

Water quality modeling of the Cahaba River, Alabama

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Abstract The Cahaba River, a sixth-order stream, tributary to the Mobile-Alabama River, is one of the few free-flowing rivers in Alabama. The Cahaba River lies in north-central Alabama and its watershed includes a variety of land uses from forested and agricultural to urban. Water quantity and quality modeling of the Cahaba River using several modules of the hydrologic simulation program FORTRAN (HSPF) and the nonpoint source model (NPSM) using the GIS-based BASINS package showed good agreement with measured flow data for low- and high-flow years but poor agreement with total nitrogen concentrations in the water column. Disparities between modeling and measured water quality data are attributed to the limited point source data available for nitrogen inputs to the stream and the lack of nitrogen-transformation process modeling with the NPSM. Future simulations should include use of models with detailed nitrogen transformation modules.

Keywords Water quality · Surface water hydrology · Cahaba River · Nitrogen · Watershed modeling · Nonpoint source pollution · Alabama, USA

Introduction

The global nitrogen cycle has been greatly altered by anthropogenic activities (Galloway and others 1995; Vitousek and others 1997). A major consequence of this alteration has been that the addition of nitrogen compounds into aquatic water bodies has greatly affected the biogeochemistry of these systems (Howarth and others 1996; Carpenter and others 1998). Numerous studies have examined the factors which affect the storage and movement of nitrogen and other nutrients in fluvial systems (Dillon and Kirchner 1975; Hill 1978; Beaulac and Reckhow 1982; Lowrance and others 1984; Correll and others 1992; Jordan and others 1997a, b, c; McMahon and Harned 1998; Correll and others 1999; Arbuckle and Downing 2001; Vanni and others 2001). Such studies have established that land use activity significantly influences nutrient loadings and discharges (Dillon and Kirchner 1975; Hill 1978; Beaulac and Reckhow 1982; Lowrance and others 1984; Correll and others 1992) or have shown that agricultural watersheds discharge higher amounts of nutrients than forested watersheds. Nutrient export from pasture and grazing activities are not significantly different than the export from forestland use (Beaulac and Reckhow 1982), but discharges of nitrogen and phosphorous significantly increased as the percent of cropland increased (Correll and others 1992). Nutrient export from row-cropped watersheds is significantly higher than from forests and animal feedlots and manure storage, with relatively little change in nutrient discharge as the percentage of pastureland increases (Correll and others 1992). Total nitrogen export from nonrow-cropped watersheds are not, however, significantly different from row-cropped or pastured watersheds.

Population density also exerts an important influence on fixed nitrogen concentrations in river systems (Caraco and Cole 1999). Predominantly urban watersheds generally have increasing nutrient loading rates with an increasing percentage of impervious land area (Beaulac and Reckhow 1982). This is attributable to the fact that hydraulic characteristics and land activities are influential factors in nitrogen loading rates in urban land use areas.

Hill (1978) found that both annual loss and mean annual concentrations of nitrate are correlated with land use activity. They also stated that land use variables considered did not fully account for the controls that rural point- and

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nonpoint-sources have on nutrient export. Seasonal and long-term variations in nitrogen export appeared to be important factors (Hill 1978; Correll and others 1992, 1999). Watershed characteristics such as drainage density, channel slope, and basin relief ratio are also significantly positively correlated with discharge and nitrogen loss (Hill 1978). Documenting long-term trends is important. There are significant differences between nitrogen fluxes in wet years and dry years, and among different watershed land uses (Correll and others 1992). A two-year study in Ontario demonstrated a strong positive relationship of nitrate nitrogen concentration with the log instantaneous discharge, but a significant negative correlation with the stations influenced by point sources (Hill 1978). There are many factors affecting the storage and transmission of nitrogen and nutrients. Due to the complexity of the nitrogen transport processes in terrestrial and aquatic systems, there is no one model which can be applied in a nitrogen budget of sources and sinks. Nonetheless, computer simulation models can be used as a tool to meet these ends and to help develop an understanding of the role of hydrological, meteorological, geological, and biological systems on nitrogen in the environment. Carried out as part of a larger study of nitrogen budgets in the Alabama River watersheds, the research reported herein developed a model to assess water quantity and quality in a small river, using the Cahaba River watershed in Alabama as a case study.

Study site description

The Cahaba River, a sixth order stream tributary to the Alabama River (Fig. 1), has a basin area of 472,675 ha (USGS 1998). Unlike most other rivers in Alabama, the Cahaba River is mostly free flowing (Ward and others

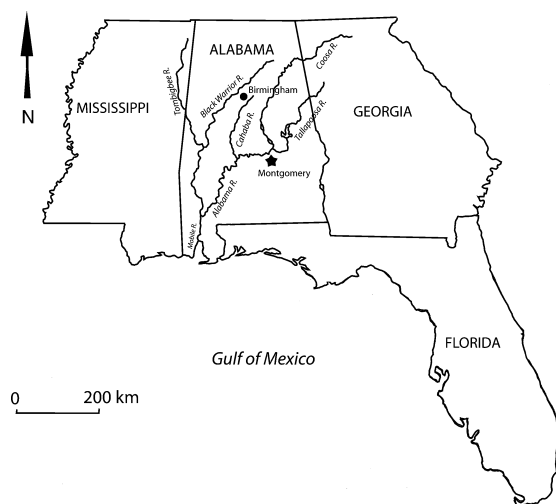


Fig. 1

The Cahaba River lies within the Mobile-Alabama River basin, which drains 11.4×10^6 ha in the states of Alabama, Mississippi, Georgia and Tennessee. The location of the Cahaba River watershed within the Alabama River basin is primarily south of the city of Birmingham, Alabama

1992). The greater Birmingham metropolitan area influences the northern portion of the river, but the less populated central and lower stretches of the river were once considered for inclusion as a Wild and Scenic River (Ward and others 1992). The Cahaba River watershed is extremely biodiverse, providing habitat to many aquatic species (Lydeard and Mayden 1995). The river serves as the primary drinking water source for the city of Birmingham, serving approximately 25% of Alabama's population.

The Cahaba River flows through two main physiographic provinces: the Valley and Ridge in the north and the Coastal Plain in the south, regions that are separated by the Fall Line. The Fall Line passes through Centreville, in Bibb County, halfway through the river's length (Fig. 1). The Upper Cahaba is above the Fall Line in the Valley and Ridge province and the Lower Cahaba is below the Fall Line in the Coastal Plain province. The Valley and Ridge province is characterized by steep banks, high bluffs, and rocky shoals through which the Cahaba River flows like a mountainous stream, swiftly and dynamically flowing through many riffles with small falls and pools (WIC 1974). In the Lower Cahaba watershed, the water flow slows down considerably, taking wide, meandering bends, and leaving many sandbar deposits (Cahaba River Society 1997).

The Valley and Ridge region is an area where sedimentary rocks have been deformed by tilting and faulting. The structural geology and the weathering of the different lithologies control the sequences of outcropping ridges and the valleys between them (King 1969). The area is underlain by Cambrian to Pennsylvanian sedimentary rocks. The Coastal Plain province is composed of marine and fluvial deltaic sediments of Cretaceous and younger age.

Differing land uses in the upper and lower reaches of the Cahaba River also affect flow characteristics. Urbanized Birmingham and its quickly expanding suburbs around the Cahaba River in Jefferson, Shelby, and St. Clair Counties are prone to frequent flooding from increased runoff rates from the river and its tributaries (WIC 1974). The Lower Cahaba is a rural region of mostly forested and agricultural land with few developed or developing areas. Groundwater is the main source of potable water used in this region (WIC 1974).

Methods

Data extraction

The BASINS software package (Lahlou and others 1998) utilizes the GIS database for all the eight-digit hydrological cataloging units (HUCs) in the United States. The core GIS dataset, the weather data management (WDM) files, and the digital elevation model (DEM) GIS coverage were obtained from the USGS (www.epa.gov/waterscience/ftp/basins/gis_data/huc) for the Cahaba River watershed (hydrological unit code 03150202). The GIS data were extracted for input to the BASINS program and projected

Table 1
Cahaba River subwatersheds

| Stream segment subwatershed | Area (ha) | Land use distribution (%) | | Assigned rain gauge |
|---|-----------|---------------------------|--------|------------------------|
| Big Black Creek segment, subwatershed 03150202033 | 25,123 | Unclassified | 0.023 | Birmingham FAA airport |
| | | Urban | 4.66 | |
| | | Forest | 84.39 | |
| | | Agriculture | 10.45 | |
| | | Rangeland | 0.0 | |
| | | Barren | 0.48 | |
| *A segment, subwatershed 03150202026 | 19,425 | Unclassified | 0.0 | Birmingham FAA airport |
| | | Urban | 7.21 | |
| | | Forest | 76.9 | |
| | | Agriculture | 12.9 | |
| | | Rangeland | 0.0 | |
| | | Barren | 2.98 | |
| Little Cahaba River segment, subwatershed 03150202019 | 74,074 | Unclassified | 0.134 | Birmingham FAA airport |
| | | Urban | 11.38 | |
| | | Forest | 76.01 | |
| | | Agriculture | 21.25 | |
| | | Rangeland | 0.0 | |
| | | Barren | 1.23 | |
| Shultz Creek segment, subwatershed 03150202036 | 19,943 | Unclassified | 0.0 | Birmingham FAA airport |
| | | Urban | 0.101 | |
| | | Forest | 90.62 | |
| | | Agriculture | 7.96 | |
| | | Rangeland | 0.00 | |
| | | Barren | 1.32 | |
| Oakmulgee Creek segment, subwatershed 03150202004 | 59,829 | Unclassified | 0.00 | Montgomery WSO airport |
| | | Urban | 0.065 | |
| | | Forest | 86.28 | |
| | | Agriculture | 10.78 | |
| | | Rangeland | 1.33 | |
| | | Barren | 0.0155 | |
| Cahaba River, watershed 03150202001 | 272,012 | Unclassified | 0.02 | Birmingham FAA airport |
| | | Urban | 5.24 | |
| | | Forest | 79.21 | |
| | | Agriculture | 13.67 | |
| | | Rangeland | 0.349 | |
| | | Barren | 1.51 | |
| Total area | 470,344 | Unclassified | 0.034 | |
| | | Urban | 3.81 | |
| | | Forest | 80.27 | |
| | | Agriculture | 4.05 | |
| | | Rangeland | 0.371 | |
| | | Barren | 1.47 | |

into the West Alabama state plane coordinate system of the North American datum of 1983. Subwatersheds were delineated with the BASINS watershed delineation tool, used in conjunction with the Reach File, Version 3, GIS data layer. Five subwatersheds were delineated in addition to the Cahaba River, for a total of six subwatersheds simulated (Table 1, Fig. 2).

HSPF is able to simulate only the most downstream reach of the delineated subwatersheds, but the model considers each subwatershed in its calculations. HSPF is a lumped parameter model, so that only the most downstream reach is simulated and all intermediate reaches are used only in routing calculations. Therefore, output for any intermediate reach only reflects flow that is being routed through the river but not the actual runoff in the river and thus runoff is greatly underestimated.

Meteorological data selection

Weather data management (WDM) files store weather data such as hourly precipitation, evaporation, temperature,

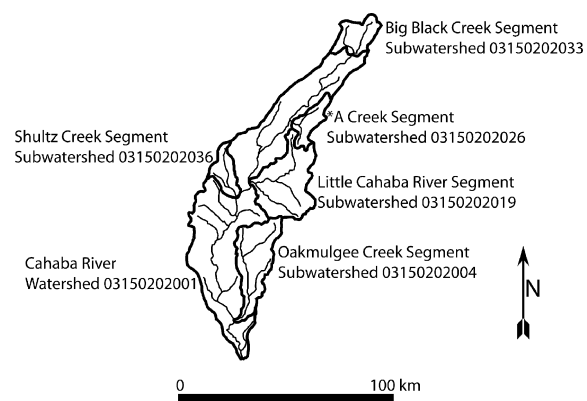


Fig. 2

Delineated subwatersheds of the Cahaba River drainage. Watershed and subwatershed boundaries are shown with *heavy black lines*. The Cahaba River and its tributaries are shown with *thinner grey lines*. The USGS Hydrologic Unit Code for the Cahaba River is 03150202. Each subwatershed (Shultz Creek, Big Black Creek, *A Creek, Little Cahaba River and Oakmulgee Creek) uses the *Cahaba's 8-digit HUC plus an additional 3 digits*, as shown on the figure

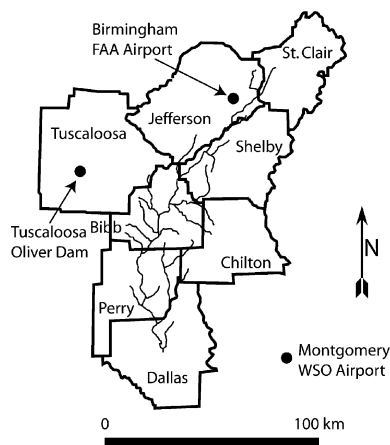


Fig. 3

Map of the Alabama counties containing the Cahaba River and its tributaries. Weather station locations (indicated by filled circles on the map) surrounding the Cahaba watershed and used in the study include the Birmingham federal aviation authority station in Jefferson County at the Birmingham airport, the Oliver dam station in Tuscaloosa County and the Montgomery weather station at the Montgomery airport

wind speed, solar radiation, potential evaporation, dew point temperature, and cloud cover, as well as daily values of the same. The WDM file downloaded for use with BASINS contains these data for all weather stations in the EPA Region 4. The nonpoint source model (NPSM) is precipitation-driven and requires hourly (or more frequent) precipitation data. Of the three weather station sites near the Cahaba River (Fig. 3), only the Montgomery WSO airport and the Birmingham FAA Airport weather station datasets were sufficiently complete to be used. The Birmingham FAA Airport weather station data were assigned to five of the delineated subwatersheds: (1) the main stem of the Cahaba River (subwatershed 03150202001); (2) *A reach (subwatershed 03150202026); (3) Big Black Creek reach (subwatershed 03150202033); (4) Little Cahaba reach (subwatershed 03150202019); and (5) Shultz Creek reach (subwatershed 03150202036). The Montgomery WSO airport weather station data were assigned to the Oakmulgee Creek reach (subwatershed 03150202004) (Table 1). Simulation was for a six-year period from 1987–1992. The first two years (1987 and 1988) served as an initialization period for the model so that the values chosen for the initial condition parameters do not affect the simulation of the years of interest. Choice of years to simulate was based on precipitation conditions. A wet (high flow) year was used for model calibration and a dry (low flow) year for model verification. Because the WDM files for the Birmingham FAA airport weather station may be missing some hourly precipitation data for the summer of 1990, output for 1989 was used for model calibration of hydrology.

Historical stream flow data from the USGS (United States Geological Survey) at the Marion Junction, Alabama gauging station (station number 02425000) for 1990–1996 were analyzed to determine which of those years best represented high-flow and low-flow years. Marion

Junction is the most downstream station in the watershed, and therefore best reflects total drainage from the Cahaba watershed. Daily stream flow data were downloaded from the USGS website and a volume integrating method was used to calculate the volume of stream flow based on the daily values in cubic meters. The algorithm used was:

$$\frac{\text{Flowrate Yesterday} + \text{Flowrate Today}}{2} * 86400$$

where: Flowrate Yesterday in cubic meters per second (cms), Flowrate Today in cms. The value 86400 is the number of seconds in a day.

The total volume of flow for each calendar year was plotted. Based on the volume of flow that passes through this gauging station for the time-series analyzed 1990 is the high-flow year, and 1992 is the low-flow year. As expected, high flow is correlated with high precipitation, and low flow is correlated with less precipitation in the watershed.

Land use assessment

For the Cahaba NPSM model, land use/land cover coverage was assessed using the Anderson level II classification. The distribution of land area for each land use type in each of the subwatersheds (Table 1) was primarily forest (80.3% of the total land area) but also included urban, agriculture, rangeland, barren and unclassified.

The NPSM model runs on three different bases: pervious land segments (PERLND), impervious land segments (IMPLND), and stream reaches (RCHRES). Perviousness, or a pervious land segment, is defined as a segment of land with a pervious surface (allows infiltration). RCHRES performs analysis through the river system. The pervious portions are simulated in PERLND, and the impervious portions of the watershed are simulated in IMPLND. Land use types in the basin were assigned a 100% perviousness, except for urban and built-up land use type, which was assigned a 70% perviousness value. This translates to 30% of the total urban and built-up land land-use type being modeled under the IMPLND module of NPSM.

Two of the land uses, rangeland and unclassified land, were reassigned to other land use classifications for simulation runs. Rangeland was reassigned to barren land, and unclassified land was reassigned to forestland.

Hydrological parameter estimation and input

Most model input parameters (Table 2) were initially estimated using the methods of Donigan and Davis (1978). Input parameters for the model in the PWATER section of PERLND were initially estimated using the method of Donigan and Davis (1978). Most other parameters were initially estimated from physical measurements and a few parameters were left with the default values and changed in subsequent model calibrations.

The parameter lower zone nominal storage (LZSN) is related to soil moisture, and typical values range from 12.5–51 cm. LZSN can be roughly estimated from:

$$\frac{\text{Annual Mean Rainfall}}{8} + 4$$

Table 2

Summary of NPSM parameters and calibration results for water quantity

| Parameter | Initial estimate/default values | Final calibration values | Comments |
|--|--|--|--|
| LZSN, lower zone storage nominal | 11 cm for all subwatersheds and all land uses | 15 cm for all subwatersheds and all land uses | LZSN is related to soil moisture conditions and the annual cycle of rainfall and evapotranspiration. It can be estimated as $(\text{annual mean rainfall}/8)+4$. This parameter has a modest effect on volume and the long-term water balance. |
| UZSN, upper zone storage nominal | 3 cm for all subwatersheds and all land uses | 2.5 cm for all subwatersheds and all land uses | UZSN is related to LZSN and watershed topography. Estimated as 10% of LZSN. This parameter has a major effect on volume and the long-term water balance. |
| CEPS, interception storage | Agricultural land: 0.4 Unclassified land: 0.03 Urban land: 0.03 Forest land: 0.4 Barren land: 0.1 Range land: 0.03 | Agricultural land: 0.4 Unclassified land: 0.03 Urban land: 0.03 Forest land: 0.4 Barren land: 0.1 Range land: 0.03 | CEPS is a function of cover density. Parameter values based on expected values cited in ARM manual. This parameter has little affect on calibration. |
| LZETP, lower zone evapotranspiration parameter | Forest land: 0.8 Barren land: 0.25 Unclassified land: 0.25 Urban land: 0.1 Agricultural land: 0.4 Range land: 0.25 | Forest land: 0.8 Barren land: 0.25 Unclassified land: 0.25 Urban land: 0.1 Agricultural land: 0.4 Range land: 0.25 | LZETP is an index to the depth of deep-rooted vegetation. It is a unitless parameter that affects evapotranspiration from the lower zone soil moisture. Values estimated from typical values cited in ARM manual. This parameter is an indicator of how much evapotranspiration occurs from the subsurface waters. Higher values indicate greater evapotranspiration rates. |
| NSUR, Manning's n for the assumed overland flow plane | Agricultural land: 0.035 Forest land: 0.05 Urban land: 0.1 Barren land: 0.03 Range land: 0.03 Unclassified land: 0.02 | Agricultural land: 0.035 Forest land: 0.05 Urban land: 0.1 Barren land: 0.03 Range land: 0.03 Unclassified land: 0.02 | NSUR is Manning's roughness factor (unitless) and affects hydrograph peaks. |
| INFILT, Index to the infiltration capacity of the soil | 0.4 cm/h for all subwatersheds and all land uses | Varies for each land use in each subwatershed (cm/h) | INFILT is an index to the mean infiltration rate and is a function of soil characteristics of cohesiveness and permeability. Initial values determined from SCS hydrological soil groups in each watershed. INFILT estimations from ARM manual. Higher values indicate that more water enters the subsurface. This parameter has a major affect on the long-term water balance and hydrograph peak and shape, and a moderate affect on seasonal flows and low flows. |
| INTFW, interflow inflow parameter | 0.75 for all subwatersheds and all land uses | 0.75 for all subwatersheds and all land uses | INTFW (unitless) is closely related to INFILT and LZSN, and controls the amount of water diverted to shallow subsurface interflow (high values indicate more flow diverted to interflow). This parameter has a major affect on hydrograph peak and shape. |

Table 2

(Contd.)

| Parameter | Initial estimate/default values | Final calibration values | Comments |
|--|--|--|--|
| LSUR, length of the assumed overland flow plane | 90 m for all subwatersheds and land uses | Varies for each land use in each subwatershed | LSUR is the length of the overland flow plane obtained from topographic maps and is the approximate length of travel to a stream channel. |
| SLSUR, slope of the assumed overland flow plane | 0.35 | Varies for each land use in each subwatershed | SLSUR is the average overland flow slope (unit-less). |
| AGWRC, basic groundwater recession rate constant | 0.98 for all subwatersheds and all land uses | 0.98 for all subwatersheds and all land uses | AGWRC is the ratio of active groundwater flow to a stream on one day to the same ratio of the previous day (unitless). This parameter affects the shape of the receding portion of the hydrograph, especially for seasonal and low-flow periods. |
| KVARY, parameter affecting the behavior of groundwater recession flow, enabling it to be nonexponential in its decay with time | 0.0 cm ⁻¹ for all subwatersheds and all land uses | 2.5 cm ⁻¹ for all subwatersheds and all land uses | This parameter has a major impact on seasonal and low-flow periods. |
| AGWETP, fraction of remaining potential ET which can be satisfied from active groundwater storage if enough is available | 0.0 for all subwatersheds and all land uses | 0.0 for all subwatersheds and all land uses | This parameter (unitless) has a major impact on seasonal and low-flow periods. |
| BASETP, fraction of potential ET which can be satisfied from base flow (groundwater flow) | 0.02 for all subwatersheds and all land uses | 0.001 for all subwatersheds and all land uses | This parameter (unitless) has little affect on calibration. |
| DEEPFR, fraction of groundwater inflow which will enter deep (inactive) groundwater and be lost | 0.10 for all subwatersheds and all land uses | 0.10 for all subwatersheds and all land uses | DEEPFR (unitless) accounts for subsurface flow that makes it to deep groundwater flow that will not contribute to surface flow. It has a moderate impact on volume. |
| CEPSC, interception storage capacity | 0.25 cm for all subwatersheds and all land uses | 0.25 cm for all subwatersheds and all land uses | CEPSC is an initial abstraction from precipitation on pervious land segments. It has a minor affect on runoff volume and peak. |
| IRC, interflow recession parameter | 0.50 for all subwatersheds and all land uses | 0.50 for all subwatersheds and all land uses | IRC is the ratio of interflow to a stream on one day to the same ratio of the previous day (unitless). This parameter has a major effect the shape of the receding portion of the hydrograph. |
| SURS, surface (overland flow) storage | 0.03 for all subwatersheds and all land uses | 0.03 for all subwatersheds and all land uses | SURS has little affect on model calibration. |
| UZS, upper zone storage | 0.75 for all subwatersheds and all land uses | 0.75 for all subwatersheds and all land uses | Initial soil moisture conditions for the upper soil zone for the beginning of the simulation period. This parameter affects volume, but only initially. |

The same value was used regardless of land use type and subwatershed.

The parameter upper zone nominal storage (UZSN) is related to LZSN and watershed topography. This parameter is normally estimated as 6–14% of the estimated LZSN parameter. Guidelines indicate that for watersheds with low depression storage, steep slopes, and limited vegetation,

UZSN is about 6% of LZSN. For watersheds with moderate depression storage, slopes and vegetation, UZSN is about 8% of LZSN, and for watersheds with high depression storage, soil fissures, flat slopes, and heavy vegetation, UZSN is about 14% of LZSN. In this study, UZSN was estimated as 10% of LZSN (UZSN=0.10*LZSN). The same value was used regardless of land use type and subwatershed.

Table 3
Typical INFILT parameter values based on SCS hydrologic soil groups

| SCS hydrologic soil group | INFILT estimate (cm/h) | Runoff potential |
|---------------------------|------------------------|------------------|
| A | 1–2.5 | Low |
| B | 0.25–1 | Moderate |
| C | 0.13–0.25 | Moderate to high |
| D | 0.03–0.13 | High |

Source: Donigian and Davis (1978)

The parameter interception storage capacity (CEPS) is a function of vegetation cover density and has units of length. Expected values are (Donigian and Davis 1978) for grassland 0.25 cm, for maximum canopy cropland ranges 0.25–0.65 cm, for light forest cover 0.4 cm, and for heavy forest cover 0.5 cm. These values were used to estimate values for each of the land cover types in the watershed and were used for each land use type, regardless of the subwatershed. Lower zone evapotranspiration (LZETP) is an index to the depth of the deep-rooted vegetation. It is a unitless parameter representing evapotranspiration from the lower zone soil moisture. Typical values range from 0.25 for open land and grassland to 0.7–0.9 for heavy forest (Donigian and Crawford 1976). These values were used to estimate values for each of the land cover types in the watershed, with identical values used for each land use type regardless of subwatershed. The Manning's n parameter (NSUR) for the assumed overland flow plane was estimated using typical literature values (White 1979; Roberson and others 1995) and identical values were used for each land use type, regardless of subwatershed. The infiltration parameter (INFILT) serves as an index to the infiltration capacity of the soil and is a function of soil characteristics. These values were estimated based on the hydrologic soil groups and the average INFILT estimate values in cm/h (Table 3). For each watershed, the soil types and the hydrologic soil group to which it belongs were listed according to the different land cover in the attribute table for soil component in the BASINS program. A weighted average of the soil group infiltration index value was calculated for each land cover type and averages, one for each land use type in each subwatershed, were used as an initial value in the model. The interflow inflow parameter (INTFW) affects the timing of runoff and is related to the infiltration and lower zone nominal storage parameters. This unitless parameter was estimated as 0.75, determined for typical values around the United States (Donigian and Davis 1978). The same value was used regardless of land use type and subwatershed. The length of the assumed overland flow plane, parameter LSUR, is an approximation to the length of the overland flow plane. LSUR, and SLSUR, the slope of the assumed overland flow plane, parameters were estimated using the digital elevation model (DEM) for the Cahaba watershed. The average elevation in each subwatershed was determined and then divided by the length of the entire overland flow plane (in that subwatershed) to give the slope (unitless). The groundwater recession rate parameter (AGWRC) was estimated using a baseflow separation/recession method.

USGS stream flow data were downloaded from several gauging stations near the stream reaches that were simulated in the model (i.e., near the downstream reaches of each subwatershed). The hydrographs (log Q vs. time) were plotted and an estimate of typical low flows based on the receding limbs was determined. The period of these low flows were plotted, a trend line added and the slope of this trend line was the parameter value. However, these parameter values were not used because the model inexplicably would not run for any value input other than 0.98. That value was used regardless of land use type and subwatershed.

Total nitrogen parameter estimation and input

Because the point source database included in the BASINS package and used by NPSM was used for all runs, additional point source loadings were not added to the simulations. None of the point source facilities (Table 4) that discharge into the reaches being simulated specifically discharge nitrogen.

Nitrogen was simulated using algorithms in section PQUAL of PERLND, IQUAL of IMPLND, and GQUAL in RCHRES and total nitrogen was modeled as associated with surface flow, interflow, and groundwater flow from the pervious and impervious land segments. It was assumed that total nitrogen is not sediment-associated and thus was modeled as a conservative pollutant. Also, constant parameter values (e. g., temperature) were used, and not changed on a monthly or seasonal basis. The algorithms in these sections are generalized such that any water quality constituents may be simulated using these sections.

No initial parameter estimation was done for the water quality simulation. Default parameter values assigned by the NPSM model were initially used, but were adjusted during model calibration (see calibration section below). The results from the sensitivity analysis aided in the determination of which parameters to change during calibration. Due to lack of available data and the large number of parameters, as few parameters as possible were used. The first-order decay parameter, FSTDEC, was set to the lowest possible value, so that nitrogen could be modeled as a conservative substance. Table 5 shows both the initial values of parameters used in the total nitrogen simulations and the final calibration values.

Modeling approach

Sensitivity analysis

A single parameter perturbation approach was used to conduct the sensitivity analysis. Each parameter is varied individually by a fixed percentage while all others remain fixed. The NPSM output, using default parameter values, served as the base output for comparison during the sensitivity testing. Each parameter in the model was adjusted by doubling and halving while all other parameters were held at their default values. The outputs were compared to the base case. The percent of relative change was used to determine to which parameters the model was most sensitive. The sensitive parameters are used to adjust

Table 4

Point sources in the Cahaba River watershed

| Discharger name | NPDES number | km point | Reach | Pollutants discharged | Flow (cms) |
|---|--------------|----------|---------------------------------|--|------------|
| Olon Belcher Lumber Company, Brent | AL0001601 | 0.9 | Cahaba River 03150202017 | Flow | 0.0091 |
| Al Ref Spec, Montevallo Pit | AL0022543 | 11.3 | Little Cahaba River 03150202019 | Flow | 0.0091 |
| Rock Wool Mfg, Leeds | AL0001431 | 0.00 | Little Cahaba River 03150202019 | Flow | 0.0001 |
| Chemical Lime Co of Alabama, Montevallo | AL0003336 | 12.4 | Little Cahaba River 03150202019 | Flow solids, total suspended | 0.0016 |
| Gold Kist Poultry, Trussville | AL0003395 | 0.00 | Little Cahaba River 03150202019 | Ammonia nitrogen, calculated BOD, 5-day (20 °C) CBODU (20 °C), calculated flow nitrogen, ammonia total (as N) nitrogen, kjeldahl total (as N) oil and grease (SOXHLET EXTR.) tot. oxygen, dissolved (DO) solids, total suspended | 0.0015 |
| Blue Circle Cement, Roberta Plt | AL0024252 | 12.4 | Little Cahaba River 03150202019 | BOD, 5-day (20 °C) CBODU (20 °C), calculated flow solids, total suspended | 0.00005 |
| Vulcan Metal Prod, Irondale | AL0003689 | 34.5 | Cahaba River 03150202024 | Flow | 0.00012 |
| Cheney Lime and Cement landmark | AL0002631 | 0.00 | *A 03150202026 | Flow | 0.00035 |
| City of Alabaster | AL0025828 | 7.8 | *A 03150202026 | Ammonia nitrogen, calculated BOD, 5-day (20 °C) CBODU (20 °C), calculated flow nitrogen, ammonia total (as N) nitrogen, kjeldahl total (as N) oxygen, dissolved (DO) solids, total suspended | 0.0037 |
| Jefferson Co Cahaba River WWTP | AL0023027 | 12.7 | Cahaba River 03150202029 | BOD, 5-day (20 °C) CBODU (20 °C), calculated flow nitrogen, kjeldahl total (as N) oxygen, dissolved (DO) solids, total suspended | 0.005 |
| Jefferson Co Trussville WWTP | AL0022934 | 28.6 | Cahaba River 03150202032 | Ammonia nitrogen, calculated BOD, 5-day (20 °C) CBODU (20 °C), calculated flow nitrogen, ammonia total (as N) nitrogen, kjeldahl total (as N) solids, total suspended | 0.0015 |
| Lehigh Port Cement, Leeds | AL0003638 | 24.6 | Cahaba River 03150202032 | Flow | 0.00009 |

the model for calibration. Percent relative change is calculated as the difference of the base output value from the output value obtained from changing the parameter, all divided by the output base value, then multiplied by 100%.

$$\frac{Out_i - Out_o}{Out_o} * 100\%$$

where: Out_i is the simulation output from varying the parameter value, and Out_o is the simulation output used as a base output from which analysis will be compared. A large percent change caused by varying the parameter value indicates a sensitive parameter. Results from the sensitivity analysis are summarized in the comments section of Tables 3 and 6.

Calibration

Calibration was accomplished by adjusting model inputs to reproduce the system or watershed behavior well enough to meet the modeling objectives (Nix and others

1999). Field data from stations in the Cahaba watershed show that total nitrogen concentrations in the stream decrease during periods of high stream flow and increase during periods of low flow. The water quality calibration was performed on the high-flow year, and validation on the low-flow year. Runoff volume at the most downstream reach of the watershed was calibrated on the high-flow year and validated on the low-flow year. Total nitrogen was calibrated, but not validated, for 1989, 1990, and 1992. This was due to the paucity of data. However, two sites on the delineated subwatersheds were chosen for model simulation of total nitrogen. Flows were re-calibrated for those sites, since the subwatersheds have different hydrological characteristics from the watershed as a whole, which was modeled only at the most downstream reach. The long-term water balance was calibrated first, then the seasonal and low flows, and finally the hydrograph shape and peak flows. The long-term water balance was influenced by the upper and lower zone nominal storage

Table 5

Summary of NPSM parameters and calibration results for water quality

| Parameter | Initial estimate/ default values | Final calibration value | Comments | | |
|--|--|--|---|---|--------|
| ACQOP, rate of accumulation of QUALOF | Unclassified | 0.0 | Unclassified | ACQOP describes the rate at which the pollutant builds up on the land surface. Values must be smaller than the SQOLIM parameter (see below). This parameter is not sensitive. | |
| | Urban | 0.02159 | Urban | | 1.95 |
| | Agriculture | 0.08066 | Agriculture | | 5.95 |
| | Forest | 0.00489 | Forest | | 0.95 |
| | Barren | 0.00623 | Barren | | 2.15 |
| | Range | 0.0 | Range | | 0.95 |
| SQOLIM, minimum storage of QUALOF | Unclassified | 0.0 | Unclassified | SQOLIM is the maximum amount of the pollutant that can be stored on the land surface. The SQOLIM and ACQOP parameters can both be adjusted to generate the desired loads. These parameters are moderate to highly sensitive. | |
| | Urban | 0.1133 | Urban | | 2.0 |
| | Agriculture | 0.72597 | Agriculture | | 6.0 |
| | Forest | 0.044 | Forest | | 1.0 |
| | Barren | 0.0561 | Barren | | 2.2 |
| | Range | 0.0 | Range | | 1.0 |
| WSQOP, rate of surface runoff which will remove 90% of stored QUALOF per hour (cm/h) | Unclassified | 0.0 | Unclassified | WSQOP describes the rate at which the pollutants are washed off the surface. This parameter has a moderate effect (maximum of about 10%) on simulation output. This parameter is moderately sensitive. | |
| | Urban | 10.7 | Urban | | 16.0 |
| | Agriculture | 9.7 | Agriculture | | 14.5 |
| | Forest | 8.1 | Forest | | 12.2 |
| | Barren | 10.7 | Barren | | 16.0 |
| | Range | 0.0 | Range | | 0.0 |
| SQO, initial storage of (sediment associated constituent) QUALOF on the surface of the PLS | Unclassified | 0.0 | Unclassified | This parameter is not used in this model because it is assumed that total nitrogen is not sediment related. | |
| | Urban | 0.01259 | Urban | | 1.259 |
| | Agriculture | 0.08066 | Agriculture | | 8.066 |
| | Forest | 0.00489 | Forest | | 0.489 |
| | Barren | 0.00623 | Barren | | 0.623 |
| | Range | 0.0 | Range | | 0.0 |
| IOQC, concentration of the constituent in interflow outflow (mg/l) | Unclassified | 0.0 | Unclassified | This parameter specifies the concentration of the pollutant in interflow and allows the user to simulate the occurrence of the pollutant in interflow. This parameter has a significant effect on simulation output, and is only used to 'tweak' the model to generate the desired loads. | |
| | Urban | 4.4E-5 | Urban | | 8.4E-5 |
| | Agriculture | 6.3E-5 | Agriculture | | 6.3E-5 |
| | Forest | 1.2E-5 | Forest | | 1.2E-5 |
| | Barren | 4.4E-5 | Barren | | 4.4E-5 |
| | Range | 0.0 | Range | | 0.0 |
| AOQC, concentration of the constituent in active groundwater outflow (mg/l) | Unclassified | 0.0 | Unclassified | This parameter specifies the concentration of the pollutant in groundwater flow and allows the user to simulate the occurrence of the pollutant in groundwater flow. This parameter has a significant effect on simulation output, and is only used to tweak the model to generate the desired loads. | |
| | Urban | 4.4E-5 | Urban | | 4.4E-5 |
| | Agriculture | 6.3E-5 | Agriculture | | 6.3E-5 |
| | Forest | 1.2E-5 | Forest | | 1.2E-5 |
| | Barren | 4.4E-5 | Barren | | 4.4E-5 |
| | Range | 0.0 | Range | | 0.0 |
| POTFS, scour potency factor | 0.0 for all land uses in all subwatersheds | N/A ^a | This parameter is not used in this model because it is assumed that total nitrogen is not sediment related. | | |
| POTFW, washoff potency factor | 0.0 for all land uses in all subwatersheds | N/A | This parameter is not used in this model because it is assumed that total nitrogen is not sediment related. | | |
| FSTDEC, first-order decay rate for qual | 0.25 | 1.00E-05 | Total nitrogen will be modeled as a conservative substance, therefore the first order decay parameter is set to the minimum possible value since the model will not accept a value of zero. | | |
| TWAT, water temperature | 16 °C | 16 °C | This is the average water temperature. | | |
| KVARY, parameter affecting the behavior of groundwater recession flow, enabling it to be nonexponential in its decay with time | 0.0 cm ⁻¹ for all subwatersheds and all land uses | 1.9 cm ⁻¹ for all subwatersheds and all land uses | This parameter has a major impact on seasonal and low-flow periods. | | |
| INTFW, interflow inflow parameter | 0.75 for all subwatersheds and all land uses | 0.5 for all subwatersheds and all land uses | INTFW (unitless) is closely related to INFILT and LZSN, and controls the amount of water diverted to shallow subsurface interflow (high values indicate more flow diverted to interflow). This parameter has a major affect on hydrograph peak and shape. | | |

^aN/A Not applicable

(UZSN and LZSN) and the index to the infiltration capacity of the soil (INFILT). Seasonal and low flows were influenced by the groundwater recession rate (AGWRC), the parameter which also affects the behavior of groundwater recession flow (KVARY), the fraction of potential ET which can be satisfied from groundwater and base flow (BASETP), and the index to the infiltration capacity of the soil (INFILT). The hydrograph shape and peak flows are calibrated by adjusting the interflow inflow parameter (INTFW). A description of the parameters, their initial or default values, and final calibration values are summarized in Table 3 for water quantity and Table 5 for water quality. The high-flow year used in the simulations is 1989. The model was run to simulate runoff from January 1, 1987 to December 31, 1989, where the first two years were discarded as the simulation warm-up period so that the parameters used to describe the initial conditions of the watershed are not significant to the simulation output. The simulated runs of runoff at the downstream reach (watershed outlet) were compared to the stream flow data

obtained by the USGS gauging station at Marion Junction (station number 02425000), the closest gauging station to the downstream reach in the model.

Parameter values were varied in a trial-and-error fashion until the simulated flow matched relatively closely the observed flow. A volume integrating method was used with the simulated results as a check to see that the model was also correctly simulating a reasonable volume of water, based on observed data. The estimated parameters were then input into the model for simulation. The parameters that were not estimated were left as the default values (Tables 3 and 6).

There are no specific guidelines for water quality calibration in HSPF/NPSM. Nitrogen data were obtained from the Geological Survey of Alabama (GSA), the Alabama Department of Environmental Management (ADEM), and the United States Geological Survey (Table 6). Two sub-watersheds were chosen for water quality calibration due to the availability of data and the delineation of the sub-watersheds. The *A segment (subwatershed 03150202026)

Table 6

Summary of water quality data for the Cahaba River watershed

| Data collection agency | Site of data collection | Dates of available data | Types of water quality data | Range of values | Comments |
|---|--|-------------------------|--|---|---|
| Alabama Department of Environmental Management (ADEM) | Cahaba River at Camp Coleman (site C1) | 1974–1995 | Total NO ₃ (mg/l as N) Flow (cms) | 0.07–13.15 0.11–15.6 | Data collected roughly once a month. |
| Alabama Department of Environmental Management (ADEM) | Cahaba River at Caldwell Ford bridge (site C2) | 1974–1997 | Total NO ₃ (mg/l as N) Flow (cms) | 0.0–3.93 0.003–243 | Data collected roughly once a month. |
| Alabama Department of Environmental Management (ADEM) | Cahaba River west of Helena (site C3) | 1974–1997 | Total NO ₃ (mg/l as N) Flow (cms) | 0.02–8.9 0.3–170 | Data collected roughly once a month. |
| Alabama Department of Environmental Management (ADEM) | Cahaba River southeast of Harrisburg (site C4) | 1974–1997 | Total NO ₃ (mg/l as N) Flow (cms) | 0.013–1.18 5–317 | Data collected roughly once a month. |
| Alabama Department of Environmental Management (ADEM) | Little Cahaba River south of Leeds (site LC1) | 1971–1997 | Total NO ₃ (mg/l as N) Flow (cms) | 0.08–9.7 0.11–45 | Data collected roughly once a month. |
| Alabama Department of Environmental Management (ADEM) | Buck Creek near Helena (site B1) | 1974–1997 | Total NO ₃ (mg/l as N) Flow (cms) | 0.04–6.7 0.2–79 | Data collected roughly once a month. |
| Geological Survey of Alabama (GSA) | Cahaba River at Centerville (station 1) | 1989–1991 | Nitrate NO ₃ (mg/l as N) | 0.03–0.98 | Minimum value indicates lower detection limit |
| Geological Survey of Alabama (GSA) | Cahaba River at Helena (station 5) | 1989–1991 | Nitrate NO ₃ (mg/l as N) | 0.34–4.0 | Data collected roughly once a month. |
| Geological Survey of Alabama (GSA) | Cahaba River at Camp Coleman (station 16) | 1992–1994 | Nitrate NO ₃ (mg/l as N) Total NO ₂ +NO ₃ (mg/l as N) | 0.03–13.1 0.03–13.1 | Minimum value indicates lower detection limit |
| US Geological Survey (USGS) | Cahaba River near Mountain Brook (station 2423380) | 1990–1995 | Nitrate NO ₃ (mg/l as N) Nitrite NO ₂ (mg/l as N) Total NO ₂ +NO ₃ (mg/l as N) | 0.16–1.19 0.01–0.03 0.1–1.2 | Some nutrient data missing in data. Scant data. |
| US Geological Survey (USGS) | Cahaba River at Centerville (station 2424000) | 1990–1994 | Instantaneous flow (cms) Nitrate NO ₃ (mg/l as N) Nitrite NO ₂ (mg/l as N) Total NO ₂ +NO ₃ (mg/l as N) | 0.45–53 0.08–0.36 0.1–0.2 0.1–0.93 | Some nutrient data missing in data. Scant data. |
| Geological Survey of Alabama (GSA) | Cahaba River at mouth (station Cah-1) | 1996 | Instantaneous flow (cms) Nitrate NO ₃ (mg/l as N) Nitrite NO ₂ (mg/l as N) Total NO ₂ +NO ₃ (mg/l as N) Flow (cms) | 5.8–112 0.008–0.335 <0.006 0.008–0.335 18.4–242 | Seven samples taken throughout the year |

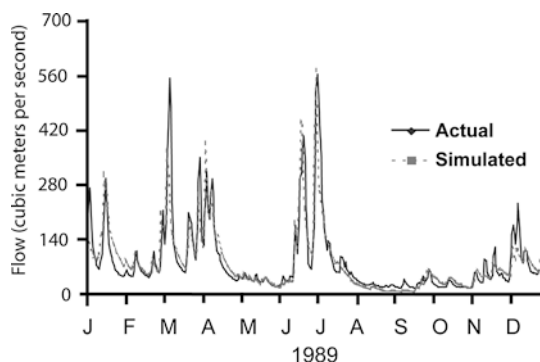


Fig. 4

Actual and simulated Cahaba River hydrographs for the calibration year of 1989. Observed hydrograph is shown as a *solid line* and the BASINS simulation is shown as a *dashed line*

and the Big Black Creek segment (subwatershed 03150202033) were both calibrated based on field data collected in 1989, 1990, and 1992. There was approximately one value for each month per year. The *A segment was calibrated to the ADEM data collected at their B1 site (Buck Creek near Helena), and the Big Black Creek segment was calibrated with ADEM data at their C1 site (Cahaba River at Camp Coleman). The stream hydrographs were re-calibrated from the Marion Junction runoff calibration because different land characteristics caused different flow patterns in these subwatersheds (Table 5). Parameter values were varied according to the results of the sensitivity analysis to fine-tune the simulation outputs. Total nitrogen was also simulated as a conservative substance with no first order decay. Model calibration was performed in a trial-and-error fashion until reasonable total nitrogen loads were achieved compared to the available data. A summary of the pertinent parameters, their default values as assigned by NPSM, and final calibration values for each subwatershed site are given (Table 5).

A validation run was executed to reproduce runoff from the entire watershed (most downstream reach corresponding to Marion Junction USGS gauging station) to see how well the model worked with the calibrated parameters on a different year. Validation was done on the low-flow calendar year of 1992 using the same parameter values determined during calibration. The model was run from 1 October 1990 to 31 December 1992 to simulate the flow at the most downstream reach (same location as the calibration run) and compared with the flow from the Marion Junction USGS gauging station (02425000). A volume integrating method was used to compare total volume of water flowing at the site. Validation for total nitrogen model outputs was not performed because there were too few data available for the two subwatershed sites.

Results and discussion

Calibration on the high-flow year (1989) simulated the hydrograph results well (Fig. 4). Peaks and low flows were well modeled, as was the general hydrograph shape.

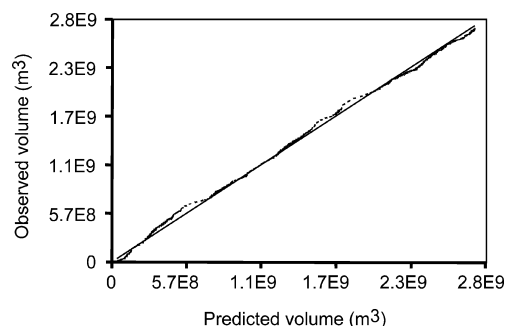


Fig. 5

Plot of actual vs. simulated Cahaba River cumulative flow volumes for 1989, shown as a *dotted line*. A 1:1 slope line is also shown as a *solid line*, indicating the good agreement between simulated and actual flow volumes

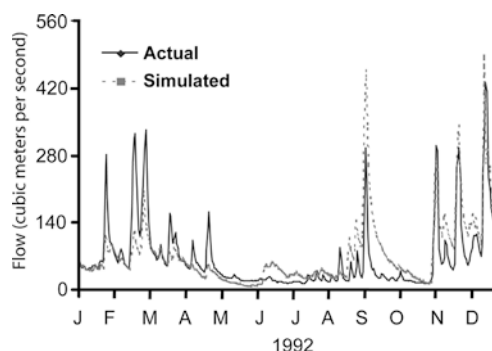


Fig. 6

Actual and simulated Cahaba River hydrographs for 1992. Observed hydrograph is shown in a *solid line* and the BASINS simulation is shown as a *dashed line*. Simulation was performed with the model calibrated using the 1989 data and with no further parameter adjustment

However, there are minor discrepancies between actual and simulated outflows. During the winter months, from mid-January through July, the model slightly overestimated peak flows, while in winter, from August through mid-January, the model tends to underestimate runoff (Fig. 4). This may be due to an inadequate precipitation gauge network, or to errors in some of the input parameter values. The model generally predicts peak flows 1 to 2 days earlier than actual peaks occur.

The total cumulative flow rate at Marion Junction for calendar year 1989 is 31,935 cubic meters per second (cms), and the simulated cumulative flow rate for 1989 was 31,621 cms. Total volume (determined by a volume integration method) at the Marion Junction USGS gauging station was 2,747,847 cubic meters (m^3) and the simulated discharge volume was 2,722,175 m^3 . This is slightly less than 1% error in the simulated results compared to the actual results. A plot of observed versus simulated cumulative volumes (Fig. 5) shows good agreement with a trend line of 1:1 slope.

The low-flow year of 1992 simulation resulted in an overestimate, compared to actual flow and volume data (Fig. 6). Simulated results for June and July produced the

largest discrepancies from observed flows. This may be due to intense, highly local, summer thunderstorms common to the region. Because the watershed area is large and only two weather stations were assigned, the discrepancy may be a result of storms recorded at the Birmingham weather station, which did not affect the southern portion of the watershed. Physical processes (e.g., infiltration capacity, soil moisture, and groundwater recession) may be inadequately modeled due to the lack of spatial variation in precipitation input or inaccurate input parameter values, which also contribute to these discrepancies. Seasonal discrepancies are also apparent. However, changing parameter values on a monthly basis to account for seasonal variations in watershed processes did not improve model results. Unlike the calibration results, the model was found to under predict the flow during the first half of the year from January to June, and over-estimate the discharge from June to December. The total cumulative flow rate at the Marion Junction USGS gauging station for calendar year 1992 was 24,566 cms, and the cumulative simulated flow rate was 28,090 cms. Total observed cumulative flow volume was 211,562,160 m³, and model simulations determined 241,803,089 m³ in discharge, an over prediction of 12.5%. A plot of observed versus simulated cumulative volumes for 1992 shows that the model under predicts flow volumes during the first part of the year, then over predicts in the middle of the year, and under predicts again towards the end of the year (Fig. 7). The limited rainfall-gauging network in the watershed may be the reason for these discrepancies. The results for the low-flow

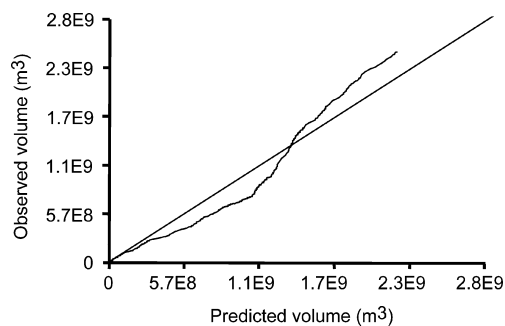


Fig. 7

Plot of actual vs. simulated Cahaba River cumulative flow volumes for 1992, shown as a *dotted line*. A 1:1 slope line is also shown as a *solid line*. The plot of the flows shows some disagreement between simulated and actual flow volumes. The model under predicts flow early in the year and over predicts later in the year, resulting in a cumulative over prediction of flow volume

validation are different from the calibration, which suggests the possibility that the differences may be due to parameter value inputs related to soil conditions and capacities. In the low-flow year, antecedent soil moisture conditions may affect estimates of low runoff during winter and high runoff during summer. Long duration, low intensity rainfall is common during winter. The model may simulate more infiltration and reduce surface runoff estimates. In the summer months, the soil may be assumed saturated by the model and therefore most of the rainfall becomes runoff, thereby increasing the simulated runoff. The KVARY parameter (which affects the behavior of groundwater recession flow) has a major impact on low-flow periods, and the value chosen in calibration may not have been appropriate during low-flow periods.

Regression and other statistical analyses were performed on the data. The regression analysis performed on the high-flow year (1989) of actual vs. simulated data gave a student's t-value of 7.5, and a student's t-value of 7.9 for the low-flow year (1992). A student's t-value greater than 2 indicates good agreement between values (here, between actual and simulated outflow). Also, the root mean squared error (RMSE) and signal-to-noise (SN) ratio were also calculated for both years. The RMSE is analogous to the standard deviation, and the SN ratio is the ratio between the actual values to the RMSE. They are computed as:

$$RMSE = \sqrt{\frac{1}{n} \sum_i^n (Q_i - Q_{i,obs})^2}$$

$$SN = \frac{\frac{1}{n} \sum_i^n Q_{i,obs}^2}{\frac{1}{n} \sum_i^n (\hat{Q}_i - Q_{i,obs})^2}$$

where:

- Q_i = simulated discharge in cms
- $Q_{i,obs}$ = observed discharge in cms
- n = number of observations

Low values of RMSE and high values of the SN ratio indicate good model simulations. The RMSE for the 1989 run was 57 cms and 54 cms in 1992. The SN ratio for 1989 and 1992 are 5.1 and 3.25, respectively.

Weighted RMSE and SN ratios were also calculated with emphasis on low flows in order to determine how well the model simulated low flows (Table 7). The weighted calculations were also performed during just the low-flow months. Low-flow months in 1989 were August through

Table 7

Results of statistical analysis for water quantity

| Year | RMSE | SN ratio | Low flow RMSE (cms) | Low flow SN ratio | Low flow weighted RMSE (cms) |
|------|-------|----------|---------------------|-------------------|------------------------------|
| 1989 | 2,025 | 5.10 | 11.3 | 6.305 | 11.2 |
| 1992 | 1,920 | 3.25 | 17.0 | 1.749 | 17.4 |

1989 low flow: August 1–October 31

1992 low flow: May 1–July 31

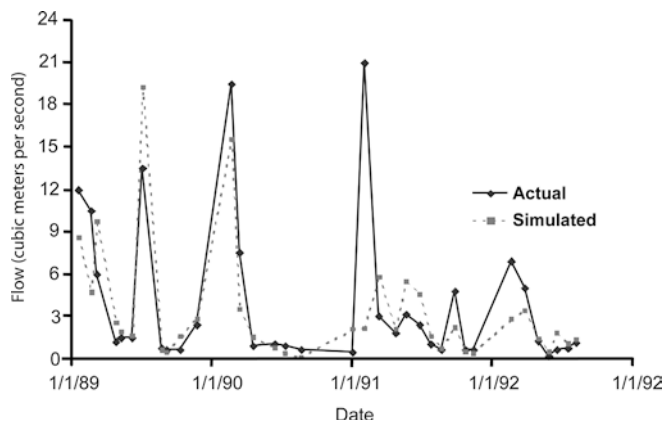


Fig. 8

Actual and simulated hydrographs in the *A segment subwatershed. Measured flows are shown with a *solid line* and simulated flows with a *dashed line*. Simulations were performed with most parameters set to the same values as those used for the entire watershed model. Infiltration capacity and slope for this subwatershed were both adjusted during calibration

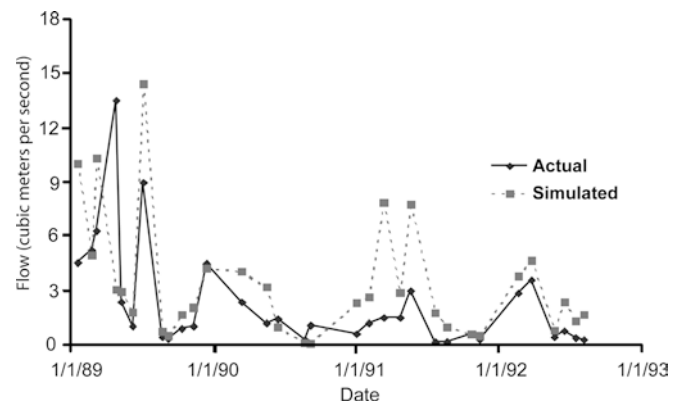


Fig. 10

Actual and simulated hydrographs in the Big Black Creek segment subwatershed. Measured flows are shown with a *solid line* and simulated flows with a *dashed line*. Simulations were performed with most parameters set to be the same as those for the entire watershed. This subwatershed model is the only model of the study which tended to over predict peak flows

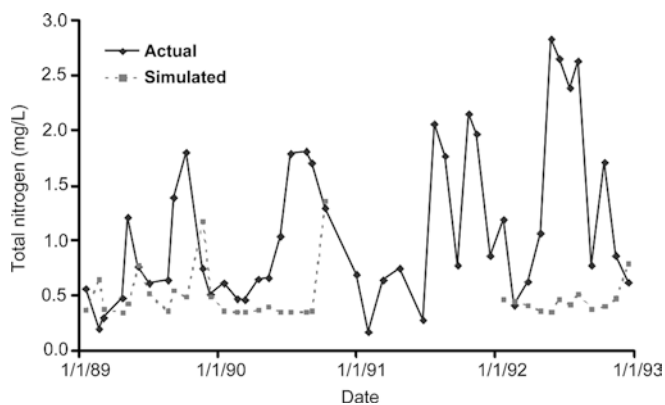


Fig. 9

Actual and simulated total nitrogen in the *A segment subwatershed. Measured concentrations are shown in the *solid line* and simulated concentrations with the *dotted line*. The model tends to under predict total nitrogen concentrations and to predict peak nitrogen concentrations later than the time at which the measured peak concentrations occur

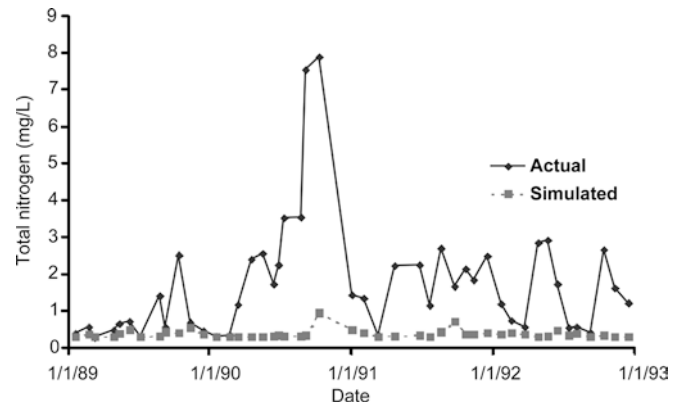


Fig. 11

Actual and simulated total nitrogen in the Big Black Creek segment. Measured concentrations are shown as the *solid line* and simulated concentrations as the *dotted line*. The model tends to under predict total nitrogen concentrations. This is probably the result of inclusion of no point source inputs of nitrogen in the model, due to data unavailability in the BASINS database

October. Low-flow months for 1992 were May through July. The weighted RMSE for low flow is calculated as:

$$RMSE_{weighted} = \sqrt{\frac{1}{n} \sum_{i=1}^n \frac{2 * \bar{Q}_{obs}}{Q_{i,obs} - \bar{Q}_{obs}} (Q_i - Q_{i,obs})^2}$$

where:

- Q_i = simulated discharge in cms
- $Q_{i,obs}$ = observed discharge in cms
- Q_{obs} = average observed discharge in cms
- n = number of observations

Results indicate that the errors made during periods of low flow are in the order of 0.6 cms in 1989 and 8.5 cms in 1992, and the SN ratio improved in both cases, with a greater improvement in 1992.

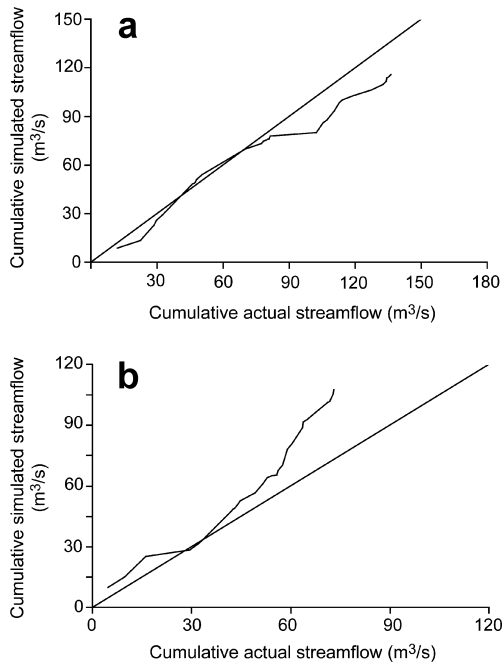
Simulated results for runoff discharge and total nitrogen in the *A subwatershed show computed results for the Big Black Creek subwatershed (Figs. 8 and 9). Two of the water parameters (infiltration capacities and slope) were adjusted for this subwatershed during calibration. The water balance was recalibrated because the subwatershed has slightly different hydrological characteristics than the watershed as a whole. The model computes daily values for runoff and total nitrogen during the simulated time period. Simulated values that correspond to the dates of measured values were compared (Figs. 8, 9, 10, and 11).

In both subwatersheds, neither the simulated hydrographs nor the simulated total nitrogen matched the measured data as well as the simulations of the entire watershed. Of the two subwatersheds, *A subwatershed hydrograph was better simulated than the Big Black Creek segment. The

Table 8

Results of statistical analysis for water quantity and water quality in the subwatersheds

| | Flow | | Total nitrogen concentration | |
|-------------------------|------------|----------|------------------------------|----------|
| | RMSE (cms) | SN ratio | RMSE (mg l ⁻¹) | SN ratio |
| *A segment | 3.7 | 2.82 | 0.978 | 1.806 |
| Big Black Creek segment | 2.8 | 1.541 | 2.041 | 1.310 |

**Fig. 12a, b**

Actual and simulated cumulative flow volumes in **a** *A creek segment and **b** Big Black Creek segment subwatersheds. Also shown on each plot is a line with a 1:1 slope. The model under predicts the water balance in the *A segment and over predicts the water balance in the Big Black Creek segment

model did a better job reproducing the trend of the actual flow hydrograph early in the year for the *A segment. The calculated RMSE for the *A and Big Black Creek segments were 3.7 and 2.8 cms respectively. The SN ratio for the *A segment is 2.82, and for the Big Black Creek segment is 1.54 (Table 8). Plots of the cumulative actual flows vs. the cumulative simulated flows show that the model moderately over predicts the long-term water balance in the Big Black Creek subwatershed, and slightly under predicts the long-term water balance in the *A subwatershed (Fig. 12). Total nitrogen for both subwatersheds was poorly simulated. In both cases, the simulated output greatly underestimated measured values, especially in the Big Black Creek subwatershed. The RMSE for the *A and Big Black Creek segments were 0.978 and 2.041 mg L⁻¹, respectively. The SN Ratio for the *A and Big Black Creek segments were 1.806 and 1.310, respectively (Table 8). Simulated peaks lag real peaks for total nitrogen. The slow response in timing of the peak values of N may be due to the routing algorithms used by the model.

These poor water quality simulation results may be due to lack of inclusion of point sources in the model. These subwatersheds are near the greater Birmingham area where point sources include water treatment plants, septic tanks, and industry. This suggests that the point sources may be responsible for greater contribution to nitrogen loads than nonpoint sources and account for significant nitrogen input to the river. That would account for the

Table 9

Results of nitrogen budget study

| | Kilograms nitrogen (kg) | | Portion of total applied N | |
|------------------------------------|-------------------------|-------------|----------------------------|------|
| | 1990 | 1992 | 1990 | 1992 |
| Cahaba River system | | | | |
| Fertilizer | 2,070,000 | 2,030,000 | 44% | 46% |
| Animal manure | 2,630,000 | 2,410,000 | 56% | 54% |
| Total inputs | 4,700,000 | 4,440,000 | | |
| Crop harvest (output) | 938,000 | 1,080,000 | 20% | 24% |
| Stored | 3,762,000 | 3,360,000 | 80% | 76% |
| Mobile-Alabama River system | | | | |
| Fertilizer | 80,800,000 | 79,000,000 | 42% | 41% |
| Animal manure | 113,000,000 | 112,000,000 | 58% | 59% |
| Total inputs | 193,800,000 | 191,000,000 | - | - |
| Crop harvest | 35,900,000 | 46,900,000 | 19% | 25% |
| Riverine transport | 14,082,999 | 9,144,140 | 7% | 5% |
| Total output | 49,982,999 | 56,044,140 | 26% | 29% |
| Stored | 143,817,001 | 134,955,860 | 74% | 71% |

Data from Carey and others 2003

under-simulation from the model. Another reason for the discrepancies between the measured and simulated total nitrogen values is the difference between the locations where these data were collected and the most downstream reach in each subwatershed for which the simulation results were calculated. There is a strong correlation between flow and drainage area. As modeled total nitrogen concentration depends on the amount of water, the model may produce more diluted concentrations. Point sources (Table 4) were not included in the model because these nitrogen data were not available in the BASINS program. There are many industries in the Birmingham area that discharge into the Cahaba River. Discharges from septic tanks, agricultural land, and other sources were not included, contributing to the low concentrations of simulated total nitrogen in the subwatersheds. Even though nitrogen was modeled as a conservative substance, simulated concentrations were lower than the measured concentrations and total nitrogen was thus greatly underestimated in both watersheds using the BASINS program. Greater flexibility within the BASINS program for inclusion of point sources would improve nitrogen modeling with BASINS.

Results of a nitrogen budget study in the Cahaba River watershed and the Mobile-Alabama River system (MARS) (Carey and others 2003) calculated inputs of total nitrogen from fertilizer and animal manure data for both systems (Table 9). Outputs of total nitrogen were calculated from crop harvest for both systems, and riverine transport for the MARS. Both systems show the total nitrogen input from fertilizer was 41–46% of the total input for 1990 (high-flow year) and 1992 (low-flow year). Total nitrogen input from both systems was 54–59% of the total input in both years. Total nitrogen output from crop harvest in both systems for both years was 19–25% of the total nitrogen input. In the Cahaba watershed, 80% of the total input nitrogen was stored on the land surface in the high-flow year of 1990, and 76% was stored in the low-flow year (1992). Riverine transport only accounted for 5–7% of the total nitrogen input in the MARS. Stored total nitrogen in the MARS in 1990 was calculated to be 74% of the total nitrogen input, and in 1992, 71%.

Conclusions

The NPSM/HSPF model performed well in simulations of rainfall-runoff processes in the Cahaba River watershed. The long-term water balance and hydrograph presentations were well simulated, although there were some seasonal discrepancies, which may be attributable to a poor distribution of meteorological data. Water volume, hydrograph shape, peak flows, and seasonal and low flows were simulated well by the model presented here. Long-term simulations were also modeled well. Total nitrogen concentrations in the watershed were less well modeled. This is likely due to the exclusion of point source inputs to the watershed and lack of detailed

nitrogen source information available to the model. The modules used herein with NPSM/HPSF for nitrogen modeling are general algorithms that are used for general water quality constituents. Because nitrogen transformation and movement are complex processes, these modules were not best suited to calculate total nitrogen concentrations in the river. More complex and detailed modules are available in NPSM/HPSF specifically for nitrogen, and should be used in future simulations. However, paucity of data precluded the use of these complex modules. An intensive data collection effort would be useful for predicting 'what-if' scenarios in a small subwatershed. These scenarios could answer questions such as 'what would happen to the total nitrogen concentrations if the land use changes?' and 'what would happen to the total nitrogen concentrations if agricultural practices were changed in a certain manner?' The HSPF model was able to predict runoff reasonably well on large temporal and spatial scales. Regional studies may be performed by use of this model. BASINS allows for watershed delineations that NPSM reads and separates. Parameter values can vary for each land use type found in each subwatershed to account for different hydrological characteristics within the region to be modeled. Such large-scale studies allow for a better overview of regional processes such that more comprehensive watershed management practices can be implemented.

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