Journal of Water Resource and Protection, 2019, 11, 554-580
http://www.scirp.org/journal/jwarp
ISSN Online: 1945-3108
ISSN Print: 1945-3094

Comparing the Effects of Inputs for NTT and ArcAPEX Interfaces on Model Outputs and Simulation Performance

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How to cite this paper: Nelson, A.M., Moriasi, D.N., Talebizadeh, M., Tadesse, H.K., Steiner, J.L., Gowda, P.H. and Starks, P.J. (2019) Comparing the Effects of Inputs for NTT and ArcAPEX Interfaces on Model Outputs and Simulation Performance. *Journal of Water Resource and Protection*, **11**, 554-580.
https://doi.org/10.4236/jwarp.2019.115032

Received: April 9, 2019
Accepted: May 19, 2019
Published: May 22, 2019

Abstract

The Agricultural Policy/Environmental eXtender (APEX) model has five different interfaces used to process and build simulation projects. These interfaces utilize different input databases that lead to different model default values. These values can result in different hydrologic, crop growth, and nutrient flow model outputs. This study compared structural and input value differences of the ArcAPEX and Nutrient Tracking Tool (NTT) interfaces. Long-term, water quality data from the Rock Creek watershed, located in Ohio were used to determine the impact of the differences on computation time, parameter sensitivity, and streamflow, total nitrogen (TN), and total phosphorus (TP) simulation performance. The input structures were the same for both interfaces for all files except soils, where NTT assigns three soil files per field, rather than a single one in ArcAPEX. As a result, computation times were three times as long for NTT as for ArcAPEX. There were twelve sensitive parameters in both cases, but the order of sensitivity was different. Both interfaces simulated streamflow well, but ARCAPEX simulated evapotranspiration, TN, and TP better than NTT, while NTT simulated crop yields better than ArcAPEX. However, none of the models met all of the performance criteria for either interface. Therefore, more work is needed to ensure models are properly calibrated before being used for scenario analysis. While it is acceptable for the values to be different from the SSURGO database, there is no documentation explaining the rationale for the modifications from the original source. This is one of the examples that highlights lack of detailed documentation that would be useful to model users. Overall, the results indicate that different interfaces lead to different model simulation results and, therefore, the authors recommend users specify the interface used and any modifications made to the associated databases when reporting model results.

Keywords

Agricultural Policy Environmental eXtender (APEX), Calibration, Sensitivity Analysis, Parameterization, Model Databases

1. Introduction

Nutrient transport to water ways is of great concern to proper land management [1] [2]. Fertilizer application, usually a combination of nitrogen, phosphorus, and potassium, is one of the important inputs in crop production [3]. However, when nitrogen is overapplied or when the nitrogen use efficiency of a crop is low, the excess of nitrogen is transported to waterbodies or leached into groundwater, which can have far-reaching effects [1]. The effects include pollution such as water contamination and eutrophication of downstream sites, and nitrogen loss from the field and hence reduced nitrogen use efficiency of crop, and increased fertilizer costs to farmers [1] [4] [5]. Hydrologic and water quality models such as the Soil and Water Assessment Tool (SWAT) [6] and the Agricultural Policy/Environmental eXtender (APEX) [7] have been widely used to quantify the impacts of various management systems on water resources [8] [9] [10] [11] [12].

There are many studies comparing the impact of models [[12] [13], etc.], soil [[13] [14] [15] [16] [17], etc.] and weather [[17] [18], etc.] data sources, evapotranspiration (ET) calculation methods [19], and digital elevation model (DEM) resolutions [[20] [21], etc.] on model outputs, performance, and scenario results. However, based on the literature review, there are no studies that report the impact of the interfaces used to build models on model outputs and performance. Interfaces developed for hydrologic and water quality models are mainly used to pre-process data and create model input files for simulations [22] [23] [24]. However, different interfaces utilize different databases to derive model input. This can result in different default parameter values, which can lead to a different set of simulated outputs, conclusions, and recommendations. Model users choose an interface based on accessibility and ease of use and could benefit from a study that determines the potential impacts of the selected interface on model outcomes.

Models and interfaces utilize regional or national DEM, soils, and crop databases in order to provide default model input values for a given study area. Many studies present the advantages, disadvantages, and best methods of using databases in modeling [14] [15] [25] [26]. Some of these databases, such as soils and crop, may be modified by the model and interface developers based on the structure and possible quality assurance/quality control procedures. Although the developers give the users the option to modify the inputs, in most cases, model users don't have measured data, especially at the watershed scale, to adjust the default parameter values. Therefore, many studies use the default values obtained from these databases without modification [19] [21] [26] [27] [28] [29] [30].

The APEX [7] [8] model is a watershed simulation model used to assess the impact of land management practices on water flow, sediment, and nutrients. APEX is a direct extension of Environmental Policy Integrated Climate Model (EPIC) [31]. There are five different interfaces used to process and build APEX model projects, including ArcAPEX [32], iAPEX [33], WinAPEX [34], APEX for Linux (https://epicapex.tamu.edu/model-executables/), and the Nutrient Tracking Tool (NTT) [35] [36]. Each of these interfaces have been used for different applications [15] [20] [29]. Monks *et al.* [15] used WinAPEX to compare the effects of different soil datasets on streamflow, surface runoff, and crop yields in Washington state, while Nelson *et al.* used ArcAPEX to build projects to compare the effect of the length of calibration period on hydrologic outputs [28] and examining the need for soft data in the calibration process [29]. Tadesse *et al.* [19] used NTT to compare the different evapotranspiration (ET) formulas available within the APEX model. One of the major structural differences between NTT and ArcAPEX interfaces is that ArcAPEX uses only the predominant soil for each subarea [37], while NTT assigns a maximum of three soils for every subarea, representing the most predominant soils in the area of interest [38]. Because model computation time takes place at the subarea level, this implies that a model built using NTT will require as much as three times the computation time to complete as one built by the ArcAPEX interface. However, one would hypothesize that although a model built using NTT requires more computation time, it should result in more realistic model outcomes because three soils for each subarea capture the variability better relative to the single soil used in ArcAPEX. However, none of the reported APEX literature presents the impact of the interface used on model outcomes. Therefore, the objectives of this study were to: 1) compare structure and input values of the ArcAPEX and NTT interfaces, and 2) determine the impact of the differences on simulated hydrology and water quality outputs, computation time, parameter sensitivity, and calibration performance.

2. Methods

2.1. Interface Input Structure

ArcAPEX is an ArcGIS-based user interface that incorporates soil data, topographic, land use, and a built-in APEX-Parameters database to simulate hydrologic and agricultural processes over a field to basin scale drainage area [32]. The NTT interface was developed to enable assessment of impacts of management practices and to facilitate water quality trading. It is a web-based interface with linkage to the APEX model [35].

The main APEX input files are CONTROL, PARM, Soils, and several management files (for operations, fertilizer, grazing, etc.). CONTROL and PARM files contain global parameters, meaning that these parameters are general and contain many coefficients used in different equations and the miscellaneous parameters used. The values of these parameters can be adjusted based on the crops, soils, and management practices representing the farming systems found in different regions of US [35] [38]. While the ArcAPEX and NTT interfaces utilize similar input files, there is a major structural difference with respect to the soil databases. Differences in soil databases include how soil properties are organized by layers for APEX and, more significantly, the number of soils for each subarea/or area of interest. In ArcAPEX, only the predominant soil is used for each subarea [37]. A dominant soil is assigned to each subarea from the list of soils in the study area (listed in the SOILCOM.DAT file). A file named filename.sol is used to describe each soil. The NTT interface allows users to verify, modify or delete soils copied from the SSURGO soil database and add or edit layers for the particular field selected in the field's page. The NTT assigns a maximum of three soils for every subarea, representing the most predominant soils in the area of interest [38].

2.2. Interface Input Values

The values of the parameters in the Control, Parameter, and Soil files for the respective interfaces were determined after the model was built (see details below). Model building includes study area description, data sources, and model setup.

2.2.1. Study Area

Nelson *et al.* [29] provide a detailed description of the study area; thus only a summary is provided here. Rock Creek, located in northern Ohio, is a third order tributary of the Sandusky River (**Figure 1**), which flows north through the middle of Seneca County and drains into Lake Erie through Sandusky Bay [39] [40] [41].

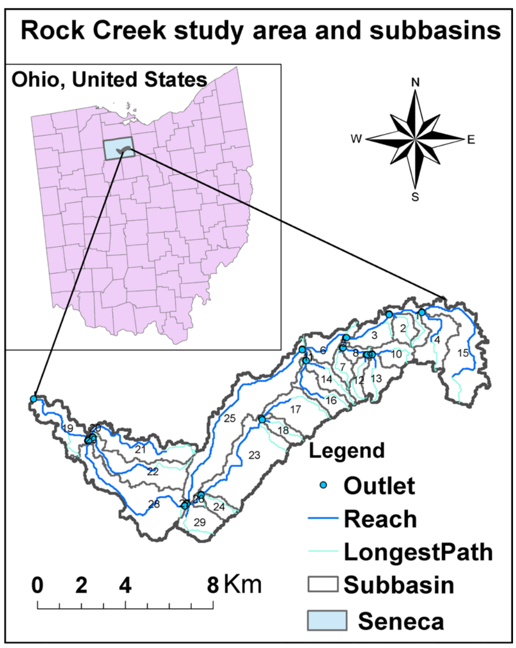

Figure 1. APEX-defined subareas for Rock Creek watershed in northern Ohio.

Rock Creek watershed is approximately 7500 ha and has nineteen identified soil series, primarily from the Blount-Pewamo-Glynwood soil group [42]. These soils are moderately well drained to very poorly drained, and are located on slopes of 0% - 7%. Tile drainage occurs in ~90% of the agricultural fields, primarily in areas with 3% or less slope. The depth of tile drainage is approximately 0.9 m [43].

Seneca County's climate is typical of the temperate mid-continent region. Rock Creek watershed is comprised of about 82% agricultural land, 13% forest land, and 6% urban land. Of the croplands, 50% are soybean, 30% are corn, and 20% are wheat [42]. Corn-soybean and corn-soybean-wheat are the most common crop rotations.

2.2.2. Data Sources

Three GIS data layers are required for the APEX model: digital elevation model (DEM), soils, and land use data. Sub-area parameters such as slope and slope length were calculated using a 30-m DEM obtained from the USGS (http://viewer.nationalmap.gov/launch/). The same DEM was used to define the stream network. The parameters required for simulating streamflow, as well as performing sediment yield using the MUSLE soil erodibility K factor, were parameterized within each interface using the Soil Survey Geographic (SSURGO; http://websoilsurvey.nrcs.usda.gov). Streamflow simulation required soil chemical, physical, and hydraulic model inputs, including maximum rooting depth, soil hydrologic group, moist bulk density, soil profile depth, saturated hydraulic conductivity, available water capacity of the soil layer, and soil texture data (% clay, sand, silt, and rock fragment content) (**Figure 2**). Surveys and reports on the study area were used to obtain land use and land cover information as well as

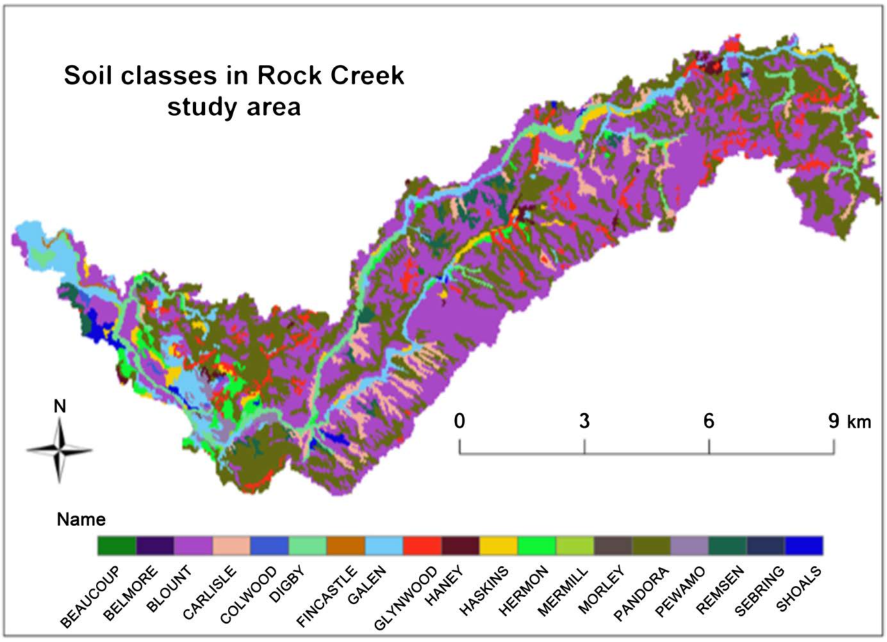

Figure 2. SSURGO soil map for rock creek, Ohio.

general land management data, including tillage types and dates, planting, fertilization, and harvests for most fields [unpublished data, Heidelberg University; [28] [29]]. Daily weather data (e.g. minimum and maximum temperature, and rainfall) were obtained from the PRISM Climate Group, Oregon State University [44].

The USGS monitors water quality at the outlet of Rock Creek, 0.8 km (0.5 mi) from the confluence with the Sandusky River (USGS station 04197170) as part of the Heidelberg Tributary Loading Program (HTLP). The station has been in operation since 1982 [45] and is described in detail in Nelson *et al.* [28]. Since the two interfaces calculated slightly different areas for the watershed, the observed values were adjusted according to each interface's calculation of watershed area (7576.54 ha for ArcAPEX and 7560.85 ha for NTT).

The APEX model was constrained with soft data, including the assurance that simulated values were within 15% of the average annual evapotranspiration (ET) and tile drainage (QDR) values of 524 mm [46] and 283 mm [43], respectively. Soft data are information on processes within a budget that may not be directly measured, including those found in literature, such as annual evapotranspiration (ET), tile drainage, crop yields, or certain species of nutrients [47]. The annual average yield ± 35% for corn, winter wheat, and soybeans was used to constrain crop yield data, which were taken from the Ohio Agricultural Statistics 2015 Annual Bulletin and 2009 Ohio Agricultural Statistics reports [48] [49].

2.2.3. Model Setup

The APEX model version 0806 [37] [50] was used in this study. It is important to note that although the NTT interface states that it uses APEX 0806, the executable has been modified. However, the modifications are not documented. ArcAPEX and NTT interfaces were each used to build one project. The APEX project was built (delineated) into subareas along with the corresponding stream network using ArcAPEX [32]. The subarea, APEX's smallest modeling unit, is a function of land use and soil type. An area upstream and contiguous to the outlet at which the flow measurements were made was delineated using the automatic subarea delineation feature on the DEM. The land use, soils, and slope definition tool was used to define the categories appropriately. Using management and land use data collected by study area personnel [51] to define the subareas for creating files resulted in delineation of 29 subareas (**Figure 1**).

Because NTT cannot currently delineate subareas, the shapefile from the ArcAPEX delineation was used to build an APEX project with the NTT interface [35] [36]. Data on land use and management practices were populated using the NTT interface subsequent to delineation and selection of soil and weather data inputs. Management operations included, but were not limited to, crop type, tillage method, planting date, fertilizer type and amount, irrigation type and amount, harvest date. Operations were the same as those entered in the ArcAPEX interface. Subareas were manually routed using the routing scheme adopted from ArcAPEX.

The model was run after creation of all subarea files, creating a default model folder for each interface. The model folder includes all necessary input, control, and executable files along with the output files. The parameterization process was then used to edit and update input and control files. The drainage code (IDR) was set to 900 mm [43] to assign tile drainage to subareas with predominantly crop coverage and slopes < 3% [52]. The Hargreaves [53] method was used to estimate ET in both interfaces.

2.3. Model Evaluation

2.3.1. Sensitivity Analysis

Important model parameters for calibration were identified by performing a global sensitivity analysis (GSA) [54] that used variance-based sensitivity analysis to quantify the contribution of change in model parameters to the change in model outputs. The GSA also provided a flexible water simulation platform for incorporating different sets of model parameters. A GSA was implemented using the APEXSENSUN software [27] which is designed for Monte Carlo-based uncertainty analysis [55]. Defaults assigned by the respective interfaces were not altered for parameters that were not being tested for sensitivity.

Forty-two parameters related to nutrients and streamflow (and defined in [37]) were tested through 20,000 simulations (*i.e.* 20,000 parameter combinations) for sensitivity. The standardized regression coefficient (SRC) was used as a GSA metric for streamflow, total phosphorus (TP), and total nitrogen (TN) predictions in the APEX model. Parameters in which SRC > 0.05 were considered sensitive. The sensitivity of parameters with an SRC > 0.05 for streamflow, TN, and TP simulation was determined based on the percentage bias [PBIAS]; [56] and Nash-Sutcliffe efficiency [NSE]; [57] performance measures. Sensitive parameters based on either NSE or PBIAS were selected and used during model calibration and validation. The equations for all simulated components are described in detail in the APEX model theoretical documentation (30).

2.3.2. Calibration and Model Evaluation

Previous [58] [59] and current literature review found that most studies used only statistical performance measures to determine adequate calibration and validation. While Wang *et al.* [60] recommends that modelers obtain a correct water balance that includes all hydrologic components (e.g. surface flow, subsurface flow, percolation, evapotranspiration) and crop yields, with crop yields as the absolute minimum criteria level if no measured water quantity data are available, few of the ensuing peer reviewed papers follow this recommendation rigorously. According to Nelson *et al.* [29], it is important to utilize the soft data to obtain realistic simulations of various management practices, thus ensuring one gets the right answers for the right reasons [61]. In this study, model performance was assessed using the NSE and PBIAS statistical performance measures calculated with APEXSENSUN [27]. The criteria thresholds for NSE and PBIAS used in this study were the same as those used by Nelson *et al.* [29]. Moriasi *et al.* [62]

considered a model to be calibrated for streamflow if the NSE ≥ 0.50 and PBIAS ≤ ±15%, and for N and P if the NSE ≥ 0.35 and PBIAS < ±30%. In addition, the model was constrained during calibration using soft data [47] value ranges for ET, QDR, and crop yields described earlier. Long-term crop yield ranges (soft data) used to bound the parameter values for corn, wheat, and soybean were 8.6 ton ha^{-1} ±35%, 4.0 ton ha^{-1} ±35%, and 2.9 ton ha^{-1} ±35%, respectively [48] [49]. The statistical performance measures and the soft data constraints together are referred to as performance criteria throughout the rest of this paper. Comparisons on model simulation performance were made for each individual criterion. According to Nelson *et al.* [29], models evaluated on a daily time step did not meet the selected criteria when simulating daily streamflow. This could be attributed to the precipitation and streamflow measurement cutoff at midnight for each day and the lag time between a precipitation event and a streamflow surge. In a study to determine the impact of length of the calibration period on model performance, Nelson *et al.* [28] found that the model performed best at an annual temporal scale when using long term (25 years) data to calibrate the model. This study was performed in the same study area with the same 25 years of measured data. Therefore, model performance was evaluated at an annual time step.

3. Results and Discussion

3.1. Impact of Interfaces on Input Values

3.1.1. Soils Input Files

The ArcAPEX interface soil database has four soil types for the study area, which include Pandora, Galen, Digby, and Blount, while the NTT database has three soils. These include "Blount silt loam end moraine 0 to 2 percent slopes", "Blount silt loam end moraine 2 to 4 percent slopes", and "Blount silt loam ground moraine 2 to 4 percent slopes". ArcAPEX assigns one soil per subarea and creates one soil file per soil type, whereas NTT builds three soil files for each subarea, leading to four soil files for ArcAPEX and 87 soil files for NTT. While both file structures include values for the 19 soil parameters, the ArcAPEX file includes an additional 23 lines of zeros in its formatting, perhaps due to programming. The number of columns beginning at Line 4 indicates the number of soil layers in each soil type, which show a key difference between the ArcAPEX and NTT interfaces and the SSURGO database. Three of the four ArcAPEX soil files had four soil layers, while one type (Pandora) had three. According to the SSURGO database, Pandora has 3 layers, Galen has 3 layers, Digby has 5 layers, and Blount has 4 layers. Each of the three NTT soil files had five soil layers.

Table 1 depicts a comparison of the soil input file values derived from the SSURGO database by ArcAPEX and NTT interfaces, as well as the values from the SSURGO database. Despite both the ArcAPEX and NTT interfaces stating that they use the SSURGO database as their source for soils data, neither match all the values found directly in the SSURGO database. For example, for the organic carbon

Table 1. Parameter values from the soil input files from NTT and ArcAPEX interfaces and SSURGO database. Soil codes and names are taken as written from the soil files.

Interface	Soil code	Name	# of layers	SALB-Soil albedo	HSG-Soil hydrologic group	RTN1-Number of Years of Cultivation at Start of Simulation	Z-Depth to bottom of layer	BD-Moist Bulk Density	UW-Soil water content at wilting point	FC-Soil Water Content at field capacity	SAN-Sand Content	SIL-Silt Content	PH-Soil Ph	SMB-Sum of Bases	WOC-Organic carbon conc. (%)	CEC-Cation exchange capacity	BDD-Dry Bulk density (oven dry)	SATC-Saturated conductivity
NTT	01	Blount silt loam end moraine 0 to 2 percent slopes	5	0.3	D	0	0.1	1.45	0	0	22	56	6.4	0	1.45	12	1.45	11.09
	02	Blount silt loam end moraine 2 to 4 percent slopes	5	0.3	D	0	0.1	1.45	0	0	22	54	6.4	0	1.16	12	1.45	8.23
	03	Blount silt loam ground moraine 2 to 4 percent slopes	5	0.29	D	0	0.1	1.45	0	0	22	54	6.4	0	1.16	12	1.45	8.23
ArcAPEX	PANDORA	PANDORA	3	0.01	B	50	0.18	1.45	0	0	18.34	52.16	7	0	2.03	0	0	1.8
	GALEN	GALEN	4	0.01	B	50	0.2	1.5	0	0	59.66	35.34	7	0	1.74	0	0	290
	DIGBY	DIGBY	4	0.01	B	50	0.28	1.3	0	0	43.81	40.19	7	0	1.74	0	0	17
	BLOUNT	BLOUNT	4	0.01	C	50	0.25	1.45	0	0	24.14	51.36	7	0	1.45	0	0	5.7
SSURGO		Pandora	3	0.3	C/D		0.18	1.66	20.9	32.7	17.5	53	6.7	6	3.5	7.5	1.66	10.152
		Galen	3	0.3	A/D		0.18	1.58	11.1	20.6	59.7	30.3	6.2		3	5.5	1.58	82.8
		Digby	5	0.3	B/D		0.3	1.47	11.3	26.4	9	75	6.5	10	2	14.5	1.47	33.012
		Blount	4	0.29	D		0.25	1.5	17	30	22	56	6.4	12	2.5	18	1.5	33.012

concentration, ArcAPEX ranged from 1.45% to 2.03%, while NTT ranged from 1.16% to 1.45%, and SSURGO ranged from 2% to 3.5%. For texture, NTT used a sand content of 22% for all three soil types, while ArcAPEX sand content ranged from 18% for Pandora to 60% for Galen and SSURGO ranged from 9% for Digby to 60% for Galen. While it is acceptable for the values to be different from the SSURGO database, there is no documentation explaining the rationale for the modifications from the original source. This is one of the examples that highlights lack of detailed documentation that would be useful to model users. Saraswat *et al.* [63] recommend that "*modifications, simplifications, or 'data cleaning' procedures used in preparing the input data, including any assumptions made to acquire or process … data to make it compatible*" be clearly documented. Such documentation is essential because these values affect different processes. For example, soil texture affects infiltration and soil water holding capacity [64] [65], as well as susceptibility of erosion [66], which in turn, affect ET, drainage, and nutrients.

Other parameters that affect the hydrologic processes include the soil water content values at "wilting point" (at 1500 KPa or −15 bars (m/m)) and "field capacity" (at 33 KPa or −1/3 bars (m/m)). While the SSURGO database has values for these parameters, both NTT and ArcAPEX provided a zero in their place. According to the APEX manual, zero is to be entered as a default integer when the value is unknown [37]. However, the zero entered does not represent a value of zero. Rather, the model takes the midpoint of the range given in the manual and utilizes that median as the value in pertinent calculations or functions. For example, for the soil water content at field capacity, the model will use 0.35, the median value of the default range of 0.1 - 0.6. The soil water content levels at the different pressures affect infiltration rates, and therefore calculations of runoff, drainage, and streamflow.

3.1.2. CONTROL Input Parameters

There are 77 Control input file parameters, most of which are held constant for all model runs, but only some of them are presented in **Table S1**. In this study, only parameters related to the equations used, the processes simulated, and where the parameter values were different between interfaces are presented. The notes column in **Table S1** provides more information about the parameters. However, there was no description for some of the parameters either in the manual [37] or the theoretical documentation [30]. As noted from **Table S1**, there are major differences in the default values used by each interface. Parameters such as Return Flow/(Return Flow + Deep Percolation) (RFPO) and Number of years of cultivation at start of simulation (RTN0) directly impact hydrologic processes and nutrient availability. As discussed above, there is no detailed documentation explaining how these default parameter values were determined.

3.1.3. PARM Input Parameters

There are 98 Parameter (Parm) input file parameters that consist of mainly equation coefficients, but only parameters where values were different between interfaces are presented in **Table S2**. Lines 1 - 30 of the Parameter file consist of two fields with one S-curve pair per line. Three of these parameters (Aeration stress—root growth, which affects crop yields and ET values; the snowmelt function, which affects tile drainage and ET; and the plant water stress factor which is based on soil water content and affects ET and crop yields) have different values between NTT and ArcAPEX. Other parameters that may impact on water availability include: Reduces NRCS runoff CN retention parameter for frozen soil, Water stress weighting coefficient, Hydrograph development parameter, Estimates drainage system lateral hydraulic conductivity, Water table recession coefficient, Limits daily water table movement, Water table recession, Subsurface flow factor, and Flood evaporation limit parameters. Sediment routing travel time coefficient and Partitions nitrogen flow from groundwater are examples of parameters that affect nutrient movement. The two parameters relating to pest damage (Pest damage moisture threshold and Pest damage cover threshold) may impact crop yields and ET.

3.2. Impact of Different Input Values

3.2.1. Default Model Simulations

The results of the comparisons between observed and simulated outputs for the two interfaces are presented in **Table 2**. The average area was used to compute the observed values used for comparison. Both ArcAPEX and NTT simulated streamflow and tile drainage within 30%. However, there were major differences in simulated ET with ArcAPEX overpredicting ET by 15%, while NTT underpredicted by 56%. In general, NTT simulated nutrients and crop yields better than ArcAPEX, with crop yield errors ranging from 13% - 35% for NTT and 37% - 69% for ArcAPEX (**Table 2**). While NTT simulated total phosphorus better than ArcAPEX, it should be noted that the ratios of the components that form total P (the summation of YP = phosphorus loss in sediment, QP = phosphorus loss in surface runoff, QDRP = phosphorus loss in drainage, and QRFP = phosphorus loss in quick return flow) are vastly different (**Table 3**). For example, 4% of TP comes from tile drainage for NTT and 60% for ArcAPEX. King *et al.* [43] reported that tile drainage accounted for 40% of the total P exported from the watershed.

The differences in simulated total nitrogen could be explained by the soil properties and the Number of years of cultivation at start of simulation (RTN0) parameter (**Table S1**). ArcAPEX has soils listed as hydrologic group B with high sand content, which have higher infiltration rates than the NTT soils, which are listed as hydrologic group D with higher clay content (**Table 1**). This can lead to higher nitrogen leaching for ArcAPEX soils, which explains the much higher simulated total nitrogen compared to measured data and NTT simulated values. The RTN0 parameter is set at 150 years for ArcAPEX and 10 for NTT (**Table S1**). This parameter affects the partitioning of nitrogen and carbon into the passive and slow humus pools. The number of years of cultivation before the simulation starts

Table 2. The average annual values using the default ArcAPEX and NTT parameter values. Evapotranspiration (ET), Drainage (QDR).

Components	Measured	Simulated		% difference from the measured mean	
		ArcAPEX	NTT	ArcAPEX	NTT
Streamflow (mm)	368	318	325	−14	−12
ET (mm)	524	603	233	15	−56
QDR (mm)	283	202	206	−29	−27
Total Nitrogen (kg/ha)	42.9	74.9	27.6	75	−36
Total Phosphorus (kg/ha)	4.8	1.3	2.1	−73	−56
Corn (tn/ha)	8.6	5.4	9.7	−37	13
Wheat (tn/ha)	4.0	1.3	2.6	−69	−35
Soy (tn/ha)	2.9	1.3	2.5	−57	−15

Table 3. Annual averages for total phosphorus (TP) and nitrogen (TN) in kg/ha. YP = phosphorus loss in sediment, QP = phosphorus loss in surface runoff, QDRP = phosphorus loss in drainage, QRFP = phosphorus loss in quick return flow, YN = nitrogen loss in sediment, QN = nitrogen loss in surface runoff, QDRN = nitrogen loss in drainage, QRFN = nitrogen loss in quick return flow, RSFN = nitrogen yield in return flow, SSFN = nitrogen loss in lateral subsurface flow.

Components	ArcAPEX	% of total	NTT	% of total
YP	0.20	15.1	1.52	71.4
QP	0.33	25.4	0.52	24.3
QDRP	0.78	59.5	0.09	4.4
QRFP	0.00	0.0	0.00	0.0
TP	**1.30**		**2.13**	
YN	1.27	1.7	6.05	21.9
QN	8.72	11.6	12.16	44.0
QDRN	64.70	86.3	9.18	33.3
QRFN	0.05	0.1	0.01	0.0
RSFN	0.20	0.3	0.20	0.7
SSFN	0.00	0.0	0.00	0.0
TN	**74.94**		**27.59**	

is used to estimate the fraction of the organic N pool that is mineralizable. Mineralization is more rapid from soil recently in sod. Also increasing the number of years the field has been in cultivation increases the amount of C and N in the passive pool. This means it will take longer for the carbon and nitrogen to become available. The increased levels of nitrogen leaching and unavailability of nitrogen from the organic pool as indicated by the number of years of cultivation at the start of simulation parameter may be the reason the crop yields are so much lower in the ArcAPEX simulations.

The comparison of simulated ET and crop yield results highlight a potential issue. For NTT to have simulated crop yields better than ArcAPEX while predicting ET so poorly, and vice versa, indicates that there is a disconnect between ET and crop yields within the model. In addition, the streamflow, drainage, and surface runoff were comparable between ArcAPEX and NTT while simulated ET values were quite different, raising the question of where that missing water in the water budget is going. These differences in the outputs from the default values from the two interfaces lead us to provide two recommendations. Model developers need to take a look at the interactions between water, nitrogen, and crop growth routines, while model users need to pay attention to the soils and control parameter values prior to beginning sensitivity analyses and the calibration process that mainly focuses on the PARM file parameters.

3.2.2. Computation Times

To run the 20,000 model simulations for calibration and sensitivity analysis, the computation time for the ArcAPEX was just over 6 days, while the NTT interface took just under 17 days (**Figure 3**). As discussed above, this is attributed to the utilization of three soil types per hydrologic subunit for NTT, whereas ArcAPEX only assigns one.

3.2.3. Sensitivity Analysis

The rankings of the parameters found to be most sensitive for the two interfaces using NSE and PBIAS are shown in **Table 4**. The same 12 parameters were found to be most sensitive for streamflow, total nitrogen (TN), and total phosphorus (TP) for the ArcAPEX and NTT interfaces. The rankings for the Root growth soil parameter had the same ranking for both the ArcAPEX and NTT interfaces for streamflow and TP (NSE and PBIAS), and the Soil evaporation-plant cover parameter had the same top ranking for streamflow (NSE and PBIAS) and third ranking for TN (PBIAS only).

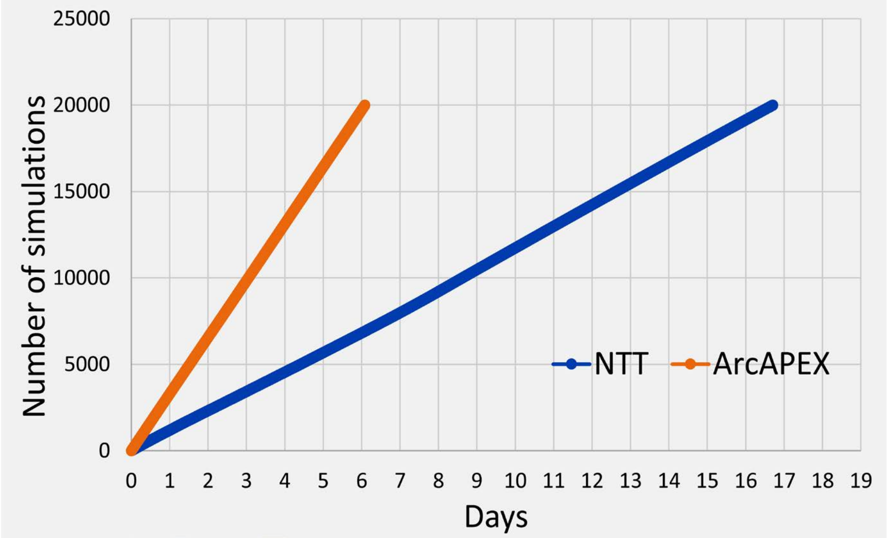

Figure 3. Computation times for the ArcAPEX and NTT interfaces for 20,000 runs.

Table 4. Sensitive parameters and their respective ranking based on PBIAS and NSE performance evaluation measures for the ArcAPEX and NTT interfaces. APEX PARM file parameter numbers in parentheses [20]. NS = Parameter with <0.05 SRC. Total nitrogen (TN), total phosphorus (TP).

	ArcAPEX						NTT					
	Streamflow		TN		TP		Streamflow		TN		TP	
	NSE	PBIAS	NSE	PBIAS	NSE	PBIAS	NSE	PBIAS	NSE	PBIAS	NSE	PBIAS
Microbial decay rate coefficient (70)	7	4	10	5	7	NS	NS	NS	6	1	NS	7
Coefficient adjusts microbial activity function in the top soil layer (69)	5	3	9	NS	4	NS	NS	4	4	5	NS	2
N fixation (7)	NS	NS	5	2	NS	NS	NS	NS	8	NS	NS	NS
Nitrate leaching ratio (14)	NS	NS	1	7	NS	NS	NS	NS	2	2	NS	NS
Rainfall interception coefficient (50)	9	NS	NS	NS	8	6	4	3	NS	NS	NS	9
Root growth-soil strength (2)	2	2	8	6	1	1	2	2	3	NS	1	1
parameter (15)	3	NS	7	8	9	NS	5	NS	NS	NS	2	5
Runoff curve number initial abstraction (20)	4	5	6	NS	2	3	3	NS	5	4	8	NS
RUSLE C-factor coefficient (46)	NS	NS	NS	NS	6	4	NS	NS	NS	NS	5	3
SCS curve number index coefficient (42)	6	NS	NS	NS	3	5	6	NS	NS	NS	3	4
Soil evaporation—plant cover factor (17)	1	1	3	3	10	NS	1	1	NS	3	4	8
Soluble phosphorus runoff coefficient (8)	NS	NS	NS	NS	5	2	NS	NS	NS	NS	NS	6
Volatilization/nitrification partitioning coefficient (72)	NS	NS	4	1	NS	NS	NS	NS	7	NS	7	NS
Water storage N leaching (4)	8	NS	2	4	NS	NS	NS	NS	1	NS	6	NS

3.2.4. Model Performance

The number and range of values of simulations that met individual performance criterion are presented in **Table 5**. For streamflow and drainage, there was little difference between ArcAPEX and NTT. However, ArcAPEX had over 12,500 models meet the criteria for ET, while NTT had zero. For corn and soybeans, NTT had over 16,000 and 14,000 models meet the ±35% target, while ArcAPEX had over 2600 simulations that met the criteria for corn and zero for soybeans. The ArcAPEX interface had three models that met all of the criteria except those for the wheat and soy crop yield. For the NTT interface, over 5800 models met all of the crop yield criteria, but no model met the criteria for ET. For those NTT simulations that met the nutrient criteria, none met the drainage criteria. This difference in model performance may lead users to choose an interface based on the criteria in which they are most interested. However, as can be noted from the results, none of the simulations from either interface met all of the criteria listed. These results can be explained by the findings from the comparison of the outputs using the default values. Based on those results, it was noted that there is a disconnect between ET and crop yields within the model. Also, the results of no NTT model meeting the ET criteria are in line with the results of the default input parameters where there were indications of issues with the water budgets.

Table 5. The number of models and range of values that met the established performance model criteria. Evapotranspiration (ET), Drainage (QDR).

			ArcAPEX		NTT	
		Target Value	#	Range	#	Range
Streamflow	NSE	≥0.50	15951	0.50 - 0.73	16,801	0.50 - 0.77
	PBIAS (%)	±15	8728	−15 - 15	9614	−15 - 15
Water Budget	ET (mm)	445 - 603	12623	445 - 603	0	NA
	QDR (mm)	241 - 325	4192	241 - 325	6474	241 - 325
Total Nitrogen	NSE	≥0.35	18	0.35 - 0.50	0	NA
	PBIAS (%)	±30	230	−30 - 30	8468	−30 - 30
Total Phosphorus	NSE	≥0.35	1528	0.35 - 0.44	1	0.36
	PBIAS (%)	±30	8760	−11 - 30	1789	−30 - 30
Crops	Corn (tn/ha)	5.6 - 11.6	2613	5.6 - 8.6	16,248	5.6 - 10.4
	Wheat (tn/ha)	2.6 - 5.4	10329	2.6 - 5	7197	2.6 - 4.9
	Soy (tn/ha)	1.9 - 3.9	0	NA	14264	1.9 - 2.5

This led us to recommend that the interaction between crop yields, water, and nutrient routines be re-evaluated by the developers, while the users take note of the soils and control parameter values before carrying out sensitivity analyses and model calibration. This indicates more work is needed to ensure models that have proper representation before being used for scenario analysis.

4. Conclusions

In this study, the structure and input values of the ArcAPEX and NTT interfaces were compared and the impact of the differences on simulated water quality and quantity outputs, computation time, parameter sensitivity, and calibration performance was determined. There were major differences in the soils, PARM, and CONTROL input values for the two interfaces that affect water budget components, nutrient transport, and crop growth. It was also noted that the soils input parameter values were different from those in the SSURGO database. While it is acceptable for the values to be different from the SSURGO database, there is no documentation explaining the rationale for the modifications from the original source. Overall, there is a lack of detailed documentation on how these default parameter values were determined that would be useful to model users. Such documentation is essential because these values affect different processes.

ArcAPEX uses only the predominant soil for each subarea, while NTT assigns a maximum of three soils for every subarea, representing the most predominant soils in the area of interest. The differences in this structure of the soils input files affected model simulation times, leading to a computation time three times longer for NTT than for ArcAPEX project.

The comparison of simulated ET and crop yield results using the default input parameter values for the two interfaces highlighted a potential issue. For example, NTT simulated crop yields better than ArcAPEX while predicting ET so poorly, and vice versa, indicating a disconnect between ET and crop yields within the APEX model. In addition, the streamflow, drainage, and surface runoff were comparable between ArcAPEX and NTT while simulated ET values were quite different, raising the question of where that missing water in the water budget is going. These differences in the outputs from the default values from the two interfaces lead us to provide two recommendations. Model developers need to take a look at the interactions between water, nitrogen, and crop growth routines, while model users need to pay attention to the soils and control parameter values prior to beginning sensitivity analyses and the calibration process that mainly focuses on the PARM file parameters.

Sensitivity analysis results indicated that twelve sensitive parameters were the same between the two interfaces, though the order of sensitivity was different. Using the sensitive parameters, calibration results showed none of the models met all of the criteria (statistical performance measures, water budget components, and crop yields) for either interface. These results can be explained by the findings from the comparison of the outputs using the default values. Therefore, more work is needed to ensure models that have proper representation before being used for nutrient and land management scenario analysis.

Acknowledgements

The authors are grateful to all Heidelberg University investigators and staff at the National Center for Water Quality Research who have supported the long term data collection in this watershed. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture.

Funding

Funding for this study was provided by USDA-Office of Environmental Markets. Project Number: 3070-11130-005-10-I.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Supplementary Materials

Table S1: Parameter values from the Control input file from NTT and ArcAPEX interfaces, **Table S2**: Parameter values from the Parameter input files from NTT and ArcAPEX interfaces.

Table S1. Parameter values from the Control input file from NTT and ArcAPEX interfaces. Descriptions under notes are directly from Steglich and Williams [15].

Parameter Name	ArcAPEX Value	NTT Value	Notes	Tested for Sensitivity
CO_2-Carbon dioxide concentration in atmosphere	330	365	Current amount of carbon dioxide in the atmosphere in ppm. Currently the level is 380 ppm.	
EXPK-Parameter used to modify exponential rainfall amount distribution	1.3	0	The modified exponential distribution is used to generate rainfall amounts if the standard deviation and skew coefficient are not available. An EXPK value of 1.3 gives satisfactory results in many locations. May be left 0.0 if unknown or if standard deviation of rainfall and skew coefficient for daily precipitation are input.	
QCF-Exponent in watershed area flow rate equation	0.5	0		
CHSO-Average upland slope (m/m) in watershed	0.5	0.1		
BWD-Channel bottom width/depth in m/m; Channel flow rate (QG) > 0	0	1		
FCW-Floodplain width/channel width in m/m	10	20		
FPSC-Floodplain saturated hydraulic conductivity in mm/h	0.1	0.01		
RFTO-Ground water residence time in days	0	5		
RFPO-Return Flow/(Return Flow + Deep Percolation)	0.4	0.95	Setting this value closer to 1.0 means more flow will be partitioned to return flow.	
SATO-Saturated Conductivity adjustment factor	1.3	1		
RTN0-Number of years of cultivation at start of simulation	150	10	This parameter affects the partitioning of nitrogen and carbon into the passive and slow humus pools. The number of years of cultivation before the simulation starts is used to estimate the fraction of the organic N pool that is mineralizable. Mineralization is more rapid from soil recently in sod. Also increasing the number of years the field has been in cultivation increases the amount of C and N in the passive pool. This means it will take longer for the carbon and nitrogen to become available.	
DTHY-Time interval for flood routing (hours)	7.55	1		
QTH-Routing Threshold (mm) – VSC routing used when QVOL > QTH	5	10	VSC = Variable Storage coefficient. QVOL = Daily volume of runoff. QTH = Routing Threshold.	
STND-VSC Routing used when reach storage > STND	5	0	VSC = Variable Storage coefficient. STND = Storage in reach daily.	
RCC0-USLE Crop Management Channel Factor	0.46	0	Must be entered. This number can be overridden if RCHC in the Subarea file is set. With bare channel condition, RCHC should be 0.1 - 0.6, and if the channel has very good land cover, it should have a value of 0. 0001 (if using USLE).	Yes
CSLT-Salt Concentration in Irrigation Water	1.58	0		

Table S2. Parameter values from the Parameter input files from NTT and ArcAPEX interfaces. Descriptions under notes are from Steglich and Williams [15], unless otherwise indicated by an asterisk.

Parameter Number	LINES 1 - 30 CONSIST OF TWO FIELDS (COLS. 1 - 8 AND COLS. 9 - 16) WITH ONE S-CURVE PAIR PER LINE	ArcAPEX Values		NTT Values		Notes	Tested for Sensitivity

SCRP7	Aeration stress-root growth. The # to the left of decimal is % of soil water storage volume between critical aeration factor and saturation, and the number to the right is % reduction in root growth caused by aeration stress. Determines the root growth aeration stress factor as a function of soil water content and the critical aeration factor for the crop.
	X = soil water-critical aeration factor
		25.1	80.9	5.25	50.95	*affects crop yields and ET	

SCRP16	Snowmelt function. Increases snow melt as a function of time since the last snowfall. The number to the left of the decimal is the time (days) since the last snowfall, and the number to the right of the decimal is the rate of melt as a function of time. X = time since the last snowfall (days)	1.1	20.99	3.1	20.99	*tile drainage and ET	
SCRP17	Component of the plant water stress factor based on soil water content. The number to the left of the decimal is the ratio of root zone soil water content to plant available water storage volume, and the number to the right of the decimal is the fraction of plant stress due to water stress. If Parm 38 = 1 then plant water stress is strictly a function of ET. X = ratio of root zone soil water content to plant available water storage volume	20.1	90.8	20.1	50.95		
1	Crop canopy-PET	1.89217		2		factor used to adjust crop canopy resistance in the Penman-Monteith PET equation	
2	Root growth-soil strength	2		1.196		normally 1.15 < parm(2) < 1.2. Set to 1.5 to minimize soil strength constraint on root growth. Setting Parm(2) > 2 eliminates all root growth stress	Yes
3	Water stress-harvest index	0.5		0.65		sets fraction of growing season when water stress starts reducing harvest index	
4	Water storage N leaching	0.926		0.137		fraction of soil porosity that interacts with percolating water as nitrogen leaching occurs	Yes

Continued

5	Soil water lower limit	0.5	0.084	lower limit of water content in the top 0.5 m soil depth expressed as a fraction of the wilting point water content	Yes
6	Winter dormancy	0	1	causes dormancy in winter grown crops. Growth does not occur when day length is less than annual minimum day length + parm(6)	
7	N fixation	0.90681	0	at 1, fixation is limited by soil water or nitrate content or by crop growth stage. At 0 fixation meets crop nitrogen uptake demand. A combination of the two previously described scenarios is obtained by setting 0 < parm(7) < 1	Yes
8	Soluble phosphorus runoff coefficient	20.001	18.983	P concentration in sediment divided by that of the water	Yes
9	Pest damage moisture threshold	20	5000	previous 30-day rainfall minus runoff. One of several parameters used to regulate pest growth. See also parm 10, PSTX in the control file, PST in the crop file and SCRP (9)	
10	Pest damage cover threshold	20	100	crop residue + above ground biomass. This is the amount of cover required for pests to begin to grow. Setting parm 10 at a large number (50) will result in little or no pest growth because it will be impossible to reach such high levels of cover. One of several parameters used to regulate pest growth. See also parm 9, PSTX in the control file, PST in the crop file and SCRP (9)	
12	Soil evaporation coefficient	2.5	1.5866	governs rate of soil evaporation from top 0.2 m of soil	Yes
13	Wind erodibility coefficient	2	2.216	adjusts wind soil erodibility factor downward as loose material is eroded.	Yes
14	Nitrate leaching ratio	0.74	0.635	Ratio of nitrate concentration in surface runoff to nitrate concentration in percolate	Yes
15	Runoff CN Residue Adjustment Parameter	0.1	0.261	Increases runoff for RSD < 1.0 t/ha; Decreases for RSD > 1.0 t/ha	Yes
17	Soil evaporation-plant cover factor	0.2	0.014	Reduces effect of plant cover as related to LAI in regulating soil evaporation	Yes
18	Sediment routing exponent	1.5	1.082	exponent of water velocity function for estimating potential sediment concentration	Yes
19	Sediment routing coefficient	0.03	0.001	potential sediment concentration when flow velocity = 1 (m/s)	yes
20	Runoff curve number initial abstraction	0.2	0.053	Carbon concentration in sediment divided by that in water	Yes
21	Soluble Carbon adsorption Coefficient	10	12.975	Carbon concentration in sediment divided by that in water	Yes
22	Reduces NRCS Runoff CN Retention Parameter for Frozen Soil	0.05	0.2	Fraction of S (Retention Parameter) Frozen Soil	
24	Pesticide leaching ratio	0.1	0.15	Ratio of pesticide concentration in surface runoff to pesticide concentration in percolation	
25	Exponential coefficient used to account for rainfall intensity on curve number	0	0.917	(Range is from 0.0 - 2.0). Setting this coefficient to 0 causes no effect. SCN = SCN * EXP(Parm 25 * (0.2 − AL5))	Yes

Continued

27	CEC effect on nitrification & volatilization	0.3	0	sets lower limit of CEC correction factor in nit/vol function. At 0 CEC should prevent nit/vol process. At 1 CEC has no effect on nit/vol	Yes
29	Biological mixing efficiency	0.23	0.001	simulates mixing in top soil by earth worms etc. Parm (31) sets depth for this action	Yes
30	Soluble phosphorus runoff exponent	1.4	1.1672	provides nonlinear effect for soluble phosphorus-runoff eq	Yes
31	Maximum depth for biological mixing	0.3	0.153		Yes
32	Organic P loss exponent	1.25	1.023	provides nonlinear effect for organic P loss equation	Yes
33	Coefficient in MUST EQ	2	3	original value = 2.5	
35	Denitrification soil-water threshold	1.01	1.1	fraction of field capacity soil water storage to trigger denitrification	Yes
36	Upper Limit of Daily Denitrification rate	0.001	0.1	maximum fraction of NO3 in a soil layer subject to denitrification	Yes
37	Exponent in Delivery Ratio for SWAT Output	0.6	0.1	transforms APEX small watershed sediment yield to 8-digit basin sediment yield for SWAT input. Normally 0.5—lower values increase sediment yield to SWAT2	
38	Water stress weighting coefficient	1	0	at 0 plant water stress is strictly a function of soil water content; at 1 plant water stress is strictly a function of actual ET divided by potential ET. 0 < parm 38 < 1 considers both approaches. See also SCRP 17	
39	Puddling Saturated Conductivity	1.00E-05	0.01	simulates puddling in rice paddies by setting second soil layer saturated conductivity to a low value	
42	SCS curve number index coefficient	0.5	1.238	regulates the effect of PET in driving the SCS curve number retention parameter. NVCN in control table = 4	Yes
43	Plow layer depth (m)	0.0508	0.1	used to track soluble phosphorus concentration or weight, organic carbon, and soil water content.	
44	Upper Limit of Curve Number Retention Parameter	1.6909	1.5	SUL = PARM(44) * S1. Allows CN to go below CN1	Yes
45	Sediment routing travel time coefficient	3	0.5	brings inflow sediment concentration to transport capacity concentration as a function of travel time and mean particle size	
46	RUSLE C-factor coefficient	0.5	1.395	coefficient in exponential residue function in residue factor	Yes
47	RUSLE C-factor coefficient	1	1.1076	coefficient in exponential crop height function in biomass factor	Yes
49	Maximum rainfall interception by plant canopy	5	9.625		Yes
50	Rainfall interception coefficient	0.1	0.284		Yes
51	Water stored in litter (residue) coefficient	0.5	0	fraction of litter weight	

Continued

54	N enrichment ratio coefficient for routing	0.78	0.6	GLEAMS equation ERTO = min (3.5, Parm 54/CIN Parm 55) (cols. 25-32) ERTO-enrichment ratio CIN-sediment concentration in inflow water	Yes
55	N enrichment ratio exponent for routing	0.2468	0.2	Used for GLEAMS equation.	Yes
57	P enrichment ratio coefficient for routing	0.78	0.509	GLEAMS equation ERTP = Parm 57/(CY) Parm 58) ERTP-P enrichment ratio CY-concentration of sediment	Yes
58	P enrichment ratio exponent for routing	0.2468	0.525	used for GLEAMS equation	Yes
59	P upward movement by evaporation coefficient	1	1		Yes
61	Soil water Upward Flow Limit	0.8	0.404	limits water tension ratio used to move water from a lower layer to the one above it. X1 = XX * min(Parm 61, (T1-T2)/T1)	Yes
62	Manure erosion equation coefficient	0.1	0.2	larger values increase manure erosion.	
68	Manure erosion exponent	0.75	0.5	modifies equation based on weight of manure on soil surface	
69	Coefficient adjusts microbial activity function in the top soil layer	1	0.352		Yes
70	Microbial decay rate coefficient	1.14	0.634	adjusts soil water-temperature-oxygen equation	Yes
73	Hydrograph development parameter	0.2	0.503	storage depletion routing exponent used to estimate travel time outflow relationship	
74	Partitions Nitrogen flow from groundwater	0.1	0.05	Parm 74 = NCH/NCV. RSFN = RSSF * NCH; DPKN = DPRK * NCV. NCH = horizontal nitrogen concentration; NCV = vertical nitrogen concentration; RSFN = Subarea soluble N yield in return flow; RSSF = Return subsurface flow; DPKN = Soluble N in deep percolation; DPRK = Deep percolation. For example, if Parm 74 is set to 5, it means RSFN will be 5 times greater than DPKN. If Parm 74 is set to 0.2, then RSFN is only 0.2 times DPKN	
76	Standing Dead fall rate coefficient	0.008	0.01	governs rate of standing dead conversion to flat residue	
78	Soil water value to delay tillage	100	0	tillage is delayed when PDSW/FCSW > Parm 78. PDSW = Plow depth soil water content; FCSW = Field capacity soil water content	
80	Upper Limit of Nitrification-Volatilization	1	0.5	fraction of NH3 present	Yes
81	Technology Coefficient	0	0.006	linear adjustment to harvest index-base year = 2000	Yes

Continued

83	Estimates drainage system lateral hydraulic conductivity	1.93	10	drainage HCL is maximum of Parm 83 * vertical SC and APEX estimate considering drainage time and storage. HCL = max (Parm 83 * SATC, (PO – S15)/24 * DRT (cols. 17-24) HCL-lateral hydraulic conductivity SATC-saturated conductivity PO-porosity S15-wilting point DRT-time for drainage to reduce plant stress	
87	Water table recession coefficient	0.001	1	small values slow the water table recession	
88	Limits daily water table movement	0.001	0.1	fraction of difference between WTBL and WTMN or WTMX	
89	Water table recession	0.1	0.5	exponent of day of year/365	
90	Subsurface flow factor	2	10	traditional value is 2.0. Larger numbers allocate more flow to SSF and QRF	
91	Flood Evaporation Limit	0.1	1	allows for limiting of evaporation of flood waters during flooding. Regulates evaporation from channel and floodplain. Small values reduce channel and floodplain evaporation	
96	Soluble Phosphorus Leaching KD value	8	7.204	this value is used in the Langemeier phosphorus leaching equations. Setting this parameter to 1 causes no effect	Yes
97		1	0.9	*not in the manual	
98		0.45	1	*not in the manual	
99		0.5	1	*not in the manual	