CALIBRATION AND VALIDATION OF THE HSPF MODEL ON AN URBANIZING WATERSHED IN VIRGINIA, USA

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Abstract: Nonpoint source pollutants from agriculture are identified as one of the main causes of water quality degradation in the United States. The Hydrological Simulation Program-Fortran (HSPF) was used to simulate runoff, nitrogen, and sediment loads from an urbanizing watershed; the Polecat Creek watershed located in Virginia. Model parameters related to hydrology and water quality were calibrated and validated using observed hydrologic and water quality data collected at the watershed outlet and at several sub-watershed outlets. A comparison of measured and simulated monthly runoff at the outlet of the watershed resulted in a correlation coefficient of 0.94 for the calibration period and 0.74 for the validation period. The annual observed and simulated sediment loads for the calibration period were 220.9 kg/ha and 201.5 kg/ha, respectively. The differences for annual nitrate nitrogen (NO_3) loads between the observed and simulated values at the outlet of the watershed were 5.1% and 42.1% for the calibration and validation periods, respectively. The corresponding values for total Kjeldahl nitrogen (TKN) were 60.9% and 40.7%, respectively. Based on the simulation results, the calibrated HSPF input parameters were considered to adequately represent the Polecat Creek watershed.

Keywords: HSPF, BASINS, Nonpoint sources pollution, Watershed Modeling

1. INTRODUCTION

Nonpoint source pollution is considered to be a major threat to the quality of surface and ground water resources in the United States. Agriculture has been identified as a major source of nonpoint source pollution (Novotny and Olem, 1994). Examples of specific nonpoint source pollutants from agricultural sources include sediment, nutrients, pesticides, and pathogens. Sediment can adversely affect the aquatic ecosystem by reducing habitats for aquatic plants and animals. Furthermore, excessive sediment may cover fish spawning areas and food supplies. Excessive nutrients levels in water bodies may accelerate eutrophication, especially in lakes and reservoirs. Agricultural nonpoint pollution has been estimated to contribute 60% of the five-day biochemical oxygen demand (BOD), 64% of total suspended solids, and 76% of total phosphorous discharged into water bodies in the United States (Duda and Johnson, 1985).

In response to the threat to water quality posed by nonpoint source pollution, the Virginia General Assembly passed the Chesapeake Bay Preservation Act in 1988, to reduce pollutant loadings from both agricultural and urban areas. To assess the efficacy of Bay Act regulations relating to urban growth, the Chesapeake Bay Local Assistance Department (CBLAD) initiated a water quality monitoring program in the Polecat Creek watershed, Virginia. The monitoring program that started in 1993 was designed to evaluate long-term impact of landuse activities on stream flow, sediment, nitrogen and phosphorus losses from the watershed (Gupta et al., 2001). While monitoring provides information about hydrologic and water quality conditions of a watershed, it does not directly link the water quality conditions observed in the stream to the land use activities. Therefore, a modeling study was conducted to analyze the potential pollutant sources and investigate the impacts of these sources on the quality of water draining the watershed.

Nonpoint source pollution models are essential tools for evaluating the existing watershed conditions and evaluating various strategies for reducing sediment and nutrient loadings to surface waters. Some commonly-used models include the Agricultural Nonpoint Source Pollution (AGNPS) model (Young et al., 1989), Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998), Generalized Watershed Loading Function (GWLF) model (Haith and Shoemaker, 1987), and Hydrological Simulation Program-Fortran (HSPF) model (Bicknell et al., 1996). HSPF, which was selected for use in this study, is a continuous, lumped parameter model. It simulates hydrologic and associated water quality processes on pervious and impervious land surface, in streams, and well-mixed impoundments (Bicknell et al., 1996).

The HSPF model has been widely used in many different watersheds throughout the United States and around the world. Moore et al. (1988) and Chew et al. (1991) tested HSPF on a northwest Tennessee watershed. Moore et al. (1988) performed a sediment and nitrogen study on an 18 ha single field watershed planted entirely in corn. Chew et al. (1991) used HSPF to simulate sediment losses on a 146 km^2 watershed in Tennessee. Laroche et al. (1996) evaluated hydrologic and pesticide transport process in HSPF using data from a 78 ha watershed in Quebec, Canada. Carrubba (2000) conducted the evaluation of HSPF's hydrologic algorithms with three 8-digit Hydrologic Unit Codes (HUCs), which were chosen from the U.S. Geological Survey National Water Quality Assessment (NAWQA) program. In Korea, HSPF was used to simulate streamflow and nonpoint pollutant loadings from the Nakdong River Basin, which is 23,800 km^2 in size (Chun et al., 2001). The future scenarios were developed and applied to evaluate basin management strategies in the Nakdong River Basin.

As with many watershed models, the HSPF model requires calibration. Therefore, the main objective of the study herein was to calibrate the HSPF model for simulating hydrologic, sediment and nitrogen outputs from urbanizing watersheds. This is an essential step before the HSPF model could be used for the larger goal of investigating the impact of different urbanization strategies on water quality.

2. MATERIALS AND METHODS

2.1 HSPF Model

The US Environmental Protection Agency (US EPA) recently commissioned the development of the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) watershed management system. The BASINS (USEPA, 2001) integrates a GIS package, ArcView® and water quality models. Three water quality models (QUAL2E, WinHSPF, and SWAT) are incorporated into BASINS 3.0 to allow the user to simulate hydrologic, point and nonpoint pollutant loading, and in-stream water quality. WinHSPF was designed as a Windows interface to HSPF version 12. All features of HSPF are available through WinHSPF. WinHSPF assists the user in building a HSPF input file, and modifying an existing input file. It also incorporated post-processing tools to facilitate display and interpretation of model results.

HSPF was designed to simulate the surface and sub-surface hydrologic and water quality processes in mixed watersheds. HSPF was primarily developed as a planning tool to assess changes in water, sediment and constituent movement as a result of land use change. The EPA commissioned the development of HSPF in 1980. The Stanford Watershed Model (SWM) was selected as the basis for its development. HSPF also incorporates two nonpoint source models, such as Agricultural Runoff Model (ARM) and Non-Point Source model (NPS). Although it is usually classified as a lumped model, it can reproduce spatial variability by dividing a watershed into hydrologically homogeneous land segments and simulating runoff for each land segment independently. A complete description of HSPF can be found in Bicknell et al. (1996).

HSPF is a watershed model that simulates runoff and nonpoint pollutant loads leaving a watershed and predicts pollutants fate and transport in streams and one-dimensional lakes (Bicknell et al., 1996). HSPF is comprised of three main modules, PERLND, IMPLND, and RCHRES. The PERLND module represents pervious land segment. The PWATER, SEDMNT, NITR and PHOS subroutine within PERLND module are required to perform the simulation of pervious upland areas. The PWATER of the PERLND module is used to model the hydrologic process of a pervious land. The pervious land is represented conceptually with a series of interconnected water storages; an upper zone, a lower zone, and a groundwater zone. The PWATER simulates the flux of water between the storage zones, and calculates surface, interflow, and active groundwater runoff from a pervious land to reaches. The subroutine SEDMNT performs calculations to estimate sediment production and removal from a watershed. The nitrogen transport and soil interaction are simulated by NITR, while phosphorous simulation is conducted using PHOS subroutine. The transport, plant uptake, adsorption/desorption, immobilization, and mineralization of the various chemical forms are modeled by HSPF.

The IMPLND module may be used for impervious surface area where little or no infiltration occurs. Simple surface processes are used to represent the hydrologic processes. Subroutine IWATER, which is similar to section PWATER of the PERLND module, simulates the retention, routing, and evaporation of water from an impervious segment. Subroutine IQUAL is used for water quality simulation within impervious area.

The RCHRES module represents the reach and reservoir in a watershed. HYDR performs

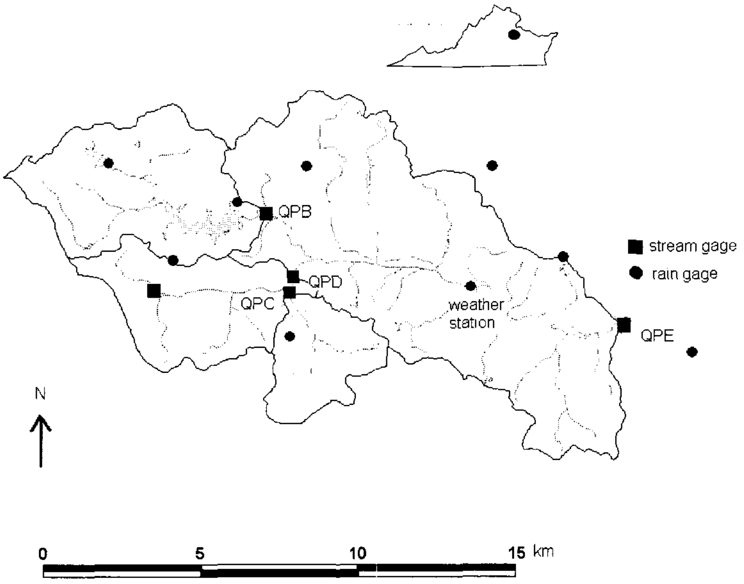

Figure 1. The Polecat Creek watershed and the monitoring stations

the basic hydraulic routing, while SEDTRN simulates transport, deposition and scour of sediment in the reach. Flow through a REHRES is assumed to be unidirectional. RQUAL is used to simulate biochemical transformation occurring in a reach or a mixed reservoir.

2.2 Study Area

The HSPF model was applied to the Polecat Creek watershed, which is located in Caroline County in northeastern Virginia (Figure 1). This watershed is a part of the Chesapeake Bay watershed. The total drainage area of the watershed is 12,048 ha and is located in the headwaters of the Mattaponi River, a main tributary of the York River. The predominant land use in the watershed is forest, followed by pasture, cropland, urban or developed land, and water (streams, rivers and lakes).

The Biological Systems Engineering Department at Virginia Tech conducted a ten-year monitoring project of the Polecat Creek watershed. The surface monitoring stations and their contributing sub-watersheds are shown in Figure 1. Stream flow is measured using a continuous stage recorder at each station. Water samples are collected at five monitoring stations and are analyzed for sediment and nutrients according to Standard method (USEPA, 1979). Volume-weighted composite samples with twenty samples per bottle were collected automatically during storm runoff events. Weekly grab samples were also collected to evaluate baseflow condition. Precipitation data are being collected at nine rain gages, which are located within and immediately surrounding the watershed (Figure 1). A weather station was established in the watershed to measure basic meteorological data, such as air temperature, solar radiation, wind speed, and evaporation. For the development of

Table 1. Land use data for selected sub-watersheds in the Polecat Creek Watershed

Land use	QPB	QPC	QPD	QPE
Area (ha)	2,658	888	2,605	12,048
Forest (%)	56.5	71.8	77.9	74.4
Cropland (%)	11.6	11.9	13.0	12.8
Pasture (%)	0.3	3.8	1.4	1.5
Commercial (%)	1.0	7.3	3.3	2.4
Residential (%)	25.4	5.2	4.4	7.8
Water (%)	5.2	0.0	0.0	1.1

the climatic input for HSPF, dewpoint temperature and cloud cover were taken from the National Weather Service (NWS) station at the Richmond International Airport (WBAN 13740), which is located 45 km south of the watershed.

Four sub-watersheds in the Polecat Creek watershed, namely QPB, QPC, QPD and QPE, were selected for the calibration and validation of hydrologic and water quality parameters. The drainage areas and land use data for each sub-watershed are summarized in Table 1.Sub- watershed QPB has a drainage area of 2,658 ha and contains the most significant developed area in the watershed. Sub-watershed QPC is located in the northwestern part of the Polecat Creek watershed and is 888 ha in size. Dominant land uses in QPC include forest and cropland. Sub-watershed QPD received inflow from sub-watershed QPC and has a drainage area of 2,605 ha. The outlet of the watershed, QPE has a drainage area of 12,048 ha. Land use for QPE includes 74% forest, 13% pasture, 2% cropland, and 10% urban or developed land.

2.3 The Input Data

HSPF requires land use data, reach data, meteorological data, and information on the pollutants of concern in the watershed and the reaches. The BASINS was used to delineate sub-watershed boundaries in the Polecat Creek watershed using the elevation and stream network map provided by BASINS database, and to create land segment for each sub-watershed from a GIS data of landuse/coverage developed by CBLAD.

The Polecat Creek watershed was subdivided into 16 land segments and 21 reaches for modeling purposes. The sub-watersheds were delineated based on topography, the stream network, land use types, and the presence of monitoring stations. Land use in the land segments was aggregated into five categories; forest, cropland, pasture, residential and commercial areas. Each of the land use categories was considered to be homogeneous for modeling purposes. Hydraulic function tables, FTABLE, were created to represent hydraulic characteristics of the reaches. Lake Caroline, located in the QPB sub-watershed, was treated as a well-mixed reservoir and a modified FTABLE was developed for the reservoir using the stage-volume relationship developed for the dam spillway (USEPA, 1999).

To estimate nitrogen loads, nonpoint sources of nitrogen species were calculated based on the number of animals, and the amount of manure and fertilizer application to the land. Dry and wet depositions from atmospheric source were also computed from rain quality data collected at the Nomini Creek watershed, which is located 60 km east of the watershed (Mostaghimi et al, 1999). These nitrogen sources were evaluated on a monthly basis for each land use, and were used as input to the model using MONTH-DATA tables in HSPF.

2.4 Calibration Procedures

HSPF includes numerous parameters to represent the hydrologic cycle, sediment, and nutrients transport processes. HSPF was calibrated for each Polecat Creek sub-watershed individually by comparing observed and simulated runoff, sediment, and nitrogen loads. A time step of one hour was chosen for model run based on the availability of required data. In the calibration of HSPF, stream flow and water quality data from September 1996 to June 2000 were used. Data collected from October 1994 to December 1995 were used for model validation.

The simulation was performed in two steps: hydrology and water quality simulations. Because hydrologic condition within a watershed may affect the variability of many water quality constituents, hydrology simulation was performed first.

The Hydrological Simulation Program-Fortran EXPert system (HSPEXP) was used to expedite the hydrologic calibration of HSPF. HSPEXP provides guidance for adjusting the hydrologic parameters by comparing the observed and simulated stream flows at the watershed outlet or at sub-watershed outlets (Lumb et al., 1994). The default criteria of HSPEXP were used to aid in obtaining agreement between simulated and observed stream flows. The percent errors between simulated and observed values were used to calibrate long-term water balance, seasonal water balance, and storm hydrographs. Additionally, we evaluated storm hydrographs graphically by comparing the observed and simulated hydrograph for selected storms.

Sediment and nitrogen calibrations were the next step in the modeling processes. Calibration of water quality components in HSPF is more difficult because there is not a decision-support system similar to HSPEXP available for this process. In addition, the limitations of observed data make it difficult to calibrate water quality

Table 2. HSPF parameters used in hydrologic calibration for the Polecat Creek watershed

Para-meters	Description	Initial Value	Final Value			
			QPB	QPC	QPD	QPE
LZSN	Lower zone nominal storage (in)	4.5	4.3	4.5	5.8	5.0
INFILT	Soil infiltration capacity index (in/hr)	0.070	0.047	0.075	0.051	0.075
AGWRC	Groundwater recession coefficient (day^{-1})	0.98	0.92	0.88	0.90	0.91
UZSN	Upper zone nominal storage (in)	0.50	0.40	1.00	0.35	0.41
DEEPFR	Fraction of groundwater inflow to deep recharge	0.00	0.40	0.05	0.45	0.10
LZETP	Lower zone ET parameter	0.5	0.2-0.7	0.2-0.7	0.2-0.7	0.2-0.7
INTFW	Interflow inflow parameter	2.0	1.0	1.7	1.5	1.5
IRC	Interflow recession parameter (day^{-1})	0.6	0.3	0.5	0.5	0.5

parameters in HSPF. Therefore, the water quality part of the model was calibrated by adjusting model parameter values to obtain agreement between simulated and observed annual load. We calculated the correlation coefficient between observed and simulated monthly loads to assess the quality of model fit.

3. RESULTS AND DISCUSSIONS

3.1 Hydrology Simulation

The hydrologic calibration was performed using observed hourly stream flow data from September 1996 to June 2000. The calibration process involved the estimation hydrologic parameters by comparing observed and simulated long-term water balance, seasonal flows, and storm hydrographs. Table 2 represents the final calibration values for each parameter used in hydrology simulation of the Polecat Creek watershed.

The major parameters that govern water balance are the soil infiltration capacity index (INFILT), lower zone nominal storage (LZSN), and lower zone evapotranspiration parameter (LZETP). These parameters were adjusted to provide a long-term water balance and seasonal variation. The remaining improvements in simulation accuracy were achieved by adjusting the parameters, groundwater inflow parameter (DEEPFR), and groundwater recession coefficient (AGWRC). The DEEPFR parameter controls the groundwater contribution to deep inactive groundwater storage. The AGWRC represents the rate of outflow from the groundwater storage. These values were adjusted to account for groundwater contribution to stream flow.

After long-term water balance and seasonal variation were properly simulated, the final step of hydrologic calibration is to fit the individual storm hydrographs to measured hydrographs. This was done by adjusting the interflow inflow (INTFW) and recession (IRC) parameters. The INTFW controls the amount of interflow by partitioning surface runoff and interflow, and IRC sets the exponential interflow recession rate The parameter UZSN, which defines the amount of upper zone storage, greatly influenced storm flow volume, and was also adjusted to satisfy the criteria in HSPEXP for the calibration period.

The annual observed and simulated runoff for the calibration and validation periods are presented in Table 3. For the calibration period on sub-watershed QPE, the average annual observed and simulated runoff were 381 mm and 384 mm, respectively, with a percent difference of 0.8%. The difference between the simulated and measured values of annual runoff volumes for the calibration period were 6.3% for QPB, 2.9% for QPC, and 4.4% for QPD; all within the criteria recommended by HSPEXP. For the calibration period, the correlation coefficients (r) of monthly stream flows between the observed and simulated values ranged from 0.75 to 0.94 for all sub-watersheds.

The calibrated hydrologic parameters were used to predict runoff for the validation period to provide a basis for evaluating the appropriateness of the calibrated parameters for different time periods and conditions. A comparison of the observed and simulated runoff for the validation period is also given in Table 3. The differences between observed and simulated annual runoff for the validation period were similar to those obtained for the calibration period. The simulated annual runoff volume for QPE was approximately 0.4% lower than the observed value. There was good agreement between the observed and simulated runoff with 6.7% error in annual runoff volume for QPB, 3.7% for QPC,

Table 3. Results of hydrology simulations for the Polecat Creek watershed

Sub-watershed	Calibration			Validation		
	Annual flow (mm)		$r^{1)}$	Annual flow (mm)		r
	Observed	Simulated		Observed	Simulated	
QPB	332	311	0.75	178	166	0.61
QPC	435	440	0.83	194	202	0.58
QPD	389	372	0.92	174	174	0.59
QPE	381	384	0.94	218	217	0.74

$r^{1)}$: correlation coefficient between observed and simulated monthly flows

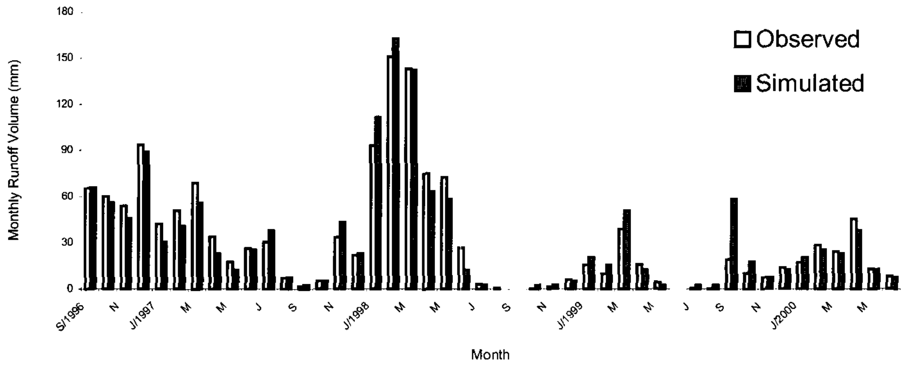

Figure 2. Observed and simulated monthly runoff for QPE during the calibration period.

Table 4. HSPF parameters used in sediment calibration for the Polecat Creek watershed

Parameters	Description	Initial Value	Final Value			
			QPB	QPC	QPD	QPE
KRER	Coefficient in the soil detachment equation	0.1	0.26	0.15	0.14	0.02
JRER	Exponent in the soil detachment equation	2.0	2.5	2.5	1.5	2.0
AFFIX	Fraction by which detached sediment storage decrease each day	0.6	0.6	0.6	0.6	0.6
KSER	Coefficient in the detached sediment washoff equation	0.15	0.05	0.05	0.11	0.15
JSER	Exponent in the detached sediment washoff equation	2.0	2.0	2.0	2.2.	2.6
KGER	Coefficient in the matrix soil scour equation	0.0	0.005	0.004	0.021	0.0002
JGER	Exponent in the matrix soil scour equation	2.0	1.1	1.8	0.7	2.1

and 0.2% for QPD. For the validation period, correlation coefficients for monthly period were not as high as those obtained for the calibration period. The lower r-values for the validation results could be attributed to the short simulation period. As the simulation period becomes smaller, the simulated results by HSPF become less precise (Moore et al., 1988; Chew et al., 1991, Laroche et al., 1996).

Figure 2 shows the time series plot of observed and simulated monthly runoff for the calibration period at the watershed outlet (QPE). The model adequately represented the monthly variations of runoff. However, there is a large discrepancy in runoff volume on September 1999. It was due to the poor prediction for a storm event (Sep. 15-16, 1999). This difference affected the simulations of sediment and nitrogen, as discussed in the following sections.

Comparison of the observed and simulated runoff for the validation period indicated that the calibrated parameters generally well-represented the hydrologic characteristics of the Polecat Creek watershed.

3.2 Sediment Simulation

Sediment calibration was the next step in the modeling processes. Calibration of HSPF for sediment was conducted by comparing monthly sediment loads during storm flow and ambient flow conditions. Storm flow sediment loads were calculated from runoff volumes and sediment concentrations collected by auto sampler during storm periods, while ambient sediment loads were calculated from ambient stream flows and mean concentrations of grab samplings for a given month.

Storm flow sediments were used to adjust sediment washoff parameters used in the soil detachment equation (KRER, JRER), the washoff equation (KSER, KGER), and the scour equation (JSER and JGER) in pervious lands. The critical shear stress (TAUCS) and erosion rate (M) in reaches were also calibrate to match simulated sediment loads to observed values during storm period. The sediment loads during non-storm periods were depended on deposition processes in the reach, rather than upland erosion of pervious lands and scour in reaches. Major parameters for deposition in RCHRES module were critical shear stress for deposition (TAUCD) and settling velocity (W). These parameters were also adjusted by comparing the observed and simulated ambient sediment loads. The final parameters for sediment calibration are summarized in Table 4.

The sediment simulation results for calibration period are listed in Table 5. Simulated annual sediment load for sub-watershed QPE during the calibration period was 201.5 kg/ha, while the observed value was 220.9 kg/ha. The difference between the observed and simulated total sediment loads for QPE was 8.8%. The simulated sediment loads were considered reasonable with a 6.8% error for QPB, 2.1% for QPC, and 16.0% for QPD.

The accuracy of model simulations of monthly sediment loads for each sub-watershed varied during the calibration period. The correlation coefficients between observed and simulated monthly sediment loads for the calibration period were 0.32 for QPB, 0.70 for QPC, 0.76 for QPD, and 0.52 for QPE. The resulting monthly sediment loads for the calibration period at QPE are shown in Figure 3. Figure 3 indicated that the model overestimated sediment load for high flows, and underestimated it for low flows.

The calibrated sediment parameter values were validated using measured data from the

Table 5. Results of sediment simulation for the Polecat Creek watershed

Sub-watershed	Calibration			Validation		
	Annual load (kg/ha)		$r^{1)}$	Annual load (kg/ha)		r
	Observed	Simulated		Observed	Simulated	
QPB	155.4	144.9	0.32	49.6	46.2	0.52
QPC	77.6	79.2	0.70	32.2	17.7	0.46
QPD	64.8	75.2	0.76	28.3	22.5	0.62
QPE	220.9	201.5	0.52	40.4	43.3	0.81

$r^{1)}$: correlation coefficient between observed and simulated monthly sediment loads

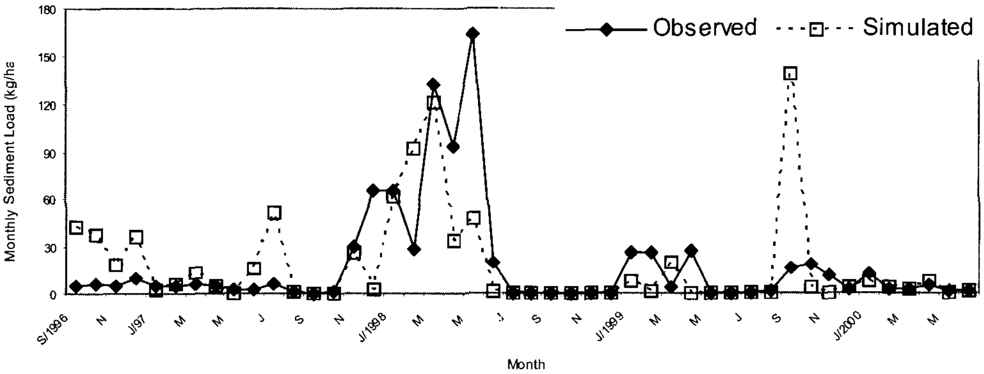

Figure 3. Observed and simulated monthly sediment loads for QPE during the calibration period.

Table 6. HSPF parameters used in nitrogen calibration for the Polecat Creek watershed

Parameter	Description	Initial Value	Final Value			
			QPB	QPC	QPD	QPE
KDNI	Denitrification of NO_3 (1/day)	0.0/0.0/0.0[a]	0.1/0.1/0.5[a]	0.0/0.0/0.1[a]	0.1/0.1/0.5[a]	0.0/0.0/0.2[a]
KPLNM (surface)	Plant uptake parameters for surface layer (/day)	0.3-0.5	0.35-0.55	0.35-0.55	0.35-0.55	0.35-0.55
KPLNM (upper)	Plant uptake parameters for upper layer (/day)	0.3-0.5	0.35-0.6	0.35-0.6	0.35-0.6	0.35- 0.6
KPLNM (lower)	Plant uptake parameters for lower layer (day)	0.0-0.2	0.1-0.2	0.1-0.2	0.1-0.2	0.1-0.2

a : surface, upper, and lower layer, respectively period of October 1994 to December 1995. The results of sediment simulation are also given in Table 5. Annual sediment load for the validation period was estimated to be 43.3 kg/ha for QPE with 7.2% error compared with the measured data. The correlation coefficients between observed and simulated monthly sediment loads were 0.52, 0.46, 0.62 and 0.81 for QPB, QPC, QPD, and QPE, respectively.

3.3 Nitrogen Simulation

Monthly concentrations of nitrogen species for the calibration period were evaluated and also compared to measured data. Nitrogen input, such as fertilizer, manure application and atmospheric deposition, were put into the model using the Month-Block of HSPF.

Monthly concentrations of nitrate (NO_3) and total kjeldahl nitrogen (TKN) were used for the calibration of the nitrogen parameters in HSPF. The denitrification (KDNI) and plant nitrogen uptake reaction parameter (KPLNM) were adjusted to achieve the long-term balance of NO_3 and TKN. Initial and final values of nitrogen parameters are shown in Table 6.

The agreement between the simulated and measured nitrogen species were good and are presented in Table 7. The simulated annual NO_3 and TKN for QPE for the calibration period were 0.37 kg/ha and 1.09 kg/ha, while the measured values were 0.39 kg/ha and 2.79 kg/ha, respectively. The correlation coefficients for NO_3 for the calibration period ranged from 0.79 to 0.91 for all sub-watersheds. Results indicated that the trends of simulated monthly NO_3 loads by HSPF were close to the observed values for the calibration period. The differences between the simulated and measured annual TKN loads during the calibration period were 4.3% for QPB, 3.3% for QPC, and 11.1% for QPD. The correlation coefficients of monthly TKN loads between observed and simulated values varied from 0.13 to 0.48 for the calibration period. The monthly variations of NO_3 load at the outlet of the watershed (QPE) for the calibration period are presented in Figure 4. HSPF adequately simulated the trend in monthly NO_3 loads during this period, except for September 1999. This might be due to the poor simulation of runoff volume for this month.

The final set of parameter values for nitrogen simulation were validated for 15 months period and resulted in correlation coefficients of 0.59 for NO_3 and 0.35 for TKN at the outlet of the watershed. For the validation period, correlation coefficients for NO_3 between observed and simulated monthly values were 0.52 for QPB, 0.62 for QPC, and 0.06 for QPD, while correlation coefficients for TKN were 0.07, 0.60, and 0.25 for QPB, QPC and QPD, respectively.

4. CONCLUSIONS

The HSPF was applied to a 12,048 ha urbanizing watershed in northeastern Virginia to validate its performance in simulating hydrologic and water quality response. The hydrology and water quality components of HSPF were calibrated against the measured data collected at the watershed outlet and at several sub-watersheds outlets. Model validation was done for the period of October 1994 to December 1995.

Long-term water balance, seasonal variability, and storm hydrographs were analyzed to calibrate and validate the hydrology parameters. The differences in annual runoff for the calibration period were 6.3% for QPB, 2.9% for QPC, 4.4% for QPD, and 0.8% at the watershed outlet (QPE). There was very good agreement between simulated and observed monthly runoff with correlation coefficients of 0.75 for QPB, 0.83 for QPB, 0.92 for QPD, and 0.94 for QPE between the measured and simulated monthly runoff. The differences in simulated and measured annual runoff for the validation period ranged from 0.2% to 6.7%.

The simulated and measured sediment loads were compared for both storm flow and ambient

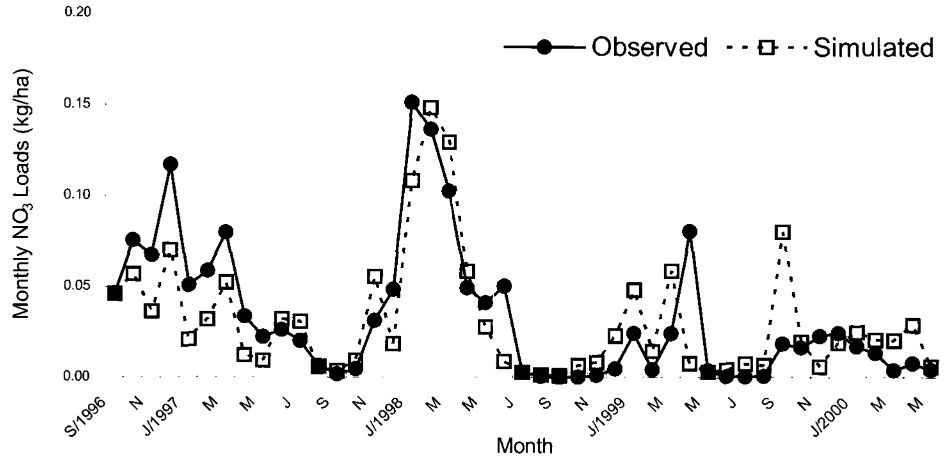

Figure 4. Observed and simulated monthly NO_3 load for QPE during the calibration period

Table 7. Results of Nitrogen Simulation for the Polecat Creek Watershed

Nitrogen Loads	Calibration			Validation		
	Annual Loads (kg/ha)		r1)	Annual Loads (kg/ha)		r
	Observed	Simulated		Observed	Simulated	
			(a) QPB			
NO_3	0.36	0.39	0.82	0.18	0.06	0.52
TKN2)	1.39	1.33	0.39	0.94	1.07	0.07
			(b) QPC			
NO_3	0.38	0.44	0.91	0.09	0.23	0.62
TKN	1.23	1.19	0.13	0.63	0.69	0.60
			(c) QPD			
NO_3	0.31	0.26	0.88	0.12	0.25	0.06
TKN	1.90	2.11	0.48	1.00	2.27	0.25
			(d) QPE			
NO_3	0.39	0.37	0.79	0.19	0.27	0.59
TKN	2.79	1.09	0.30	1.35	0.80	0.35

r1) : correlation coefficient between observed and simulated monthly loads

TKN2) : total Kjeldahl nitrogen

flow conditions. The simulated sediment load at the outlet of the Polecat Creek watershed for calibration period was 201.5 kg/ha per year, while observed load was 220.9 kg/ha per year. For the validation period, the simulated and observed annual loads were 43.3 kg/ha and 40.4 kg/ha, respectively. The correlation coefficients of monthly sediment load ranged among the stations from 0.32 to 0.76 for calibration and from 0.52 to 0.81 for validation.

Nitrogen was also simulated by considering landuse inputs, such as fertilizers and manure applications. The simulated NO_3 and TKN loads for the calibration period were 0.37 kg/ha, and 1.09 kg/ha at QPE, while observed values were 0.39 kg/ha and 2.79 kg/ha, respectively. The correlation coefficients for NO_3 loads ranged from 0.79 to 0.91 for the calibration period. For the validation period, the correlation coefficient for NO_3 was 0.59 for sub-watershed QPE. The correlation coefficients of TKN load for QPE were 0.30 and 0.35 for the calibration and validation periods.

Based on the calibration and validation results, it was concluded that HSPF performed reasonably well for the Polecat Creek watershed and these calibrated input data will be used in future assessments of the impact of urbanization on the water quality of Polecat Creek as a part of a larger effort to evaluate the efficacy of development policies in protecting the water quality of Virginia's waters.

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