Application of SWAT and APEX Models Using SWAPP (SWAT/APEX Program) for the Upper North Bosque River Watershed in Texas

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Abstract

In response to the Clean Water Act of the early 1970s, the Agricultural Research Service (ARS) branch of the United States Department of Agriculture (USDA) initiated the development of several process-based nonpoint source models. These models are used to assess and evaluate various best management practices (BMPs) at field (e.g., Agricultural Policy/Environmental eXtender, APEX) and watershed (e.g., Soil Water Assessment Tool, SWAT) levels. However, models such as SWAT and APEX are only capable of simulating mechanistically a limited number of BMP scenarios individually.

In this study, the SWAPP (SWAT/APEX) program was developed to facilitate the simultaneous use of these two models. SWAT (version 2000) and APEX (version 2110) were utilized within SWAPP. The SWAT and APEX models in SWAPP were calibrated and verified against historical measured data collected in the upper North Bosque River (UNBR) watershed. Stream flow and losses of sediment and nutrients from all crop and pasture lands within the UNBR watershed were simulated by APEX. The results obtained from APEX and remaining land uses (e.g., forest) simulated by SWAT were routed to the outlet of the watershed using SWAT. The UNBR watershed was simulated from 1988 through 1999; model output was calibrated for flow, sediment, and nutrients measured at three sites within the UNBR watershed for the period of January 1994 through December 1995 and verified for the period of January 1996 to July 1999. The results obtained from the three sites within the UNBR watershed show that the pattern (model efficiencies) and average monthly values of flow and loadings predicted by the SWAPP were generally close to the measured values.

The SWAPP program is able to simulate management scenarios, such as multicropping or filter strips, at the field level by utilizing APEX, whereas SWAT alone currently has limited capability to simulate those practices. In addition, SWAPP can be used to convert SWAT data files, generated from Geographical Information System (GIS) layers, to APEX data files format.

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Introduction

In response to the Clean Water Act of the early 1970s, the Agricultural Research Service (ARS) branch of the United States Department of Agriculture (USDA) initiated the development of several process-based non-point source (NPS) models. Knisel (1980) developed the field-scale CREAMS (Chemical, Runoff, and Erosion from Agricultural Management Systems) model to simulate the impact of land management on water, sediment, nutrients, and pesticides leaving the edge of a field. The EPIC (Erosion-Productivity Impact Calculator) model was initially developed (Williams, 1990) to simulate the impact of erosion on crop productivity but has evolved into a comprehensive agricultural management and nonpoint source loading model.

The APEX (Agricultural Policy/Environmental eXtender) model was developed for use in whole farm/small watershed management (Williams et al., 2000). The individual field simulation component of APEX is taken from EPIC. Continuous time watershed models, such as SWRRB (Simulator for Water Resources for Rural Basins; Williams, 1990; and Arnold et al., 1990), were developed to simulate NPS pollution from watersheds. However, these models lacked sufficient spatial detail. Therefore, SWAT (Soil Water Assessment Tool; Arnold et al., 1998) was developed to simulate streamflow in much larger basins by allowing the division of a basin into hundreds or thousands of grid cells or subbasins. The land area in a subbasin may be further divided into hydrological response units (HRUs). The HRUs within SWAT are portions of subbasins that possess unique land use, management, and soil attributes. The concept of the HRU is based on the assumption that there is no interaction between HRUs in one subbasin, therefore it is only at the subbasin level that spatial relationships can be specified. SWAT is a continuous time model that operates on a daily time step. SWAT is able to evaluate management effects on water quality, sediment, and agricultural chemical yield in large ungauged basins. In addition, SWAT is based on a command structure for routing runoff and chemicals through a watershed. These commands allow the user to input measured data (e.g., weather) and point source pollution loadings.

The major components of SWAT include hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. The hydrology components of SWAT include surface runoff, percolation, lateral subsurface flow, groundwater flow, evapotranspiration, and transmission loss subroutines. The minimum weather inputs required by the SWAT are maximum and minimum air temperature and precipitation. Sediment yield is estimated by the Modified Universal Soil Loss Equation (MUSLE; Williams, 1975). Daily average soil temperature is simulated using the maximum and minimum annual air temperatures, surface temperature, and damping depth. SWAT is also able to accept output data from other simulation models such as APEX.

APEX is a field-scale model designed to simulate edge-of-field nutrient concentration, runoff volume, and nutrient loadings from specific field management practices on a daily timestep for multiple fields within one simulation. Similar to HRUs in SWAT, the fields within APEX are portions of a subbasin that possess unique land use, management, and soil attributes. However, in contrast to HRUs in SWAT, interactions between fields simulated by APEX are possible (e.g., one field representing a filter strip for an upgradient field). APEX simulates weather, hydrology, soil temperature, erosion-sedimentation, nutrient cycling, tillage, field management practices, crop management and growth, pesticide and nutrient fate and transport as well as costs and returns of the various management practices. APEX is applicable to a wide range of soils, climates, and cropping systems.

The advantages of using APEX at the field level as compared to SWAT are: 1) in contrast to SWAT HRUs, field units within APEX have spatial relationship and can be routed in a specified order; 2) simultaneous multiple cropping simulation within SWAT is not possible at this time, while APEX is capable of this function; 3) the simulation of filter strips, a common BMP, by SWAT is currently only possible by adjusting coefficients based on academic literature, whereas in APEX "filter strips" are simulated based on physical-based functions; and 4) APEX is capable of simulating the detailed field conditions including management practices related to farm animal production, economic impacts of BMPs, and wind erosion, which is currently not possible with SWAT. The strengths of SWAT are: 1) the capability of generating the required database through its interface known as AVSWAT (Di Luzio et al., 2002); 2) the secondary routing function at subbasin level; and 3) the capability of accepting input from other models, such as APEX, and representing point sources, such as municipal wastewater treatment plants (WWTPs).

Saleh et al. (2000), Osei et al. (2000), and Gassman et al. (2001) report on studies that have taken advantage of the capabilities of the combined SWAT and APEX models by simulating an environmental baseline and BMPs at the field level with APEX and routing the results from APEX and the remaining land uses within a watershed using SWAT. This arrangement of the two models provides the opportunity to simulate scenarios, such as filter strips, at the field level using APEX, which is not feasible in SWAT. Because of the manual transformation of files from SWAT to APEX, however, the simulation process was often tedious and subject to a number of assumptions that could affect simulation results.

Hence, there was a need to establish a direct link between SWAT and APEX where the simulation process is automated and results are less subject to errors. Recently Williams et al. (2003), presented a program to convert SWAT files to APEX format. However, many parts of their program are still performed manually, and a direct linkage of these two models is missing. Also, their program has not been verified against measured data.

Therefore, this study was conducted to: 1) develop an automated program referred to as SWAPP to convert SWAT files to-and-from APEX format and simulate SWAT and APEX simultaneously; and 2) to evaluate this program using measured data from the upper North Bosque River watershed in central Texas.

Methods and Materials

SWAPP Program Description

The SWAPP process starts with data files created by the AVSWAT program. As Figure 1 shows, the SWAPP process occurs in four major phases:

> *Phase I*. In this phase, the user specifies the type of land use(s) to be simulated by APEX rather than by SWAT. By using the "SWAT-APEX" subprogram of the SWAPP, all the required APEX data files for selected land use(s) from SWAT format are transferred to APEX format (Figure 1). These files include management, soil, subfile, weather, and all general databases, such as crop.dat, fert.dat, parm.dat, and till.dat, which are commonly used by SWAT and APEX.

Also, the land use areas simulated by APEX are subtracted from the original subbasins area simulated by SWAT to avoid duplicate simulation of APEX land areas by SWAT. During this phase the SWAT datafiles, such as soil and management, related to selected land use(s) for APEX simulation are converted to APEX format. In addition, SWAT "HRUs" are transformed to APEX "fields" files. The "fields" structure within APEX in contrast to HRUs in SWAT (as illustrated in Figure 2) is spatially identified within a subbasin, which provides an option to simulate any specified field (e.g., the field next to the stream) as filter strip by specifying surface and subsurface flow from at least one other field entering the filter strip. The "fields" structure in APEX also allows the flow, sediment, and nutrient loadings from each field (HRU) to be either simulated individually (case A), be routed through one field to another (case B) using the APEX routing function, or combinations of cases A and B as indicated by topography (Figure 2).

> *Phase II.* During this phase the specified land use(s) are simulated by APEX and the results, including the daily flow and loading of sediment and nutrients, are stored in .SWT file (Figure 1). As example, in case A (Figure 2), the .SWT files obtained from each individual field (HRUs) within a subbasin are merged together in one .SWT file, while in case B, a single .SWT is obtained from the last routed field within a subbasin (Figure 2).

Figure 1 Flow chart of SWAPP program.

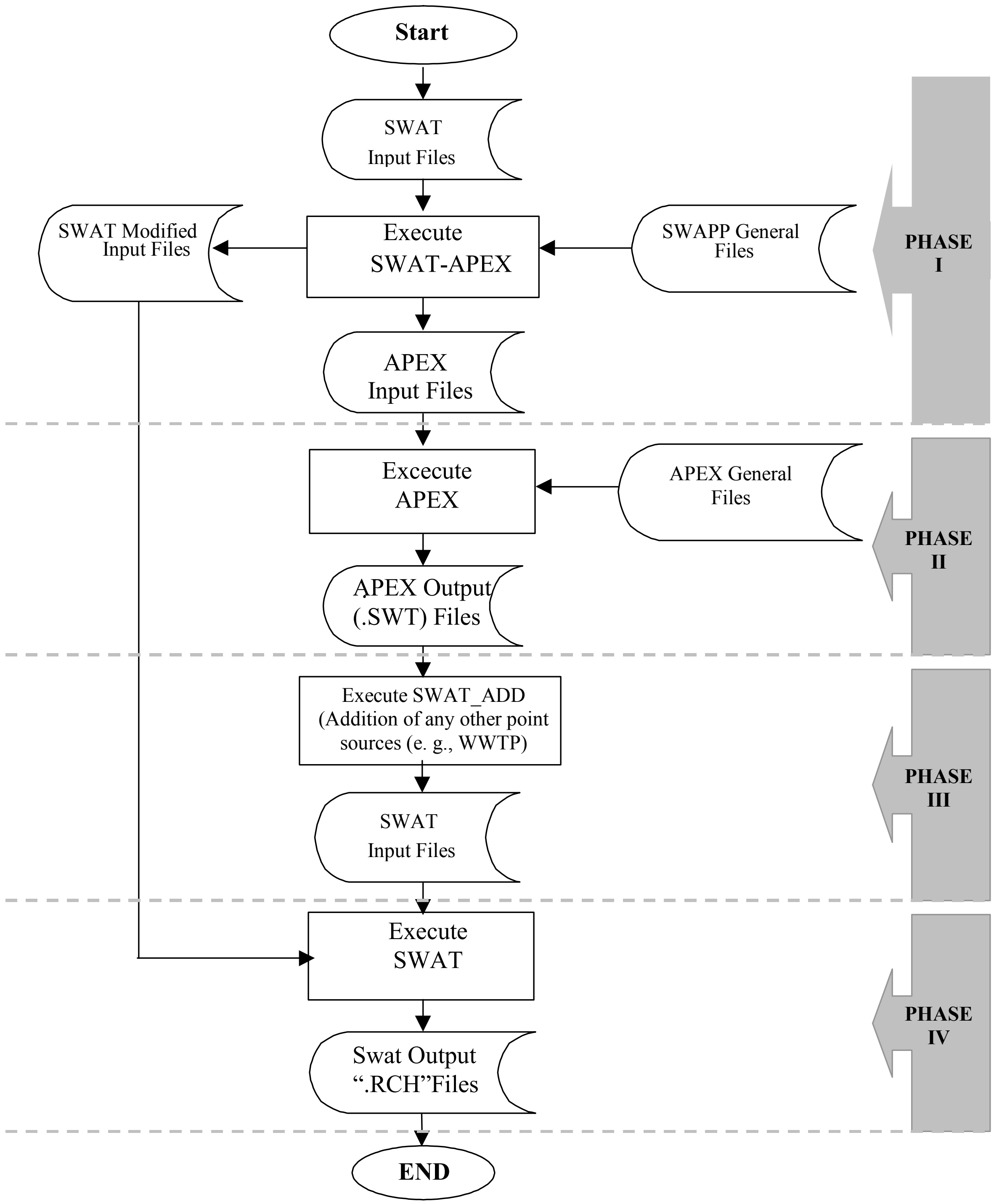
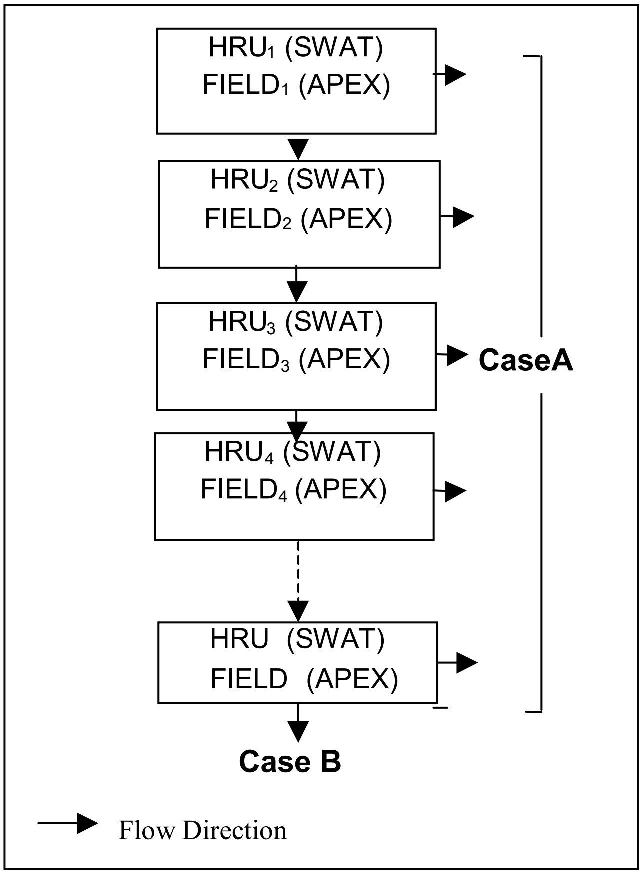


Figure 2 Transformed SWAT HRUs to APEX fields with spatial location within a subbasin.



Phase III. In this phase the "SWAT_ADD" subprogram of the SWAPP is used to add daily inputs from any possible point sources (e.g., WWTP effluents) to appropriate subbasin(s) to the APEX input files (.SWT). The results obtained from this process are input into SWAT at the subbasin level (Figure 1). The "recday" command within SWAT program reads in the daily flow, sediment and nutrient loading stored in the ".SWT" files as point source input at the outlet of each appropriate subbasin.

Phase IV. In the last phase, the SWAT program, which includes the .SWT files, is operated. The combined simulation results of SWAT and APEX are presented in SWAT ".RCH" output file (Figure 1).

Watershed Description

The UNBR watershed is defined as the contributing drainage area above sampling site BO070, located on the North Bosque River at Hico, Texas (Figure 3). The UNBR watershed is 98 percent rural with the primary land uses being rangeland (43 percent), forage fields (23 percent), and dairy waste application fields (7 percent). Dairy production is the dominant agricultural activity; other important agricultural enterprises include peanut, range-fed cattle, pecan, peach, and forage hay production. The watershed lies primarily in two major land resource areas, known as the West Cross-Timbers and the Grand Prairie. The soil in the West Cross Timbers is dominated by fine sandy loam with sandy clay subsoil, while calcareous clays and clay loam are the predominant soil types in the Grand Prairie (Ward et al., 1992). The elevation in the watershed ranges from 305 to 496 meters.

The City of Stephenville (population 16,000) and portions of the smaller cities of Dublin and Hico are located within the UNBR watershed. The Stephenville wastewater treatment plant (SWWTP), with an average discharge of 6,380 m^3 per day during the simulation period, is the only point source permitted to discharge in the watershed. The average annual precipitation in the area is approximately 750 mm, and the average daily temperature ranges from 6 ^{o}C in winter to 28 ^{o}C in summer (McFarland and Hauck, 1999). Winter and fall rainfall is induced by continental polar fronts, which produce low-intensity, long-duration storms. In the spring and summer, the majority of rainfall events are squall line thunderstorms, which produce high-intensity, short-duration storms that can result in flooding in small watersheds.

A consistent period of monitoring from October 1993 through July 1999 was available for three stream sites for the model calibration and verification (Figure 3). As Figure 3 and Table 1 show, the three sites are located throughout the watershed and represent contributing drainage areas ranging from 254 square kilometers to the entire watershed area. Each of these sites was instrumented with an automated sampler to monitor storm events. Monthly or biweekly grab sampling was also taken to represent base flow water quality characteristics. Routine chemical analyses of water samples using USEPA approved analytical methods included total suspended solids (TSS), total Kjeldahl- N (TKN), ammonia-N (NH_3- N), nitrate-N (NO_3-N) plus nitrite-N (NO_2-N), total-P, and soluble reactive P (PO_4-P) (USEPA, 1983).

Particulate-P was estimated by subtraction of PO_4-P from total-P, and organic-N was determined by subtraction of NH_3-N from TKN. Herein total-N is defined as TKN + NO_3-NO_2. Water levels monitored at each stream site at five-minute intervals were combined with a site-specific stage-discharge curve to develop a historical flow dataset. Flow information and water quality data were then combined using a midpoint rectangular integration method to calculate nutrient and TSS loadings at each site. Specifics of the monitoring program and loading calculations are presented in McFarland and Hauck (1999).

Figure 3 Location of sampling stations, dairies, streams, and subbasins within UNBR watershed.

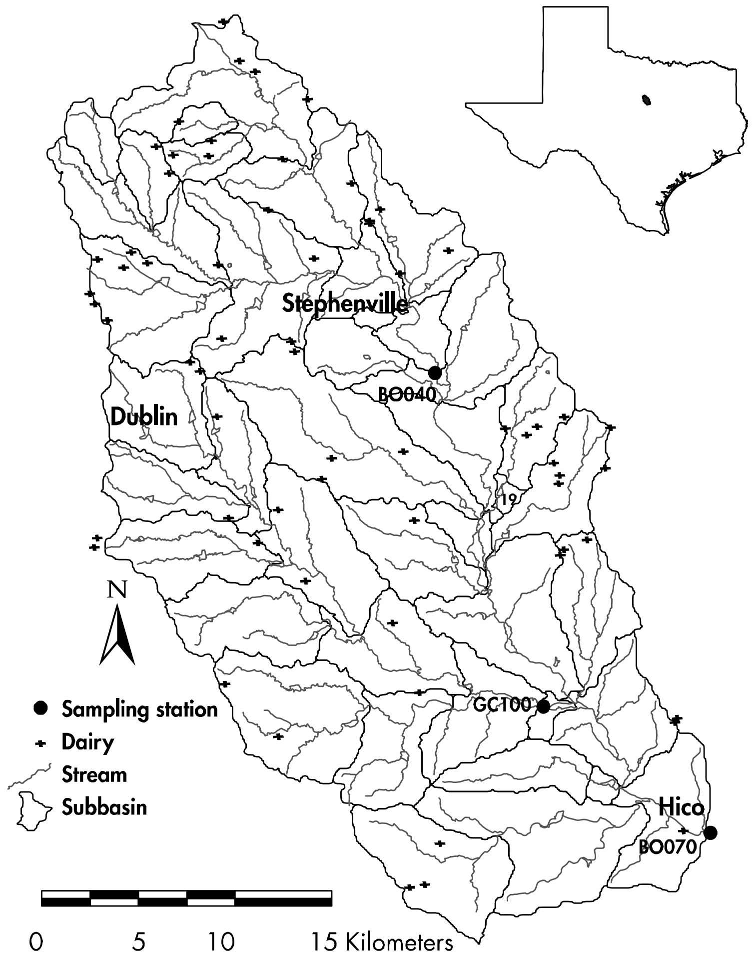


Table 1 Land use characteristics for drainage basins above stream sampling sites.

Sampling Site	Area (km^2)	Woodland (%)	Range (%)	Forage Fields(%)	Peanuts (%)	Orchard (%)	Water (%)	Urban (%)	Barren (%)	Waste Application Field (%)
BO040	254	23.7	27.4	32.2	1.6	0.3	0.7	3.8	0.7	11.7
GC100	261	21.4	46.7	21.1	2.2	0.3	0.5	0.7	0.2	6.9
BO070	921	22.6	43.1	22.7	1.4	0.4	0.5	1.7	0.4	7.3

SWAT and APEX Input Data Descriptions

Topographic, land use and cover, and soil data required by SWAT and APEX for this study were generated from GIS maps using the AVSWAT. Topographic data were created from existing 1:24,000 scale United States Geological Survey (USGS) Digital Elevation Model (DEM) and digitized USGS 7-1/2 minute quadrangle maps. A subwatershed map required for SWAT and APEX was then generated from the topographic data with consideration of current locations of sampling sites. Based on this procedure, the UNBR watershed was divided into 41 subwatersheds (Figure 3).

The land use categories in the watershed were developed from the classifications of Landsat Thematic Mapper images created from an overflight taken on August 28, 1992. Ground truthing was performed to assist in the imagery classification and to verify the final results. The minimum mapping unit for land use characterization was about 0.1 hectare. Land use categories included in the final land use map were rangeland, forage fields (Coastal bermuda grass and some double-cropped wheat and Sudan grass), woodland (trees and heavy brush), orchards and groves, peanuts, urban, and water. The size and location of animal waste application fields (WAFs) were obtained from the Texas Commission on Environmental Quality (TCEQ) dairy permits and available waste management plans.

Soil data used for this study was obtained using a digital soil map of the UNBR watershed developed by the USDA-NRCS. The major soil series in the watershed are the hydrologic group C Windthorst series (fine, mixed, thermic Udic Paleustalfs), the hydrologic group D Purves series (clayey, montmorillonitic, thermic Lithic Calciustolls), and the hydrologic group B Duffau series (fine-loamy, siliceous, thermic Udic Paleustalfs). A complete list of the soil series and their associated textures used in the simulation runs are given in Table 2. Daily rainfall data obtained from 14 gauges (including several National Weather Service and study associated sites located throughout the watershed) were processed into the proper format for the simulation period. A similar procedure was used to convert daily temperature data available from the National Weather Service sites into the required SWAT and APEX input data files.

NO_3-N, NO_2-N, organic-N, particulate-P, and PO_4-P are common forms of nutrients simulated by SWAT and APEX. Based on the surveys of local farmers, the WAFs were simulated as pasture fields in SWAT and APEX receiving four applications of manure, totaling an average annual rate of 35.8 t/ha. The nutrient content of manure included NO_3-N (0.17 percent), organic-N (2.18 percent), particulate-P (0.38 percent), and PO_4-P (0.66 percent)., Based on standard farming practice in the UNBR watershed, other improved pasture fields were assumed to receive four applications of N and P fertilizer at an annual rate of 336 and 49 kg/ha, respectively.

Table 2 Textural characteristics and percent cover of soils within the UNBR watershed.

Soil Series	Texture	Area (%)	Clay (%)	Silt (%)	Sand (%)	Hydrologic Group
Altoga	Silty Clay	0.4	45.0	47.6	7.4	C
Blanket	Clay Loam	2.3	31.0	33.6	35.5	C
Bolar	Clay Loam	3.1	26.5	35.8	37.8	C
Bosque	Loam	1.9	23.5	37.2	39.3	B
Brackett	Clay Loam	3.0	27.5	37.8	34.7	C
Bunyan	Sandy Loam	5.0	14.0	19.9	66.1	B
Denton	Silty Clay	1.9	46.0	48.3	5.7	D
Duffau	Sandy Loam	5.9	11.5	26.0	62.5	B
Frio	Silty Clay Loam	4.5	39.5	53.3	7.2	B
Gullied land	Sandy Loam	0.3	15.0	30.0	55.0	B
Hensley	Loam	0.3	22.5	37.7	39.8	D
Houston Black	Clay	1.1	55.0	27.8	17.2	D
Lamar	Clay Loam	1.1	27.5	45.1	27.4	B
Lindy	Clay Loam	0.3	27.5	37.8	34.7	C
Maloterre	Clay Loam	2.6	37.5	32.3	30.2	D
Arenosa	Sand	8.4	1.5	0.6	97.9	A
Nimrod	Sand	2.7	3.0	0.6	96.4	C
Purves	Clay	21.0	47.5	29.2	23.3	D
Selden	Loamy Sand	2.3	9.0	6.5	84.5	C
Venus	Loam	0.1	24.0	37.0	39.0	B
Windthorst	Sandy Loam	31.7	11.5	26.0	62.5	C

The measured daily loading of NO_3-N, organic-N, PO_4-P, TSS, and flow from the SWWTP were added as a point source to SWAT model. The input data regarding the SWWTP were determined from average daily discharge information reported by the treatment plant and biweekly or monthly water quality samples collected and analyzed by the Texas Institute for Applied Environmental Research.

The basic data files for APEX simulation, including subarea, management, weather, soil, control, and other required data, were created through the SWAPP program, as outlined in Figure 1.

Model Simulations

SWAT (version 2000) and APEX (version 2110) within the SWAPP program were calibrated and verified using the daily and monthly measured data from the UNBR watershed from January 1994 to July 1999. The measured flow, sediment, and nutrient (NO_3-N+NO_2-N, organic-N, particulate-P, and PO_4-P) loadings at the outlet (site BO070) and two other sites (sites BO040 and GC100) (Figure 3) within the UNBR watershed from January 1994 through December 1995 were used for the calibration and from January 1996 through July 1999 for the verification. The stream water quality component of SWAT was not utilized during this study. Therefore, the loss of NH_3-N from landscapes was not computed from SWAT simulations. The final value of input parameters adjusted during calibration of SWAT and APEX were used without further adjustment to simulate the verification period.

The APEX output from simulation of pasture and agricultural lands were input as a point source into the SWAT using the automated functions of the SWAPP program.

Measure of Model Performance

The predicted and measured values were compared using standard deviation and the Nash and Sutcliffe (1970) equation as:

$$E = 1 - \frac{\sum_{i=1}^{n} (X_{mi} - X_{ci})^2}{\sum_{i=1}^{n} (X_{mi} - \overline{X}_m)^2} \qquad (1)$$

where E = the efficiency of the model, X_{mi} = measured value i, X_{ci} = predicted value i, and $\overline{X}_m$ = average measured values. A value of $E = 1.0$ indicates a perfect prediction, while negative values indicate that the predictions are less reliable than if one had used the sample mean instead.

Results and Discussions

Flow

The average annual precipitation during the simulation period ranged from 600 mm in 1999 to 1200 mm in 1997 (Figure 4), indicating SWAPP was evaluated under a range of moisture regimes. Measured and simulated average, standard deviation, and E values of monthly daily-flow during the calibration (January 1994 through December 1995) and verification (January 1996 through July 1999) periods are provided in Table 3. The SWAPP average monthly daily-flow and the standard deviation of these monthly flow at the outlet of UNBR watershed (BO070) simulated by SWAPP are close to the measured values during calibration and verification periods (Table 3). The patterns of the measured and predicted average monthly daily-flow by SWAPP at site BO070 are relatively close during calibration and verification periods as indicated by E values (Table 3) and visual comparison (Figures 5). Similar to site BO070, the predicted flows by SWAPP for sites BO040 and GC100 were also close to the measured values (Table 3 and Figures 6 and 7).

Figure 4 Average annual precipitation in UNBR watershed.

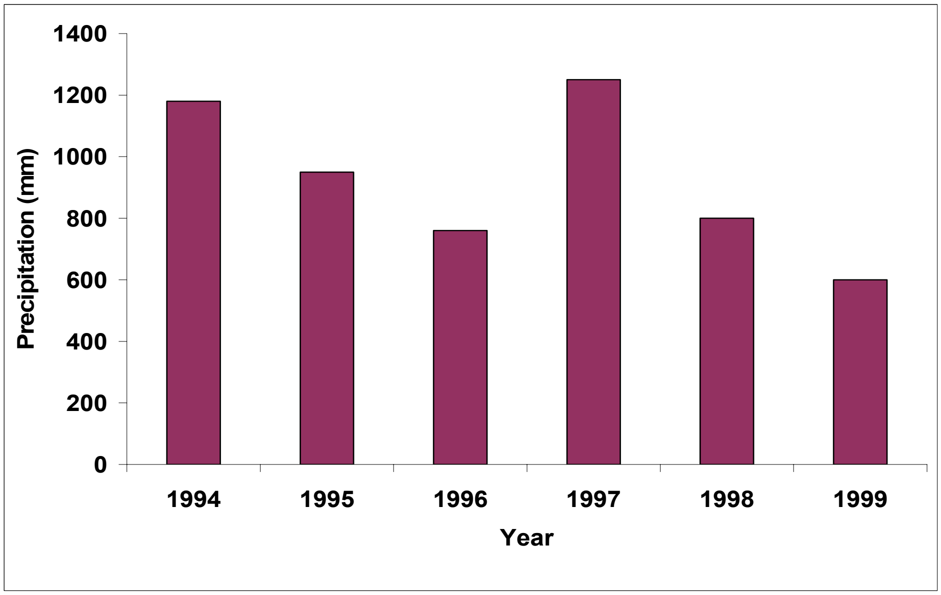


Table 3 Measured and predicted mean, standard deviation (SD), and model efficiency (*E*) of monthly flow and sediment loading by SWAPP at various sites in UNBR watershed during (a) calibration and (b) verification periods.

(a)

		Flow ($m^3 s^{-1}$)			Sediment (t)		
		Mean	**SD**	**E**	**Mean**	**SD**	**E**
BO040	Measured	0.78	0.93	----	807	1,697	----
	SWAPP	0.91	1.02	0.75	570	669	0.37
GC100	Measured	1.25	1.90	----	922	1,846	----
	SWAPP	1.32	1.77	0.64	993	1,364	0.64
BO070	Measured	3.49	4.60	----	4,407	8,236	----
	SWAPP	4.17	4.93	0.72	2,959	3,511	0.50

(b)

		Flow ($m^3 s^{-1}$)			Sediment (t)		
		Mean	**SD**	**E**	**Mean**	**SD**	**E**
BO040	Measured	0.92	1.28	----	700	1,423	----
	SWAPP	0.85	1.33	0.77	553	943	0.72
GC100	Measured	1.04	1.96	----	737	1,803	----
	SWAPP	1.09	1.53	0.65	811	1,142	0.53
BO070	Measured	3.03	5.36	----	3,620	9,134	----
	SWAPP	3.96	5.65	0.80	2,834	4,072	0.54

Figure 5 Measured and predicted monthly flow at the outlet of UNBRW (BO070).

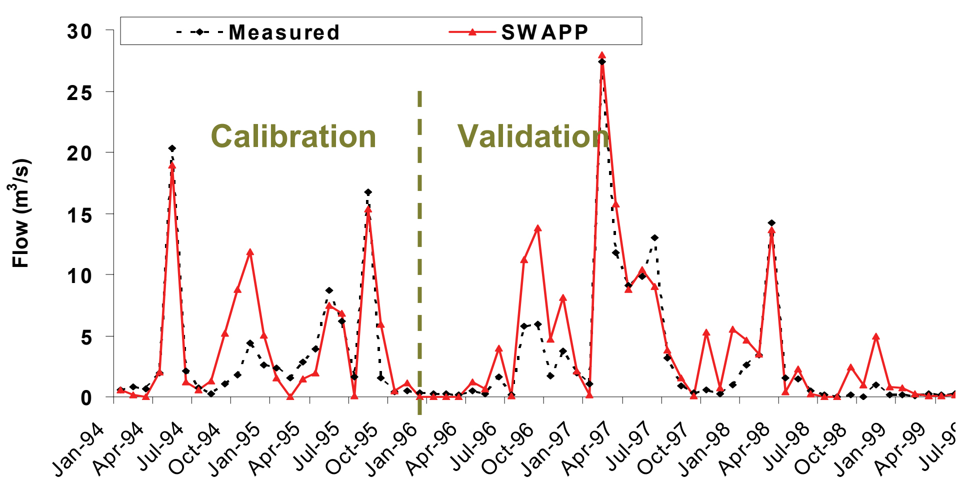


Figure 6 Measured and predicted monthly flow at site BO040.

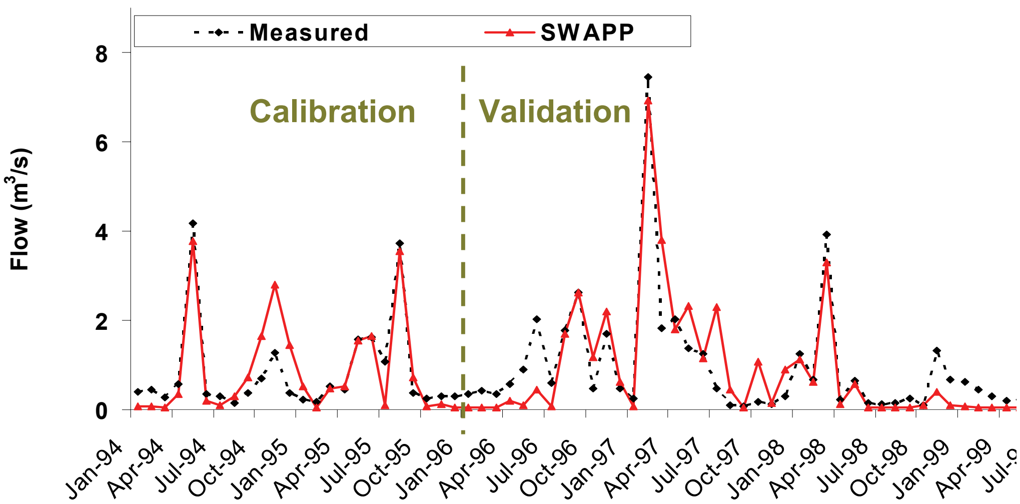
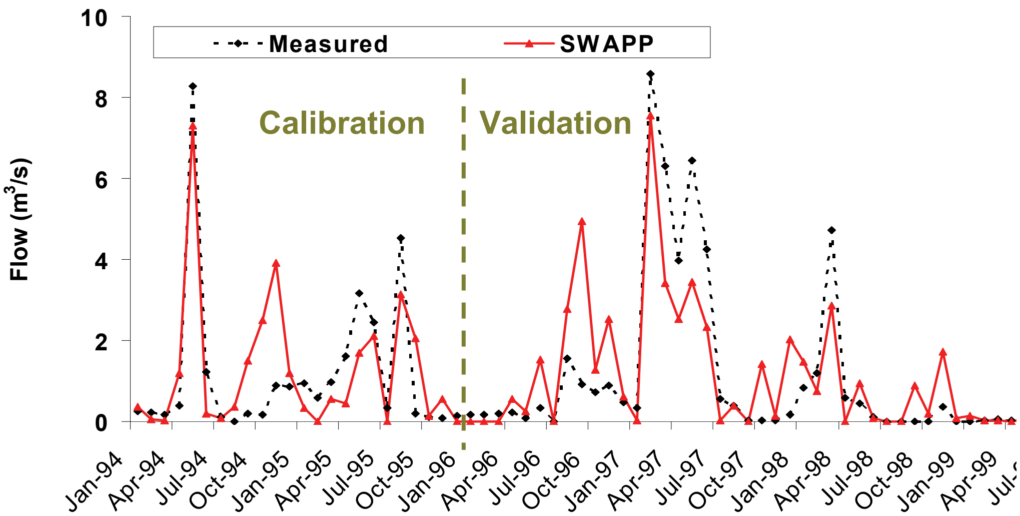


Figure 7 Measured and predicted monthly flow at site GC100.



Sediment (TSS)

As expected, the predicted and measured TSS loading from landscapes within the UNBR watershed indicates a significant TSS transport from the watershed (Tables 3), since a major portion of the watershed is covered by erosive soils. The accuracy of the predicted TSS by SWAPP varies at different sites within the UNBR watershed. The average monthly TSS loading and temporal patterns predicted by SWAPP at site BO070 are close to measured values during calibration and verification (Table 3 and Figure 8). However, the average monthly TSS loading predicted by SWAPP during the larger storm events was less than measured loadings.

The average monthly TSS predicted by SWAPP at sites BO040 and GC100 are generally close to those measured (Table 3). Similar to site BO070, the trends of predicted sediment by SWAPP are similar to those of measured during the calibration and validation periods (Table 3 and Figures 9 and 10).

Figure 8 Measured and predicted monthly TSS at the outlet of UNBRW (BO070).

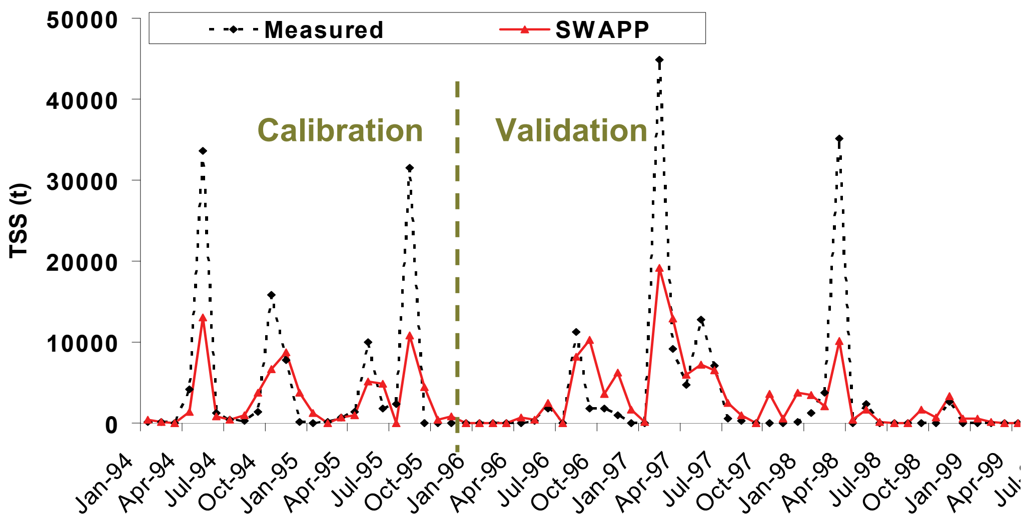


Figure 9 Measured and predicted monthly TSS at site BO040.

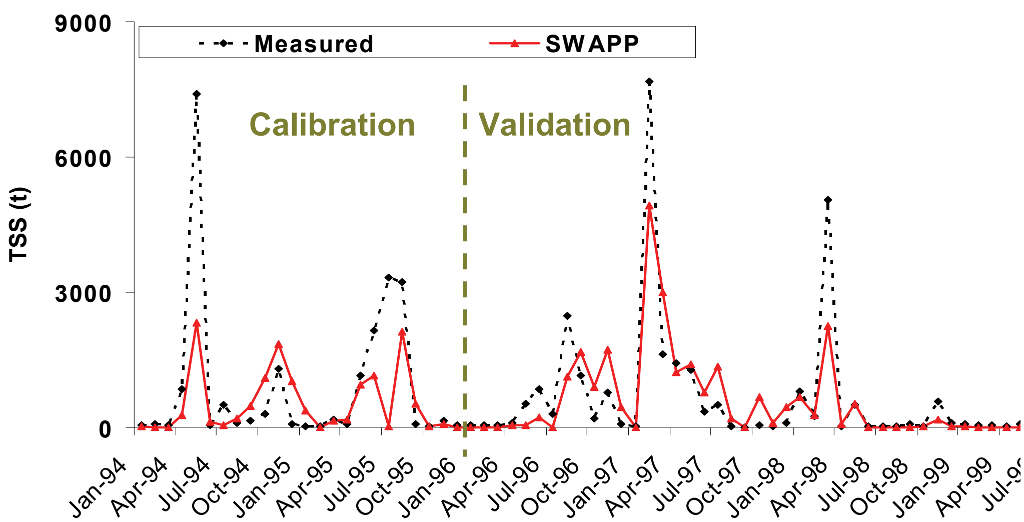
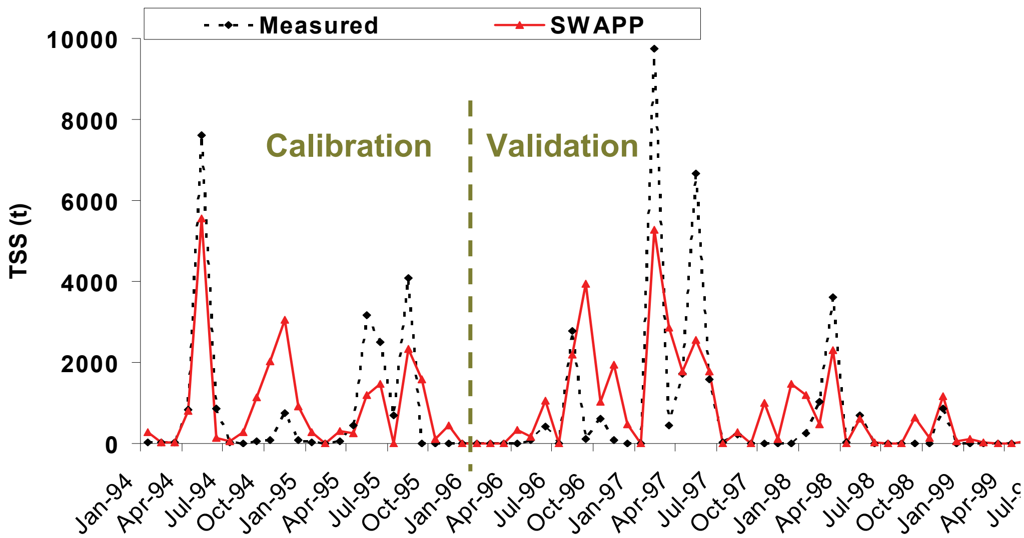


Figure 10 Measured and predicted monthly TSS at site GC100.



Nutrients

As Tables 4 and 5 show, the average monthly NO_3-N+NO_2-N, PO_4-P, organic N, and organic P loadings predicted by SWAPP at all sites in most cases are close to the measured values during both calibration and verification periods.

Table 4 Measured and predicted mean, standard deviation (SD), and model efficiency (*E*) of monthly NO_3-N+NO_2-N, Organic N, and Total-N loadings by SWAPP at various sites in UNBR watershed during (a) calibration and (b) verification periods.

(a)

		NO_3-N+NO_2-N (kg)			Organic N (kg)			Total N (kg)		
		Mean	SD	E	Mean	SD	E	Mean	SD	E
BO040	Measured	5,744	3,608	----	5,689	8,038	----	11,433	11,104	----
	SWAPP	3,516	3,091	0.00	4,657	4,122	0.35	8,173	6,621	0.43
GC100	Measured	2,270	3,547	----	5,288	9,449	----	7,559	12,898	----
	SWAPP	2,142	3,055	0.57	5,675	8,178	0.72	7,817	11,202	0.69
BO070	Measured	7,025	8,639	----	16,516	25,383	----	23,541	33,617	----
	SWAPP	7,973	9,360	0.78	17,055	18,463	0.78	25,028	27,599	0.82

(b)

		NO_3-N+NO_2-N (kg)			Organic N (kg)			Total N (kg)		
		Mean	**SD**	**E**	**Mean**	**SD**	**E**	**Mean**	**SD**	**E**
BO040	Measured	4,734	3,972	----	6,407	9,444	----	11,141	12,794	----
	SWAPP	2,731	3,335	0.22	3,983	7,957	0.82	6,713	10,629	0.71
GC100	Measured	1,977	3,899	----	4,341	8,664	----	6,319	12,374	----
	SWAPP	1,691	2,289	0.46	4,890	8,192	0.67	6,581	10,314	0.64
BO070	Measured	5,459	9,621	----	14,414	28,893	----	19,873	37,964	----
	SWAPP	7,086	10,015	0.63	16,064	27,090	0.92	23,149	36,226	0.89

Table 5 Measured and predicted mean, standard deviation (SD), and model efficiency (*E*) of monthly PO_4-P, Particulate P, and Total-P by SWAPP at various sites within UNBR watershed during (a) calibration and (b) verification periods.

(a)

		PO_4-P (kg)			Organic P (kg)			Total P (kg)		
		Mean	**SD**	**E**	**Mean**	**SD**	**E**	**Mean**	**SD**	**E**
BO040	Measured	1,288	1,344	----	1,005	1,458	----	2,293	2,760	----
	SWAPP	1,236	1,175	0.34	1,314	1,475	0.55	2,550	2,599	0.53
GC100	Measured	565	1,279	----	814	1,214	----	1,378	2,304	----
	SWAPP	560	1,102	0.88	801	1,389	0.37	1,361	2,468	0.79
BO070	Measured	1,913	3,622	----	3,259	4,358	----	5,172	7,703	----
	SWAPP	2,079	2,659	0.77	2,829	3,479	0.83	4,908	6,045	0.87

(b)

		PO_4-P (kg)			Organic P (kg)			Total P (kg)		
		Mean	**SD**	**E**	**Mean**	**SD**	**E**	**Mean**	**SD**	**E**
BO040	Measured	1,703	1,554	----	1,110	1,796	----	2,813	3,222	----
	SWAPP	1,248	1,899	0.21	1,386	2,522	0.22	2,633	4,346	0.32
GC100	Measured	476	1,043	----	649	1,297	----	1,126	2,254	----
	SWAPP	494	1,073	0.59	708	1,356	0.80	1,202	2,414	0.78
BO070	Measured	1,980	3,891	----	2,775	5,730	----	4,754	9,430	----
	SWAPP	2,138	3,853	0.84	3,043	5,410	0.75	5,181	9,192	0.82

The model efficiencies of predicted monthly NO_3-N+NO_2-N, PO_4-P, organic N, and organic P by SWAPP seem reasonable (Tables 4 and 5) at all sites in the watershed. Also, the patterns of predicted values by SWAPP are generally similar to those measured (Figures 11 through 22). It is important to note that some of the observed differences between measured and predicted values are because of both inaccuracy of the models and problems associated with field measurements. The later is more noticeable at the sampling sites with more intermittent flow and under dryer conditions, where field measurements become more challenging.

Figure 11 Measured and predicted monthly NO_3-N+ NO_2-N at the outlet of UNBRW (BO070).

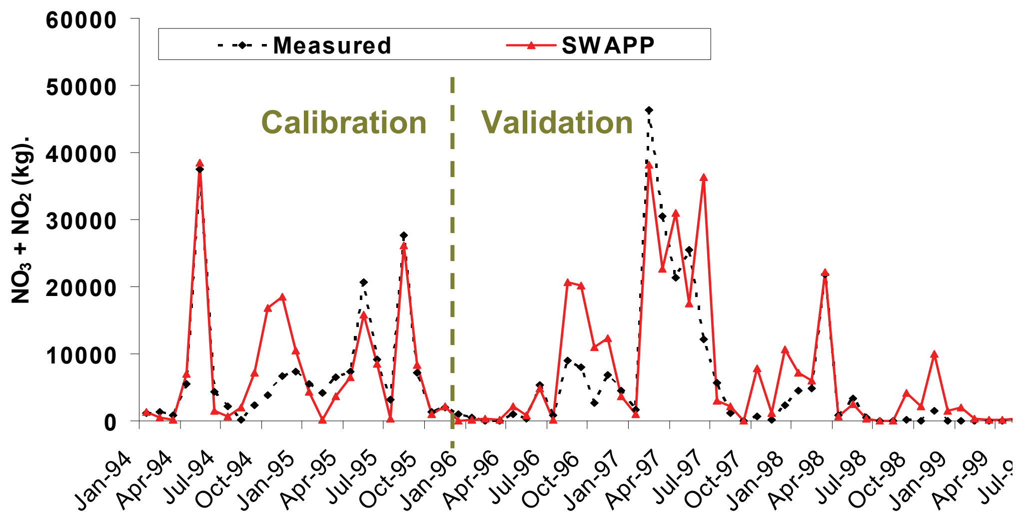


Figure 12 Measured and predicted monthly Organic-N at the outlet of UNBRW (BO070).

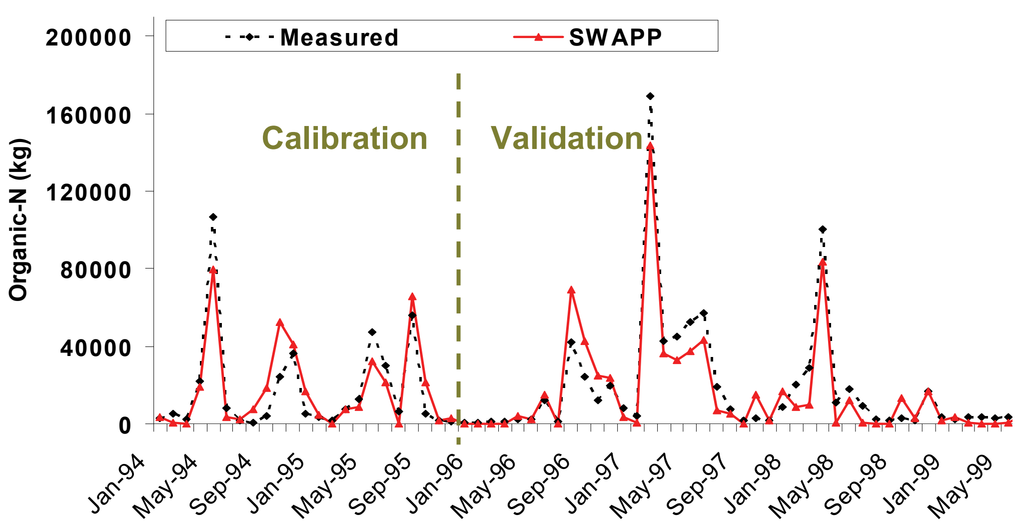


Figure 13 Measured and predicted monthly PO_4-P at the outlet of UNBRW (BO070).

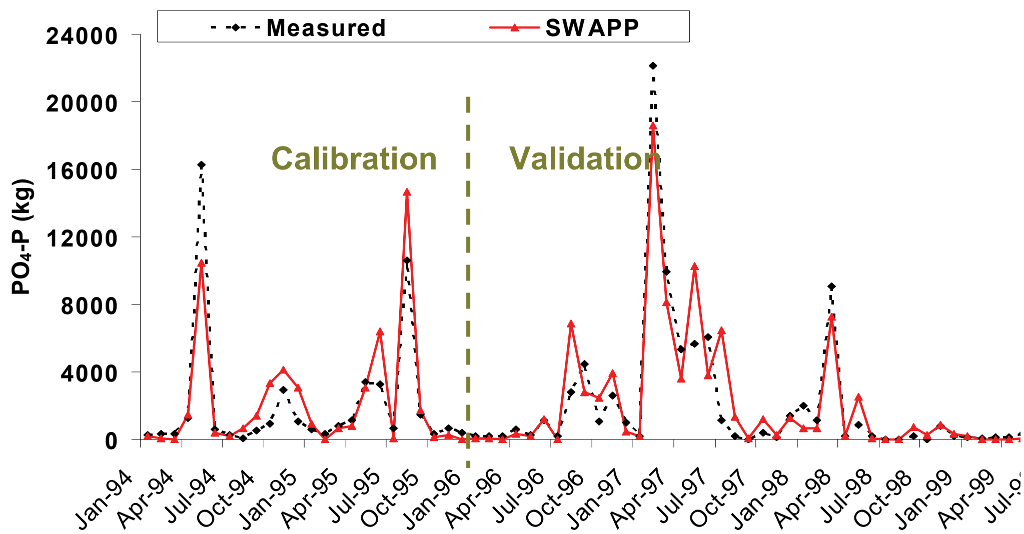


Figure 14 Measured and predicted monthly particulate-P at the outlet of UNBRW (BO070).

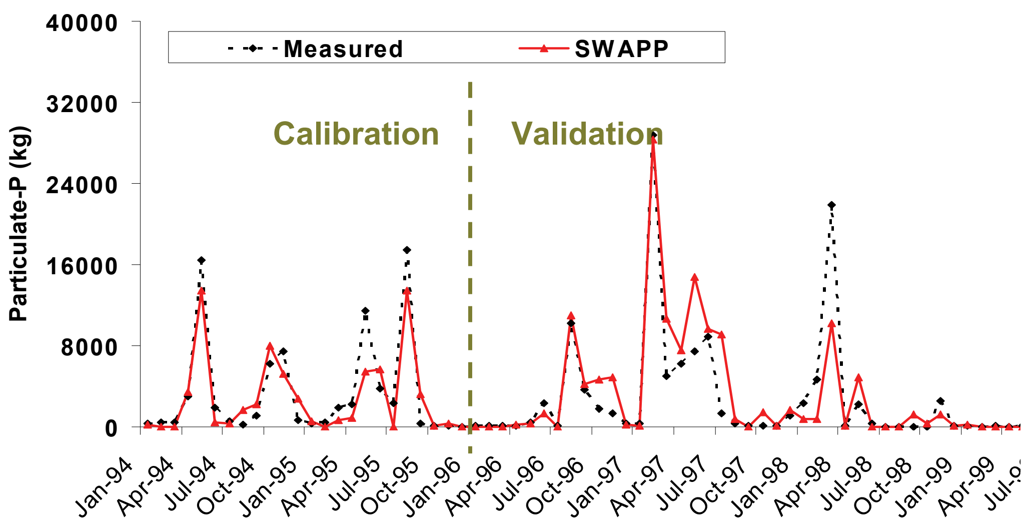


Figure 15 Measured and predicted monthly NO_3-N+ NO_2-N at site BO040.

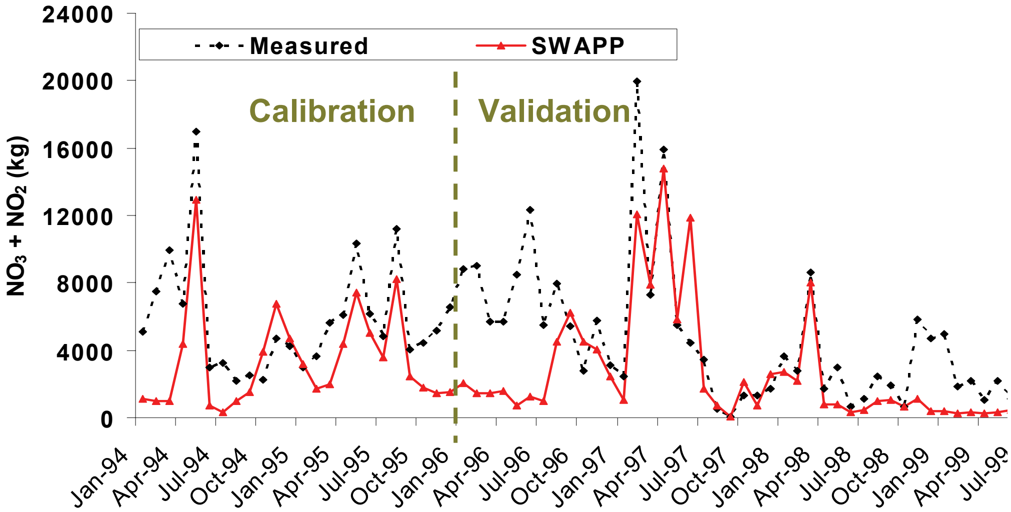


Figure 16 Measured and predicted monthly Organic-N at site BO040.

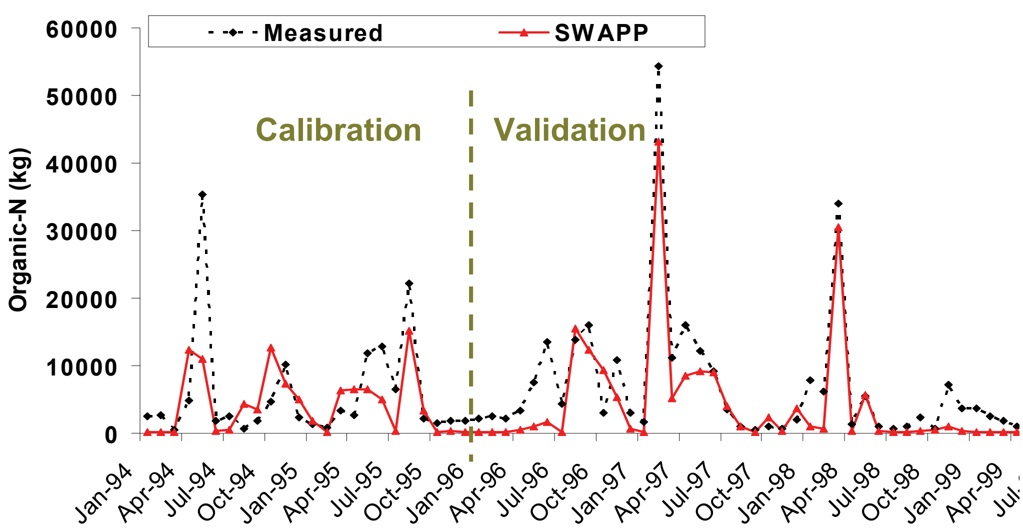


Figure 17 Measured and predicted monthly PO_4-P at site BO040.

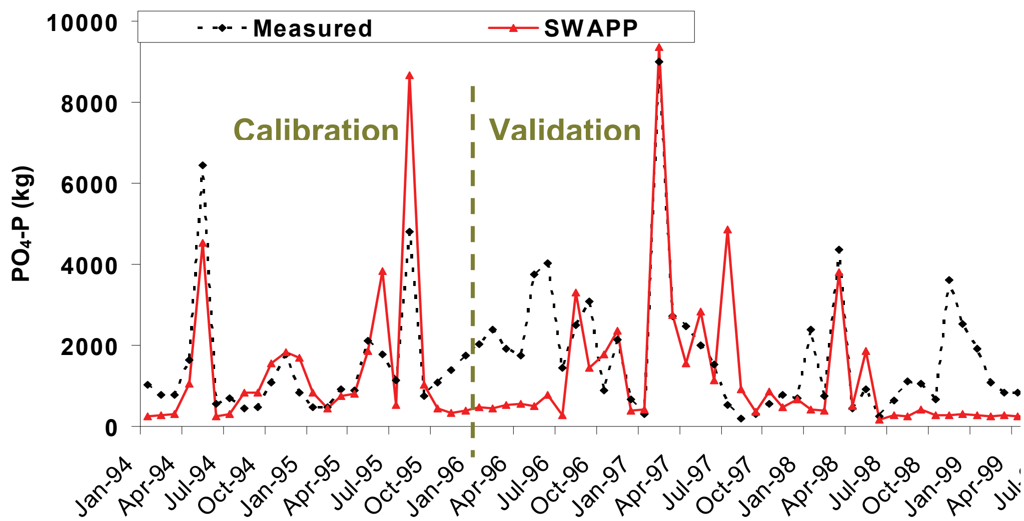


Figure 18 Measured and predicted monthly particulate-P at site BO040.

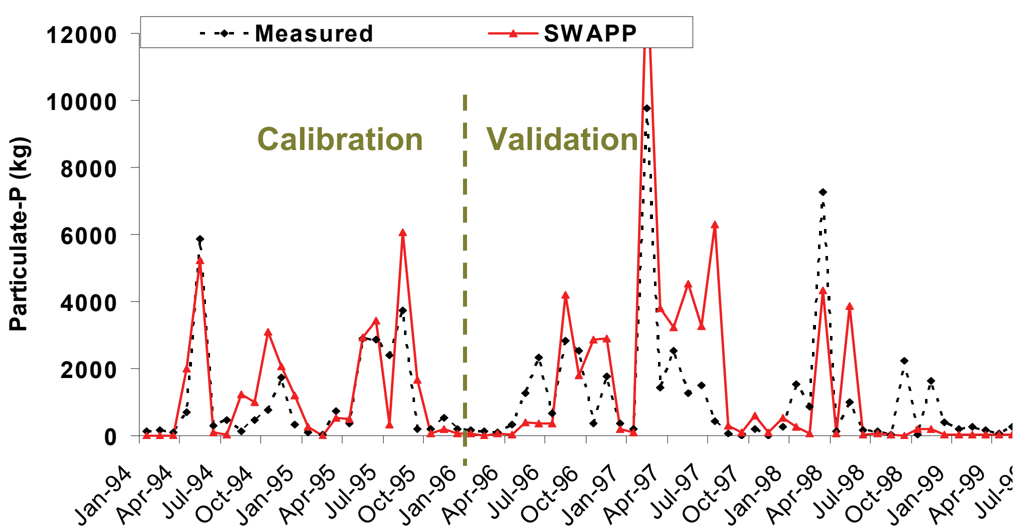


Figure 19 Measured and predicted monthly NO_3-N+ NO_2-N at site GC100.

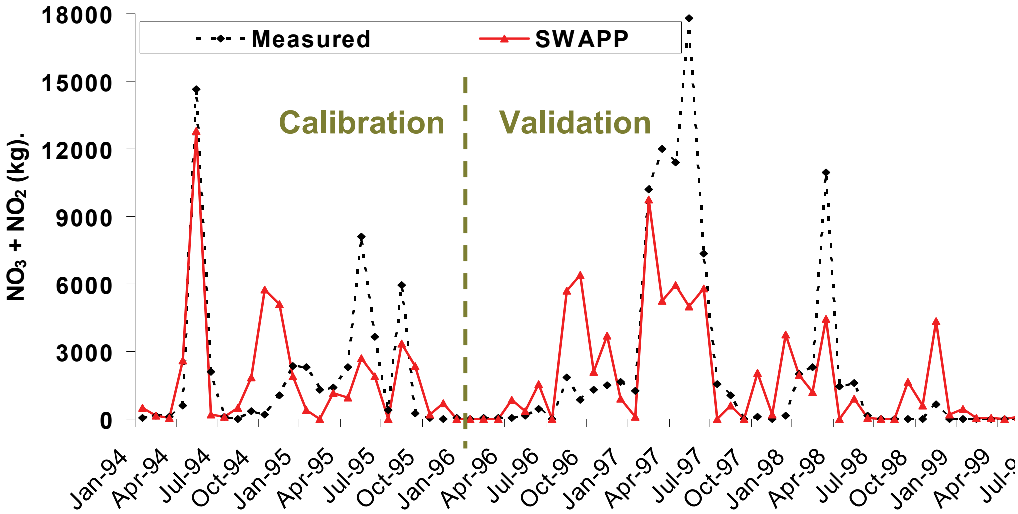


Figure 20 Measured and predicted monthly Organic-N at site GC100.

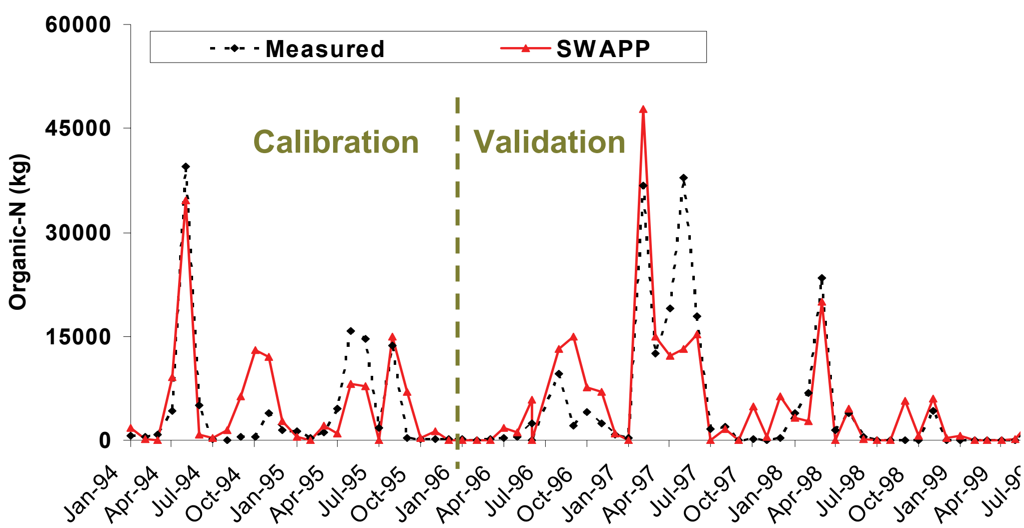


Figure 21 Measured and predicted monthly PO_4-P at site GC100.

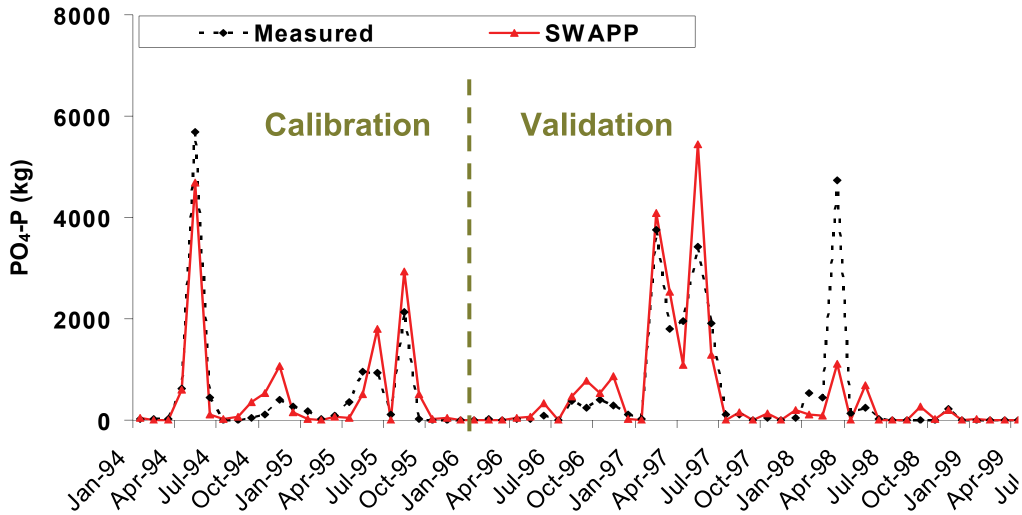
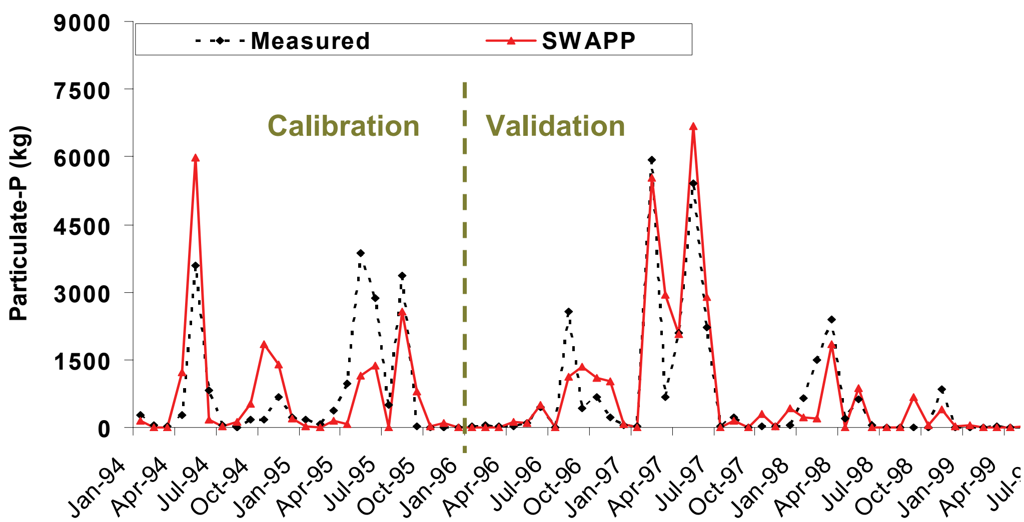


Figure 22 Measured and predicted monthly particulate-P at site GC100.



To overcome the differences associated with different forms of N and P between laboratory analytical procedures and those described by equations within the models, the sum of simulated monthly total-N and total-P were compared to the measured values. Tables 4 and 5 show a closer average of total-N and total-P from the SWAPP to measured values than the individual nutrient comparisons. The efficiencies of both models also improved for total-N and total-P as compared to the individual nutrient forms (Tables 4, 5, and Figures 23-26). These improvements in model efficiencies could be due to the elimination of any error in splitting the soluble and organic N and P in collected samples in the laboratory.

Figure 23 Measured and predicted monthly Total-N at the outlet of UNBRW (BO070).

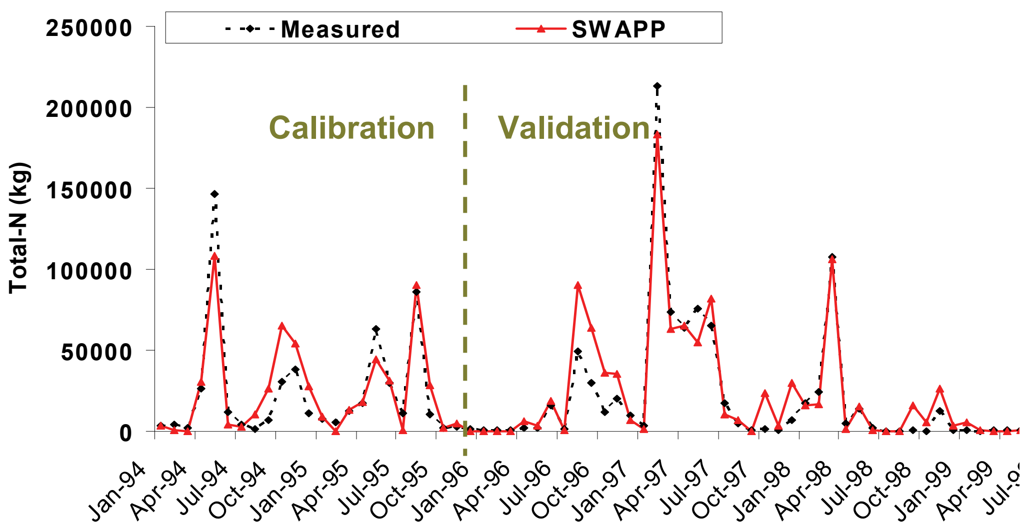


Figure 24 Measured and predicted monthly Total-P at the outlet of UNBRW (BO070).

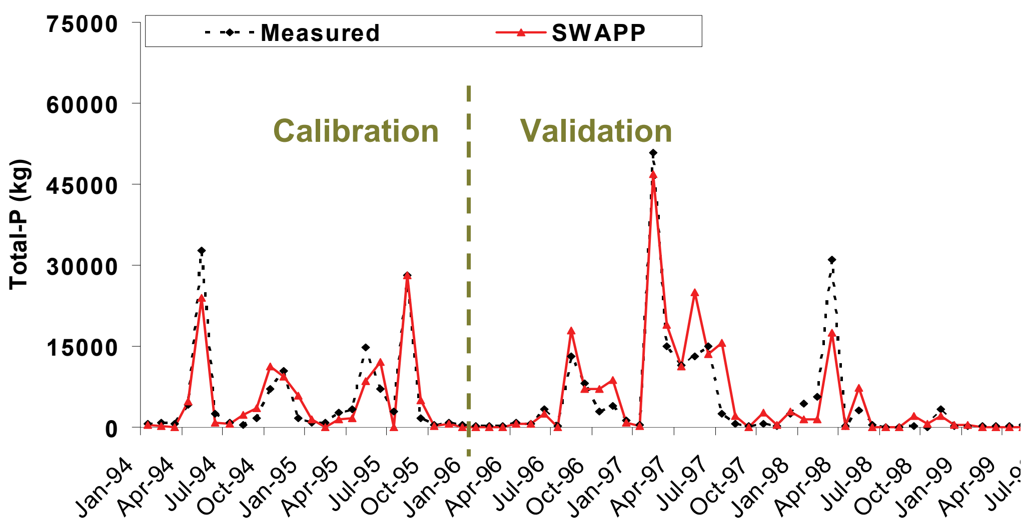


Figure 25 Measured and predicted monthly Total-N at site BO040.

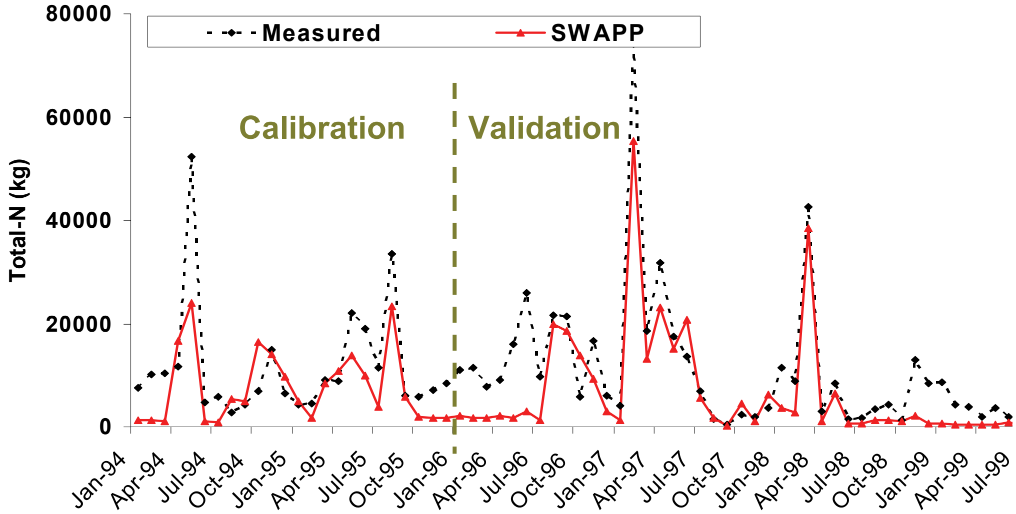


Figure 26 Measured and predicted monthly Total-P at site BO040.

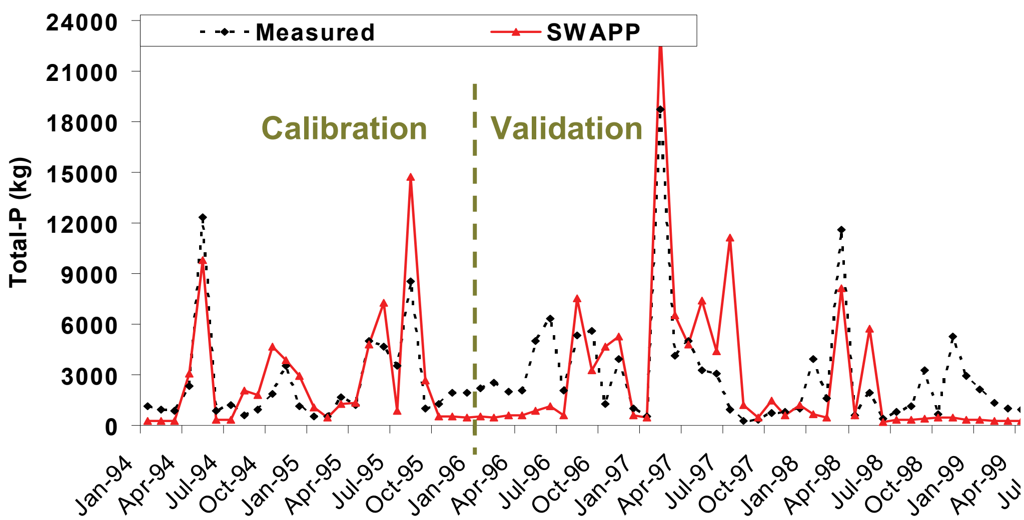


Figure 27 Measured and predicted monthly Total-N at site GC100.

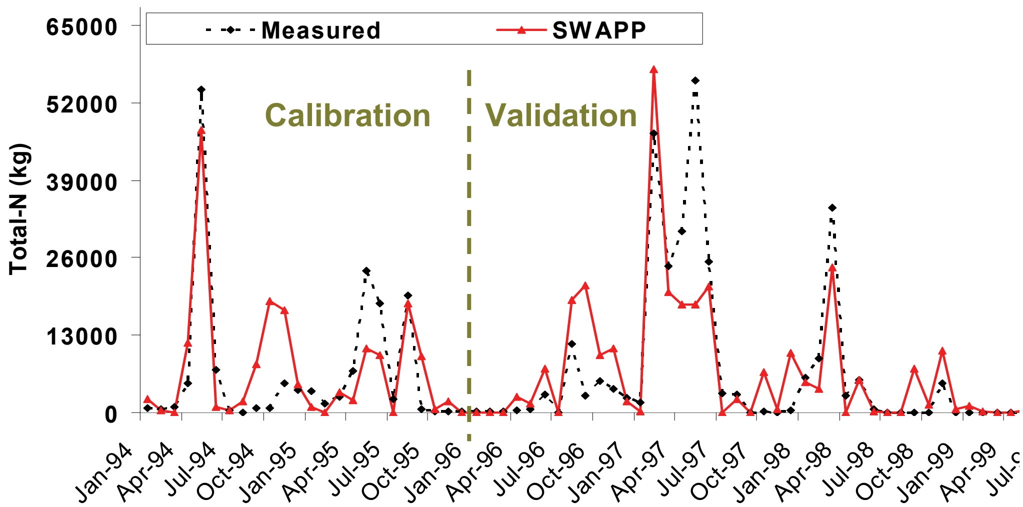
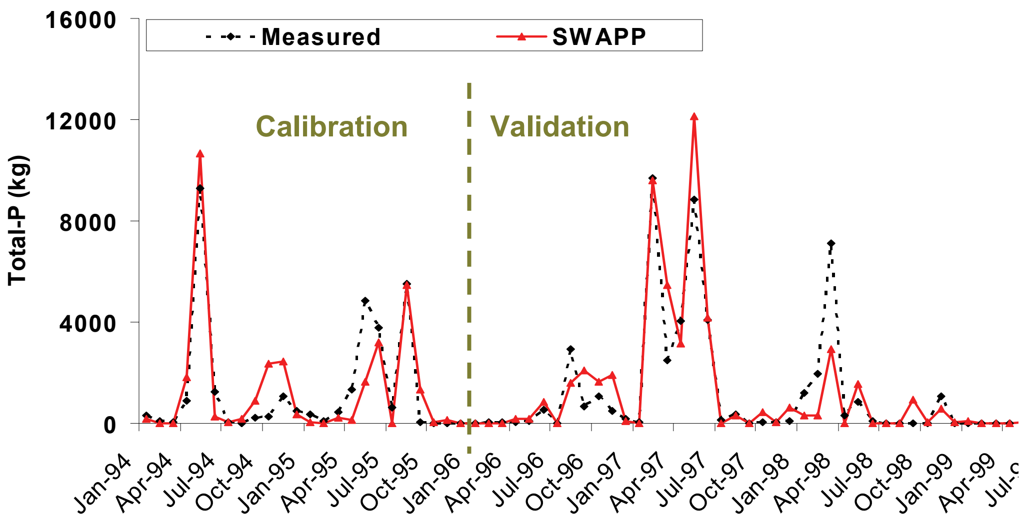


Figure 28 Measured and predicted monthly Total-P at site GC100.



Summary and Conclusions

The watershed-scale SWAT and field-scale APEX models within the SWAPP program were evaluated by comparing the predicted and measured flows, TSS, and nutrient loadings from the UNBR watershed (a watershed that is highly impacted by dairy operations). A GIS-based AVSWAT interface was used to generate much of the required data for both models. The SWAPP program was used to transfer data files of selected land uses within the watershed to and from SWAT and APEX.

The SWAPP provided reasonable and relatively close predictions of daily-flow, TSS, and nutrient loadings during the calibration and verification periods for three sites in the UNBR watershed.

The results of this study showed the procedures to use a field-scale models such as APEX to simulate the baseline and BMP scenarios (such as filter strips) at the field-level, and to use the SWAT program to route the results from APEX through the watershed stream system. The SWAPP program enables simulation of conditions and BMPs scenarios that are difficult to simulate at the field-level with SWAT at this time. The automated process of SWAPP makes it easier for users to transfer files between SWAT and APEX. SWAPP also provides an opportunity to users, based on additional information (such as knowledge of sequence of land usess within a subbasin), to locate each randomized “HRUs” in SWAT within sequential “fields” in APEX. Recently, the SWAPP program was modified to link the latest version of SWAT (SWAT 2003) and APEX (version 2110).

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