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Hydrologic Modeling of the Iroquois River Watershed Using HSPF and SWAT

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Abstract

Watershed scale hydrologic simulation models HSPF (Hydrologic Simulation Program – FORTRAN) and SWAT (Soil and Water Assessment Tool) were used to model the hydrology of the 2150 square mile Iroquois River watershed (IRW) located in the east central Illinois. Both models are part of the BASINS modeling system that facilitates pre- and post-processing of data, as well as data input to the models using an ArcView GIS interface and GUI. HSPF has been widely used for different watersheds all over the US. SWAT was added to BASINS in 2001 and is currently under evaluation. Based on the completeness of the meteorological data, a nine year period of 1987-1995 is used for model calibration, and a 15-year period of 1972-1986 for model validation. Time series plots as well as statistical measures such as Nash-Sutcliffe efficiency (NSE), coefficient of correlation (r), and the percent volume error between observed and simulated streamflow values on both monthly and annual bases were used to verify the simulation abilities of the models. Calibration and validation results from both HSPF and SWAT show that the models generally predict daily, and average monthly and annual stream flows close to the respective observed stream flows.

Introduction

Nutrient and sediment inputs from agricultural as well as urban areas result in elevated concentrations of these pollutants in a river. Sufficiently high concentrations of these pollutants can impair a river/stream’s water quality and cause excess biological growth. Major restoration efforts are underway in the State of Illinois to improve the hydrology, reduce sediment loads and nutrient concentrations, and improve habitat along the Illinois River and its watershed. Proper understanding of the Illinois River watershed’s hydrology is important to guide and evaluate the impacts of proposed or ongoing restoration efforts in the watershed. The objective of this study is to assess the suitability of two popular watershed scale hydrologic and water quality simulation models HSPF (version 12.0, Bicknell et al., 2001) and SWAT (Arnold et al., 1998) to simulate the hydrology of a sub-watershed (the Iroquois River Watershed) of the Illinois River Basin. In this study HSPF was used under the BASINS3.0 (USEPA, 2001) framework whereas a version of SWAT called AVSWAT-2000, which has its own GIS interface similar to BASINS3.0 was used. HSPF has been widely used for watershed scale hydrologic simulations and for assessing the effects of land use changes on watershed scale hydrology and water quality.

Iroquois River Watershed

The IRW is part of a larger study area of Illinois River Basin which is a focus of the long-term ecosystem restoration assessment study. The land use, physiography, and soils in this watershed closely represent conditions existing in most of the Illinois River Basin. The Iroquois River watershed drains about 2,137 square miles and is located in eastern Illinois and western Indiana (Figure 1). A USGS gauging station at Chebanse, IL has observed daily mean streamflow data for the study period of 1970-1995. The 94 mile long Iroquois River is a tributary of the Kankakee River that drains into the Illinois River. The average daily minimum and maximum temperatures are 6° and 16 °C, respectively, and average annual precipitation is 990mm in the IRW.

Originally, a large portion of the IRW was prairie having nearly level to gently sloping topography and poor drainage (Knapp, 1992). Much of the region is an old glacial lake bed (Lake Watseka) and has predominantly flat topography since 75% of land area has slopes less than 2%. Soil is predominantly a heterogeneous mix of silts or clays with some local deposits of sand in the Indiana portion of the watershed and in northern Iroquois County of Illinois. Average slope for the lower 80 miles of the Iroquois River is less than 0.02%. The predominant land use is agriculture which covers 95% area of the watershed. Soybean and maize are commonly grown row crops with subsurface tiles draining fields predominantly under the silty-clay loam soils. Forest and urban land use cover 2.9% and 1.2% of the watershed area, respectively.

Materials and Methods

Brief Description of Models

HSPF is a comprehensive, conceptual, dynamic watershed scale model which simulates non-point source hydrology and water quality, combines it with point source contributions, and performs flow and water quality routing in the watershed reaches. Values of a large number of HSPF parameters can not be obtained from field data and need to be determined through model calibration exercise. However, many of these parameters were conceived to index properties of specific factors that influence events such as water storage and fluxes in the land phase of the hydrologic cycle (James, 1972). Thus, one may categorize HSPF as moderately physically based. The model has three main modules viz. PERLND, IMPLND, and RCHRES which help simulate pervious land segments, impervious land segments, and free-flow reaches/mixed reservoirs, respectively. HSPF uses a Storage Routing technique to route water from one reach to the next during stream processes. Actual evapotranspiration (ET) is a function of the potential ET (user input) demand and the amount of water available in the soil and on the land surface for ET. As there is no plant-growth component in the HSPF, effect of vegetation type, density, root growth, and stage of development along with the moisture characteristics of the soil layer is lumped into the parameter that controls actual ET from the lower zone storage. There is no tile flow component in the HSPF. However, the efficient water removal effect from the field due to tiling is lumped in the parameters that control lower and upper zone storage.

SWAT, developed at the USDA-ARS (Arnold et al., 1998), is a physically based, distributed parameter continuous simulation model that runs on daily time step. SWAT has been used to predict, over long periods of time, the impact of land management practices on water, sediment, and agricultural chemical loads in large complex watersheds with varying soils, land use, and management conditions. Major model components describe processes associated with water movement, sediment movement, soils, temperature, weather, plant growth, nutrients, pesticides and land management. In each spatial subunits water balance is represented by several storage volumes e.g. canopy storage, snow, soil profile, shallow aquifer and deep aquifer. Surface runoff is calculated using a curve number technique. The curve number varies non-linearly with the moisture content of the soil. Soil water processes include infiltration, evaporation, plant uptake, lateral flow and percolation to deeper layers. Actual ET is computed as sum of actual evaporation from soil and plants. Actual soil evaporation is estimated by using exponential functions of soil depth and water content. Plant water evaporation is simulated as a linear function of potential ET, leaf area index and rooting depth, and can be limited by soil water content. SWAT has a simple tile flow component in which the user specifies tile depth, the amount of time required to drain the soil to field capacity, and the time lag between the water enters the tile and leaves it and enters the main channel. Tile drainage occurs when the soil water content exceeds the field capacity.

Model Preparation using HSPF and SWAT

Based on its topography and existing stream network, the IRW was divided into 19 smaller, hydrologically connected sub-watersheds and their stream reaches using the automatic delineation tool of each model's GIS interface. For this the DEM data layer for the region and a pre-digitized stream network data layer (National Hydrography Dataset, NHD of the USGS) were used. A digitized soil information layer (NRCS-STATSGO soil data base) and land use/land cover data layer (USGS-GIRAS data base) were used for further sub-classification of areas in the watershed. All the above GIS data layers were obtained from the BASINS-3.0 database. In HSPF each sub-watershed was partitioned into pervious and impervious areas based on land use such as urban, agriculture, forest, barren, and wetland/water. Since BASINS-HSPF did not automatically create segments based on soil types, the dominant soil (hydrologic soil group B) was considered as representative type. Such an approach has been used in some previous HSPF studies (Donigian et al., Jones and Winterstein). Because major hydrologic differences occur between pervious and impervious land use types, and since agriculture is the major land use in the IRW, all pervious land segments in the model were assigned same hydrologic parameters.

In SWAT, functional modeling units called Hydrologic Response Units (HRUs) were created in each sub-watershed based on the unique intersection of the land use and soils. Area under row-crops was equally split between soybean and maize. All possible combinations of soil types and land use covering more than one percent area were included, resulting in 252 HRUs. Other model parameters such as length and slope of overland flow path, and channel geometry, which relate to physical dimensions of the watershed, were kept same in both models.

The hourly time-series of climate data required for the HSPF include precipitation, potential ET, air temperature, dew-point temperature, wind speed, and solar radiation. Only one station with this information was available in the BASINS3.0 database for this watershed. Thus, five additional stations with daily precipitation and temperature data, maintained by the Midwest Climate Center (MCC), were identified in or near the watershed. For use with HSPF, daily precipitation data was disaggregated into hourly data on these five stations using the Data

Disaggregation Tool in the Watershed Data Management Utitlity (WDMUtil) of the HSPF. Three nearest stations from the BASINS3.0 database that had hourly precipitation time-series data were used as reference stations for this purpose. Other hourly climatic time series for the five MCC stations were borrowed from the nearest BASINS climate station as found in the BASINS3.0 data base. Potential ET in BASINS climate stations is based on the standard class-A pan evaporation data.

In case of SWAT only daily precipitation, and maximum and minimum air temperature data were input from the above six stations. Other daily time-series of wind speed, solar radiation, and relative humidity were simulated based on nearest climate station using the weather generator in SWAT. In SWAT potential ET was computed using Penman-Monteith (Monteith, 1965) method. Weather stations were assigned to each sub-watershed based on proximity.

Model Calibration and Verification

The hydrologic components of HSPF and SWAT were calibrated to fit the observed daily streamflow data from a USGS streamflow gauging station (#05526000) at Chebanse, IL for years 1987-1995. This period was chosen because it represents a combination of dry, average, and wet years (annual precipitation 684 to 1472 mm). The model was run for 11 year period of 1985-1995 but the first two years (1985 and 1986) were used for stabilization of model runs and simulated streamflow for 1987-1995 only was used for comparison purposes. Values of selected model parameters were varied iteratively within a reasonable range during various calibration runs until a satisfactory agreement between observed and simulated streamflow data was obtained. Both HSPF and SWAT with calibrated parameters were then verified by using an independent set of streamflow data that was not used for model calibration. In this study streamflow data for a 15-year period (1972-1986) from the same USGS gauging station (#05526000) was used during model verification. The model was run for 17 year period of 1970-1986 but the first two years (1970 and 1971) were used for stabilization of model runs and simulated streamflow for 1972-1986 only was used for comparison purposes.

During calibration as well as verification agreement between observed and simulated streamflow data, on an annual, monthly, and daily basis was determined using subjective as well as quantitative measures. The fit between daily observed and simulated streamflows was checked graphically by plotting the runoff-duration curves and time series. General agreement between observed and simulated runoff-duration curves indicates adequate calibration over the range of the flow conditions simulated. Quantitative measures of agreement were based on observed and simulated mean daily streamflows and their standard deviations (SD), correlation coefficient (r), Nash-Sutcliffe model efficiency (NSE) (Nash and Sutcliffe, 1970), root mean squared error (RMSE), mean absolute error (MAE), and the percent volume error in streamflow on long term, annual, and monthly basis. The NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. Both RMSE and MAE describe the difference between model simulations and observations in the units of the variable. Their values close to zero indicate perfect fit, however, values less than half of the SD of the observations may be considered low. Based on other studies reported earlier using HSPF and SWAT models, model calibration was considered satisfactory when the NSE and r values for monthly flow comparisons exceeded 0.80 and 0.90, respectively. Donigian et al. (1984) state that in HSPF simulations the long term, annual and monthly fits can be considered 'very good' when the absolute value of the volume error for these individual fits is less than 10 percent, 'good' when the error is between 10 and 15 percent, and 'fair' when the error is between 15 and 25 percent. Same criteria were adopted for SWAT model also in this study. Studies using HSPF and SWAT indicate that comparison of observed and simulated monthly or annual streamflows yields better statistics than those obtained from the daily streamflow comparison. Thus, model calibration and verification were considered satisfactory in this study only when NSE ≥ 0.65 and r ≥ 0.80 were obtained for daily streamflow comparison.

Definition of various HSPF model parameters calibrated in this study is given in Table 1. These parameters and the respective ranges within which their values were varied were selected based on other evaluation studies using HSPF (Duncker et al., 1995; Jones and Winterstein (2000), Laroche et al. (1996), Chew et al. (1991), Bergman and Donnangelo (2000), and the BASINS Technical Note-6 (USEPA, 2000). The model was run on an hourly time step and output was obtained on daily basis. A stepwise approach was used for HSPF calibration in which first an acceptable match was obtained between annual and monthly streamflows. Model parameters were then further adjusted to obtain a satisfactory agreement between observed and simulated streamflow hydrographs and daily flow-duration curves. This approach was supported by the hierarchical structure in HSPF in which annual streamflow values are affected by one set of parameters (e.g. LZETP, DEEPFR, LZSN, and INFILT parameters), monthly flows by another set (UZSN, BASETP, KVARY, AGWRC, and CEPSC), and storm flows by a third set (e.g. INFILT, INTFW, and IRC). Snowmelt and freezing phenomena in the watershed were simulated by changing the values of SNOWCF, TSNOW, and CCFACT parameters associated with the snow simulation component of the HSPF.

SWAT was also calibrated using a similar stepwise procedure as followed for the HSPF. Model parameters to be calibrated and ranges within which their values were varied (Table 2) were selected based on calibration guidelines provided in Neithch et al. (2002), Arnold et al. (2000), Santhi et al. (2001). SWAT runs on daily time step and output was also generated on daily basis. Estimates of values of all the four parameters (Table 2) were obtained during initial model calibration runs which focused on fitting the long term, annual, and monthly streamflows. Fine tuning of only most sensitive parameters – CN2 and ESCO, was done further so as to obtain a reasonable match between streamflow hydrographs and flow-duration curves. Surface runoff is extremely sensitive to parameter CN2. Decreasing the CN2 values results in decreasing runoff, and increasing infiltration, base flow and recharge. Parameters ESCO and EPCO were varied to adjust depth distribution for evaporation and plant uptake of water, respectively, from the soil profile. Depth of subsurface drains was adjusted between 950 to 1250mm. Values of other two parameters that affect time to drain the soil profile, and time till water enters the channel network after entering the tiles were set to 24h and 48h, respectively.

Results and Discussion

HSPF Calibration

During the nine year calibration period (1987-1995) the absolute value of the volume error between observed and HSPF simulated annual streamflows was less than 10% (very good simulation) in three years and 10-15% (good simulation) in four years (Table 3). Out of the nine years, HSPF oversimulated (2.6% to 49.5%) the streamflow in seven and undersimulated (-0.2 and -13.8%) it in two years. Model oversimulated streamflow in 1988 by 49.5% which was a dry year that had received 31% less precipitation than the average. The average observed streamflows, and HSPF simulated streamflows and actual ET during calibration period were 37%, 38%, and 59% of the total precipitation received by the IRW during that period.

Model predicted mean monthly streamflows satisfactorily as indicated by NSE = 0.88 and r = 0.94 (Table 4). Visual comparison of observed and HSPF simulated mean monthly hydrographs (Figure 2) also shows this satisfactory agreement. Out of 108 months in calibration period, the absolute volume error between observed and simulated mean monthly values were less than 10% in 24 months, 10-15% in 11 months, and 15-25% in 13 months, as shown in Table 4.

Statistics resulting from comparison of daily observe and simulated streamflows for the calibration period for the two models are given in Table 5. HSPF simulated and observed streamflow values and their SD were close with a mean volume error of only 4.7% (very good fit) over the nine year period. Low RMSE (= 0.57mm) and MAE (= 0.33mm), and high NSE (= 0.81) and r (= 0.90) values for daily flow comparisons suggest that the model was well calibrated to simulate daily streamflows satisfactorily. Also, flow-duration curves for observed and simulated daily streamflows closely match for the most part (Figure 3). Only some low flows in the exceedance range of 75-95% were oversimulated by the model. Overall, the calibrated model simulated the range in magnitude of daily streamflows reasonably well. Comparison of daily observed and HSPF simulated streamflow time-series for a four year period from 01/01/1992 to 12/31/1995 is shown in Figure 7. Despite high variability of annual precipitation during this period (49% above average in 1993, 10% and 13% below average in 1992 and 1994, and near average precipitation in 1995) shape and timing of the observed and simulated streamflow hydrographs agree for most part of this period. This agreement is evidenced in high values of daily NSE (=0.83) and r (= 0.91) obtained during this four year period (Figure 4).

SWAT Calibration

The absolute value of the volume error between SWAT simulated and observed annual streamflows was less than 10% for 4 years, 10-15% for 3 years, and 15-25% for one year (Table 3). Out of the nine years, SWAT oversimulated (6.8% to 35.0%) the streamflow in three and undersimulated (-0.4 to -24.2%) it in six years. Like HSPF, SWAT also oversimulated the flow during the dry year of 1988, but by a smaller difference of 35%. Thus, average annual streamflows were slightly better simulated with SWAT than with the HSPF. SWAT simulated streamflow and actual ET during calibration period as 35% and 63% of the total rainfall that occurred during that period.

For the mean monthly streamflow comparison for SWAT the NSE and r values were 0.89 and 0.94 (Table 4), indicating satisfactory calibration of the model. This agreement between observed and HSPF simulated mean monthly hydrographs is also evidenced in Figure 2. Like HSPF, the absolute volume error between observed and SWAT simulated mean monthly flows were less than 10% for 24 months, and 10-15% for 11 months. However, in case of SWAT the number of months with volume error 15-25% (= 32) was more than two times the number of months with volume error in this range during HSPF simulations.

For SWAT also mean observed and simulated daily flows and their SD matched well during calibration period and model undersimulated the streamflows by 4.7% indicating 'very good' fit during this nine year period. The low daily RMSE (= 0.60mm) and MAE (= 0.35mm) values, and high daily NSE (= 0.79) and r (= 0.90) values for SWAT simulations (Table 5) over this period suggest that the model was well calibrated to simulate daily streamflows. Observed and SWAT simulated daily flow-duration curves also matched well (Figure 3) except that model undersimulated some very low flows in the exceedance range of 90-100%. Comparison of observed and simulated daily streamflow time-series for 01/01/1992 to 12/31/1995 (Figure 4) showed that shape and timings of the observed and simulated hydrographs agree for most part of the four year period. High daily NSE (=0.84) and r (= 0.92) values obtained during this four year period (Figure 4) indicated that model was calibrated satisfactorily to simulate daily streamflows adequately despite extreme variations in the annual precipitation amount during this period, as explained earlier.

Comparative Performance of HSPF and SWAT during Model Verification Period

During model verification period of 1972-1986, absolute volume error between observed and HSPF simulated average annual streamflows were less than 10% for ten years, 10-15% for one year, and 15-25% for two years, respectively (Figure 5). The absolute volume errors for SWAT simulations during this period were less than 10% for seven years, and 10-15% for five years as shown in Figure 5. In genreal, both models mostly oversimulated the annual streamflow during fifteen year verification period. HSPF oversimulated (1.5% to 35.3%) streamflow during eleven years and undersimulated (-4.5 to -16.9%) it during four years. Likewise, SWAT oversimulated (0.6% to 33.2%) streamflow during ten years and undersimulated (-0.7 to -26.4%) it during five years. These statistics indicate that calibrated HSPF and SWAT models can simulate the average annual flows satisfactorily for period outside the calibration period. However, HSPF performance was slightly better than SWAT when compared based on the number of years for which the absolute volume error was less than 10%.

Various model performance evaluation statistics for simulating mean monthly streamflows during verification period were determined and are presented in Table 4 for both the models. For HSPF, the mean monthly NSE (= 0.82) and r (= 0.91) values suggest that calibrated HSPF simulated mean monthly streamflows satisfactorily during verification period also. This agreement between observed and HSPF simulated mean monthly hydrographs for the verification period is also shown in Figure 6. Absolute volume error for HSPF simulated mean monthly flows were less than 10% for twenty eight months, 10-15% for eleven months, and 15-25% for thirty two months. For SWAT simulations during verification period, slightly smaller RMSE (=0.38mm) but same MAE (= 0.28mm) were obtained compared to HSPF simulations. Also, the NSE (= 0.83) and r (= 0.92) values obtained for SWAT simulations were marginally better than those obtained for the HSPF (Table 4). Observed and SWAT simulated mean monthly hydrographs, as shown in Figure 6 for the verification period, also show close agreement between the two. For SWAT simulated mean monthly flows, the absolute volume errors were less than 10% for thirty three months, 10-15% for nineteen months, and 15-25% for twenty eight months, respectively (Table 4). Though both models simulated mean monthly streamflows satisfactorily during verification period, overall performance of SWAT was slightly superior than that of the HSPF as shown by marginally better statistics.

Model performance evaluation statistics for simulating daily flows during verification period are given in Table 5 for both HSPF and SWAT. Observed and HSPF simulated mean daily flow values and their SD were very close and model oversimulated streamflow by only 5.3% (very good fit) for this fifteen year period. As shown in Figure 7, flow-duration curves of observed and simulated daily flows matched well for the most part except for some low flows which were oversimulated by the model. Low daily RMSE and MAE values of 0.73mm and 0.39mm, and high daily NSE and r values of 0.70 and 0.84 (Table 5) for the HSPF simulations indicate that the model simulations of daily streamflows during the verification period were satisfactory. Comparison of observed and HSPF simulated daily streamflow time-series for 01/01/1978 to 12/31/1981 is illustrated in Figure 8 along with various model performance statistics. Precipitation was highly variable during this period with 19% and 14% below average precipitation in 1978 and 1980, near average in 1979, and 5% above average precipitation in 1981. Some discrepancies can be seen between high as well as low observed and simulated streamflows. However, the daily NSE = 0.69 and r = 0.83 values obtained for this period indicate that overall model performance was satisfactory in simulating streamflow hydrographs for this four period with highly variable annual precipitation values.

SWAT, like HSPF, also oversimulated streamflow during the 1972-1986 model verification period but by a smaller error of 3.2% only (Table 5) which indicated 'very good' fit for this period. Performance of SWAT in simulating daily streamflows outside the calibration period was slightly better than the HSPF as indicated by marginally better values of RMSE (= 0.69 mm), MAE (= 0.36mm), NSE (= 0.73), and r (= 0.88) obtained for model verification (Table 5) This is despite better calibration of the HSPF as indicated by slightly better values of RMSE, MAE, and NSE for HSPF calibration (Table 5). For most part, close agreement between SWAT simulated and observed daily streamflow-duration curves was obtained (Figure 7). Only some very low flows in the exceedance range of 90-100% were undersimulated. Visual comparison of flow-duration curves for both HSPF and SWAT (Figure 7) also confirmed better overall performance of SWAT. Observed and SWAT simulated daily streamflow time-series comparison and resulting statistics are presented in Figure 8 for the four year period from 01/01/1978 to 12/31/1981. Though, like HSPF, results for SWAT also show discrepancies between some hydrograph peaks as well as low flows, overall performance of SWAT for this period was better as evidenced in relatively higher NSE (= 0.79) and r (= 0.90) values (Figure 8).

In both HSPF and SWAT poor simulation of low flows could be due to inadequate model representation of sub-surface storage and subsequent release of water from that storage as baseflow for large watershed area. In HSPF parameters LZSN and INFILT control the amount of water in ground water storage component, and parameter AGWRC governs the rate of release of baseflow from this storage. Model allows only one value each of these parameters for an HRU for the entire year resulting in inadequate spatio-temporal representation in this study to account for effects of land use management and heterogeneity in soil physical properties on water storage in and release from ground water component. In this study HRUs were created based on dominant landuse (95% agriculture) and soil types (hydrologic soil group B). Also, tile drainage, which is mostly practiced on flat and poorly drained soils in the IRW is not modeled by HSPF, may have also resulted in poor simulation of low flows. The water removal effect from the field due to tiling is estimated in HSPF only by adjusting parameters such as INFILT, UZSN, and LZSN. In SWAT simulation of low flows may be improved to some extent by calibrating the baseflow recession and groundwater delay parameters. However, simplifications that exist in the model that describe subsurface flow and channel transmission losses may also be the cause of discrepancies between observed and simulated flows.

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Table 1. Input Parameters Calibrated for the HSPF

Parameter	*Definition*	*Range*	*Calibrated value*
KVAR (1/in)	Variable ground water recession flow	0.0 - 3.0	3
INFILT (in/h)	Index to soil infiltration capacity	0.01 - 0.25	0.2
AGWRC (1/d)	Basic ground water recession rate	0.92 - 0.99	0.98
LZSN (in)	Lower zone nominal storage	3.0 - 8.0	5
UZSN (in)	Upper zone nominal storage	0.05 - 2.0	0.2 - 1.4*
BASETP	Baseflow evapotranspiration	0.0 - 0.2	0.1
DEEPFR	Fraction of inactive ground water	0.0 - 0.2	0.05
NSUR	Manning's n for overland flow	0.15 - 0.35	0.2
CEPSC (in)	Interception storage capacity	0.03 - 0.20	0 - 0.1*
INTFW	Interflow inflow parameter	1.0 - 3.0	1.2 - 1.8*
IRC	Interflow recession constant	0.3 - 0.85	0.6 - 0.8*
LZETP	Lower zone evapotranspiration	0.1 - 0.9	0.1 - 0.75*
TSNOW (°F)	Temp. at which precipitation is snow	31 - 33	33
SNOWCF	Snow gage catch correction factor	1.1 - 1.5	1.2

Note: * Monthly value range

Table 2. Input Parameters Calibrated for the SWAT

Parameter	*Definition*	*Range*	*Calibrated value*
CN2	Runoff Curve Number	64 - 76	67
ESCO	Soil evaporation compensation factor	0.7 - 1.0	0.95
EPCO	Plant uptake compensation factor	0.4 - 0.9	0.7
DDRAIN, mm	Depth of subsurface drains	950 - 1250	1100

Table 3. Observed Precipitation and Streamflow, and HSPF and SWAT Simulated Actual Evapotranspiration, Streamflow, and Percent Error for Calibration Period

	Year								
	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*
Precipitation, mm	850	684	863	1230	794	903	1472	858	987
Obs-Q, mm	192	159	245	490	363	272	832	284	330
<u>HSPF:</u>									
Actual ET, mm	593	427	552	612	502	564	631	591	618
Sim-Q, mm	248	238	278	503	356	278	717	319	371
Error,%	29.1	49.5	13.4	2.6	-2.0	2.3	-13.8	12.5	12.4
<u>SWAT:</u>									
Actual ET, mm	648	459	625	667	517	654	684	615	608
Sim-Q, mm	156	215	262	422	362	206	764	264	369
Error,%	-18.8	35.0	6.8	-14.0	-0.4	-24.2	-8.1	-6.9	11.8

Note: Obs-Q = Observed streamflow, Sim-Q = Simulated streamflow

Table 4. Model Calibration and Verification Statistics for HSPF and SWAT for Monthly Streamflow Comparison

	Calibration Period (1987-1995)		*Verification Period (1972-1986)*	
	HSPF	*SWAT*	*HSPF*	*SWAT*
NSE	0.88	0.89	0.82	0.83
r	0.94	0.94	0.91	0.92
RMSE, mm	0.33	0.31	0.39	0.38
MAE, mm	0.23	0.21	0.28	0.26
Number of months with volume error:				
<10%	24	24	28	33
10-15%	11	11	11	19
15-25%	13	32	32	28

Table 5. Model Calibration and Verification Statistics for HSPF and SWAT for Daily Streamflow Comparison

	Calibration Period (1987-1995)		*Verification Period (1972-1986)*	
	HSPF	*SWAT*	*HSPF*	*SWAT*
Observed mean (SD), mm	0.96(1.31)	0.96(1.31)	0.95(1.33)	0.95(1.33)
Simulated mean (SD), mm	1.01(1.26)	0.92(1.35)	1.00(1.22)	0.98(1.41)
Mean volume error, %	4.70	-4.71	5.26	3.20
NSE	0.81	0.79	0.70	0.73
r	0.90	0.90	0.84	0.88
RMSE, mm	0.57	0.60	0.73	0.69
MAE, mm	0.33	0.35	0.39	0.36

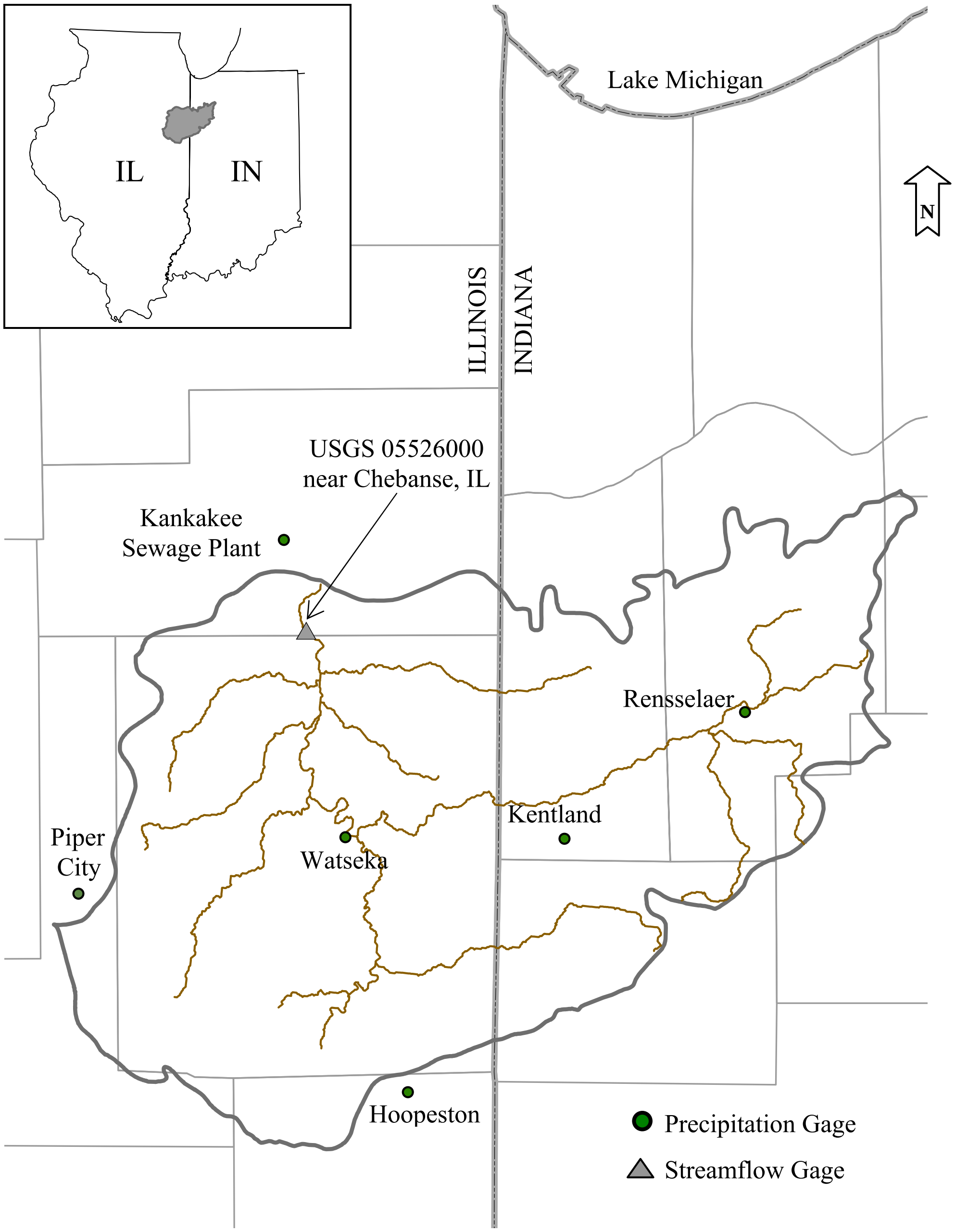

Figure 1. Iroquois River watershed and location of precipitation and streamflow gaging stations

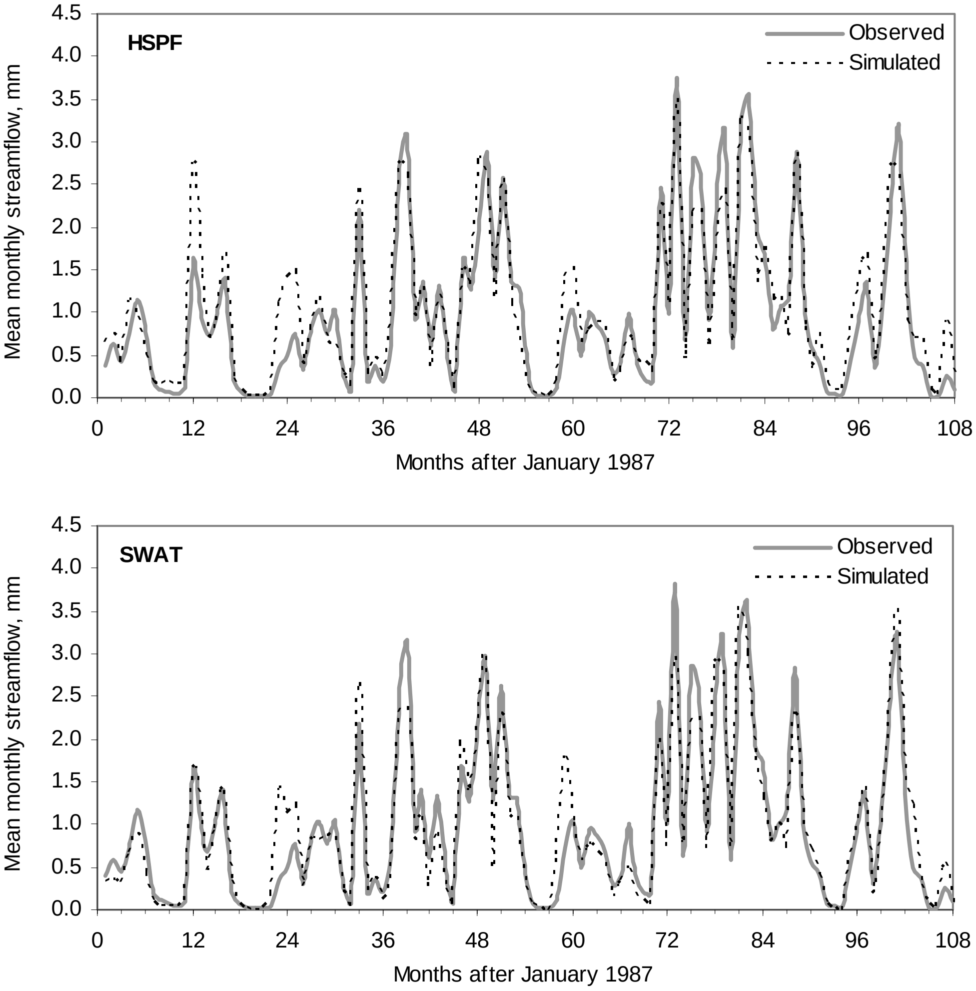

Figure 2. Comparison of observed and simulated monthly streamflows for HSPF and SWAT for model calibration period

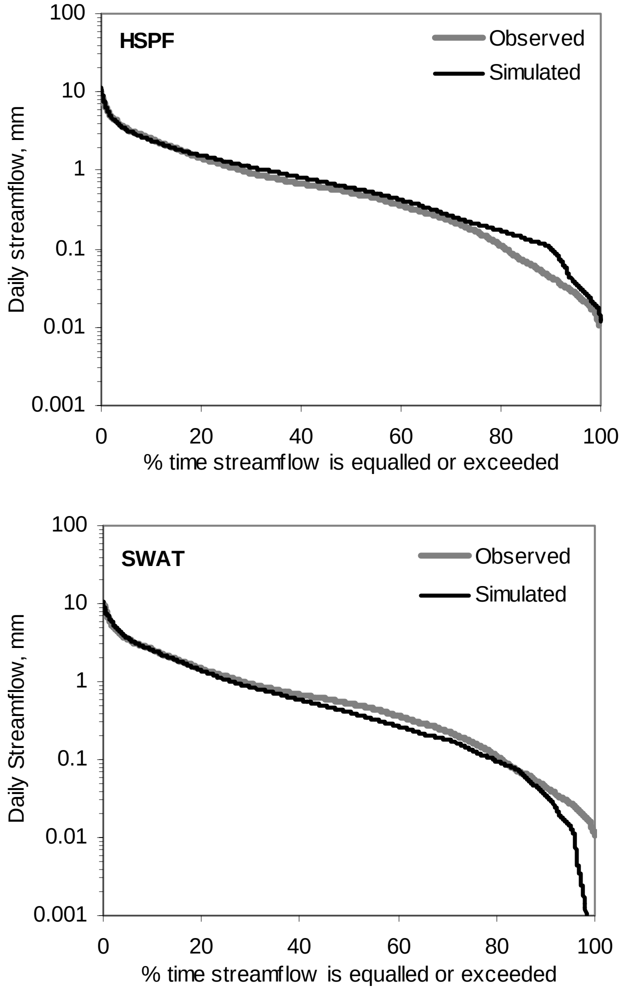

Figure 3. Comparison of observed and simulated daily streamflow-duration curves for the model calibration period

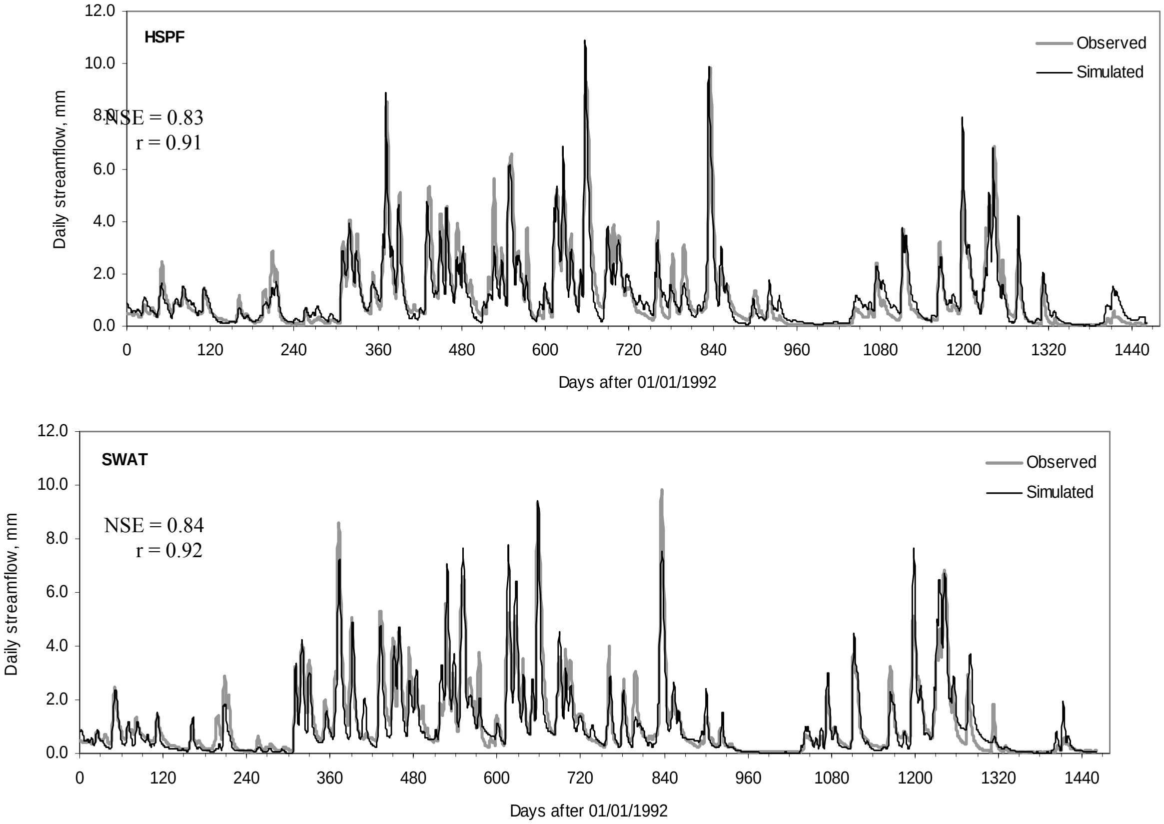

Figure 4. Comparison of observed and simulated daily streamflow time-seris for HSPF and SWAT for 1992-1995

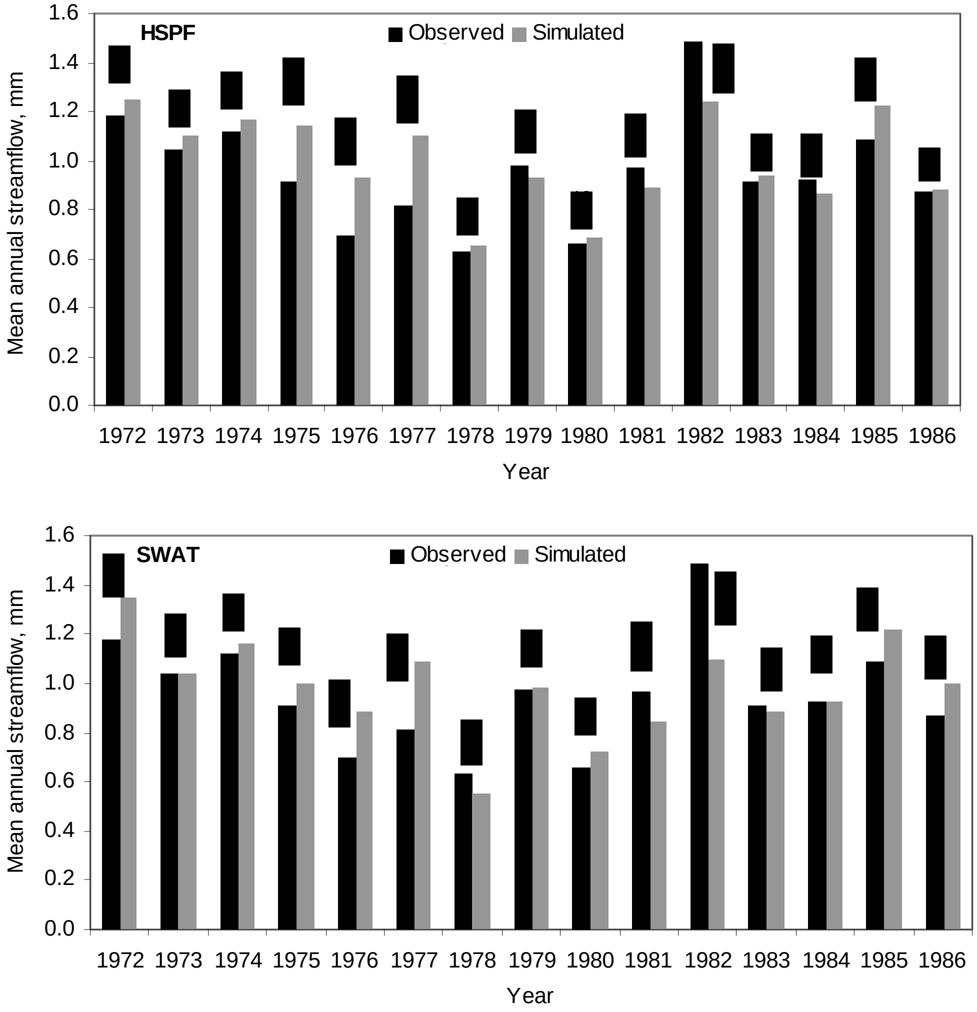

Figure 5. Comparison of observed and simulated annual streamflows and their percent errors for HSPF and SWAT for model verification period of 1972-1986

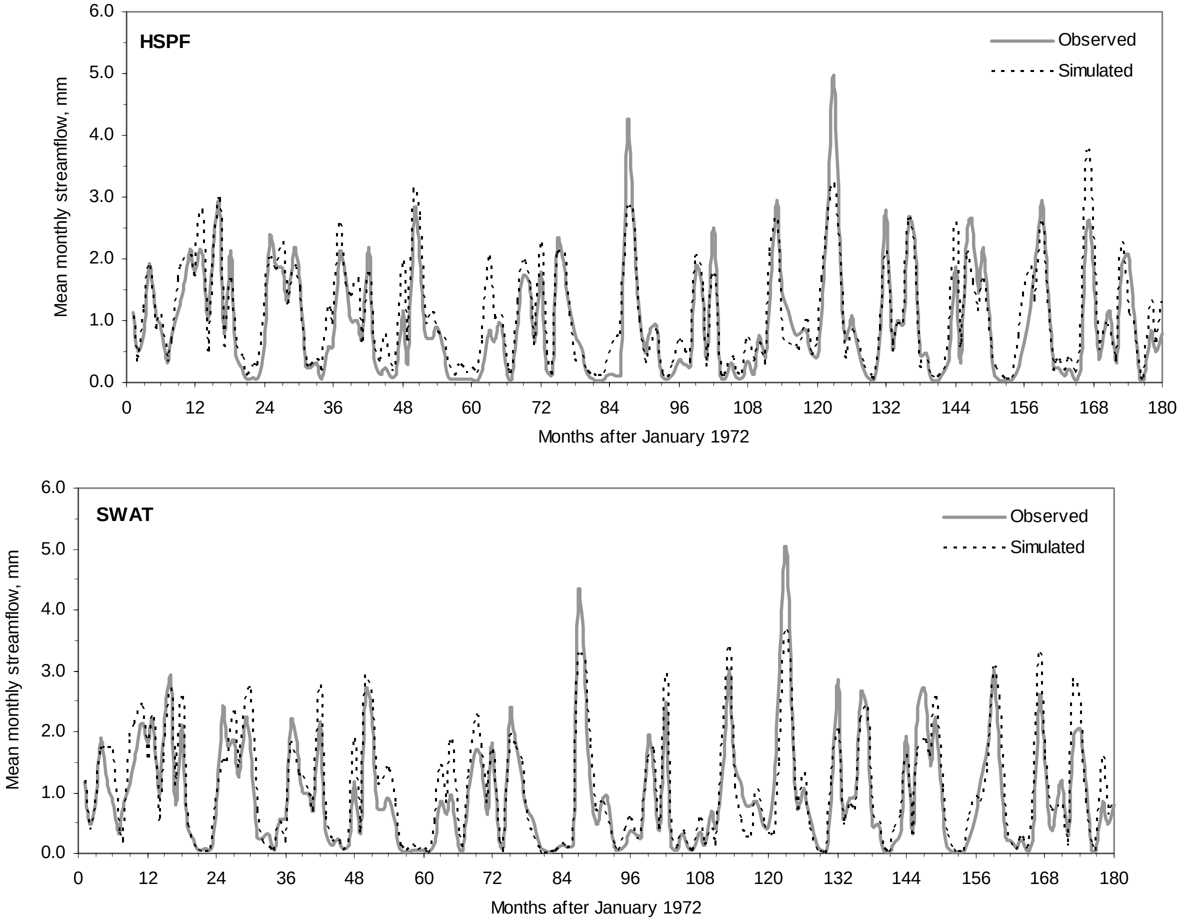

Figure 6. Comparison of observed and simulated monthly streamflows for HSPF and SWAT for model verification period of 1972-1986

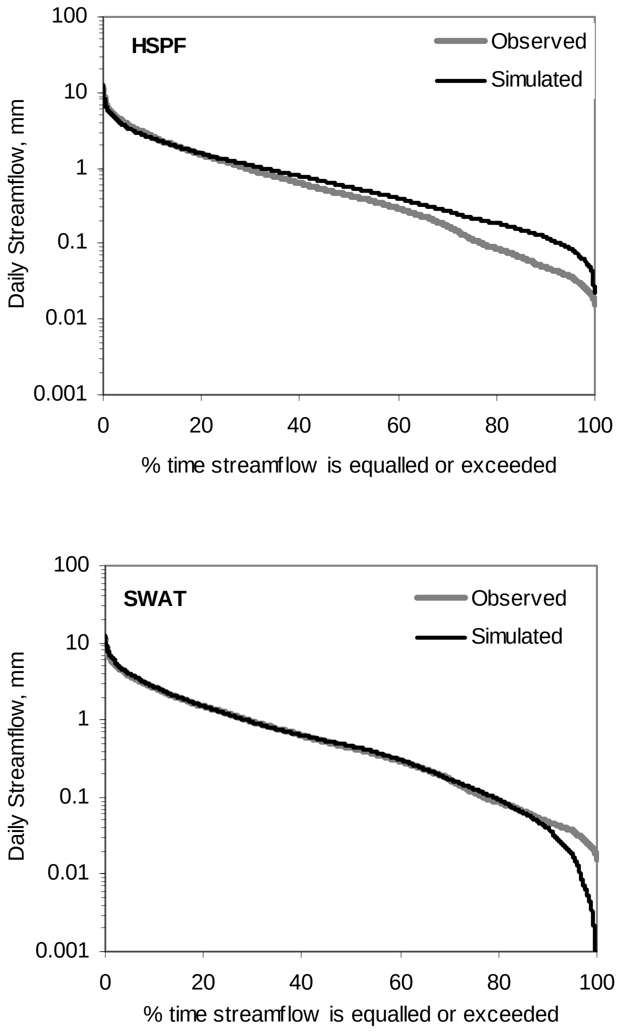

Figure 7. Comparison of observed and simulated daily streamflow-duration curves for the model verification period

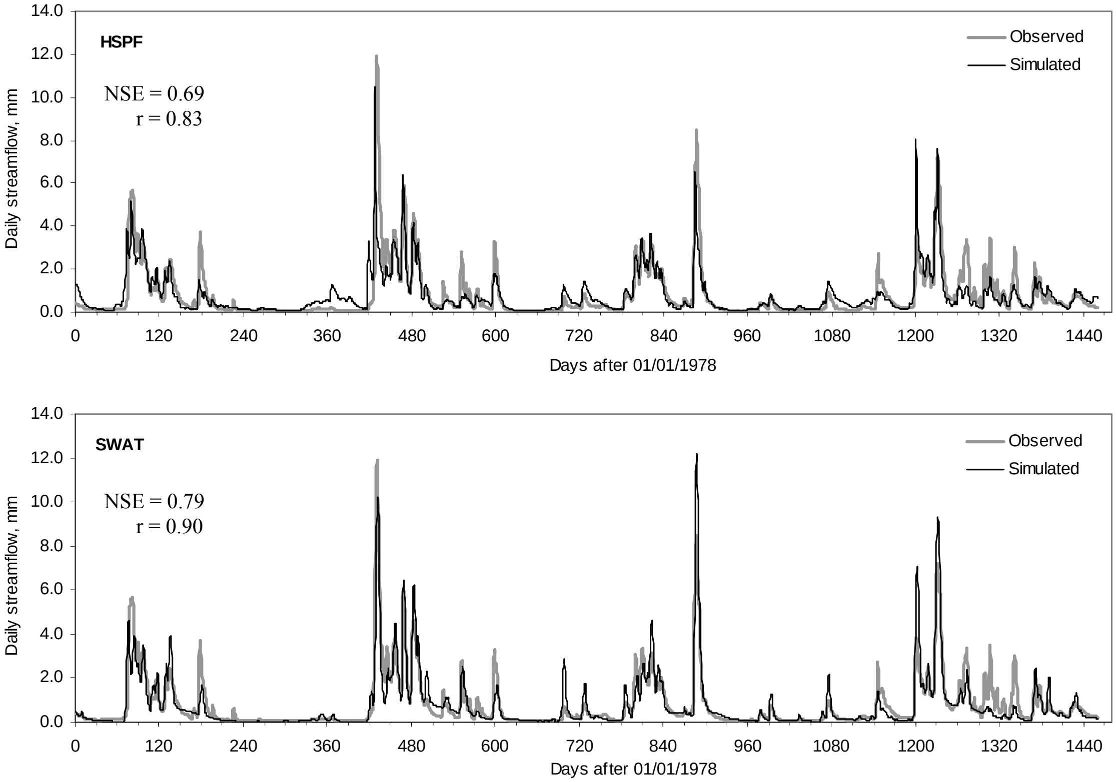

Figure 8. Comparison of observed and simulated daily streamflow time-series for HSPF and SWAT for 1978-1981