well crop yield. It has applications in farm planning, producer outreach, Total Maximum Daily Loads (TMDLs), market-based programs such as water quality trading, as well as education and research. Finally, NTT can also serve as an easy to use interface for APEX model.

Currently, there are two versions of NTT available:

- The NTT version which includes the essential NTT functions required for use for general public.
- The Research and Education version which will be used by researchers and educational institutes for teaching and training purposes. NTT-RE includes additional functions allowing the user to view and edit soil layers, view crop water and nutrient stresses, and modify and the APEX parameters file for calibration and validation purposes. Both versions of NTT use identical versions of the APEX model, parameter files, and simulation methods.

This report is structured as follows:

Section one provides a general description of NTT and its development process. The datasets that have been compiled for use in NTT and for populating the APEX model will also be described in this section.

Section two addresses the methodology for simulating structural and non-structural conservation practices within NTT.

The NTT Users manuals at the NTT and NTT-RE internet sites provide additional information, features, and functionality that are not discussed in this report.

1. NTT DEVELOPMENT

2.1 Overview of NTT

The Nutrient Tracking Tool (NTT) is an internet application that allows individuals interested in assessing non-point source runoff from farms evaluate different scenarios for nutrient and sediment reduction. Farmers, government officials, researchers and other users can determine the impacts of various conservation practices and other scenarios on nutrient and sediment losses from individual fields. In addition, impacts on crop yields and other indicators of relevance are provided to the user.

2.1.1 Historical Background

USDA-NRCS developed the Nitrogen Trading Tool as a farmer-friendly web-based application that can be used to calculate nitrogen load reductions for use in a WQT program. The Nitrogen Trading Tool is focused

on nitrogen because its estimations are based on the Nitrate Leaching and Economic Analysis Package (NLEAP; Shaffer et al., 1991). While very useful, its exclusive focus on nitrogen limited the applicability of the Nitrogen Trading Tool and to evaluation of very few N-related management scenarios. In fact, in many agricultural watersheds, particularly those with significant livestock numbers, phosphorus is the nutrient of primary concern. Phosphorus losses from agricultural fields have been linked to eutrophication of downstream waters in many areas in North America and Europe (Sharpley and Rekolainen, 1997).

In an effort to address the limitations of the Nitrogen Trading Tool, USDA-NRCS USDA commissioned Texas Institute for Applied Environmental Research Modeling Team (TIAERMT) at Tarleton State University to in the development of Nutrient Tracking Tool (NTT) for Water Quality Trading (WQT). While the Nutrient Tracking tool does not calculate WQT nutrient credits directly, the load reductions provided by the tool can be used along with WQT program trade ratios to calculate nutrient and sediment credits (Saleh et al., 2011). The current version of NTT also can be used for other water quality/quantity and air quality programs.

NTT was developed by using the Agricultural Policy Environmental eXtender (APEX; Williams et al., 2000). APEX, is a computer simulation model that has significant reputation for estimating the impacts of field-scale practices on a wide array of environmental indicators including air and water-borne pollutants. Inclusion of APEX also allows users to evaluate other farm level conservation practices such as filter strips, terraces, buffer strips, etc., that could not be evaluated using the Nitrogen Trading Tool. As a result of this effort, users also have access to various other relevant indicators (e.g., water quantity, sediment losses and crop yield changes) to help them make informed decisions about conservation practice implementation.

2.2 Key Features of NTT

The NTT program consists of following three main components:

1. Web interface, which is visible to the user
2. Computer simulation programs, which run in the background in response to user requests
3. Supporting databases, subsets of which can be viewed and customized by the user, based on the selections they make via the NTT web interface.

2.2.1 Web Interface

NTT is a web-based program. Users can access the tool by using their internet browser to go to the main NTT home page: (<http://ntt.tiaer.tarleton.edu>; for general users) and (<http://ntt.tiaer-re.tarleton.edu>; full version for research and educational proposes). The current versions have all required data to be simulated for lands within the mainland US and Puerto Rico territory. However, NTT has been tested for a number of sites within the US while additional testing is being performed in various states. Users can select the state and county relevant for their applications and then proceed to define scenarios and run NTT to obtain estimates of nutrient and sediment losses as well as other indicators for each scenario they define.

NTT is a user-friendly program where virtually all the data required for all of states and counties of US and Puerto Rico territory are available on the NTT server. NTT provides regional default management scenarios that can be used as-is or be modified by the user. In addition, users can evaluate structural and non-structural conservation practices that are typical for their area. Site-specific information used in the simulation (i.e. soils, weather and slope) are determined based on the user-defined area of interest (AOI) or field in a GOOGLE-based mapping system (Figure 1).

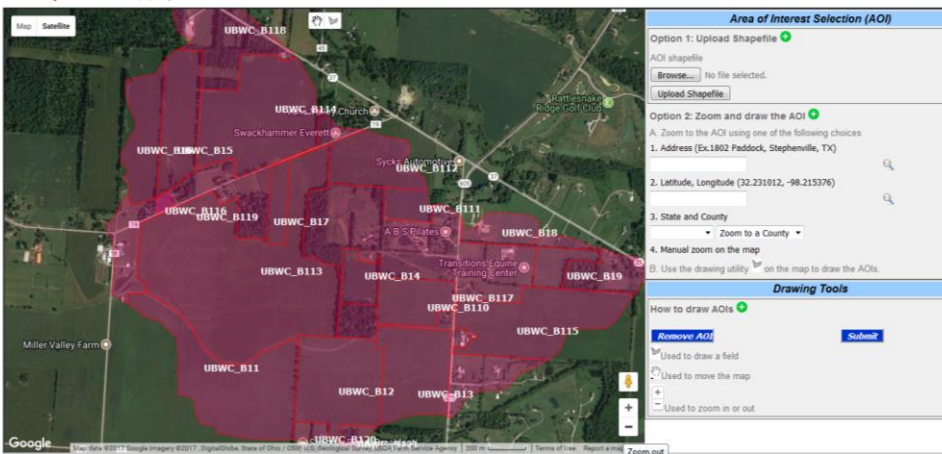


Figure 1. NTT GOOGLE-based mapping system

All other data required for the area of interest can be selected by users from drop-down list boxes in the NTT user interface. If users desire to estimate nutrient and sediment losses for management practices that are not available in the NTT default choices, they can select other options to either modify existing management practices (operations) or create new ones.

A farm or small watershed can be subdivided as much as necessary to ensure that each subarea is relatively homogeneous in terms of soil, land use, management, etc. NTT also has a field routing feature that allows the user to evaluate the interactions between subareas involving surface runoff, return flow, sediment deposition, nutrient transport, and groundwater flow.

2.2.2 NTT's Computer Simulation Programs

APEX (version 0806) is the core simulation model in NTT. APEX was selected for the NTT application because of its prediction capability regarding N and P losses, crop yields, and sediment losses during evaluations of numerous management alternatives, such as installing filter strips. APEX also has other capabilities that can be useful in future potential augmentations of the tool, such as simulation of pesticide losses and carbon cycles.

APEX is a modified version of the Environmental Policy Integrated Climate model (EPIC) (Williams, 1990), a field-level model that was developed in the early 1980s to assess the effects of management strategies on water quality. APEX extends the functionality of EPIC by allowing the simultaneous simulation of multiple contiguous subareas (fields) for a wide range of soil, landscape, climate, crop rotation, and management practice combinations. It is designed for whole farm or small watershed analyses, and can be used for applications, such as filter strip impacts on nutrient losses from manure application fields, that require the configuration of at least two subareas. Alternatively, it can be run for single fields in the same manner that is allowed in models such as EPIC. The ability to simulate liquid applications from animal waste storage ponds or lagoons is a key component in APEX. Other components include weather, hydrology, soil temperature, erosion-sedimentation, nutrient cycling, tillage, dairy management practices, crop management and growth, pesticide and nutrient movement, and costs and returns of various management practices.

Recently, the carbon fate and transport functions of the CENTURY model (Parton, 1996) were incorporated into APEX (version 0604 and higher), which allows APEX to simulate carbon dynamics in the soil-plant system. APEX also has groundwater and reservoir components. A field or small watershed can be subdivided as much as necessary to ensure that each subarea is relatively homogeneous in terms of soil, land use,

management, etc. The routing mechanisms in APEX provide for evaluation of interactions between subareas involving surface runoff, return flow, tile flow, sediment deposition, irrigation, nutrient transport, and groundwater flow.

2.2.3 Supporting Databases

All the datasets required for running NTT are housed on the NTT server for ready user access. However, users may enter management information that is different from the pre-defined set available on the NTT program for their county of interest and can also save their information for future use. The following are the NTT databases that are available on the NTT server for states and counties in the U.S.

- A. Weather data:** Precipitation, minimum and maximum temperature, from 1981-2017 at 4-KM² resolution available throughout the US. The source of the weather data is from the USDA Parameter-elevation Regressions on Independent Slopes Model (PRISM) database. The weather data is updated yearly in order to access the latest information.

The monthly Weather files (MWF) are required by APEX to generate all the missing weather data (e.g., solar radiation). NTT also generates the MWF at the 4-km² grid for any part of US mainland and Puerto Rico territory using the recent local (PRSM) weather data. This makes the APEX calculations (e.g., ET) more precise.

The weather data in NTT is automatically generated for the area of interest based on its vicinity to specific weather station(s).

- B. Soil Data:** Soil data, including soil texture, calcium carbonate, PH, bulk density, and organic carbon, are obtained from the USDA-NRCS soil survey (SURGGO) databases. Currently NTT host a copy of USDA-SURGGO at its site which is accessed by a GOOGLE-based mapping system. The soil database in NTT is also updated annually. Also, the soil routine in NTT will modify and replace the missing data from soil survey as follows:

- a. Soil layers where sand, silt, and clay are not present are not selected
- b. Soil layers with depth = 0 are not selected
- c. Soil layers where depth <= 5 mm and silt and sand = 0 and organic matter > 25 and bulk density < 0.8 are not selected
- d. Only soils with area type "Non-MLRA Soil Survey Areas" are selected.
- e. Soil layers with Organic Matter less than 0.5 is set to 0.5
- f. Soils with Albedo <= 0 use default 0.37
- g. Soil layers PH is validated to be between 3.5 and 9
- h. Soil layers Organic carbon is validated to be between 0.0 and 2.5
- i. Soil layers Bulk density is validated to be between 1.1 and 1.79
- j. Default for soil P is 3.0
- k. If sand, silt, and bulk density are missing the values are estimated from Saxton et al., (1986) method as shown in Table 1. However, the user has the opportunity to modify these values in NTT-RE version.

Table 1. Soil texture properties estimated from Saxton et al., (1986) method

Texture	Sand	Silt	Clay	BD
Sandy clay loam	53.2	20.6	26.2	1.49
silty clay loam	8.9	58.9	32.2	1.2
loamy sand	80.2	14.6	5.2	1.44
sandy loam	63.4	26.3	10.3	1.46
sandy clay	52	6	42	1.49
silt loam	15	67	18	1.31
clay loam	29.1	39.3	31.6	1.33
silty clay	7.7	45.8	46.5	1.21
sand	84.6	11.1	4.3	1.45
loam	41.2	40.2	18.6	1.4
silt	4.9	85	10.1	1.42
clay	12.7	32.7	54.6	1.24

- l. If depth is duplicated the layers is not added.
- m. If first layer depth is > 10 mm a new first layer is added with depth = 10mm
- n. Apply Saxton (1986) equations to calculate bulk density, field capacity, wilting point, hydraulic conductivity.

Soil test phosphorus (STP), obtained by the following methods are converted to Mehlich-3 (M3) before inputted in soil data database (The STP-depth is set at 0-6-inch depth by default). The user STP input in NTT is converted Mehlich-3 equivalent using the following equations:

1. Modified Morgan (MM) method (Winchell et al., 2011)

$$M3 = 6.718 \times MM - 11.83 \times PH - 32.757 \times MM/AL + 90.73$$

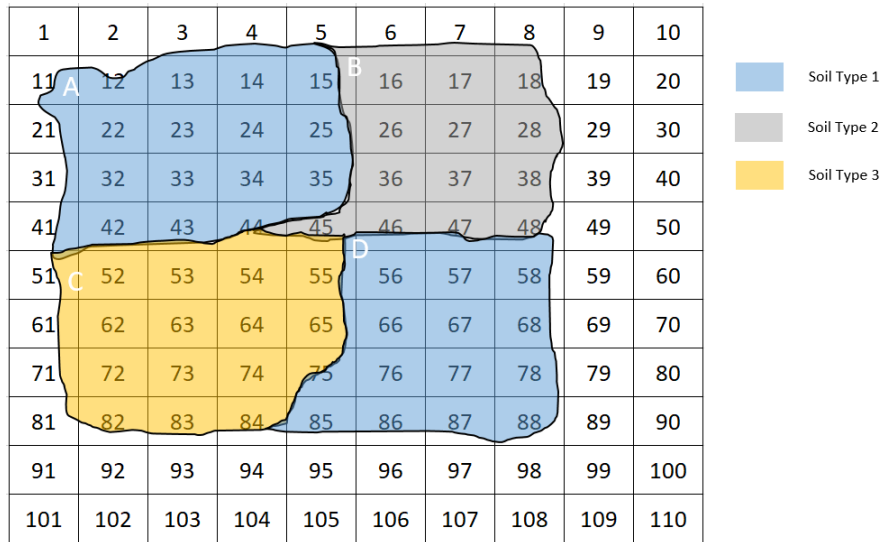
Where PH soil PH and AL is soil Aluminum at the top soil 6-inch depth.
2. Fe_strip method (Peter et al., 2007)

$$M3 = 0.10 + 1.61 \text{ Fe-strip P}$$
3. Olsen_P method (Peter et al., 2007)

$$M3 = 14.8 + 1.54 \text{ Olsen P}$$
4. Modified Bray-1) method (Peter et al., 2007)

$$M3 = 10.8 + 0.99 \text{ Bray-1 P}$$

Finally, the soil routine in NTT computes the soil surface slope (SL) using the 30-m DEM resolution for each soil type for simulated area. The slope is calculated by averaging the slope for cells in each polygon and averaging the result for each soil type.



For example, slope for soil type 1 in above field is calculated from:

$$S_A = \frac{S_{12} + S_{13} + S_{14} + S_{15} + S_{22} + S_{23} + S_{24} + S_{25} + S_{32} + S_{33} + S_{34} + S_{35} + S_{42} + S_{43} + S_{44}}{15}$$

Slope for polygon D:

$$S_D = \frac{S_{56} + S_{57} + S_{58} + S_{66} + S_{67} + S_{68} + S_{75} + S_{76} + S_{77} + S_{78} + S_{85} + S_{86} + S_{87} + S_{88}}{14}$$

And since the soil A and D are the same type, then

$$S_{Soil\ 1} = \frac{S_A * A_A + S_D * A_D}{A_A + A_D}$$

Where, $S = \frac{\text{hight}}{\text{length}}$ and S_{12} is calculated slope of cell no. 12, and S_A is calculated slope of soil polygon A, and $S_{Soil\ 1}$ is slope of subarea with soil type 1. A similar process is followed for up to three soil types for each selected field.

This dataset was extracted from USGS National Elevation Dataset (NED) 1/3 arc second data. A slope grid was calculated from the elevation grid for use in the NTT Program.

C. Management Schedule Data: The default major local cropping rotations and conservation practices management systems at the State-level are available for all part US mainland. However, the users have the opportunity to insert their own and/or modify any default management system based on their own management practices. For the instructions please refer to NTT user's manual.

The tillage operations, fertilizer and manure types and application, and conservation practices (CPs) have also been customized at the state-level in order to be useful for local model users. The tillage information was obtained from local producers and litteratures. Fertilizer application was modified based on the local crop historical yield published by The National Agriculture Statistics Service, USDA (NASS 2017). List of CPs were obtained from USDA-NRCS Field Office Technical Guide (FOTG) (www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/?cid=NRCSDEV11_001020)

2.2.4 Scope, Capabilities, and Limitations of NTT Applications

The capabilities and scope of NTT applications are based primarily on the range of applications afforded by APEX, its core simulation model. Currently, NTT can simulate virtually most crop operations – any crop operations that can be simulated in APEX. NTT can also simulate a number of structural conservation practices. The following table 2 summarizes the most common CPs practices simulated by NTT. The applications that are yet to be tested or incorporated in the NTT interface are marked with an asterisk.

Table 2. Range of NTT Applications

Category	Application
Field operations	Tillage
	Nutrient applications
	Irrigation and fertigation
	Liming
	Grazing (continuous & rotational)
	Planting and harvest
	Burning
	Pesticide applications*
Structural practices	Filter strip
	Buffer zone and grass waterways
	Terraces
	Riparian forest buffer
	Wetlands
	Stream stabilization
	Fencing
	Ponds/Water & Sediment Control Basin
	Land leveling
	Contour farming
	Tile and surface drainage systems

Since APEX is a field-scale model, the results obtained from NTT are edge-of-field estimates impacted by the given scenarios.

3. TESTING AND EVALUATING THE APEX MODEL

Testing and evaluating the APEX model within NTT consists of sensitivity analysis and verification processes. The sensitivity analysis process is an important step to evaluate the reliability and robustness of a model, while, the verification process assists us in examining the accuracy of model output by comparison with independent experimental data.

The following procedures are preferably performed in an NTT verification process: 1) Calibration: this includes parameterization of the model (according to the range of parameters determined during the sensitivity analysis) using any existing independent experimental data. This step is usually limited to the period of available measured data, usually much less than the >30-year period of a typical NTT model simulation. In the calibration process, model input parameters are adjusted for the area of interest so that simulation results closely match results from measured data. There are four major stages are followed to validate for region of concern (e.g., State level):

Stage 1. To obtain a general parameterization for each state/region, a series of NTT runs simulating common crop rotations, soils and, weather patterns for the region is done and the results are compared with expected crop yield and nutrient and sediment loss values obtained from National Agriculture Statistics Service, USDA (NASS 2017) and any local data.

Stage 2. During this stage, the field-scale measured data from various sources (e.g., local measured studies and collaborators) are used to finalize the regional APEX parameters.

Stage 3. The final parameters obtained from stage 2 will be used to repeat the process described in stage 1. However, the various conservation practices, common to the local region, are also simulated and evaluated for all soils and weather conditions during this stage.

Stage 4. The final results obtained from stage 3 are evaluated and presented to local stakeholders (e.g., local producers, agencies, and research centers) and collaborators. The results of for all stages would be available on the NTT site.

3.1 Sensitivity Analysis Procedure for APEX

The model sensitivity procedure is performed to determine the most important parameters to consider in the verification process. Sensitivity analysis also helps ensure that the most appropriate range of parameters is used for various management and structural practice conditions.

Sensitivity analysis was performed for APEX within NTT by adjusting each input variable in a predetermined fashion. After each input adjustment NTT's calculation tool was run to produce the output corresponding to that input adjustment. The output data were then stored in a database file for subsequent processing. In this section of the report the procedures and results of sensitivity tests that were performed on APEX program within NTT is outlined.

The following specific adjustments were made in each input variable prior to running NTT's calculation tool.

1. Fertilizer application rate and precipitation: Fertilizer application rates and precipitation values were adjusted upwards by 50% and downward by 50%. These adjustments were made by simply multiplying the original input value by 1.5 (for the 50% upward adjustment) and by 0.5 (for the 50% downward adjustment).

2. Minimum and maximum temperature: Minimum and maximum temperature records were also adjusted upwards by 50% and downward by 50%. However, because temperature values can be negative, the adjustments were performed differently. To adjust a temperature value upwards by 50%, it was multiplied by 1.5 if its original value was positive and by 0.5 if its original value was negative. Conversely, to adjust the temperature value downwards by 50%, it was multiplied by 0.5 if its original value was positive and by 1.5 if its original value was negative.
3. Date variables: Dates for field operations were adjusted differently. For the NTT sensitivity analyses, operation dates were adjusted upwards and downwards by the following specific number of days in an iterative fashion (Table 3).

Table 3. Date Adjustments Used in NTT Sensitivity Analyses

Iteration	Date adjustments (days)
1	0
2	-1
3	1
4	-3
5	3
6	-7
7	7
8	-30
9	30

4. Other parameters: Other NTT input and model parameters were adjusted by selecting two separate values within the range of acceptable values of each parameter. The NTT simulations were then repeated for each parameter adjustment using those two values in turn in two separate simulations. The following table (Table 4) shows the parameters adjusted, the acceptable range of values, and the values used for the sensitivity simulations.

Table 4. Input (A) and Model (B) Parameter Values Used in Sensitivity Analyses Simulations

Parameter	Description	Range		Values used
		Lower	Upper	II
<u>A: Input Parameters</u>				
	Slope (m/m)	0	0.1	0.1
	Slope length (m)	0	100	80
	Erosion control practice factor	0	1	0.9
	Soil pH	3	9	9
	Soil Organic carbon concentration (%)	0.1	10	5
	Initial soluble P concentration (Mg/kg)	0	500	500

	Bulk density (Mg/m³)	0.5	2	1.8
	Fraction of organic C in passive pool	0.3	0.7	0.7
	Saturated hydraulic conductivity (mm/hr)	0.0000 1	100	40
	Runoff curve number	30	90	85
	Fertilizer application depth (mm)	0	500	200
	Plant population (#/ha)	0	500	500
	RFPO	0	1	0.9
<u>B: Model Parameters</u>				
Parm 7	N Fixation	0	1	1
Parm 8	Soluble P runoff Coefficient	10	20	20
Parm 14	Nitrate leaching ratio	0.1	1	1
Parm 46	RUSLE C-factor coefficient	0.5	1.5	1.5
Parm 47	RUSLE C-factor coefficient	0.5	1.5	1.5
Parm 49	Maximum rainfall interception by plant canopy	2	15	15
Parm 52	Tillage effect on residue decay rate coefficient	5	15	15

For each sensitivity analysis iteration, all other variables were held fixed at their pre-adjustment levels while the values of the variable being investigated were adjusted using the procedure described above. Here in, as example each sensitivity analysis iteration was performed for all the soils in Delaware County, Ohio, in order to avoid biases that might be introduced by different soil types. Delaware County, Ohio was chosen. The results presented in the following section are averages across all soil types in Delaware County, Ohio. Results for specific soil types and for specific crop rotations would show much greater output variable sensitivity than the averages reported here portray.

The sensitivity of an output variable to a change in an input parameter is generally defined as:

$$s = \frac{\Delta y / y}{\Delta x / x} = \frac{(y_1 - y_0) / y_0}{(x_1 - x_0) / x_0}$$

where s is the sensitivity of the output variable y to a change in the input parameter x , x_0 is the initial parameter value with corresponding model output y_0 for the output variable of interest, and x_1 is the second value of the parameter, corresponding to a model estimate of y_1 for the output variable of interest. Thus s represents the percentage change in the output variable for a one percent increase in the input parameter.

With the exception of operation dates, output variable sensitivities were computed for each output variable and for each input parameter. The results presented here for operation dates are simply the percentage changes in the output variables for each of the predefined changes in operation dates. In general, a safe rule of thumb is that if the percentage change in the output variable is greater than the percentage change in the input parameter (the sensitivity has an absolute value greater than 1), then the output variable is very sensitive to changes in that input parameter. In many practical applications output variables with much smaller sensitivity values are still regarded as very sensitive. The value beyond which a variable is regarded as sensitive depends largely on the specific application.

3.2 Results of NTT Sensitivity Analyses

Results are presented in this section for sensitivity testing that was performed using the following variables. Minimum and maximum temperature values were adjusted and simulated jointly. Dry and moist bulk density parameters were also adjusted jointly. All other variables were adjusted separately. Results are first presented in tabular format for user and weather parameters that were adjusted 50% up and 50% down. Then the results for model parameters are presented in charts.

3.2.1 NTT Sensitivity Analyses Results for User and Weather Parameters

- A. Fertilizer application rate sensitivity:** Application rates for all fertilizer nutrients (nitrogen and phosphorus) were adjusted upward and downward by 50% for all operations. The results presented in Table 5 are averages across all soil types and all crop rotations. The summary results Table 5 suggest that soluble nutrient indicators are particularly sensitive to inorganic fertilizer application rates.

Table 5. Sensitivity of Output Variables to Fertilizer Application Rates: Average Across All Soil Types and Crop Rotations

Output variable	Percentage change in output indicator from a	
	50% increase in fertilizer rate	50% decrease in fertilizer rate
Organic N	2.1	4.8
Organic P	13.5	-9.7
Nitrate	57.7	-42.0
Soluble P	30.0	-31.1
Leached N	2.2	-9.8
Volatilized N	5.4	-5.7
Flow	-1.4	4.3
Sediment	-5.4	14.1
Total N	38.0	-25.5
Total P	17.9	-15.3

- B. Operation date sensitivity:** Field operation dates were adjusted from the original crop management information in order to determine how sensitive output indicators are to changes in when field operations are performed. For this sensitivity test, all field operation dates were adjusted by a specific number of days (-1, 1, -3, 3, -7, 7, -30, and 30 days) depending on the specific

iteration reached. Since field operation dates are never the same from one farm to another or across years, this input parameter is one that will certainly vary markedly within a watershed.

The results of the sensitivity analyses simulations are presented in Table 6. As expected larger changes in operation dates have much greater impacts – though not necessarily larger sensitivity ratios – than smaller changes in operation dates.

Table 6. Sensitivity of Output Variables to Field Operation Dates: Average across All Soil Types and Crop Rotations

Output variable	Percentage change in output variable when operation date is changed							
	-1 day	+1 day	-3 days	+3 days	-7 days	+7 days	-30 days	+30 days
Organic N	-1.3	-3.4	1.9	-3.0	2.6	0.3	4.0	-1.1
Organic P	-2.0	-3.7	1.6	-2.7	2.8	0.1	6.8	-2.1
Nitrate	-1.3	-1.9	-1.3	-0.6	2.9	-0.7	7.9	7.6
Soluble P	-1.2	-1.0	0.3	-1.4	0.9	-0.5	4.0	-0.7
Leached N	0.2	3.3	-7.0	3.8	-12.5	2.0	-27.2	10.1
Volatilized N	-1.0	-0.7	-0.3	-1.1	-0.5	1.2	-1.9	11.6
Flow	-0.6	-0.6	0.1	-0.6	0.1	0.1	-1.4	-2.0
Sediment	-1.7	-3.8	1.2	-0.3	1.7	2.1	4.2	4.5
Total N	-1.3	-2.4	-0.2	-1.5	2.8	-0.3	6.5	4.5
Total P	-1.8	-3.0	1.2	-2.4	2.3	-0.1	6.0	-1.8

C. Temperature sensitivity: To evaluate temperature sensitivity, daily maximum and minimum temperatures were adjusted upward or downward by the same percentage in each simulation. For the temperature sensitivity runs, all the daily maximum and minimum temperature records were adjusted upward or downward (depending on the iteration) for all the years of simulation prior to the NTT simulation. The average results shown here (Table 6) indicate that all output variables are very sensitive to temperature changes. Furthermore, the results indicate that, for the UBWC, output variables are more sensitive to a 50% reduction in maximum and minimum temperatures than a 50% increase in the same.

Table 6. Sensitivity of Output Variables to Temperature Variations: Averages across All Soil Types and Crop Rotations

Output variable	Percentage change in output indicator from a	
	50% increase in	50% decrease in
Organic N	18.1	110.3
Organic P	23.3	145.4
Nitrate	258.1	310.8
Soluble P	41.2	63.4
Leached N	-63.7	3057.6

Volatilized N	-11.9	-38.0
Flow	35.0	83.9
Sediment	21.6	161.1
Total N	93.8	173.5
Total P	24.8	138.7

D. Precipitation sensitivity: Precipitation sensitivity was performed by adjusting the precipitation data in all daily weather records for all years of simulation prior to each NTT simulation. The 50% upward and downward adjustments in precipitation data essentially represent very wet and extremely dry weather conditions in the UBWC watershed, while maintaining the frequency of historic precipitation events. Summary output from NTT simulations suggests that all output variables are very sensitive to precipitation amounts (Table 7). Once again, the results have been somewhat modulated by averaging across all soil types and all crop rotations. The sensitivity for specific soil types or crop rotations would be higher than the results reported here would indicate.

Table 7. Sensitivity of Output Variables to Precipitation: Average across All Soil Types and Crop Rotations

Output variable	Percentage change in output indicator from a	
	50% increase in precipitation	50% decrease in precipitation
Organic N	100.0	-70.9
Organic P	107.9	-74.1
Nitrate	11.5	272.8
Soluble P	70.2	-46.3
Leached N	5283.4	-100.0
Volatilized N	-5.6	-33.4
Flow	98.9	-47.9
Sediment	160.2	-77.6
Total N	72.1	37.5
Total P	104.8	-71.8

3.2.2 NTT Sensitivity Analyses Results for Input and Model Parameters

The following charts display the results of NTT sensitivity simulations based on adjustments in model parameters. Each pair of plots represents output variable sensitivity charts in response to changes in various parameters. The first chart for each output variable shows sensitivities to soil and other parameters. The second chart shows sensitivity to APEX PARM file parameters.

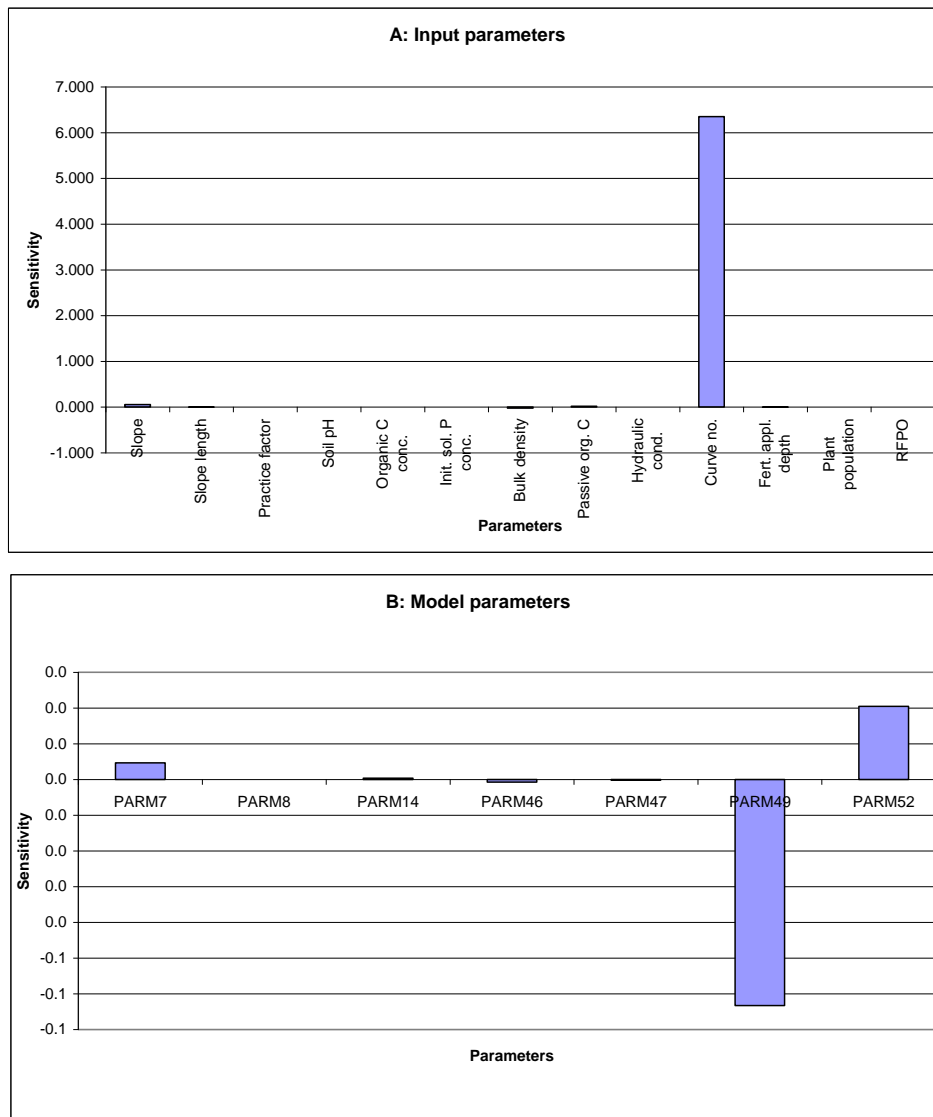


Figure 2. Sensitivity of Edge-of-Field Runoff to NTT Input and Model Parameters

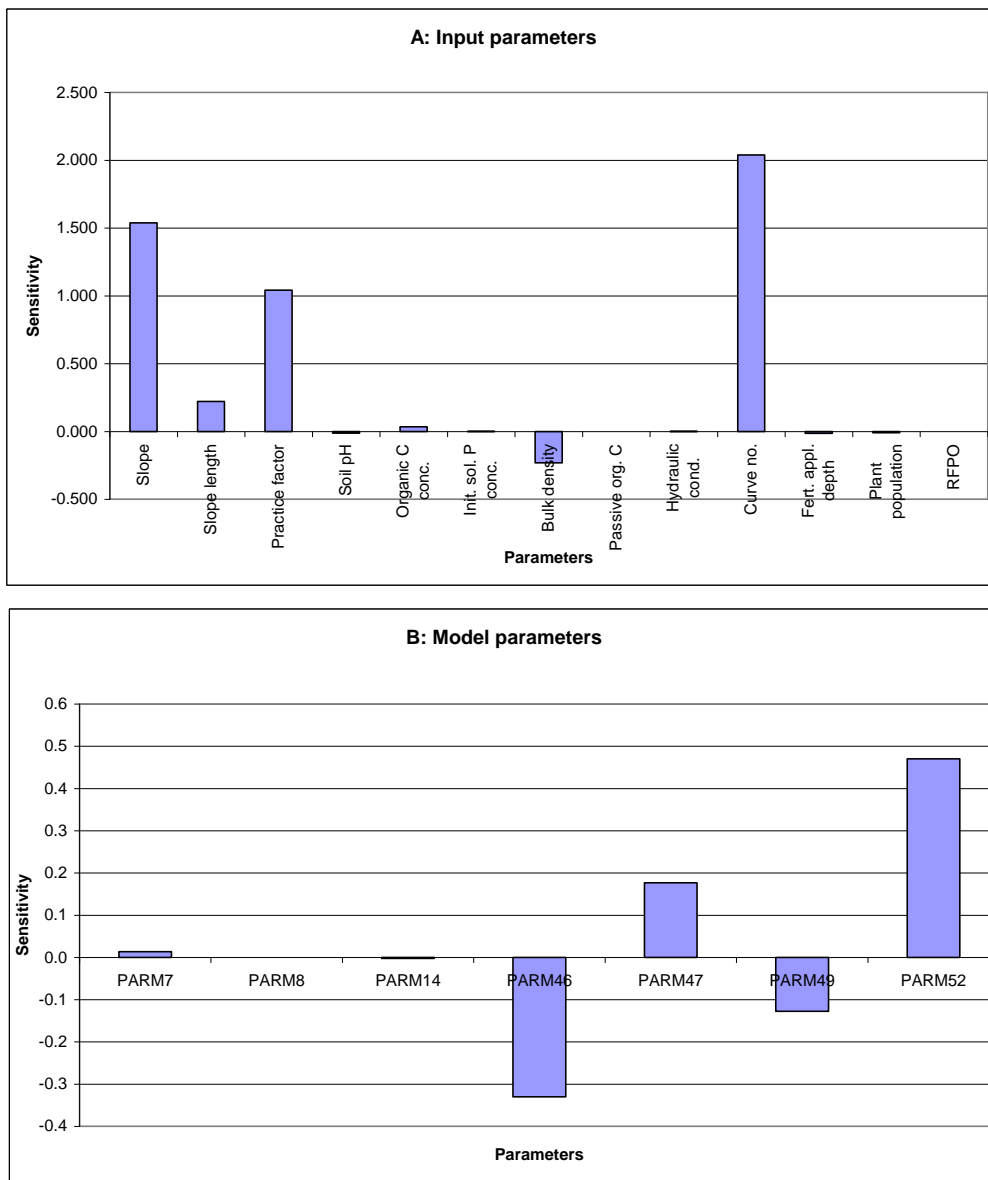


Figure 3. Sensitivity of Edge-of-Field Sediment Losses to NTT Input and Model Parameters

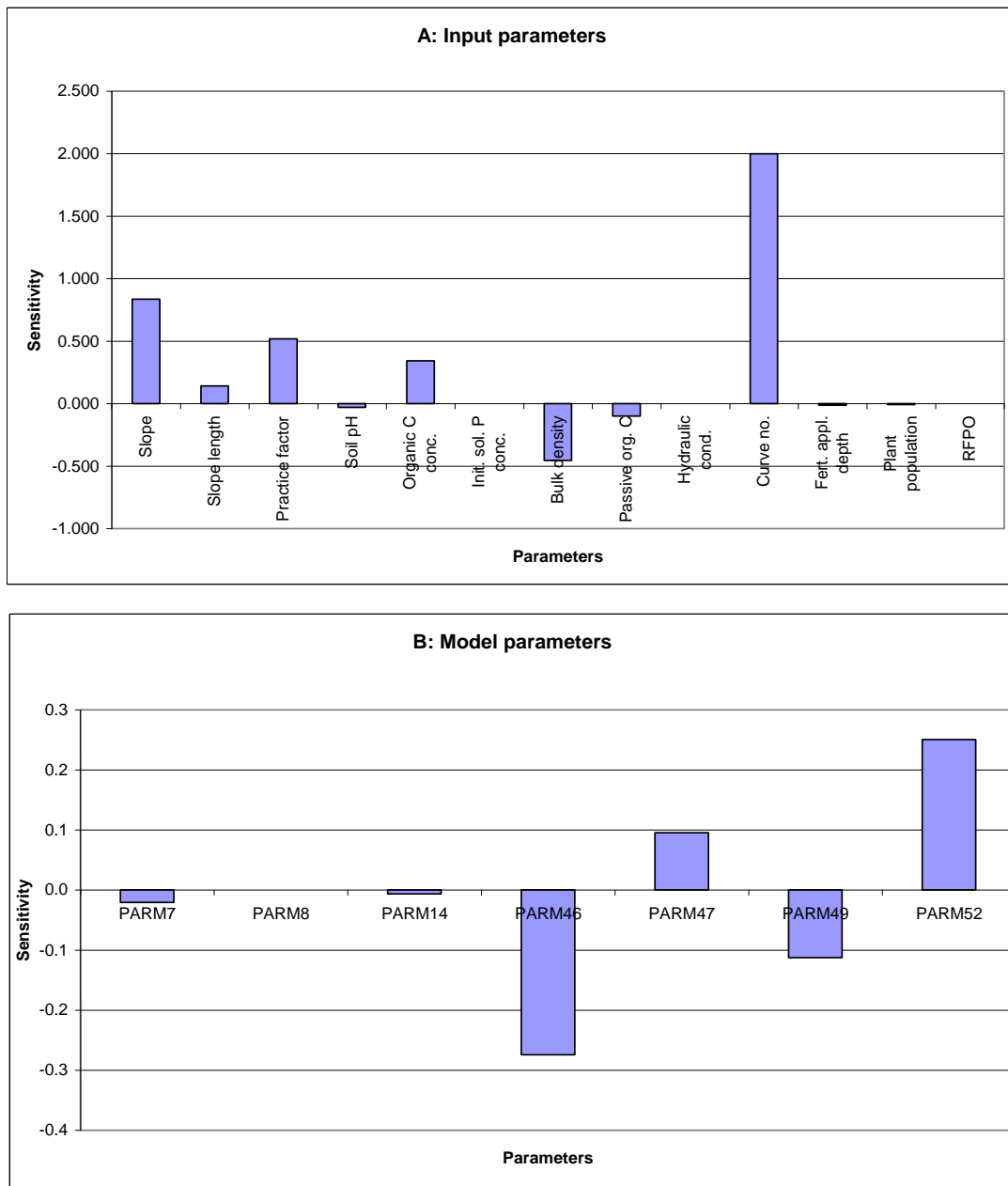


Figure 4. Sensitivity of Edge-of-Field Organic N Losses to NTT Input and Model Parameters

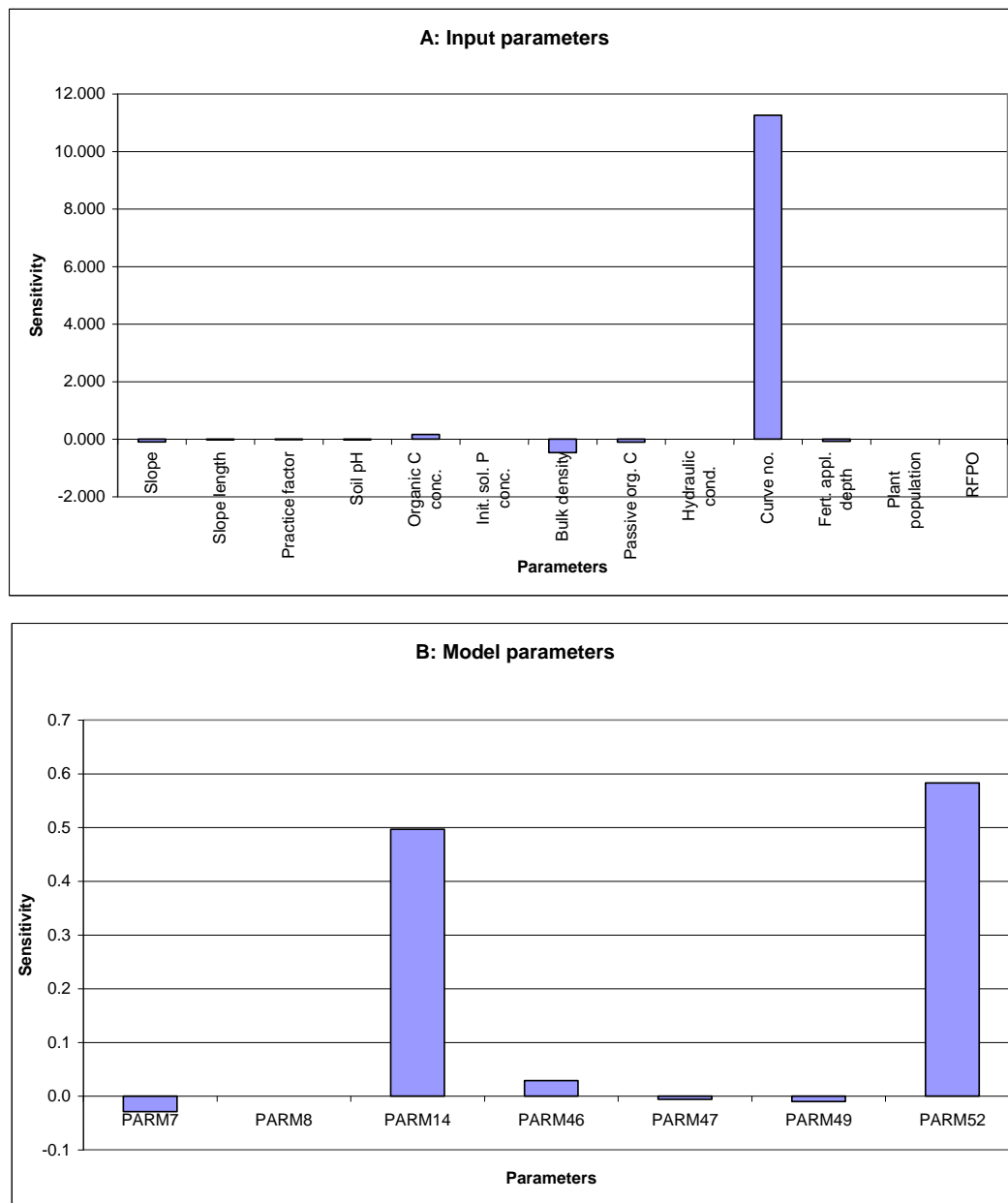


Figure 5. Sensitivity of Edge-of-Field Nitrate Losses to NTT Input and Model Parameters

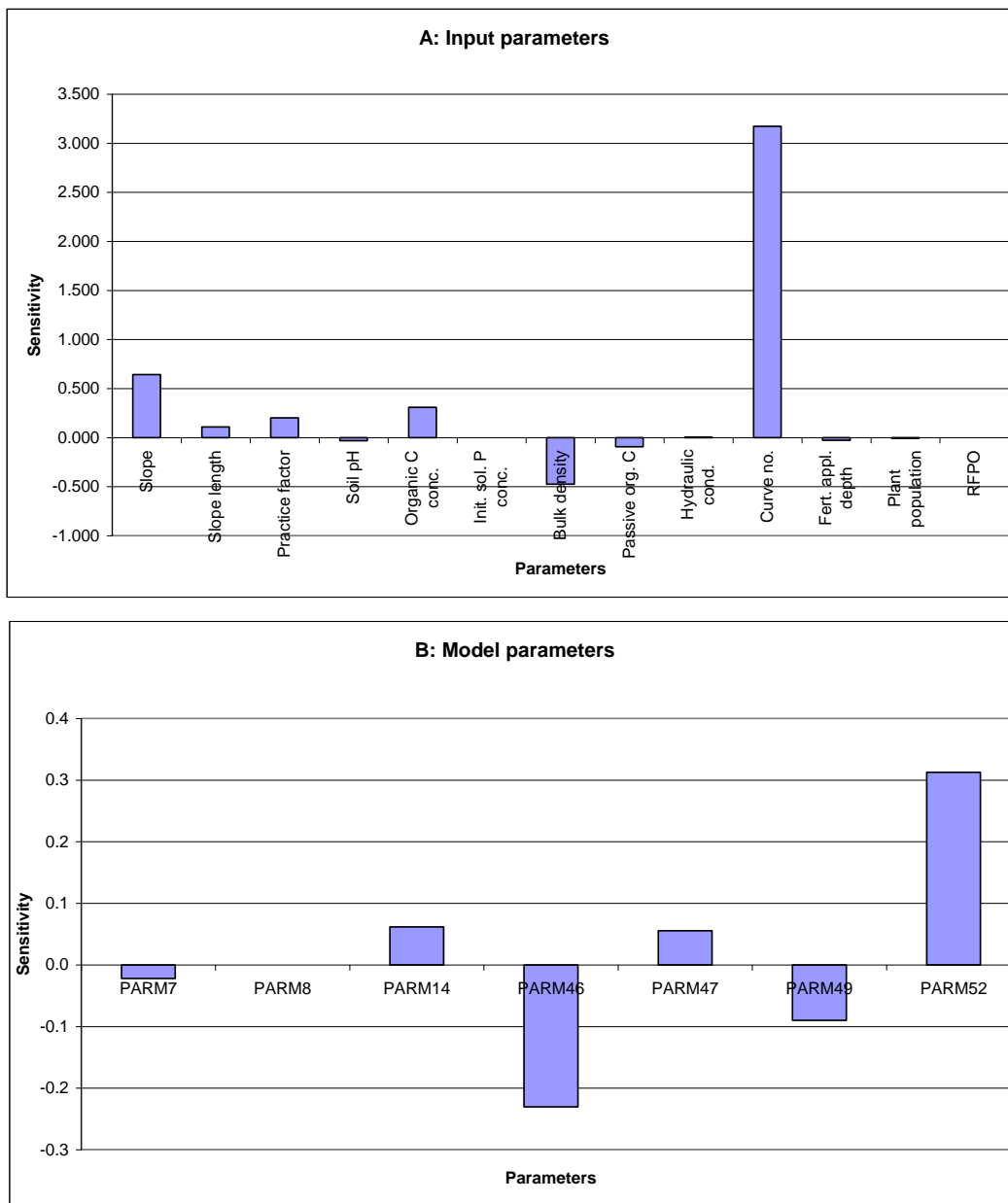


Figure 6. Sensitivity of Edge-of-Field Total N Losses to NTT Input and Model Parameters

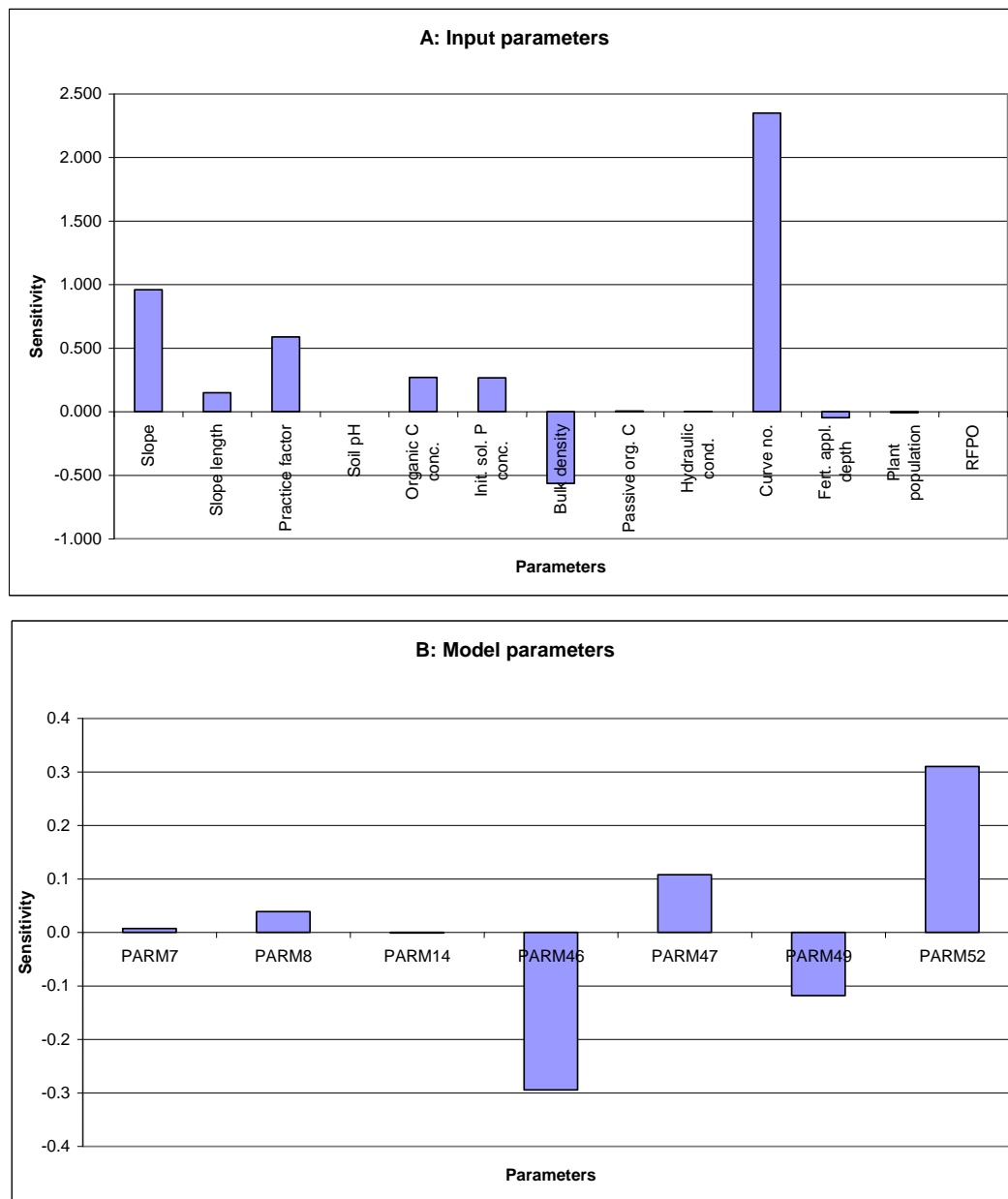


Figure 7. Sensitivity of Edge-of-Field Organic P Losses to NTT Input and Model Parameters

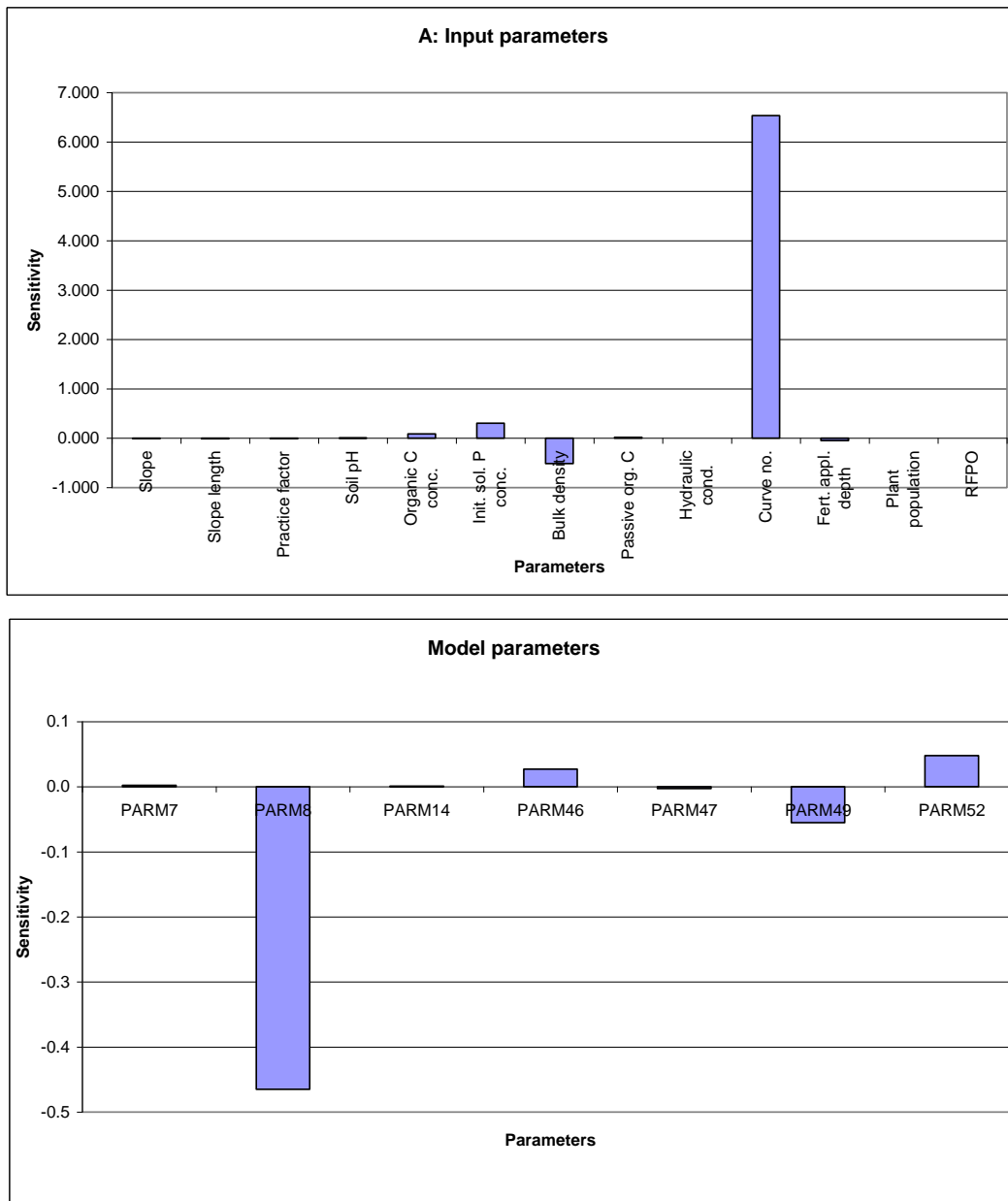


Figure 8. Sensitivity of Edge-of-Field Soluble P Losses to NTT Input and Model Parameters

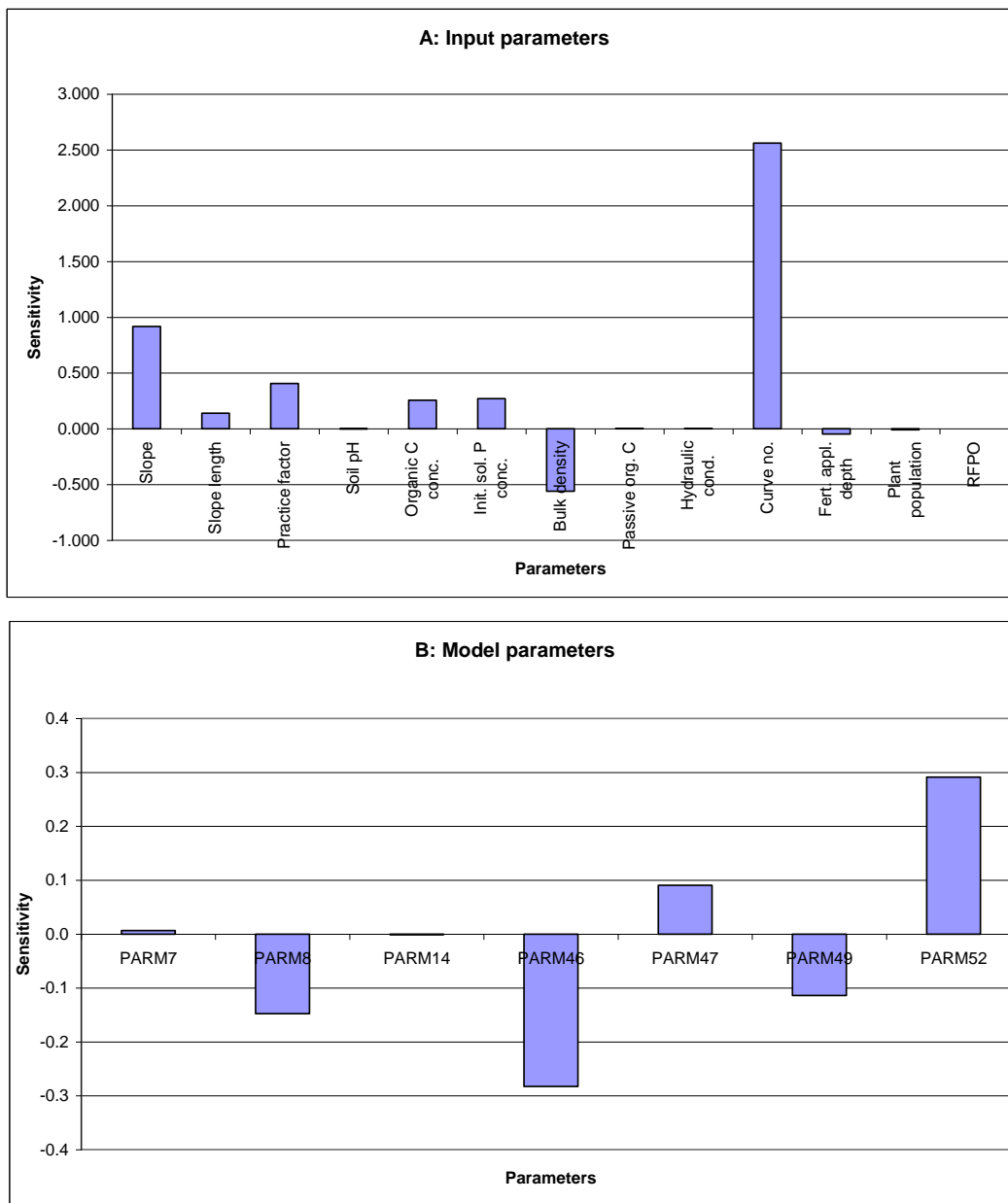


Figure 9. Sensitivity of Edge-of-Field Total P Losses to NTT Input and Model Parameters

4. EVALUATION OF CONSERVATION PRACTICES

The NTT interface has been developed to allow users to select specific practices to be simulated on each field in in a conservation plan. This listing of conservation practices available in NTT was provided in previous section 2. The user interface and backend database were developed to provide users the feedback on how each practice will be implemented by NTT to parameterize APEX. As much as possible, the interface and database were designed to make the necessary parameter adjustments to APEX automatically, with limited additional user interaction. For some types of practices, the user must provide additional information (such as the specific location of a grassed waterway) in order for APEX to be accurately parameterized. For these types of practices, NTT provides additional user feedback as guidance for properly setting the additional inputs.

In the NTT program, conservation practices are categorized into the structural practices (STPs) and non-structural practices (NSTPs). In general NSTPs include practices such as tillage, nutrient management, cropping system changes, and other cropland activities based on knowledge and experience of farmers. In other words, NSTPs are management practices that a farmer or land manager implements and are usually based on annual decisions, which involve changing the way cropland is managed to achieve production or conservation goals. In contrast, STPs are considered as more permanent practices and require more than annual management decisions and usually require engineering designs, surveying, and other technical work.

4.1 Simulation of Non-Structural Practices (NSTPs)

NTT provides flexible options for simulating alternative tillage practices as well as nutrient applications on crop and/or pasture lands at the “Management Information” page.

The underlying APEX model within NTT simulates each individual field operation separately. Nutrient applications are specified by date of application, frequency within a year, rate, form (i.e., dry or liquid commercial fertilizer and/or solid or liquid manure application), and mode (i.e., surface or injected) of application. A fertilizer data file that is modified by the NTT program allows users to specify any combination of nitrogen and phosphorus in each nutrient application. Any number of nutrient applications can be made on each day of the simulation period. Thus the tool provides great flexibility for evaluating a wide range of nutrient management practices including split nitrogen applications, reduced nutrient rates, and other changes in timing, frequency, as well as method and depth of nutrient application.

The APEX model within NTT simulates the fate and transport of nutrients and the resulting impacts on crop yields, sediment losses, and associated nutrient losses from the field.

NTT also provides flexibility in simulating tillage operations by selecting the tillage operation from the list of “tillage operation list. The impacts of tillage operations on soil conditions are controlled by various APEX parameters as well as a tillage data file that contains corresponding parameters for each tillage operation. The tillage parameters can be modified, and these parameters control tillage depth, harvesting efficiency, field efficiency of tillage operations, and many other factors that indicate how each tillage pass is performed on the field.

Other farm management practices such as cover crops, contour buffer strips, various crop rotations, change of land use, prescribed grazing, and many combinations of NSTPs and STPs could be simulated (evaluated) in NTT. In the following sections some of these practices will be discussed.

4.2 Simulation of Structural Practices (STPs)

A number of the farm structural practices described in the USDA-NRCS “National Conservation Practice Standards (www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/?cid=NRCSDEV11_001020) can be evaluated by NTT. The following practices are among the most common management STPs that can be simulated in NTT:

4.2.1 Tile Drainage (DRT)

Tile drainage is a practice for removing excess water from the subsurface of soil intended for agriculture. Drainage brings excessive soil moisture levels down for optimal crop growth. Tile drainage is often the best

recourse for reducing high subsurface water levels to improve crop yields. Excessive water also can limit access to the land, particularly by farm machinery.

Tile drainage simulation in NTT increases subsurface flow, which may provide an avenue for increased nutrient losses, particularly nitrate-nitrogen ($\text{NO}_3\text{-N}$) and soluble- P ($\text{PO}_4\text{-P}$), in subsurface flow. Drainage via underground drainage systems is treated as a modification of the natural lateral subsurface flow of the area. Drainage is simulated by the user indicating the depth of the drainage system (TD) and the time required for the drainage system to reduce plant stress (DRT). The value of DRT is set at two-day as default in NTT for simulating tile drainage.

4.2.2 Wetland

Wetlands are those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support under normal circumstances a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands include swamps, marshes, bogs and similar areas. The wetland area is simulated as a shallow reservoir (0.3-m depth) at the outlet of the simulated farm with growing wetland vegetation – it is essentially simulated as an artificial wetland and not a natural wetland. The slope of wetland area is set as one percent. The surface area of the wetland must be inputted by the user.

Simulated wetlands trap sediment, reduce runoff, increase infiltration and also increase uptake of water and nutrients by the vegetation in the area covered by the wetland.

In the future version of NTT the users will be able to modify/input the wetland physical properties. Similarly, users would be able to simulate reservoir as well.

4.2.3 Filter Strips, Riparian Forest Buffers, Waterways, and Contour Buffer Strips

A. Filter Strip (FS)

FS is an area of vegetation, generally narrow in width and long across the downslope edge of a field, that slows the rate of runoff, allowing sediments, organic matter, and other pollutants that are being conveyed by the water to be removed by settling out. Filter strips reduce erosion and the accompanying sediment-bound pollution.

The original method is to route flow from an upstream area through a filter strip. In this case the filter strip is a separate subarea and is considered a routing reach. The second method of filter strip simulation is useful in watersheds with fairly large subareas where the exact location of the filter strips is not known. In this case the user simply inputs the filter strip flow length and the fraction of the subarea that is controlled by filter strips. In all cases sediment, nutrient, and pesticide loads in surface runoff are reduced as the surface runoff passes through the filter strip.

Filter strip is specified in NTT by indicating its width and the type of crop planted. The width of filter strip is used to calculate its area. The inputted FS area along with its width can identify the FS shape. The area of filter strip is subtracted from the main farmland and is simulated as a separate field (i.e., subarea) and is considered a routing reach. Flow, sediment, and nutrients are routed from the farmland (i.e., upland field) to the filter strip before leaving the edge of the farmland.

In NTT, filter strips function by providing for better infiltration of soluble nutrients, trapping of sediment, and uptake of water and nutrients by the filter strip vegetation. Management for the FS includes planting of a proper FS crop that can be selected from a choice list by the users. Also, the fraction of buffer/floodplain flow (FFPQ; 0-1.0) – that is, the percentage of upland flow that goes through the FS need to be entered by the user. The saturated hydraulic conductivity values in the filter strip subarea are modified for this practice

(it is set to 0.1 mm hr^{-1}). Also, the FS field's Manning's N, channel C (USLE Crop Management Channel Factor, RCHC) and Channel Manning's n are all adjusted to reduce channel erosion in the vegetation strips under this scenario. The modified upland field area is used to adjust the final crop yield.

B. Riparian Forest Buffer (RFB)

RFB is a grassed and forested (predominantly trees and shrubs) zone of land adjacent to a body of water such as a river, stream, pond, lake, marshland, estuary, canal, playa or reservoir. The RFB includes a grass filter strip, and an area of forest buffer that includes planted pine as well as a perennial grass. The routed water, sediment, and nutrient from the upland first passes through grass filter strip and then through the forest area before they reach the water body at the edge of the field. The grassed strip and forested area trap sediment and increases infiltration, thereby reducing sediment and nutrient losses. Plant uptake of nutrients in the forested area also reduces nutrient losses downstream. RFB is simulated in a manner similar to the filter strip practice with the additional assumption that there are trees and shrubs along the length of the riparian zone in addition to the grasses that are growing in the simulated area.

Also, field (RFB) Manning's N, channel C (RCHC) and Channel Manning's N are all adjusted to reduce channel erosion in the vegetation strips under this scenario.

Flow from cropland is routed across the grass filter strip and then routed through the riparian forest. Both grass and forest zones are simulated as floodplains. In the RFB the fraction of surface runoff, simulated as overland flow (FFPQ; 0-1.0) is defined by users. The remaining surface flow is assumed to pass through small channels, which are parameterized in APEX as a single reach channel. Slope length for the FS and RFB are computed based on the upland field slope. Similar to FS, area of upland field is adjusted by subtracting the area of the RFB. The modified upland field area is used to adjust the final crop yield.

C. Grassed Waterways (GW)

GW are natural or constructed vegetated channels that conduct and dispose of overland flow from upstream areas. Simulated grassed waterways reduce flow, trap sediment, and increase infiltration within the area of the grassed waterway. Grassed waterways typically work by increasing surface roughness which reduces the velocity of flow. Grassed waterways are simulated in NTT as a function of their width and the type of vegetation planted. The width of the waterway is used to calculate its area. The area of upland field is adjusted by subtracting the area of the grassed waterway. The modified upland field area is used to adjust the final crop yield. Also, field (grassed waterway) Manning's N, channel C (RCHC) and Channel Manning's N are all adjusted to reduce channel erosion in the vegetation strips under this scenario.

D. Contour buffer strip (CBS):

CBS is an area of land maintained in permanent vegetation (such as perennial grass) that helps to control air, soil, and water quality and address other environmental problems primarily on land that is used for agriculture. Buffer strips trap sediment and enhance filtration of nutrients and pesticides by slowing down runoff that could enter the local surface waters.

The contour buffer strip is simulated based on the width of the buffer and main field crop and management practices, and the type of the crop planted and management on the buffer strips. The number of strips and area are calculated according to the total field area and the widths of buffer and main field, which are inputs to the model. The surface and subsurface flow are routed from one strip to another until it reaches the edge of the field. Also, the grassed-buffer strip Manning's N, channel C (RCHC) and Channel Manning's N are all adjusted to reduce channel erosion in the vegetation strips under this scenario. The area of upland field is adjusted by subtracting the total area of the CBS (permanently vegetated) portion of the field. The modified upland field area is used to adjust the final crop yield.

4.2.4 Stream fencing (Livestock Access Control) (SF)

SF is to keep cattle out of streams, is seen as a way to improve water quality. Fencing will prevent animal defecation in streams, which constitutes a direct contribution of manure, manure nutrients, and pathogens to the surface water resource. In addition, stream fencing prevents bank erosion and protects the aquatic habitat.

SF is simulated by indicating the number of animals in the stream, the daily amounts of manure produced by the selected animal (including horses, dairy cows, swine, cattle, sheep, and goats), and the time (hours/day) and days of a year the animals spend in stream. In NTT, stream fencing eliminates or reduces direct nutrient deposition in streams as point source and stops the destabilization of stream banks that is often caused by livestock traffic. This is done by simulating the area between the fence and edge of stream as FS field. The user has the choice to describe the area, efficiency, and the type of grass growing for the new FS. It is important to know that NTT would not allow the selection of another FS for the same stream channel from the “management Information” page.

The defecated manure from animals in the stream is considered as a point source of nutrients in the water. The amounts of nutrients (N and P) in solid and liquid forms are calculated based on the type of manure produced from the specific animal (provided by the user or default values) and the period of the year they spend a portion of their time in the stream.

4.2.5 Terrace System (TS)

TS is a leveled section of a hill sited cultivated area, designed as a method of soil conservation to slow or prevent the rapid surface runoff of water. Terraces decrease hill slope-length, reduce formation of gullies, and intercept and conduct runoff to a safe outlet thereby reducing sediment content in runoff water. Often, in application the landscape is formed into multiple terraces, giving a stepped appearance. Terracing in NTT is simulated by reducing the “erosion control practice factor” (PEC) and initiated by simply turning the switch on at the “Conservation Practices” page. The PEC factor reduction is based on field slope. Table 8 provides the PEC factor reduction as related to field slope.

Table 8. Upland field slope and PEC factor

Upland Field Slope % (SLP)	PEC Factor (0-1)
< 2	0.60
2.01 to 8	0.50
8.01 to 12	0.60
12.01 to 16	0.70
16.01 to 20	0.80
20.01 to 25	0.90
>25	1

4.2.6 Pond (PND)

A PND is a water impoundment made by constructing an embankment or by excavating a pit or dugout. Ponds are usually constructed to provide water for livestock, fish and wildlife, recreation, fire control,

development of renewable energy systems and other related uses, and to maintain or improve water quality. In NTT the fraction of the field controlled by ponds (FCO) is the only input data required for simulating ponds. The water, sediment, and nutrient storage and release are calculated in NTT on a daily basis.

4.2.7 Streambank stabilization (SBS)

Erosive stream banks are re-shaped and seeded, and sometimes protected with rock rip-rap or seeded with bio-engineering materials under this management practice. Stabilizing the streambank of the streams protects water quality, improves fish habitat, and the vegetation provides habitat for birds and small animals. Upon the selection of this management practice by the user, the channel USLE C and K along with channel Manning N factors are adjusted in NTT to reflect the effect of this management practice on water quality in the stream channels.

4.2.8 Land leveling (LL)

LL will facilitate the efficient use of water on irrigated land and is accomplished by reshaping the surface of land to be irrigated, to planned lines and grades. To simulate this management practice in NTT, users need to provide the new average field slope (SLP) after the land treatment. NTT will use the new average field slope for simulating the leveled field.

4.2.9 Grazing (GRZ)

GRZ operations in NTT can be simulated for different types of animals (including beef cattle, dairy cows, horses, goats and sheep). Each simulated farm is represented as an owner (or even multiple owners) in NTT each owner may have up to ten herds or groups of animals. Each herd is characterized by forage intake rate in kg/head/day, grazing efficiency (accounts for waste by trampling, etc.), manure production rate from defecation in kg head/day, urine production in liters/head/day, and carbon and soluble and organic N and P fractions in the manure.

Grazing may occur throughout the year or may be allowed only at certain times. There are two types of grazing managements available in NTT:

- A. Continuous Grazing:** Under this system, grazing may be started and stopped for any field by using a start and stop grazing command in the management file. Grazing corn stubble after harvest is a good example of initiating and stopping grazing. In addition, grazing stops automatically when a user-adjustable “grazing limit” for each herd is reached. The “grazing limit” is the minimum vegetation biomass cover. However, this limit might be adjusted for different management practices.
- B. Rotational Grazing:** Under this management system, the animals are rotated in set of paddocks during specific period and kept out for selected period during the year. The rotational grazing is all automated process in NTT.

4.2.10 Irrigation and Fertigation

NTT simulates four types of irrigation (sprinkler, drip, furrow/flood, and furrow diking) by following two methods:

- A. MANUAL:** if manual irrigation is used, irrigation is applied according to the amounts and dates specified by the user in the management operation page.

- B. AUTOMATIC:** If automatic irrigation is used, the amount applied per application is equal to the maximum single application amount and frequency set by the user for each farm. Under auto-irrigation option, the irrigation is applied when the irrigation trigger (frequency and plant water stress level) is reached. Frequency is the days when user is irrigating and water stress is simply the percentage of plant-water stress (0-100%) set by the user. For instance the user might wishes to make irrigation available to the plant at 0.0 percent stress level (IEF = 0), however, might not be able to irrigate every 14 days. The irrigation characteristics in NTT set by user governs the auto-irrigation process in NTT,

Runoff based on irrigation efficiency EFI is removed through runoff prior to infiltration into the soil. If the amount of irrigation is greater than the amount of water needed to bring the soil to field capacity, the model will run off the fraction (EFI), fill the profile to field capacity and the remaining water will be percolated through the soil. This may cause leaching of nutrients, however. Soluble nutrients are leached through the soil or removed with runoff.

Fertigation by NTT is similar to general irrigation. However, user can apply N by entering the N-concentration with irrigation water. NTT also can provide the auto N application in fertigation process. In this case yuer should set the N concentration at 0.0.

4.2.11 Furrow Dikes

Furrow dikes are a type of surface (furrow) irrigation system Furrow dikes are a small earthen dams formed periodically between the ridges of a ridge-furrow tillage system or, alternatively, small basins created in the loosened soil behind a ripper shank or chisel. The furrow diking practice is known by many names, including tied ridges, furrow damming, basin tillage, basin listing, and microbasin tillage. The dikes or basins store potential runoff on the soil surface, allowing the water to infiltrate thus, decreasing storm or irrigation runoff and increasing storage and plant available water in the soil. The required input data for furrow diking are similar to those of auto irrigation and are easily entered in the NTT management screen. However, the “Furrow diking safety factor” needs to be entered by the user in the NTT. FDSF is the fraction of furrow dike volume available for water storage. FDSF controls the volume of water that can be stored in the dike before water tops over the dike. This variable is used to account for uncertainty in the volume of the furrow dike.

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