SWAT 2000

ABE 6254 – Dr. Campbell

Model Review Part II

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BASIC PROCEDURE USED TO RUN MODEL

SWAT2000 can be easily downloaded from the following site: http://www.brc.tamus.edu/swat/swat2000.html (MODEL, DOCUMENTATION) . A sample data set is provided with model and SWAT2000 can be run immediately. The sample data set is for a large watershed with several subbasins and HRU's. The primary soil type for this data set was silt, very low sand content. The first step in modifying the files in order to model the beef cattle pasture at Buck Island Ranch, was to manipulate the figuration file (.fig) so that the model would run for a single subbasin, rather than eight subbasins (which was the case for the sample data set). SWAT2000 was developed to model large, complex watersheds; therefore, the model had to be significantly simplified in order to model the small watershed at Buck Island. The next step in the modeling procedure was to create the precipitation, temperature, wind, and solar radiation files. The files were created in excel and then converted into word pad files. Each file contained the four-digit year, the Juliann date, and the observed value. The manual specifies the spacing required for each line so that the model can read each file appropriately. Once these files were created, the control files were modified to read in the newly created climate files. The weather generator had to be turned off in both the CIO file and the COD file. A "1" or a "2" on the COD files tells the model to simulate climatic data with the weather generator or to read in the created files. The model was initially run for the year 1998 from day 1 to 365. The sample data set was set up to run the model for six years worth of data. The rest of the files were altered to represent conditions at Buck Island Ranch. The HRU file was modified to show the appropriate watershed area. The HRU file is an important file because this is where the curve number, Manning's n, etc. are input. A uniform soil type was assumed for the entire watershed for simplification. If multiple subbasins are used, the user must specify the fraction of the watershed each subbasin occupies. Most of the changes were made to the management file. The management file controls the type of land cover in the watershed as well as the management practice-taking place, in our case, grazing by beef cattle. The user can specify the day a particular management practice begins and how long it lasts. For Buck Island, the management file was altered to indicate grazing taking place at the beginning of October and lasting until the end of the year.

SWAT MODEL CALIBRATION

The calibration process for SWAT is divided into four basic categories:

- Water Balance and Stream Flow
- Sediment
- Nutrients
- Pesticides

For our purposes, the calibration process discussed in this paper will focus primarily on the water balance/stream flow and the nutrients. The simulated results were calibrated using the 1998 observed data from winter pasture 6 (W-6) at Buck Island Ranch, Highlands County, FL.

The first step in any calibration process is to have a basic understanding of the physical processes taking place within the system. Weather stations and stream gages can either be located within the watershed being studied or near the outlet of the watershed. The further the gages are from the actual study site, the more likely spatial variability will affect model results. SWAT2000, as mentioned in the previous paper, is capable of simulating weather data for temperature, precipitation, wind, solar radiation and relative humidity or this information can be formulated into files and input into the model. For this project, temperature, precipitation, wind data, and solar radiation were provided as inputs and relative humidity was simulated using the weather generator. These climate files are important because this is the first step that may introduce inaccuracy in the results. Because the area of this project was small, as well as the time frame, using the weather generator for all of the climate inputs requires much more calibration compared to using collected climate inputs.

Calibrating the water balance and stream flow begins by comparing average annual conditions such as the average annual total water yield, base flow, and surface flow. Average annual values are calibrated as the depth of water in millimeters over the drainage area. Once the average annual values are calibrated, the monthly or daily values can be fine-tuned for accuracy. The output files for SWAT2000 are very detailed and easy to read. The output files provide daily results as well as average monthly and annual average results. The observed data was only provided from day 182 to 365 for the year 1998; therefore, the comparisons in the chart below are from this same time frame for 1998.

	Total Water Yield (mm)	Base flow (mm)	Surface Runoff (mm)
Actual	?	?	212
SWAT	778	137	309

Although the manual recommends this as the process for calibrating the model, there were not good values to compare for total water yield or base flow; therefore, the calibration procedure focused on matching the simulated surface runoff with the observed surface runoff graph.

Calibration of Surface Runoff

The manual for SWAT2000 has a very specific calibration procedure. It recommends first adjusting the curve number until surface runoff is acceptable. A table of curve numbers for several types of land cover is provided in the manual. SWAT has a Land Cover/Plant database that lists various plants and their characteristics, which is useful for determining the initial curve number. If altering the curve number does not produce reasonable results for surface runoff, the manual recommends adjusting the soil available water capacity ($\pm$ 0.04) (SOL_AWC in .sol) and/or the soil evaporation compensation factor (ESCO in .sub).

Because this Land Cover/Plant database was provided with SWAT, a land cover was chosen from the list for simplification. The land cover for the ranch was defined as *Bahiagrass* or native grass and after some research, *Little Bluestem* was chosen as an appropriate and comparable land cover. The land cover/plant database did not contain information on *Bahiagrass*. Another important characteristic of SWAT to keep in mind is that the model was developed in Texas; therefore, some of the values (for example, plant biomass) may be lower than values that would generally be used for Florida plants due to differences in humidity, etc. This was also taken into consideration during the calibration process. The relative biomass produced for a certain land cover is a required input in the management file. It is important in determining the curve number as well as transpiration rates, etc. If the biomass falls below a certain input value, grazing by the beef cattle will no longer take place. For this project, the minimal biomass allowed for grazing was set to 0 so that grazing would be a continual process during the time frame for which is was specified to occur.

Calibration of Subsurface Flow

Base flow can be calibrated once surface runoff values are relatively accurate. This is done by adjusting a number of parameters including the groundwater "revap" coefficient (GW_REVAP in .gw), the threshold depth of water in the shallow aquifer for "revap" to occur (REVAPMN in .gw), and the threshold depth of water in the shallow aquifer for base flow to occur (GWQMN in .gw). These parameters are either increased or decreased depending on whether or not the simulated base flow is over predicted or under predicted.

Several adjustments of the curve number, soil available water capacity, soil evaporation compensation factor, groundwater "revap" coefficient, threshold depth of water in the shallow aquifer for "revap" to occur, and threshold depth of water in the shallow aquifer for base flow to occur will hopefully and ultimately yield good surface runoff and base flow values.

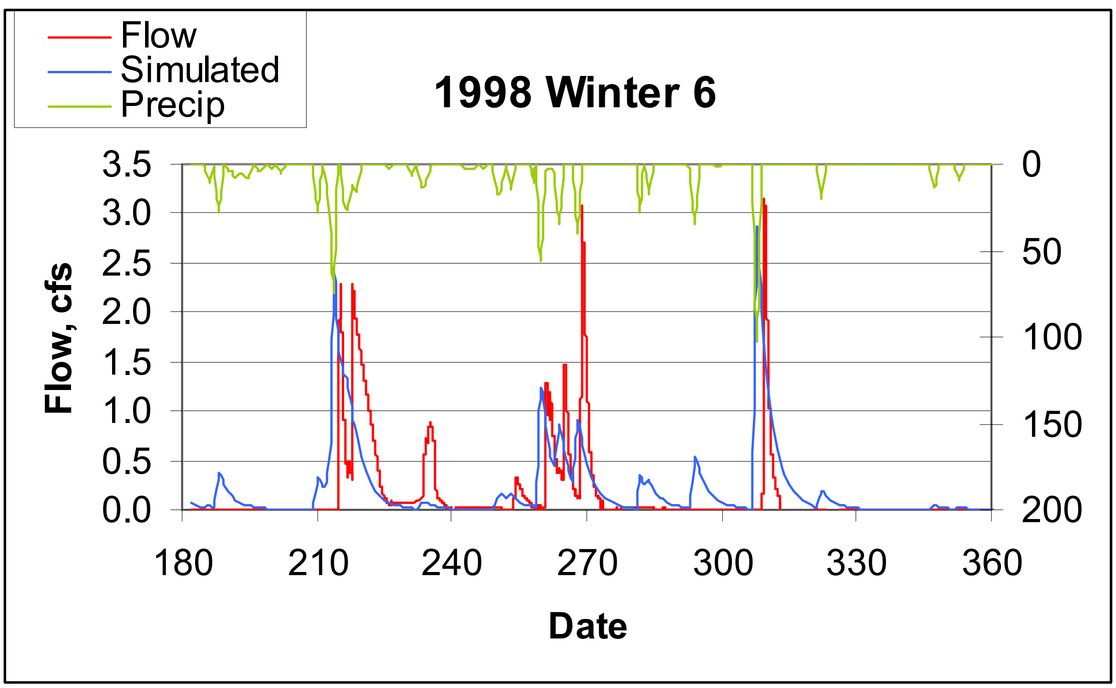
SIMULATION RESULTS

Once all the files for the model were updated with known parameters, the surface runoff was compared to the observed data for the 1998 Winter 6 pasture. For this project, the SCS curve number method was chosen to predict surface runoff. The curve number method is a function of the soil's permeability, land use, and antecedent moisture conditions. The curve numbers provided in the manual were based off of areas with a 5% slope therefore the values chosen for our project had to be adjusted for a smaller slope. The results were initially under predicted; therefore adjustments were made to increase the amount of surface runoff that was being predicted by the model. Some of the parameters adjusted were the following: 1) Curve Number, 2) Manning's n, 3) Slope, 4) Lateral Flow (days), and 5) Average Slope length. Adjusting the curve number, Manning's n, slope, and average slope length proved to be the most effective adjustments for improving the accuracy of the surface runoff prediction. Changing the lateral flow did not improve the results. The following is a table of values used in the calibration process.

Parameter	Value Used	Range	Sensitivity
CN	80	74-87	high

Manning's n	1.4	0.14-1.4	low
Slope	0.1	.0001-0.1	med/high
Lateral Flow (days)	0.0	0-1	low
Ave. Slope Length	50	50-1000	low

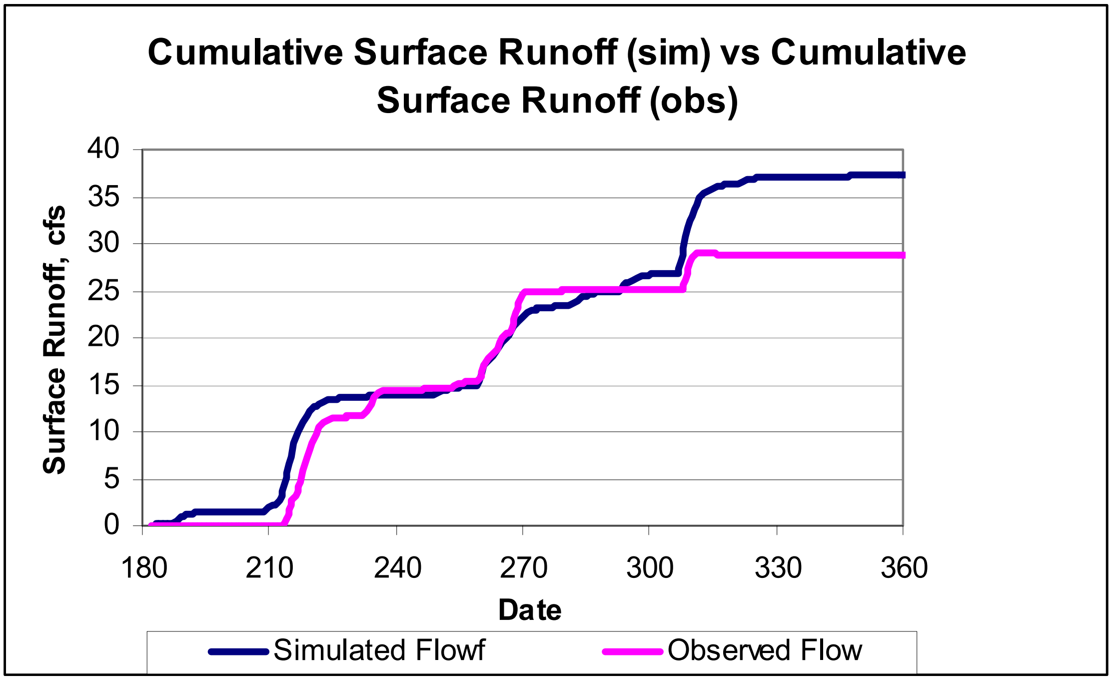
The following is a graph comparing the observed surface runoff for W-6 in 1998 and the simulated surface runoff for 1998. The precipitation is along the top to indicate when an event occurred relative to the time surface runoff occurred.



SWAT2000 predicted surface runoff relatively well. There are a couple of runoff events that were simulated that do not show on the observed data. This could be due to improper collection of the original data. As discussed in class, there are several factors that could influence the results of observed data. A comparison was conducted to compare the results of surface runoff when precipitation data was used from gages inside the watershed and outside the watershed. A combination of the two gages appears to provide the most realistic results. The peak the occurs prior to day 240 was best predicted from precipitation data collected at station 329 which was located the closest to the winter pasture. The graph above uses precipitation data collected at the ONA weather station, which is slightly farther away than station 329.

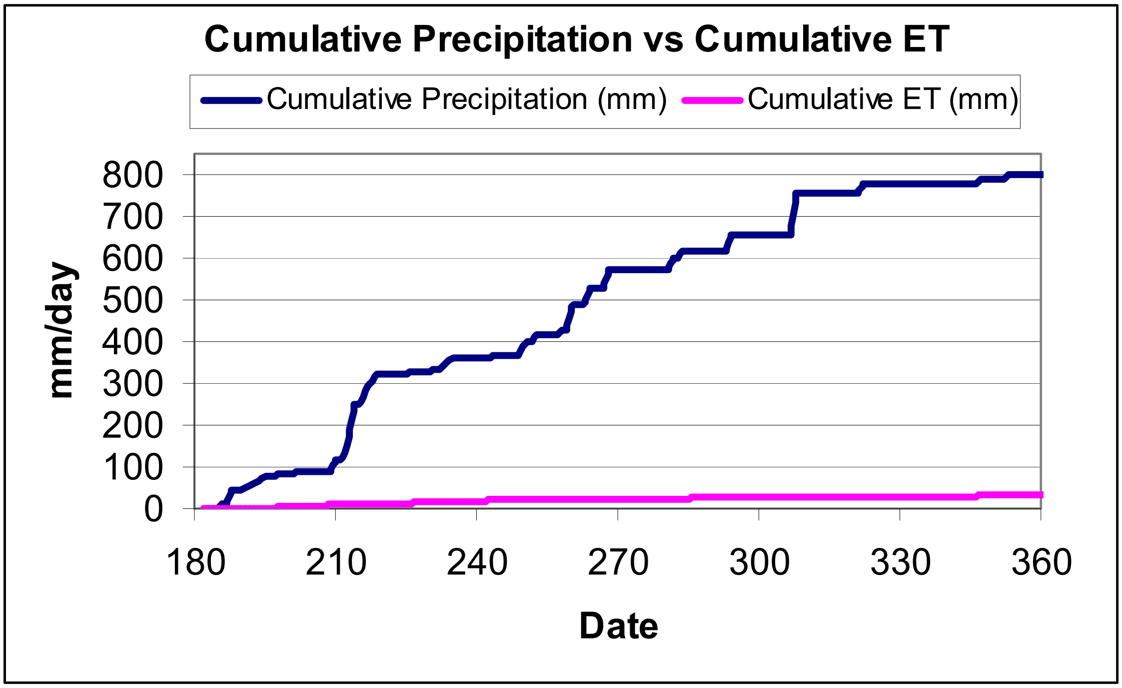
The peak flow rate is calculated in SWAT using the rational method, which is not affected by topography. This could have led to some of the problems with our results and also may explain why some factors such as the slope proved not to be extremely sensitive parameters for this project. The peak rate tends to be overestimated when using the rational method to predict peak runoff rate. This method may be useful for very large watersheds but did not prove very successful for the small area of this particular project. Over estimating peak runoff can eventually lead to problems with sediment loss predictions.

This next graph compares observed and simulated cumulative surface runoff for 1998.



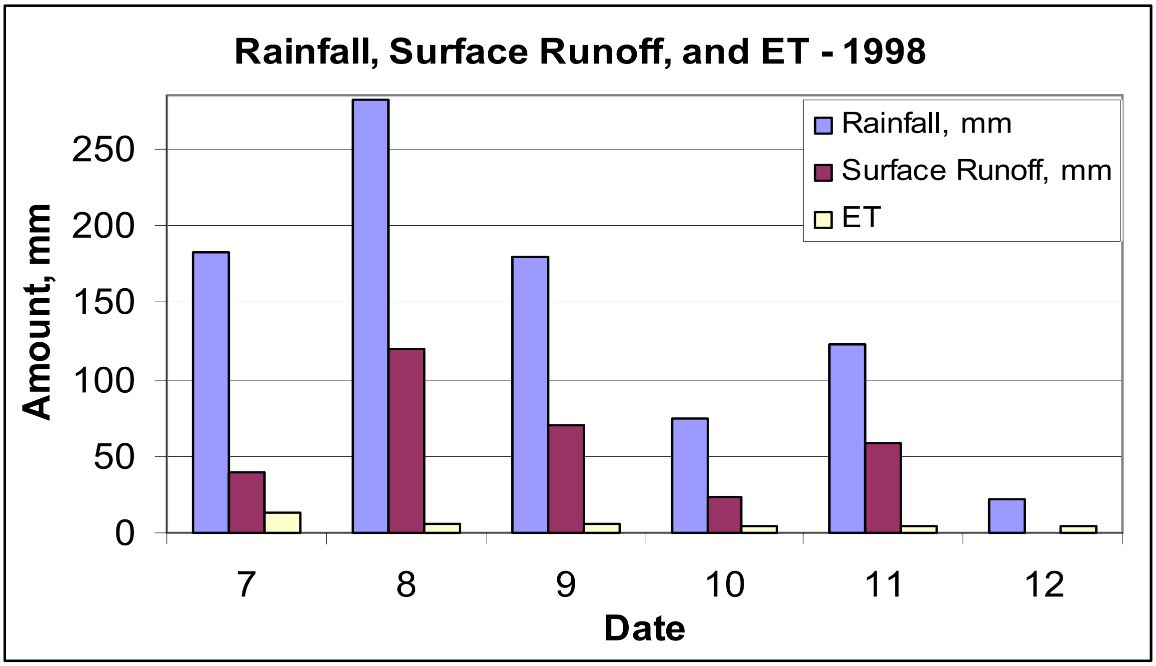
Although SWAT2000 did not predict every single runoff event precisely, the cumulative results appear to be relatively close. Cumulative surface runoff is slightly over predicted by SWAT. The general shape of the lines follows a similar pattern.

The next graph shows a comparison of cumulative precipitation verses cumulative ET.



SWAT2000 calculates values for ET from the graph and it is evident that ET is very low compared to precipitation. Evaporation is greatly affected by temperature and solar radiation. Evaporation is the primary water removal mechanism in the watershed; therefore, the energy inputs are critical in producing an accurate water balance. Evaporation is proportional to the difference between vapor pressure of the surface layer and the overlying air. The Penman-Monteith method was used to calculate PET in order to capture the effects of wind and relative humidity. Relative humidity affects the amount of water vapor and is also a function of temperature. Our relative humidity values were simulated using the weather generator, which may have led to some of the discrepancies in the results for PET.

This is a chart comparing simulated results for rainfall, surface runoff and ET for the months of July through December of 1998. Again, it is apparent that the simulated values for ET are very low.

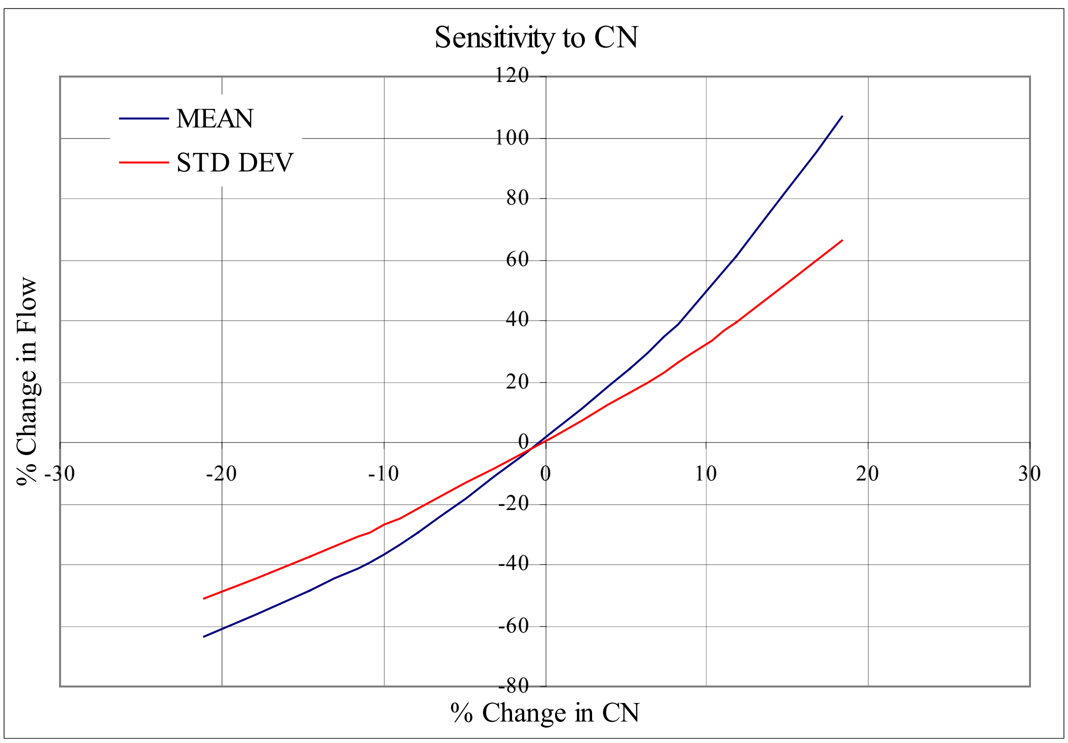


Sensitivity

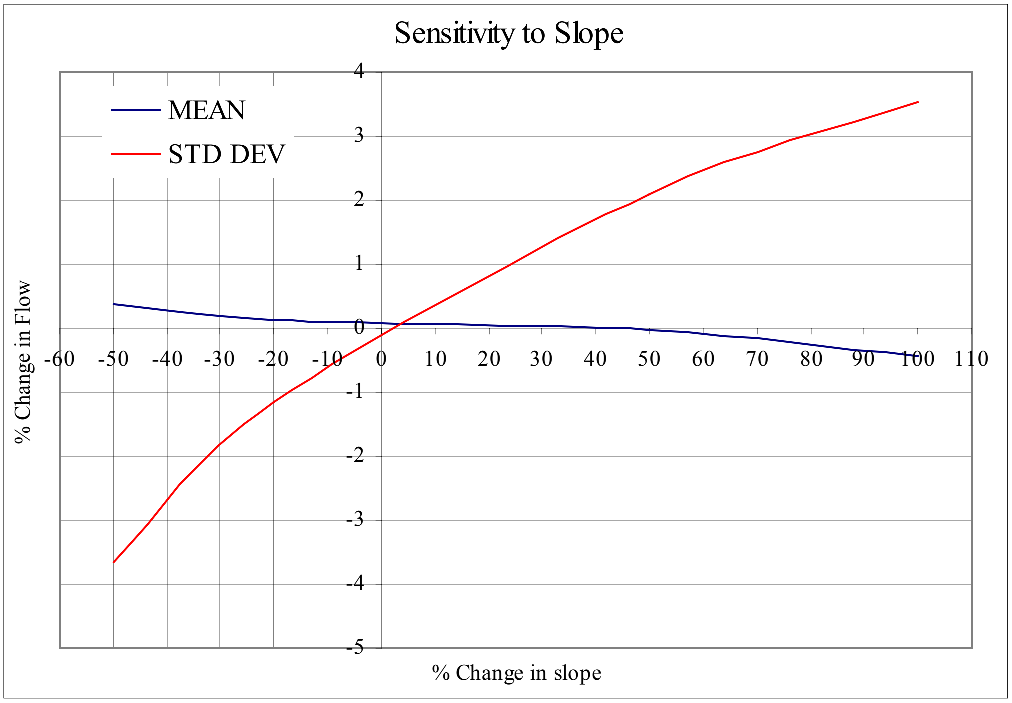
A sensitivity analysis was done to study the effects of these various parameters on the runoff from the study area. The parameters chosen for the sensitivity analysis were – curve number, Manning's n, slope, lateral flow (days), and average slope length. SWAT2000 is a watershed scale model developed to model land surface processes on large watersheds. Application of this model to this particular field site changed the influence of these parameters on the total runoff. The sensitivity results presented here are for the field scale application of this model.

The sensitivity analysis was carried out using two year model runs with the same input data used in the calibration study. The values of the parameters obtained during calibration were used as a 'baseline' and the changes in the runoff were plotted against the percentage changes in these parameters. During the sensitivity analysis it was apparent that several of these parameters modified the shape of the output hydrograph without affecting the total runoff. The changes in the standard deviation of the runoff were also studied in an attempt to quantify this behavior.

It was seen that the runoff was not sensitive to changes in Manning's n and lateral flow length for any reasonable values for these parameters. The model was highly sensitive to curve number and slope. The following figure shows the sensitivity to the curve number. It can be seen that the runoff is highly sensitive to changes in CN.



The runoff was also seen to be very sensitive to slope especially the standard deviation of the runoff changed with the slope. This was also reflected in the shape of the outflow hydrograph.



NUTRIENT CALIBRATION

The processes for nutrients loading calibration is carried out by calibrating hydrological components first then followed by calibrating sediment loading in the surface runoff. This is because the runoff volume is the dominant component that governs the amount of nutrients that will be transported to the main channel from the watershed. The sediment yield relates closely to the surface runoff volume as well as the peak runoff rate as shown here in the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975).

$$Sed = 11.8 * (Q*q*Area)^{0.56} * K * C * P * LS * CFRG$$

The hydrology calibration and validation processes are described in the earlier section. The first step after the hydrologic components of the model are calibrated is to calibrate the sediment yield by adjusting the coefficients in the MUSLE that are affecting the erosion processes. There is not observed sediment data available for the study area. However, the assumption is made that the sediment yield in the surface runoff is very small during storm events. This assumption is supported by the topographically flat nature in the area and the short duration of the livestock present on the pasture. The peak flow rate is much smaller in a flat area in compare to an area with steep slope when land cover and soil characteristics are similar. Therefore the erosion force of the flow should smaller too for the flat area. The short during livestock presence in this area means lesser land disturbances and higher plant cover for most of the year therefore minimized the potential soil erosion. The other reason for validating the assumption is that the sediment yield is miniscule based on many years observation by professional staff. So, our goal for sediment calibration is to have a near zero sediment loading rate for most storm events and some sediment loading for large intensive rainfall event. The soil erodibility factor (K-USLE) is a key factor that can affect the sediment yield. The initial setting for K-USLE for the top layer is 0.10 (metric ton m^2 hr)/(m^3 -metric ton cm), and the sediment loading rate is 0.082 kg/ha during the period of day 182 to day 365 in 1998. We think the value might be high, so we adjusted the K-USLE to 0.013 and the sediment loading rate reduced to 0.008 kg/ha.

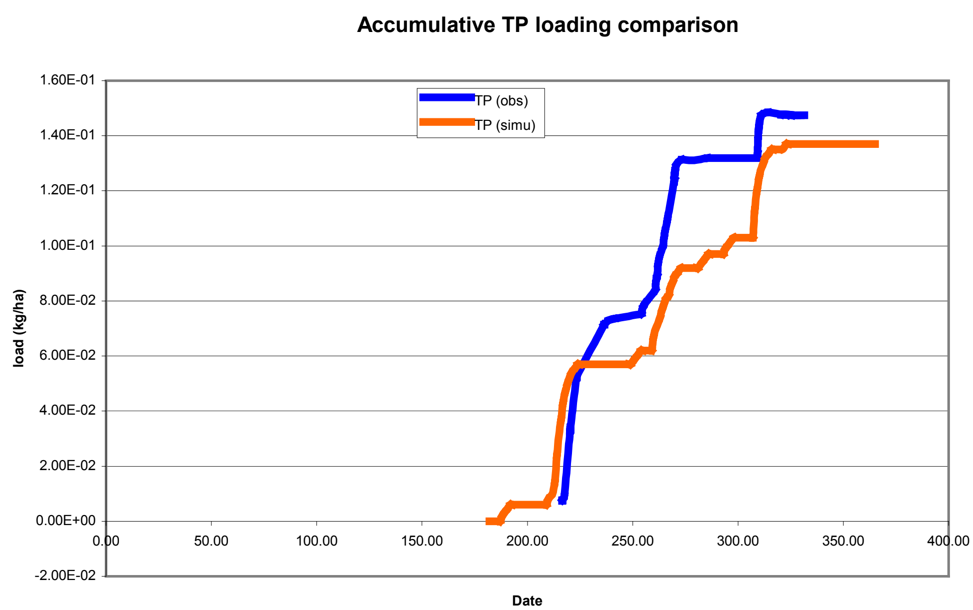
Phosphorus Calibration

To calibrate total P in the runoff we focused on the model parameters that govern the initial amount of soluble P and organic phosphorus in the soil and their availability to be carried away by surface runoff during storm event. SWAT sets the concentration of solution phosphorus in all layers and is initially set to 5-mg/kg soil. Concentrations for all other initial P pools (active mineral pool, stable mineral pool, organic P pool) are calculated used default functions in SWAT. Due to the time constrain and lack of information regarding the nutrient condition in the soil, we decided not to adjust the initial nutrient values in the different pools. Other than allowing the user to adjust the P concentrations in different P pools, SWAT also allows the user to calibrate P in the surface runoff by adjusting Phosphorus percolation coefficient (PPERCO), Phosphorus soil partitioning coefficient (PHOSKD), Phosphorus availability index (PSP) and others in basin input file. For all the parameters, PPERCO and PHOSKD are the most sensible parameters for simulation of solution P loading in the runoff.

PPERCO (10 m^3/mg) is the ration of the solution phosphorus concentration in the surface 10 mm of soil to the concentration of phosphorus in percolate.

POSKD (m^3/mg) is the ratio of the soluble phosphorus concentration in the surface 10 mm of soil to the concentration of phosphorus in the surface runoff.

The primary mechanism of phosphorus movement in the soil is by diffusion. Diffusion is the migration of ions over small distances (1-2 mm) in the soil solution in response to a concentration gradient. Due to the low mobility of solution phosphorus, surface runoff will only partially interact with the solution P stored in the top 10 mm of soil. SWAT allows soluble P leach from the top 10 mm of soil into the first soil layer. The range for PPERCO is from 10 to 17.5. The default values for PHOSKD and PPERCO in SWAT are 175 and 10 respectively. By using these two default values, the model under-estimated the P loading the surface runoff. Since the P loading in the surface runoff is inversely related to the phosphorus soil partitioning coefficient and it is positively related to the phosphorus percolation coefficient, so we calibrated the P loading in the surface runoff by increasing PPERCO and decreasing POSKD. By trying and error, we found PPERCO at 17 and PHOSKD at 80 give us the best P loading calibration result (Fig below).



Nitrogen calibration

Similar to phosphorus, nitrogen also underwent similar calibration processes. The initial concentrations for nitrate, organic nitrogen in different soil layers are calculated using SWAT predefined functions (SWAT 2000 technique manual). Initial nitrate in the soil is a function of soil depth from the soil surface and the initial organic nitrogen in a layer is a function of organic carbon in that layer. The ammonium pool for soil nitrogen is initialized to 0 ppm. Because the same reason that we described during the P calibration section, we did not modified the initial concentration of different nitrogen pools in the soil.

SWAT models two forms of nitrogen, nitrate and organic nitrogen, in the surface runoff. Nitrate may be transported with surface runoff, lateral flow or percolation. To calculate the amount of nitrate moved with the water, the concentration of nitrate in the mobile water is calculated first. This concentration is then multiplied by the volume of water moving in each pathway to obtain the mass of nitrate lost for the soil. The nitrate removed in the surface water runoff, in lateral flow, and moved to the underlying layer by percolation are expressed in the following three equations respectively:

$$NO3_{surf} = \beta_{no3} * C_{no3,\, mobile} * Q_{surf}$$

$$NO3_{lat,ly} = \beta_{no3} * C_{no3,\, mobile} * Q_{lay,ly}$$

$$NO3_{perc,ly} = \beta_{no3} * C_{no3,\, mobile} * W_{perc,ly}$$

Where:

$NO3_{surf}$ is the nitrate removed in surface runoff (kg N/ha)

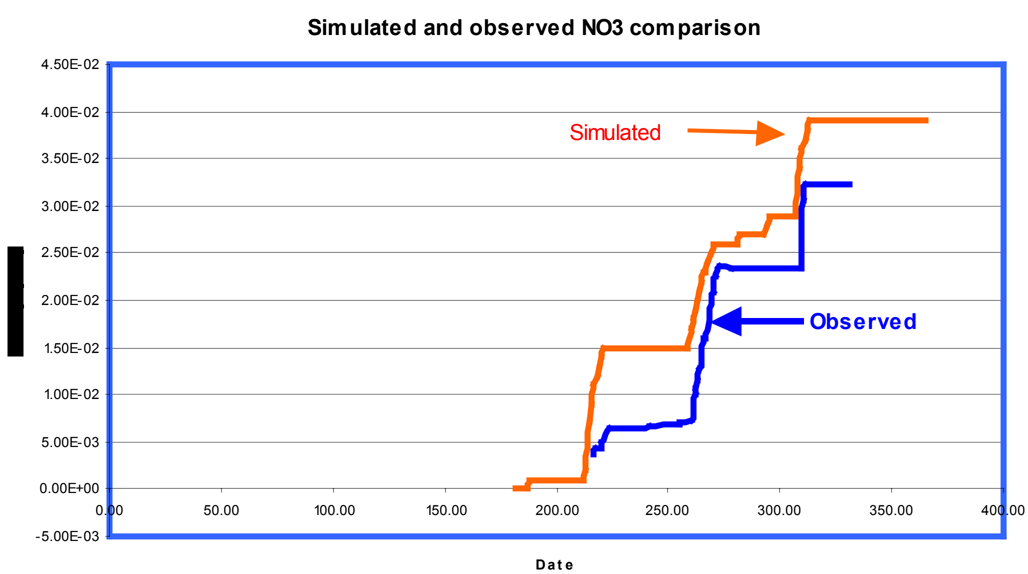
$NO3_{lat,ly}$ is the nitrate removed in lateral flow for top 10 mm

$NO3_{perc,ly}$ is the nitrate moved to the under layer by percolation

β_{no3} is nitrate percolation coefficient (NPERCO)

$C_{no3, mobile}$ is the concentration of nitrate in the mobile water.

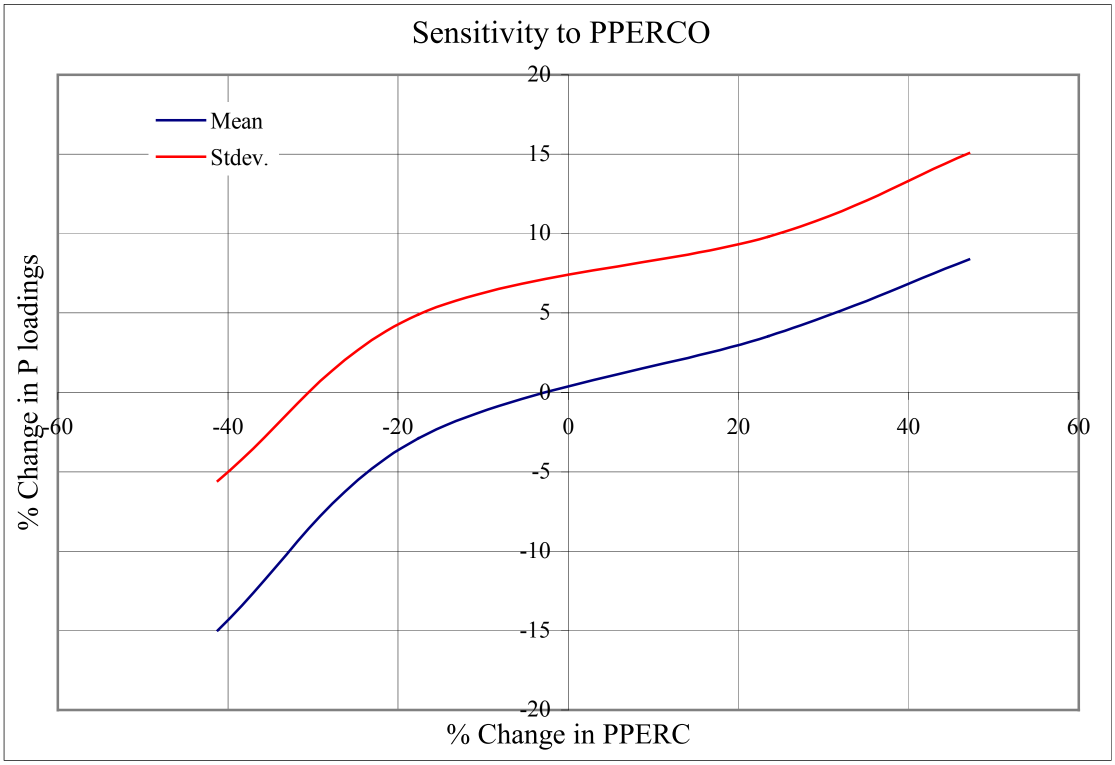
It is clear by examination of the three equations, the key calibration parameter is the nitrate percolation coefficient (NPERCO) for the nitrate loading once the hydrology has been calibrated. This is because the NPERCO is in all three equations and it controls the amount of nitrate removed from the surface layer in runoff relative to the amount removed via percolation. The value of NPERCO can range from 0.01 to 1.0. As NPERCO approaches 0.0, the concentration of nitrate in the runoff approached to 0. As NPERCO approaches 1.0, surface runoff has the same concentration of nitrate as the percolate. The initial run without the calibration, the model significantly under estimated the nitrate in the runoff. Relatively speaking, the simulated nitrate level is easily calibrated to the similar level as the observed data only after few tries by adjusting the NPERCO (Figure below).



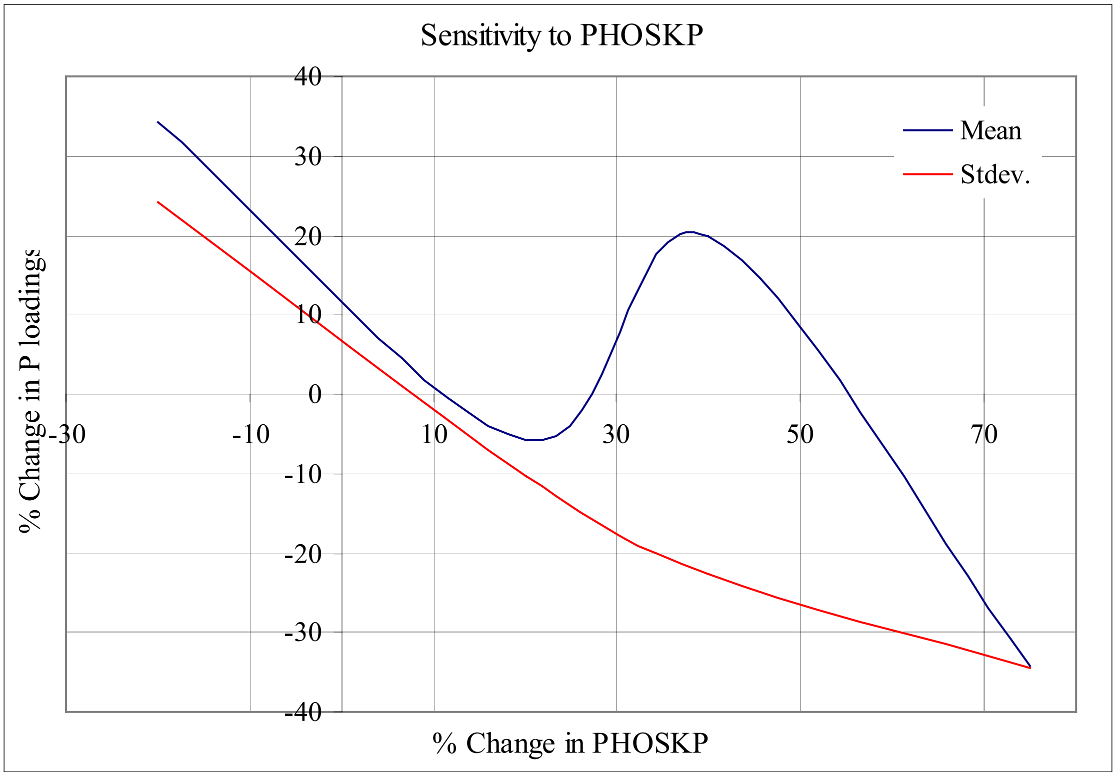
Organic nitrogen attached to soil particles may be transported by surface runoff to the main channel. This form of nitrogen is associated with the sediment loading form the HRU and changes in sediment loading will be reflected in the organic nitrogen loading. SWAT simulates the amount of organic nitrogen transported with sediment to the stream is calculated with a loading function developed by McElroy et al. (1976) and modified by Williams and Hann (1978). Since the sediment yield is very small, there for we believe that it is that model will not provide valid organic N simulation result for this area.

Sensitivity

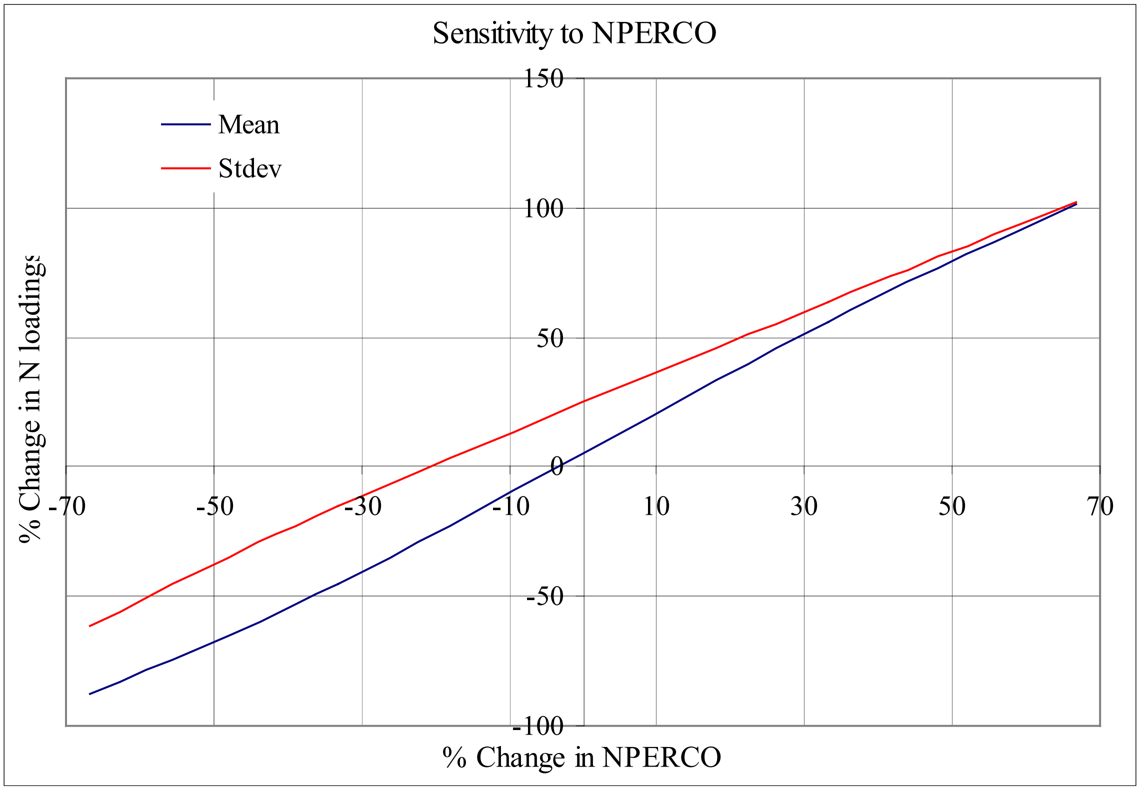
The sensitivity analysis was conducted on PPERCO, the ratio of the solution phosphorus concentration in the soil surface to the concentration of phosphorus in the percolate, POSKD, the ratio of the soluble phosphorus concentration in the soil surface to the concentration of phosphorus in the surface runoff and the nitrate percolation coefficient NPERCO. As in the case of the hydrologic parameters the values of the parameters obtained during calibration were used as the baseline and the changes in phosphorous and nitrogen loadings with the change in the parameters was computed.



Phosphorous loadings are sensitive to PPERCO as can be seen from the Figure above. A 20% decrease in the value of PPERCO caused a 15 % decrease in P loadings. The relationship between POSKD and P loadings is more complex as can be seen from the Figure below. The P loadings behave in a non-linear manner with changes in POSKD.

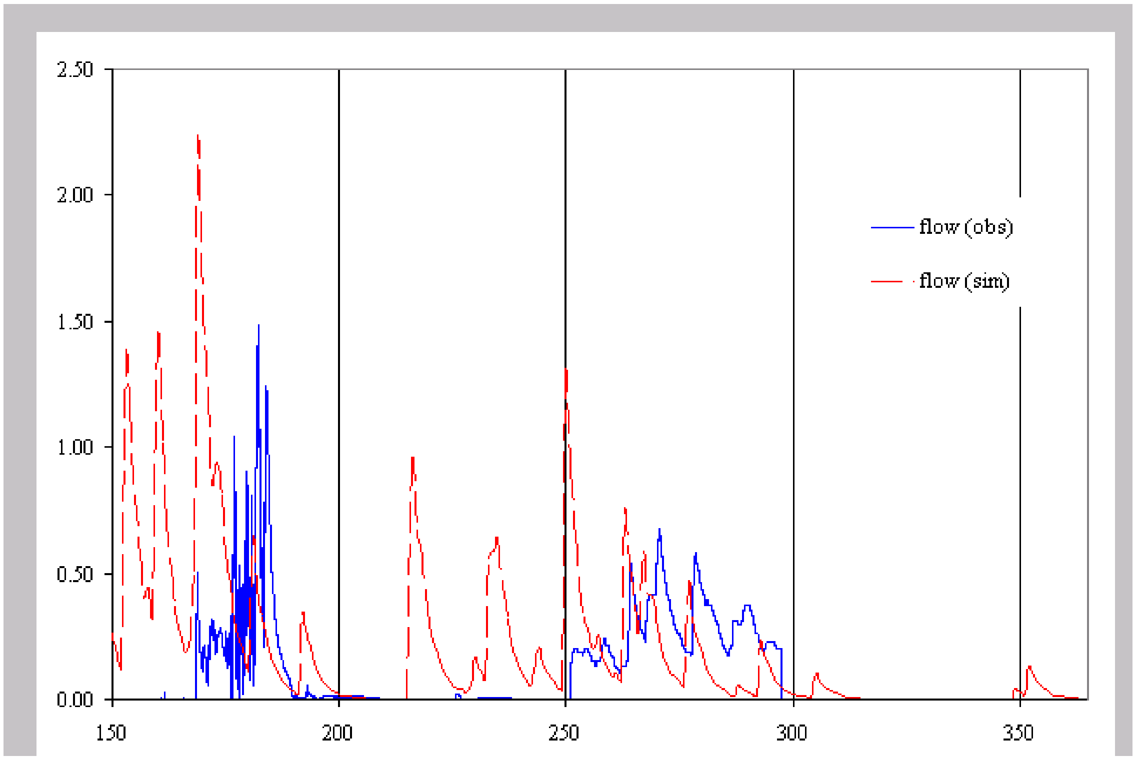


Nitrogen loading was studied with the parameter NPERCO. The N loadings showed a linear behavior with changes in NPERCO. This is seen in the Figure below.

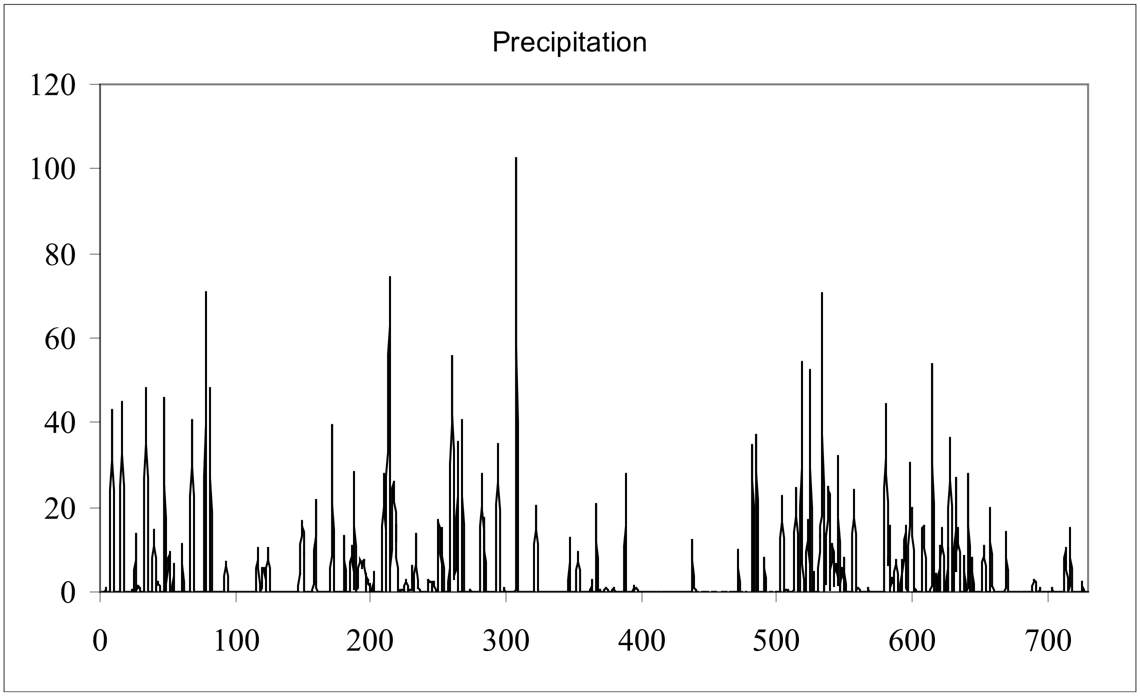


Validation

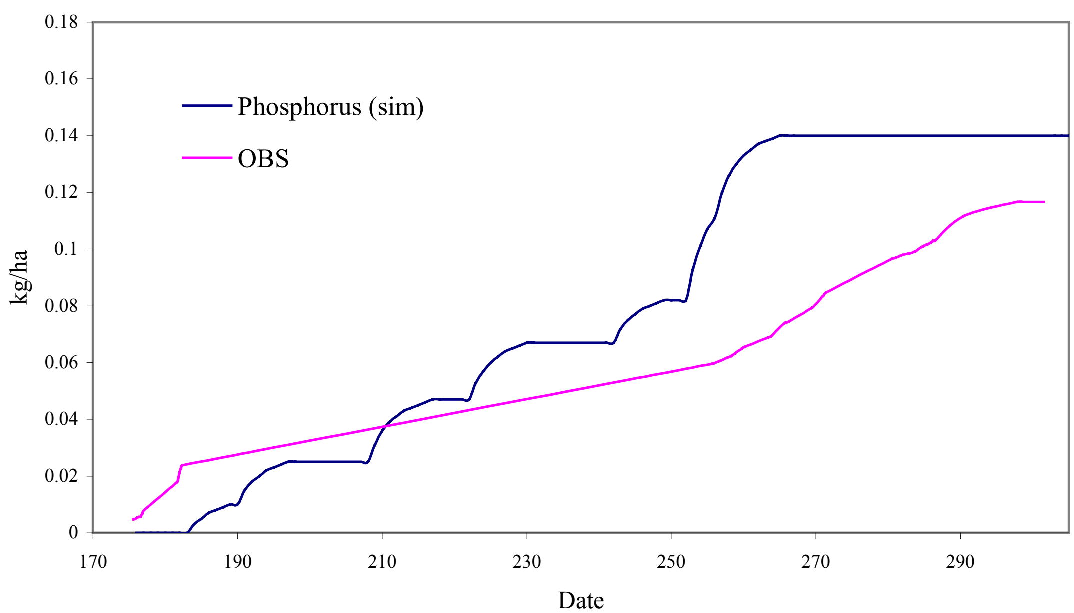
Validation of the model was attempted by comparison of the model results with an independent data set (without further adjustment). We used the 1999 data for validation. The runoff comparisons are shown in the Figure.



The 1999 data shows a similar behavior to the 1998 data. The simulated runoff seems to precede the actual runoff by a short interval of time. In the period between day 200 and 250 a number of rainfall events are indicated in the simulated results but are not seen in the observations. The Figure below shows the record of one rain gage for the entire two year period. As can be seen in the figure there are significant rain events between day 565 and day 615, which is the corresponding period when the observations show no significant surface runoff. This leads us to believe that there might be inaccuracies in the outflow measurements.



The N and P loadings were also compared between the 1999 observed and modeled data.



The behavior is different between the observed and the simulated. Again the apparent lack of an outflow event between day 200 and 250 contributes significantly to the differences.

CONCLUSIONS

SWAT2000 was primarily developed for large scale, long-term applications. We were able to simulate a small, field scale application of the model. The results were reasonable, however, improvements to the water balance were needed. Due to very low predictions of ET, a large amount of percolation was simulated to counter this effect. There are numerous parameters that can be altered in SWAT2000 and due to time limitations; we were not able to fully understand the interactions of all parameters. Although surface runoff results were fairly good, there was some trade-off in the representation of certain parameters in order to obtain these good results. The nutrient results were dependent on the accuracy of the hydrology and sediment calibration. Our results were acceptable for phosphorus, but not for all forms of nitrogen. We believe that this model is very flexible and has extremely good potential for applications on various scales and land uses.

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