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SIMULATION OF STREAMFLOW AND WATER QUALITY IN THE CHRISTINA RIVER SUBBASIN AND OVERVIEW OF SIMULATIONS IN OTHER SUBBASINS OF THE CHRISTINA RIVER BASIN, PENNSYLVANIA, MARYLAND, AND DELAWARE, 1994-98

by Lisa A. Senior and Edward H. Koerkle

Water-Resources Investigations Report 03-4193

In cooperation with the

DELAWARE RIVER BASIN COMMISSION,

DELAWARE DEPARTMENT OF NATURAL RESOURCES AND ENVIRONMENTAL CONTROL, and the

PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION

New Cumberland, Pennsylvania
2003

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
acre	.4047	hectare
square mile (mi^2)	2.590	square kilometer
	Volume	
million gallons (Mgal)	3,785	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
	Flow rate	
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
inch per hour (in/h)	0.0254	meter per hour
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram
ton, short (2,000 lb)	0.9072	megagram
pound per acre per year (lb/acre)/yr	1.123	kilogram per hectare per year
ton per acre per year (ton/acre)/yr	3.6712	metric ton per square kilometer per year
	Temperature	
degree Fahrenheit (°F)	°C=5/9 (°F-32)	degree Celsius

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 1929); horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 1927).

Abbreviated water-quality units used in report:

ft/mi, foot per mile
µg/L, micrograms per liter

µm, micrometer

µS/cm, microsiemens per centimeter at 25 degrees Celsius

mg/L, milligrams per liter

SIMULATION OF STREAMFLOW AND WATER QUALITY IN THE CHRISTINA RIVER SUBBASIN AND OVERVIEW OF SIMULATIONS IN OTHER SUBBASINS OF THE CHRISTINA RIVER BASIN, PENNSYLVANIA, MARYLAND, AND DELAWARE, 1994-98

By Lisa A. Senior and Edward H. Koerkle

ABSTRACT

The Christina River Basin drains 565 square miles (mi^2) in Pennsylvania and Delaware and includes the major subbasins of Brandywine Creek, Red Clay Creek, White Clay Creek, and Christina River. The Christina River subbasin (exclusive of the Brandywine, Red Clay, and White Clay Creek subbasins) drains an area of 76 mi^2. Streams in the Christina River Basin are used for recreation, drinking water supply, and support of aquatic life. Water quality in some parts of the Christina River Basin is impaired and does not support designated uses of the stream. A multi-agency water-quality management strategy included a modeling component to evaluate the effects of point- and nonpoint-source contributions of nutrients and suspended sediment on stream water quality. To assist in nonpoint-source evaluation, four independent models, one for each of the four main subbasins of the Christina River Basin, were developed and calibrated using the model code Hydrological Simulation Program–Fortran (HSPF). Water-quality data for model calibration were collected in each of the four main subbasins and in small subbasins predominantly covered by one land use following a nonpoint-source monitoring plan. Under this plan, stormflow and base-flow samples were collected during 1998 at two sites in the Christina River subbasin and nine sites elsewhere in the Christina River Basin.

The HSPF model for the Christina River subbasin simulates streamflow, suspended sediment, and the nutrients, nitrogen and phosphorus. In addition, the model simulates water temperature, dissolved oxygen, biochemical oxygen demand, and plankton as secondary objectives needed to support the sediment and nutrient simulations. For the model, the basin was subdivided into nine reaches draining areas that ranged from 3.8 to 21.9 mi^2. Ten different pervious land uses and two impervious land uses were selected for simulation. Land-use areas were determined from 1995 land-use data. The predominant land uses in the Christina River subbasin are residential, urban, forested, agricultural, and open.

The hydrologic component of the model was run at an hourly time step and calibrated using streamflow data from two U.S. Geological Survey (USGS) streamflow-measurement stations for the period of October 1, 1994, through October 29, 1998. Daily precipitation data from one National Oceanic and Atmospheric Administration (NOAA) meteorologic station and hourly data from one NOAA meteorologic station were used for model input. The difference between observed and simulated streamflow volume ranged from -2.3 to 5.3 percent for a 10-month portion of the calibration period at the two calibration sites. Annual differences between observed and simulated streamflow generally were greater than the overall error for the 4-year period. For example, at Christina River at Coochs Bridge, near the bottom of the free-flowing part of the subbasin (drainage area of 21 mi^2), annual differences between observed and simulated streamflow ranged from -6.9 to 6.5 percent and the overall error for the 4-year period was -1.1 percent. Calibration errors for 36 storm periods at the three calibration sites for total volume, low-flow-recession rate, 50-percent lowest flows, 10-percent highest flows, and storm peaks were within the recommended criteria of 20 percent or less. Much of the error in simulating storm events on an hourly time step can be attributed to uncertainty in the rainfall data.

The water-quality component of the model was calibrated using nonpoint-source monitoring data collected at two USGS streamflow-measurement stations and other water-quality monitoring data. The period of record for water-quality monitoring was variable at the stations, with a start date ranging from October 1994 to January 1998 and an end date of October 1998. Because of availability, monitoring data for suspended-solids concentrations were used as surrogates for suspended-sediment concentrations, although suspended-solids data may underestimate suspended sediment and affect apparent accuracy of the suspended-sediment simula-

tion. Comparison of observed to simulated loads for up to six storms in 1998 at the two nonpoint-source monitoring sites (Little Mill Creek near Newport and Christina River at Coochs Bridge, Del.) indicate that simulation error is commonly as large as an order of magnitude for suspended sediment and nutrients. The simulation error tends to be smaller for dissolved nutrients than for particulate nutrients. Errors of 40 percent or less for monthly or annual values indicate a fair to good water-quality calibration according to recommended criteria; much larger errors are possible for individual events. Assessment of the water-quality calibration under stormflow conditions is limited by the relatively small amount of available water-quality data in the subbasin.

Users of the Christina River subbasin HSPF model and HSPF models for other subbasins in the Christina River Basin should be aware of model limitations and consider the following if the model is used for predictive purposes: streamflow-duration curves suggest the model simulates streamflow reasonably well when measured over a broad range of conditions and time although streamflow and the corresponding water quality for individual storm events may not be well simulated; streamflow-duration curves for the simulation period compare well with duration curves for the 58-year period ending in 2001 at Christina River at Coochs Bridge, Del., and include all but the extreme high-flow and low-flow events; and calibration for water quality was based on limited data, with the result of increasing uncertainty in the water-quality simulation.

INTRODUCTION

The Christina River Basin (fig. 1), which includes Brandywine Creek (drainage area of 327 mi^2), Red Clay Creek (54 mi^2), White Clay Creek (108 mi^2), and the Christina River itself (76 mi^2), drains approximately 565 mi^2 in southeastern Pennsylvania, northern Delaware, and a small part of northeastern Maryland. The Christina River and its tributaries provide drinking water for more than 40 percent of the residents of Chester County, Pa., and more than 50 percent of the residents of New Castle County, Del.

Stream waters of the Christina River Basin are used for public water supply and recreation and to support aquatic life. Some of these uses are threatened because water quality is impaired by point and nonpoint sources of contamination. Causes of impairment have been identified as sediment, nutrients, and bacteria (Greig and others, 1998). In addition, some agricultural areas of the basin are undergoing urbanization, and the effects of land-use changes on water quality and quantity are unknown. The states of Delaware and Pennsylvania need tools to evaluate alternative approaches for addressing existing water-quantity and water-quality problems and for forecasting future conditions.

A 5-year water-quality management strategy for the Christina River Basin starting in 1995 was conceived and directed by the Delaware Department of Natural Resources and Environmental Control (DNREC), Pennsylvania Department of Environmental Protection (PADEP), Chester County Conservation District (CCHD), Water Resources Agency of New Castle County, Chester County Water Resources Authority (CCWRA), New Castle County Conservation District (NCCCD), Delaware River Basin Commission (DRBC), U.S. Environmental Protection Agency (USEPA), watershed groups and other concerned organizations, groups, and individuals. To assist water-resources managers and others interested in addressing water-quality problems, the U.S. Geological Survey (USGS) developed a nonpoint-source monitoring plan and constructed a hydrologic and water-quality model of the basin to estimate sediment and nutrient contributions from nonpoint sources. USGS conducted the Christina River Basin nonpoint-source monitoring and modeling in cooperation with DRBC, DNREC, and PADEP.

A widely used model, Hydrological Simulation Program–Fortran (HSPF), was selected to estimate the nonpoint-source loads of nutrients and sediment for the Christina River Basin. Each of the four major subbasins in the Christina River Basin was modeled separately because HSPF can be applied only to free-flowing, nontidal streams. The lower reaches of the Christina River and its tributaries, Brandywine Creek, White Clay Creek, and Red Clay Creek, are tide-affected and, therefore, are not included in the HSPF models. The watershed model, HSPF, can be used to simulate the delivery of nonpoint-source contaminants to mainstem streams. The model can simulate hydrologic processes, physical transport of nonpoint-source contaminants, and in-stream chemical reactions. Data required for this watershed model include concentrations of contaminants of interest over a range of hydrologic conditions from various land-use areas that are expected to differ in contribution of nonpoint-source contaminants and hydrologic response.

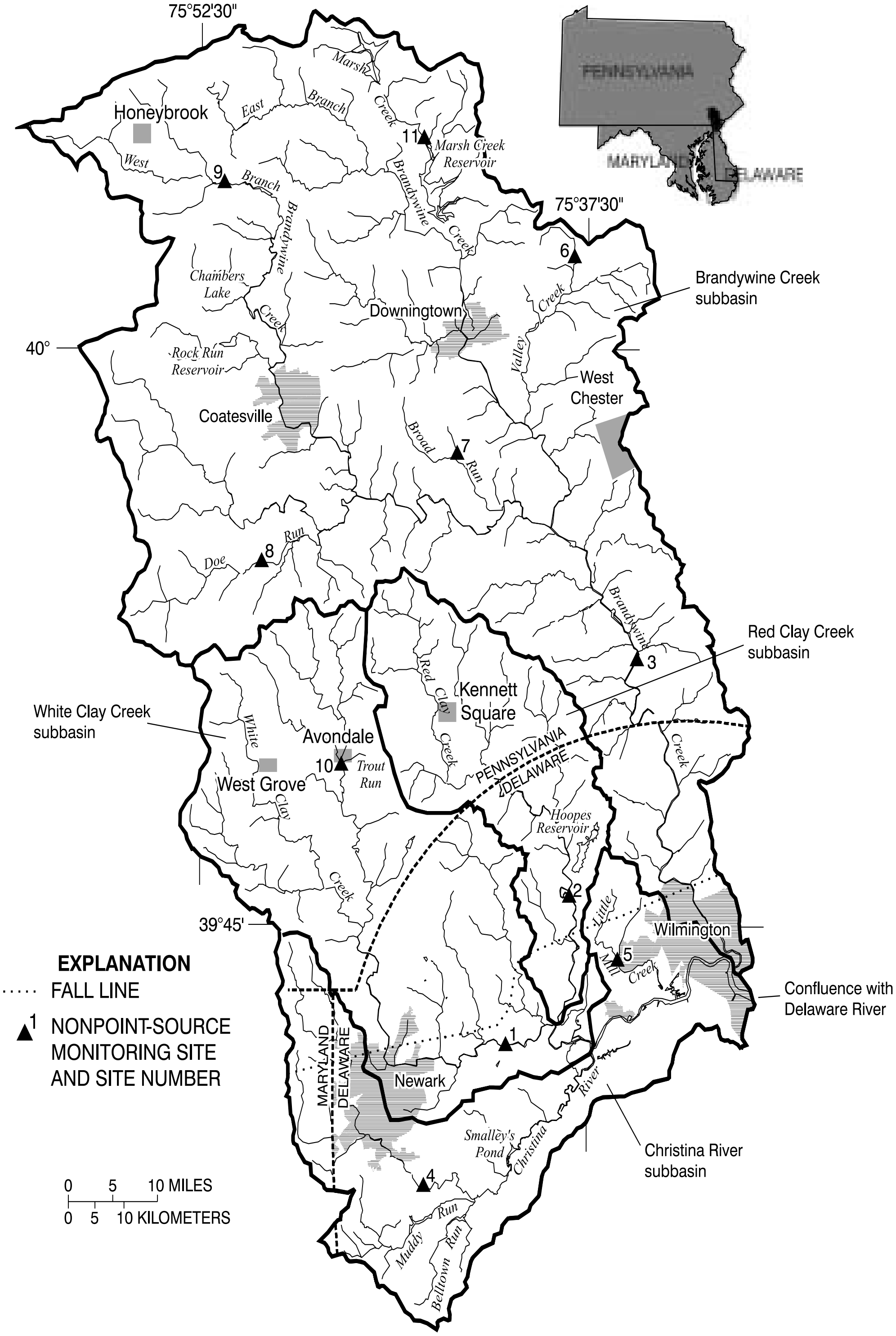


Figure 1. Location of the Christina River Basin and its four major subbasins and nonpoint-source water-quality monitoring sites, Pennsylvania, Delaware, and Maryland.

The nonpoint-source water-quality sampling plan, executed in 1997-98, provided streamflow, nutrient, and suspended-solids data that were used to (1) estimate concentrations and loads of the selected constituents from various land uses in the Christina River Basin; and (2) calibrate an HSPF model of each major subbasin for these selected constituents. Nonpoint-source water-quality and streamflow data were collected at four main-stem sites on the lower free-flowing reaches of the Christina River and Brandywine, White Clay, and Red Clay Creeks and at seven subbasin sites throughout the Christina River Basin selected principally for land-use characterization (fig. 1; table 1). All sites were equipped for continuous streamflow recording and automated water-quality sampling. Six sites were at existing USGS streamflow-measurement stations (gages), one site (01480095) was at a discontinued streamflow-measurement station recommissioned for the study, and four new streamflow / water-quality sites (01480878, 01480637, 014806318, 01478137) were constructed (table 1).

The HSPF model for the largest of the subbasins, the Brandywine Creek Basin, was developed first (Senior and Koerkle, 2003a), followed by the White Clay Creek Basin (Senior and Koerkle, 2003b). These first two models were the basis for models in the other two subbasins, Red Clay Creek (Senior and Koerkle, 2003c) and the Christina River. Model input parameters affecting suspended sediment and nutrient contributions from selected land uses were calibrated for the Brandywine Creek model and transferred to the White Clay Creek model, where applicable, with additional calibration in the White Clay Creek model for mushroom-growing agricultural land use. The model parameters affecting water quality from the Brandywine Creek and White Clay Creek models were then transferred to the Red Clay Creek and Christina River models with minor adjustments to obtain similar sediment and nutrient yields by land use. The HSPF model may be used by water-resources managers to evaluate options for managing contaminants from nonpoint and point sources and can provide a comprehensive method of calculating nonpoint-source loads to meet total maximum daily load (TMDL) requirements. Currently (2003), TMDL assessments by the states of Pennsylvania and Delaware are ongoing in the Christina River Basin.

Table 1. *Nonpoint-source water-quality monitoring sites, Christina River Basin, Pennsylvania and Delaware (See figure 1 for location of sites)*

Type of nonpoint-source water-quality sampling site	Site number on map	Location	U.S. Geological Survey streamflow-measurement station number	Drainage area (square miles)
Overall basin main-stem site				
White Clay Creek	1	White Clay Creek near Newark, Del.	01479000	89.1
Red Clay Creek	2	Red Clay Creek near Wooddale, Del.	01480000	47.0
Brandywine Creek	3	Brandywine Creek at Chadds Ford, Pa.	01481000	287
Christina River	4	Christina River at Coochs Bridge, Del.	01478000	20.5
Single land-use basins				
Urban	5	Little Mill Creek near Newport, Del.	[1]01480095	5.24
Residential - sewered	6	Unnamed tributary to Valley Creek at Highway 30 at Exton, Pa.	[2]01480878	1.47
Residential - unsewered (on septic systems)	7	Little Broad Run near Marshallton, Pa.	[2]01480637	.6
Agricultural - row crop	8	Doe Run above tributary at Springdell, Pa.	[2]014806318	11.7
Agricultural - livestock	9	West Branch Brandywine Creek near Honey Brook, Pa.	01480300	18.7
Agricultural - mushroom	10	Trout Run at Avondale, Pa.	[2]01478137	1.31
Forested	11	Marsh Creek near Glenmoore, Pa.	01480675	8.57

[1] Streamflow-measurement station restarted for study.

[2] New streamflow-measurement station constructed for study.

Purpose and Scope

This report describes the development of an HSPF model constructed for the Christina River subbasin of the Christina River Basin and subsequent hydrologic and water-quality simulations. The main objective of modeling was to create a tool for water-resources managers to estimate nonpoint-source loads of selected constituents over a range of hydrologic conditions. The model description includes explanation of the general aspects, model structure, spatial segmentation, parameterization, and limitations. In addition, data used for model-input and calibration are described. The HSPF model for the Christina River subbasin was used to simulate streamflow, water temperature, suspended sediment, and nutrients, including nitrate, ammonia, and orthophosphate, on an hourly basis for the calibration period October 1, 1994, through October 29, 1998. Additionally, the model was used to simulate water temperature, dissolved oxygen, biochemical oxygen demand, and plankton as secondary objectives needed to support the sediment and nutrient simulations. Calibration results, analysis of the model's sensitivity to parameter variation, and model limitations are discussed for simulations of streamflow and water-quality constituents. An overview of the HSPF models for the four major subbasins of the Christina River Basin is given, including examples of model applications and comparison of model output for each of the four major subbasins, quantification of nonpoint-source loads from selected areas of the Christina River Basin, and discussion of model uncertainty.

Previous Studies

Water-quality samples have been collected by the DNREC in the Christina River subbasin as part of state monitoring programs at various sites since 1974. Data on land use, water quality, and water-management issues were compiled by Greig and others (1998) as part of the Christina River Basin Water-Quality Management Strategy. This compilation documented that elevated concentrations of phosphorus were of concern for nutrient enrichment, bacteria concentrations frequently exceeded DNREC standards for swimming, and levels of PCBs in fish were the basis of fish consumption advisories in the Christina River.

Acknowledgments

Water-use data were obtained with the assistance of Gerald Kauffman of the Water Resources Agency at the University of Delaware, Robert Struble of the Brandywine Valley Association, and Craig Thomas of the CCWRA. Water-quality data for PADEP monitoring sites in Pennsylvania were provided by William Goman of PADEP. Information about agricultural uses was obtained from Daniel Greig and others at the CCCD and the NCCCD. Overall guidance for the project was provided by the modeling technical committee of the Christina River Basin Water-Quality Management group, including David Pollison of DRBC, Richard Greene and Hassan Mirsajadi of DNREC, William Goman of PADEP, Janet Bowers of CCWRA, Gerald Kauffman of the Water Resources Agency, and Larry Merrill of USEPA. In addition to those mentioned above, those who helped identify the need for the project include Nancy Goggin and Jennifer McDermott of DNREC, and Niki Kasi and Russell Wagner of PADEP.

DESCRIPTION OF STUDY AREA

The Christina River subbasin drains an area of 76 mi^2 in southeastern Pennsylvania, northeastern Maryland, and northern Delaware. Most of the subbasin is in Delaware and includes only small parts of Pennsylvania and Maryland. The headwaters of Christina River are in Chester County, Pa., and Cecil County, Md., and the stream flows south into New Castle County, Del., where it turns east and is tributary to the Delaware River (fig. 1). Major tributaries to the Christina River that are not included in the Christina River subbasin area as defined for this report are White Clay Creek and Brandywine Creek, which flow south to the Christina River. Smaller named tributaries to the Christina River subbasin include Little Mill Creek, which flows south, and Belltown Run and Muddy Run, which flow north to the Christina River. The Christina River is tidal below the dam at Smalley's Pond (fig. 1). The largest population centers in the Christina River subbasin are the cities of Newark and Wilmington, Del.

Physical Setting

The Christina River subbasin encompasses areas in the Piedmont Physiographic Province in southeastern Pennsylvania (Berg and others, 1989) and northeastern Maryland and the Piedmont and Coastal Plain Physiographic Provinces in northern

Delaware. The topography of the Piedmont Physiographic Province is characterized by gently rolling uplands dissected by narrow valleys, whereas the topography of the Coastal Plain Physiographic Province is characterized by nearly flat terrain. Elevation of the land surface in the Christina River subbasin ranges from near sea level to about 440 ft above sea level. Most of the basin is in the Coastal Plain Physiographic Province, which is underlain by unconsolidated sediments. Small parts of the basin in the headwaters of the Christina River and of the tributary, Little Mill Creek, are above the Fall Line (fig. 1) in the Piedmont Physiographic Province, which is underlain by bedrock.

Climate

The Christina River subbasin has a modified humid continental climate. Winters are mild to moderately cold and summers are warm and humid. Normal mean annual air temperatures at the National Oceanic and Atmospheric Administration (NOAA) weather station near the western part of the subbasin at Newark (fig. 1) for 1971-2000 is 54.8°F (12.7°C) (National Oceanic and Atmospheric Administration, 2000a). Normal mean annual air temperatures (1971-2000) are cooler north of the basin (51.5°F at Coatesville, Pa.) than south of the basin (54.4°F at Wilmington, Del.) (National Oceanic and Atmospheric Administration, 2000a; 2000b). At Newark, the normal mean temperature (1971-2000) for January, the coldest month, is 32.5°F (0.3°C), and normal mean temperature (1971-2000) for July, the warmest month, is 76.4°F (24.7°C). Normal mean annual precipitation (1971-2000) at Newark is 45.35 in. Precipitation is distributed fairly evenly throughout the year. In southeastern Pennsylvania and northern Delaware, snowfall is mainly in December, January, February, and March.

Geology

The northern headwater areas of the Christina River subbasin are underlain by Paleozoic and older metamorphosed sedimentary and igneous rocks. The metasediments include schist, quartzite, and carbonate rocks. The Paleozoic and older rocks have been folded, faulted, and metamorphosed several times, resulting in a structurally complex assemblage. The primary structural trends are east-northeast. In the southern part of the subbasin, below the Fall Line, these rocks are overlain by Cretaceous and Quaternary sands, clays, and gravels of the Coastal Plain. These Coastal Plain sediments were deposited on the older bedrock, forming beds that thicken to the southeast.

Soils

Fifteen soil associations that include 21 soil series are found in the Christina River subbasin (fig. 2) (Kunkle, 1963; Matthews and Lavoie, 1970). In general, the soils have developed in place and are derived from the underlying bedrock or unconsolidated sediments. The Chester, Glenelg, Glenville, Manor, Neshaminy, Talleyville, and Wachtung soils series are developed on schist, gneiss, quartzite, gabbro, and diabase. The Aldino soil series is developed on serpentinite, and the Delanco and Elsinboro soil series are developed on old alluvium washed from crystalline rocks. Soils south of the Fall Line include the Butlertown, Fallsington, Keyport, Matapeake, Mattapex, Othello, and Sassafras soil series, which are developed on unconsolidated Coastal Plain sediments, and urban and tidal marsh soils.

The principal soil association is Sassafras-Fallsington-Matapeake, which overlies about 44 percent of the Christina River subbasin. Soils in this association generally are gently to moderately sloping and moderately well drained. Permeabilities of individual soil series range from less than 0.2 to 6.3 in / hr, and the Keyport, Matapeake, Othello, Glenville, Neshaminy, Talleyville, and Wachtung soil series have some of the lowest permeabilities in this range.

Hydrology

The metamorphosed sedimentary and igneous rocks that underlie the northern part of the Christina River subbasin form fractured-rock aquifers. The competent bedrock is overlain by weathered rock, saprolite, and soil. The bedrock and overlying materials are recharged by precipitation. Ground water flows through the secondary openings (fractures) in fractured-rock aquifers and discharges locally to streams and springs. The sands, clays, and gravels of the Coastal Plain that underlie the southern part of the Christina River subbasin also are recharged by precipitation. Recharge to these sedimentary beds may discharge locally to streams and may recharge the individual beds that dip to the southeast. Ground water in the Coastal Plain sands and gravels flows through primary openings (pore spaces).

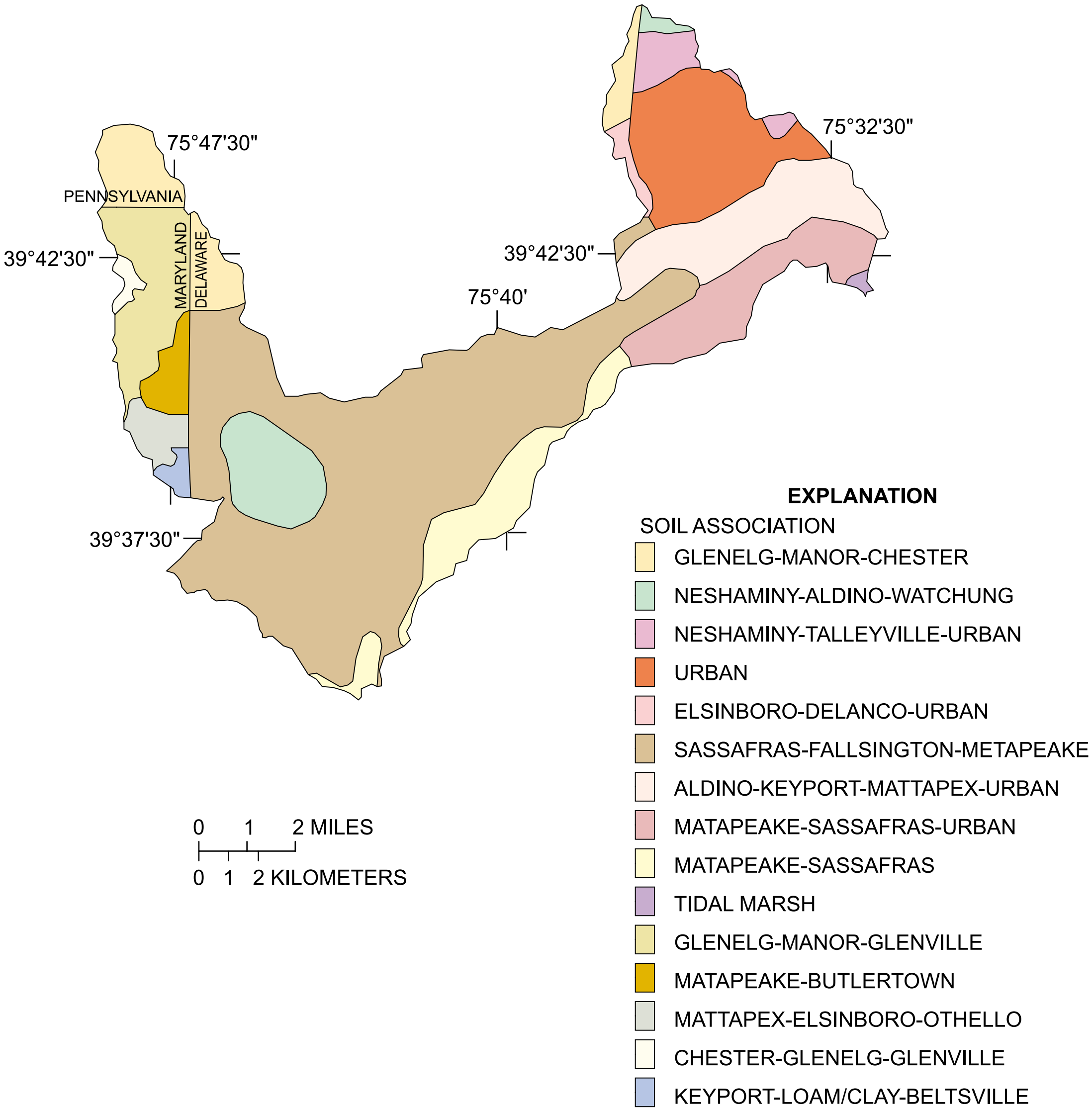


Figure 2. Mapped soil associations in the Christina River subbasin, Pennsylvania, Maryland, and Delaware.

In a water budget for the nearby Red Clay Creek subbasin, which is underlain by fractured-rock aquifers, about 40 percent of the annual input of precipitation is estimated to discharge as streamflow (Vogel and Reif, 1993). The remaining precipitation is lost to evapotranspiration. Streamflow in the Red Clay Creek is composed of, on average, 65 percent base flow (ground-water discharge) and 35 percent surface runoff (Vogel and Reif, 1993) with between-year variations of 10 percent. In the Christina River subbasin, base flow appears to represent a smaller proportion of total streamflow than in Red Clay Creek. Using a base-flow-separation technique (Sloto and Crouse, 1996), the median percentage of base flow relative to total streamflow is estimated to be about 46 percent for Christina River at Coochs Bridge, 1944-2001, and 44 percent for Little Mill Creek near Newport, 1991-94 and 1998. The differences between the percentages of base flow for Red Clay Creek and the Christina River subbasin may be partly due to differences in the hydrology of areas underlain by Piedmont fractured rocks and of areas underlain by the Coastal Plain sediments and partly due to differences in the amount of impervious areas in the basins. In many areas underlain by Coastal Plain sediments, base flow is the majority of streamflow. For example, in a water budget for a nearby area of the Coastal Plain in southwestern New Jersey near the Delaware River, base flow was estimated to be about 90 percent of total streamflow (Barton and Kozinksi, 1991). The presence of soils with low permeabilities in the Christina River subbasin may impede infiltration and therefore reduce ground-water recharge and consequent discharge (base flow).

Stream gradients range from about 50 ft / mi to less than 10 ft / mi in the Christina River subbasin. The highest gradient reaches (greater than 15 ft / mi) are in the Piedmont. Streambeds in reaches with gradients greater than about 15 ft / mi primarily are composed of silt, sand, and gravel. Streambeds in lower gradient reaches (less than 15 ft / mi) tend to be covered with silt and sand. Stream gradients in the tidal portion of the Christina River are less than 5 ft / mi.

The largest hydraulic structure in the Christina River subbasin is the dam at Smalley's Pond, near the middle of the subbasin. Other dams in the subbasin are on Muddy Run and Belltown Run and form Sunset Lake and Becks Pond, respectively. The primary purposes of these structures are impoundment. The dam at Smalley's Pond is at the upper limit of tidal movement in the Christina River.

Land Use

Land use in the Christina River subbasin in 1993-95 (Greig and others, 1998) was predominantly residential, urban (including industrial and commercial uses), and forested, with lesser amounts of agricultural and open land. From data compiled for this period, estimated land use in the basin is about 25 percent residential, 22 percent urban, 22 percent forested, 12 percent agricultural, 12 percent open, and 7 percent other.

Water Use

Water use in the Christina River subbasin consists of withdrawals and discharges of surface water and ground water for residential, commercial, and industrial consumptive and non-consumptive uses. Typically, water from a surface-water intake or ground-water well is withdrawn, used as needed, and returned to the source as waste flow minus consumptive losses. Consumptive loss refers to water that is used and is not returned to the hydrologic system in wastewater flow. Waste flows return to surface waters through wastewater treatment facilities and industrial discharges. In the less urbanized parts of the basin, ground water is the primary water supply and is provided by wells on individual properties. Wastewater in these non-sewered areas typically is discharged and infiltrates to ground water mainly through septic systems on individual properties. In and near population centers, public water suppliers use surface water as the main water source but may augment with ground water. Wastewater in urban areas generally is carried by sewers to treatment facilities that typically discharge to streams. In the Christina River subbasin, there are two small wastewater treatment facilities that discharge into the headwaters in Maryland. Wastewater from the Newark area is piped to the Wilmington sewage-treatment facility that discharges treated effluent to the Delaware River.

Some of the larger public water systems maintain complex withdrawal, distribution, and discharge facilities that allow water redistribution within or between basins. The two main surface-water withdrawals in the Christina River subbasin are from the impoundment upstream of the dam at Smalley's Pond.

In the Christina River Basin, impaired water quality has been linked to water-use processes such as wastewater treatment, industrial discharges, and septic systems (Greig and others, 1998). The effects of these processes on streamflow and water quality in the Christina River subbasin can vary depending on their location and volumes.

DESCRIPTION OF MODEL

The numerical model HSPF includes a set of computer codes for algorithms used to simulate the hydrologic response of land areas to precipitation and flow through stream channels in a basin. The algorithms used to simulate these processes are described in detail by Bicknell and others (1997). The rainfall-driven simulation of streamflow includes response from pervious and impervious land areas and routing of water in the stream channel. Pervious and impervious land areas are assigned hydrologic-response parameters on the basis of land use and other characteristics such as slope. Streamflow routing is controlled by channel characteristics of model reaches. The HSPF model can be used to simulate free-flowing streams and well-mixed reservoirs but cannot be used to simulate tidal streams.

The HSPF model structure requires dividing the basin into multiple elements whose number and size reflect the range of selected hydrologic characteristics and the scope of available input data. A first step in structuring the model is segmenting the basin. Segmentation often is delimited by climatological or physical characteristics that would determine specific hydrologic response to precipitation. When little differences are apparent in physical characteristics, segmentation may be determined by the number and location of precipitation stations available for input. The basin also is subdivided into characteristic pervious (PERLND) and impervious (IMPLND) land-use types. Within each segment, each PERLND and IMPLND is assigned hydrologic-response parameters. These parameters control the partitioning and magnitude of hydrologic outputs in response to input precipitation. The stream channel is then partitioned into reaches (RCHRES). A RCHRES generally is delimited by major flow inputs (tributaries, etc.), calibration locations (streamflow gages, water-quality sites), and time-of-travel considerations. Each RCHRES receives flow from land area draining to that reach and from upstream RCHRES. Runoff, interflow, and ground water from each PERLND and IMPLND is directed to a RCHRES. Point-source withdrawals and discharges can be specified for the RCHRES where they are located. The overall model structure including assignment of time-series data (meteorologic, streamflow, point-source withdrawals and discharges), reach connections, land-area to reach relations, channel characteristics, and land-use category response parameters are described in the user control input (UCI) file.

The hydrologic response of PERLNDs and IMPLNDs is handled by their respective modules. The water budget, or predicted total runoff, for pervious land is simulated using the section PWATER of the PERLND module. Total runoff is the sum of base flow (ground-water discharge to streams), interflow, and surface runoff. The hydrologic processes modeled by PWATER include infiltration of precipitation, interception by plant materials, evapotranspiration, surface runoff, interflow, and ground-water flow. Precipitation may be evaporated from, move through, and(or) remain in storage in surface interception, surface detention, interflow, upper soil zone, lower soil zone, and active ground water. Predicted total runoff for impervious land is simulated using the section IWATER of the IMPLND module. The hydrologic processes modeled by IWATER include retention, routing, and evaporation of water from impervious areas.

Runoff derived from snowfall, snow accumulation, and snow melt is simulated using the module SNOW. Meteorologic data are used to determine when precipitation is rain or snow, calculate an energy balance for the snow pack, and determine the effect of heat fluxes on the snow pack. The amount of precipitation that occurs as snow in the Christina River subbasin is variable. Some years have little to no snow; others may have snow and snow cover for most of the winter months. The assumption was made that simulating snow would result in a more accurate streamflow simulation. However, periods cold enough to have substantial snowfall also are likely to suffer from poor observed streamflow record because of channel ice at stream-gaging locations.

The routing of water in the stream channel is simulated by the section HYDR of the module RCHRES. Routing is based on kinematic-wave or storage-routing methods, where flow is assumed to be unidirectional. HYDR calculates rates of outflow and change in storage for a free-flowing reach or completely mixed reservoir. RCHRES inflows include runoff from PERLND and IMPLND land areas draining to that reach, water from upstream RCHRES, precipitation falling directly on the RCHRES surface area, and other discharges to the reach. RCHRES outflows include flow to the downstream reach, withdrawals from the reach, and evaporation. A series of reaches are used to represent the actual network of stream channels.

For each RCHRES, a relation between depth, surface area, volume, and outflow (discharge) is assigned and specified in an F-TABLE. When available, data for the F-TABLEs were derived from stage-discharge ratings for stream-gaging stations at RCHRES endpoints. For reaches that do not end at a stream-gaging station, data for the F-TABLE were generated using the computer program XSECT. XSECT calculates depth-discharge relations for a hypothetical stream channel, assuming a trapezoidal shape and using specified stream length, stream slope, channel width, channel depth, floodplain slope, Manning's n for the stream channel, and Manning's n for the floodplain.

The water-quality component of HSPF simulates contributions from pervious and impervious land areas and accounts for chemical reactions in the stream reaches. The model includes algorithms to describe the transport of constituents from the land to the stream reach, chemical reactions affecting constituents in the reach, sediment exchange between channel bed and water column, and the temperature of runoff to and water in a reach. Contributions of constituents from land areas may vary by land-use category in the model. Water-quality simulation requires a calibrated hydrodynamic model.

Water temperature, dissolved oxygen, and carbon dioxide in surface runoff, interflow, and ground-water outflows from pervious land areas are simulated in the PWTGAS section of the PERLND module and from impervious lands in the IWTGAS section of the IMPLND module. Water temperature in each reach is simulated by the HTRCH section of the module RCHRES and includes heat transported by PERLND and IMPLND outflows and point-source discharges. The main heat-transfer processes considered are transfer by advection, where water temperature is treated as a thermal concentration, and transfer across the air-water interface. Heat gain and loss by radiation also is simulated. Meteorologic data, such as air temperature and wind speed, are used in the simulation of stream temperature. In-stream dissolved oxygen concentrations are simulated by the OXRX section of the RCHRES module that includes the processes of advection, aeration, and consumption of oxygen by biochemical oxygen demand.

The simulation of sediment includes transport of sediment from land areas and transport within the stream channel. Sediment release from pervious areas is simulated in the SEDMNT module. Sediment available for transport is generated by detachment associated with rainfall. Detached sediment is transported to the stream as washoff. Scour also may be simulated for pervious areas. Sediment release for impervious areas is simulated in the SOLIDS module. Buildup of solids on impervious areas is transported to the stream in surface runoff. Sediment transport in the stream channel is simulated in the SEDTRN module. The channel simulation includes scour and deposition of bed material but not bank material.

The transport of nutrients from the land to the stream is simulated in the PQUAL module for pervious areas and IQUAL module for impervious areas. For pervious areas, nutrients associated with soil are transported with sediment in surface runoff. Nutrients also enter the stream in interflow and ground-water discharge. For impervious areas, nutrients accumulate on the surface and are washed into the stream during storm events. Once in the stream, the transport and chemical interactions of nutrients are simulated by the modules NUTRX and PLANK. The NUTRX and PLANK simulations require that the in-stream simulation of oxygen, OXRX, is active and are interactive in the oxygen simulation. The NUTRX module includes physical transport and inorganic chemical reactions affecting nutrients. The PLANK module simulates the role of periphyton and phytoplankton in the stream and includes uptake and release of nutrients.

DATA FOR MODEL INPUT AND CALIBRATION

HSPF requires a large amount of data to characterize effectively the hydrologic and water-quality response of the watershed to precipitation and other inputs (Donigian and others, 1984). Data used in creating and defining the model structure and parameters were derived principally from spatial analysis of basin characteristics and previously published information. Spatial data analyzed for model construction includes land use, land-surface slope, and soil associations. Time-series input for streamflow and water-quality simulation include meteorologic, precipitation quality, water-use, and discharge quantity and quality data. Calibration data consisted of observed streamflow for the hydrodynamic simulation and observed water temperatures and laboratory analyses of grab and composite stream samples for the water-quality simulation.

Time-series data for model input and model output were processed and stored in the binary format Watershed Data Management (WDM) database. The WDM format is the standard format for input to and output from HSPF. The computer programs ANNIE (Flynn and others, 1995), IOWDM (Lumb and others, 1990), METCMP (Alan Lumb, U.S. Geological Survey, and John Kittle, Aqua Terra Consultants, written commun., 1995), WDMUtil (U.S. Environmental Protection Agency, 1999), and GenScn (Kittle and others, 1998) were used in the processing of WDM time-series data. Parameter and model-structure data were processed independently of the time-series data and are defined in the UCI, an ascii text file.

Model-Input Data

The types, resolution, and quantity of the data needed for input are determined by (1) the hydrologic and water-quality processes to be included in the model; (2) the time step selected for simulation; (3) the length of the simulation period; and (4) the spatial scale of interest. For example, simulation of streamflow requires time-series inputs of precipitation, potential evaporation, withdrawals from streams, and discharges to streams. Simulation of stream water quality requires, in addition to parametric estimates of chemical inputs from pervious and impervious land areas, time-series inputs of water-temperature data and constituent loads in point-source discharges. Observed water-temperature time-series data may be supplied as input, but because only a limited amount of recorded water-temperature data were available for the Christina River subbasin, water temperature was simulated. The simulation of water temperature requires input of additional meteorologic data.

The Christina River subbasin model was run on a 1-hour time step. Time-series data available only at time intervals greater than hourly required disaggregation. For the simulation period of October 1, 1994, through October 1998, more than 4 years of reported or estimated hourly values were needed for the time-series input data sets.

Meteorologic Data

Simulation of mean hourly streamflow in HSPF required inputs of hourly precipitation and potential evapotranspiration. Daily precipitation data used for model input were selected from local NOAA raingages based on Thiessen polygon delineations and analysis of the precipitation records. The daily precipitation data were disaggregated using METCMP into hourly data based on hourly precipitation recorded at the NOAA meteorologic station at the Wilmington, Del., Airport. Daily potential evapotranspiration data was disaggregated at the time of simulation.

Thiessen polygons created for all local NOAA meteorologic stations (raingages) overlaid the Christina River subbasin in three areas (fig. 3). Newark University Farm raingage polygon covered about 65 percent of the western subbasin; Wilmington Airport raingage polygon covered about 20 percent of the southern subbasin; and Porter Reservoir raingage polygon covered about 15 percent of the eastern subbasin. Precipitation for these raingages is listed in table 2.

The 1994-98 period of simulation spanned relatively normal, dry, and wet years of precipitation. For example, the long-term (1971-2000) “normal” annual precipitation as calculated from monthly precipitation at Newark University Farm meteorologic station is 45.35 in. (National Oceanic and Atmospheric Administration, 2000a). In comparison to the “normal” annual precipitation at Newark, the years 1994 and 1995 and the 10-month period of 1998 were within 15 percent of normal (table 2). The greatest departures were in 1996 when annual precipitation was 33 percent above normal and in 1997 when annual precipitation was about 19 percent below normal.

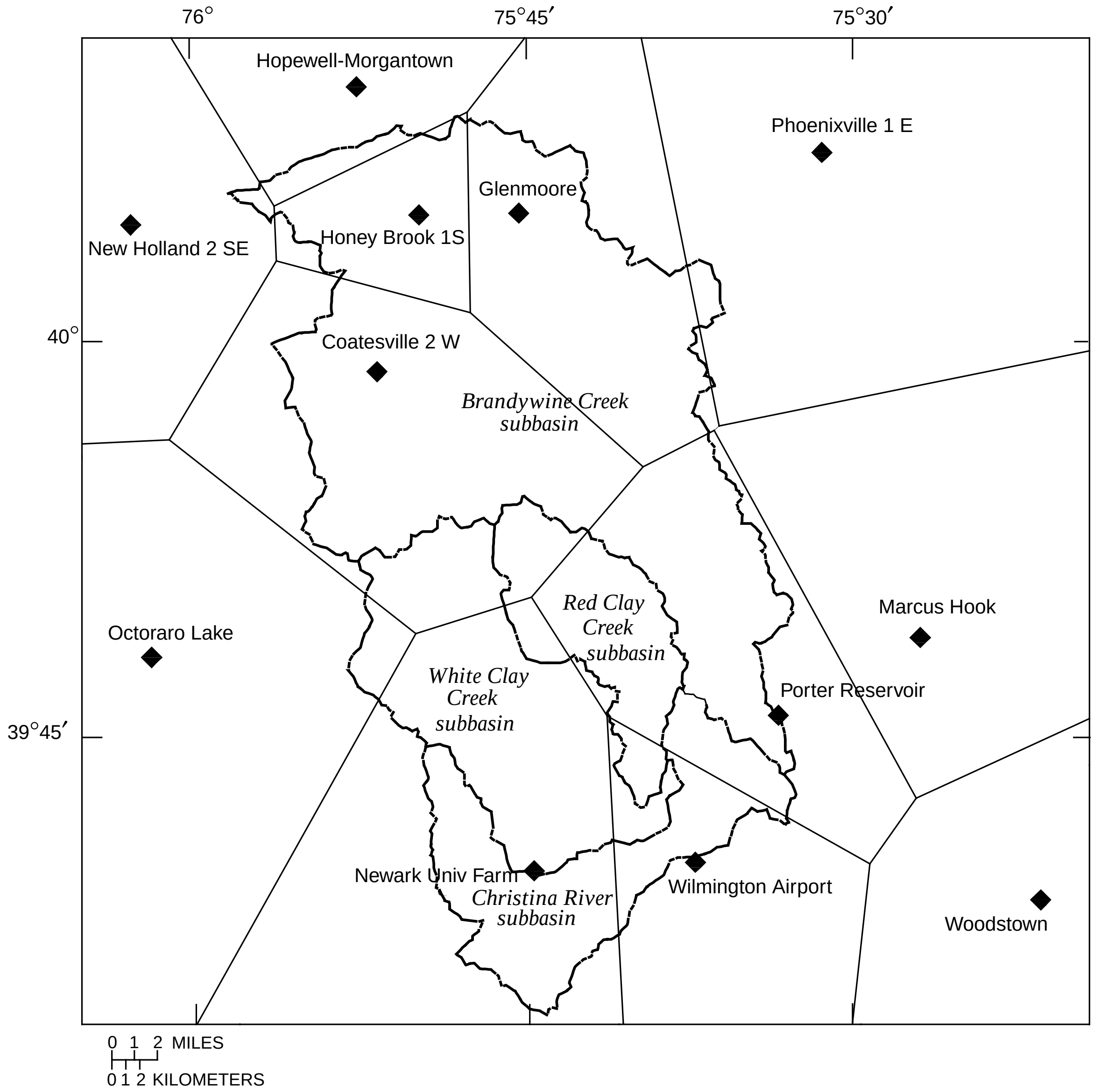


Figure 3. National Oceanic and Atmospheric Administration meteorologic stations and calculated Thiessen polygons in the vicinity of the Christina River subbasin, Pennsylvania, Maryland, and Delaware.

Table 2. *Annual and total precipitation at meteorologic stations near the Christina River subbasin, 1994-98*

Raingage	Precipitation, in inches						
	1971-2000 normal[1]	1994	1995	1996	1997	[2]1998	Total
Newark University Farm	45.35	43.9	40.6	60.5	36.9	32.2	214.1
Porter Reservoir	[3]49.40	57.4	45.1	68.9	38.9	37.0	247.3
Wilmington Airport	42.81	45.4	40.1	52.4	28.0	34.2	200.1

[1] Data from National Oceanic and Atmospheric Administration (2000a) unless noted.

[2] Precipitation for January 1 through October 29.

[3] Data from the Delaware State Climatologist (2001).

Comparison of the period-of-simulation precipitation totals shows substantial differences (table 2) between meteorologic stations. For the 4-year, 10-month period, Porter Reservoir reported 23 percent more precipitation than Wilmington Airport. Wilmington Airport is 7.5 mi southwest of and 185 ft lower in elevation than Porter Reservoir. Although some disagreement in total precipitation can be expected as a result of natural spatial variability and elevation differences, the difference between Porter Reservoir and the Wilmington Airport shows a consistent recording bias throughout the period (fig. 4). Monthly precipitation (fig. 4) totals show even greater departure between the Porter Reservoir and Wilmington Airport meteorologic stations; differences of 30 percent or more were not unusual. Comparison of Porter Reservoir and Newark University Farm data shows precipitation totals for the period to be 15.5 percent greater at Porter Reservoir (table 2). The Newark University Farm meteorologic station is approximately 13.5 mi west southwest of and 169 ft lower in elevation than Porter Reservoir. As with the Wilmington Airport meteorologic station, natural spatial variability and an elevation difference at Newark University Farm likely contribute to a portion of the difference in precipitation totals. Comparison of Wilmington Airport and Newark University Farm precipitation data shows 7 percent more precipitation at Newark University Farm. These meteorologic stations lie on an east-west line approximately 7.5 mi apart with an elevation difference of 16 ft.

Considering their proximity, the differences between the Porter Reservoir data and the Wilmington Airport and Newark University Farm data are unusually large. A review of numerous raingage network studies in the eastern United States showed that annual differences at adjacent gages averaged 5 percent or less (Winter, 1981) and that those differences tend to decrease over longer periods of record. In addition, the precipitation record of other NOAA raingages surrounding the Christina basin suggests that annual totals generally decrease from northeast to southwest across the basin but to a lesser extent than the differences observed between Porter Reservoir and the Wilmington and Newark University Farm stations. Elevation difference is likely the most significant factor in explaining these differences. The Porter Reservoir station is higher in elevation than the other two meteorologic stations, which have minimal elevation difference and which at 74 and 90 ft are closer to the mean basin elevation of approximately 125 ft.

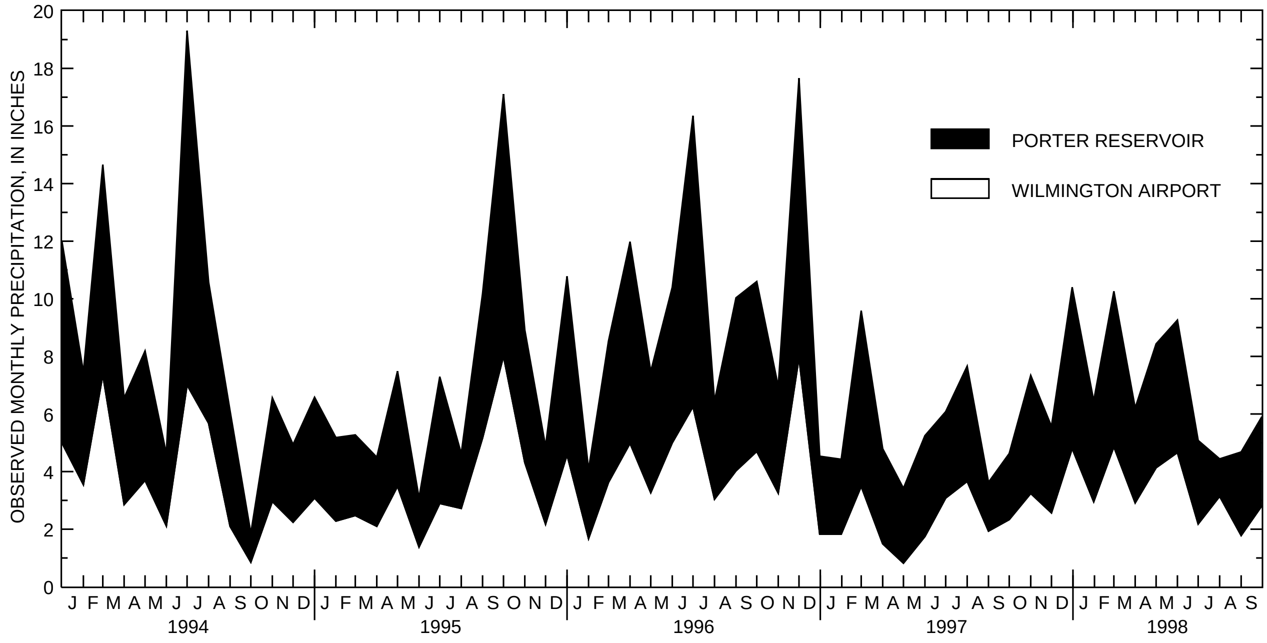


Figure 4. Monthly precipitation measured at the Wilmington Airport National Oceanic and Atmospheric Administration and Porter Reservoir meteorologic stations near the Christina River subbasin in Delaware.

Because of the substantial differences in precipitation totals for these raingages, adjustment factors to the precipitation record were required in order to complete a satisfactory water balance for the simulation period (Donigian and others, 1984). Moreover, in the eastern part of the Christina River subbasin, the water balance could only be approximated by applying about 15 percent less rainfall than was recorded at Porter Reservoir. Thus, on the basis of the water balance issue and in consideration of the greater elevation difference between Porter Reservoir meteorologic station and the mean basin elevation of approximately 125 ft, Wilmington Airport precipitation data were selected to represent precipitation input in place of Porter Reservoir data where the Theissen polygon for Porter Reservoir meteorologic station overlays the modeled area.

Precipitation data may contain a number of errors. Measurement errors, while known in general, are not specifically known for the raingages used in the Christina River subbasin model. These errors may include malfunctioning equipment, incorrect calibration, and environmental influences (Winter, 1981). Precipitation data from NOAA raingages adjacent to the raingages selected for the model show departures as great as 15 percent over the simulation period whereas individual storm events exhibit departures as much as several hundred percent. Thus, storms with substantial precipitation in one part of the basin may appear to result in little or no streamflow response. Disaggregation of daily precipitation values to hourly values by applying the hourly distribution of precipitation at the Wilmington, Del., Airport excludes the spatial and temporal variations in rainfall distribution across the Christina River subbasin. Disaggregation errors can appear as timing shifts in storm hydrographs.

Potential evapotranspiration at the Wilmington, Del., Airport meteorologic station was used for model input. The daily estimates of potential evapotranspiration for Wilmington were calculated by the Northeast Regional Climate Center using a method described by DeGaetano and others (1994). This method has its basis in the British Meteorological Office Rainfall and Evaporation Calculation System (MORECS) and uses the Penman-Monteith equation for estimating evapotranspiration. Monthly totals of potential evapotranspiration are shown in figure 5. Disaggregation of daily potential evapotranspiration was done automatically by HSPF. Daily potential evapotranspiration totals were divided into 24 equal hourly values during an HSPF run.

Snow simulation requires precipitation, air temperature, solar radiation, dewpoint, and wind speed data. Hourly air temperature, solar radiation, dewpoint, and wind speed from Wilmington, Del., Airport were compiled and used as input to the model. Snow accumulation and melt are influenced directly by air temperature. In HSPF, snow melt also is controlled by solar radiation, dewpoint, and wind speed. Wind speed is the most variable of these three inputs and is a first-order factor in the calculation of evaporative heat loss from a snowpack and of heat gain through the condensation of warm humid air.

Observed snowfall at the Newark NOAA station was used to assess the need for using the SNOW simulation module and for calibration of the SNOW parameters. Total snow accumulation for the simulation period was just over 41 in. at

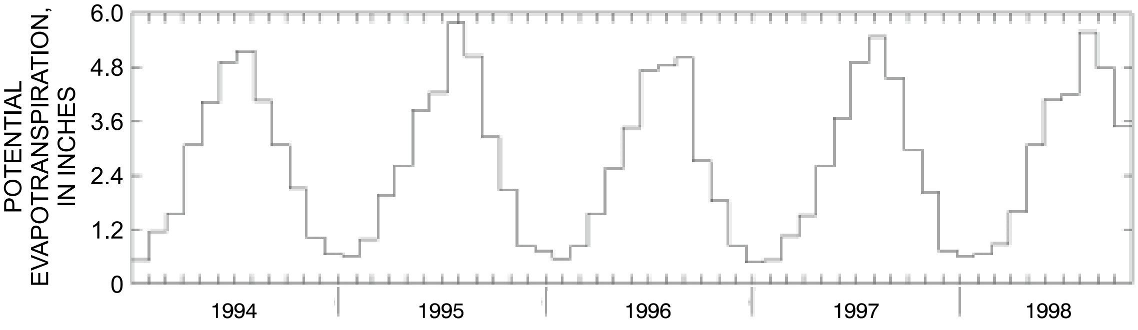


Figure 5. Monthly estimates of potential evapotranspiration for Wilmington Airport, Delaware.

Newark. Given an average water equivalent estimate of 8 in. of snow to 1 in. of rain, snowfall accounted for about 5 in. or 3 percent of total rainfall at Newark for the simulation period. Snow accumulation was greatest in the year 1996 and accounted for three quarters of the snowfall at Wilmington Airport. The days of snowfall and days that snow covered the ground at the Newark gage for the years 1994-98 are listed in table 3. The longest periods of snow cover were 17 days in February 1996 and 11 days in February 1995. In 1997, snow cover lasted at most 3 days.

Table 3. *Days of snowfall and snow-on-ground at the National Oceanic and Atmospheric Administration meteorologic station at Newark University Farm, 1994-98*

Year	Days of snow fall (maximum in inches[1])		Days of snow on ground (maximum in inches[1])		Days of greater than 2 inches[1] of snow on ground
[2]1994	0	(0)	0	(0)	0
1995	4	(7.0)	19	(6)	7
1996	8	(13.2)	30	(16)	21
1997	7	(3.0)	5	(1.5)	0
[3]1998	1	(trace)	1	(trace)	0

[1] Inches of snow, not inches of water equivalent.

[2] October 1 through December 31.

[3] Through October 29.

Simulation of stream water temperature requires air temperature, dewpoint, wind speed, cloud cover, and solar radiation. Hourly air temperature, dewpoint, windspeed, and cloud cover from the Wilmington, Del., Airport were used as input to the model. In the northern parts of the basin, air temperatures for input to the model were derived from data at the Coatesville 2 W NOAA meteorologic station. Minimum and maximum daily air temperatures for the Coatesville 2 W station were disaggregated to hourly air temperature with METCMP, using the Wilmington Airport hourly data. Hourly estimates of solar radiation for Wilmington, Del., were calculated by the Northeast Regional Climate Center using a method described by DeGaetano and others (1993).

Water-Use Data

Simulation of streamflow and water quality requires information about stream withdrawals and discharges. Water withdrawal and discharge data were obtained from CCWRA, Water Resources Agency at the University of Delaware, DNREC, and the Brandywine Valley Association who compiled water-use information from various sources including PADEP, DNREC, and individual water users. Many of these data were reported on a monthly or annual basis, and in many cases, were available for only 1, 2, or 3 years of the 1994-98 simulation period. Where at least 1 year of acceptable monthly withdrawal data were available, the remaining years of missing information were filled by copying data from the most recent year prior to the missing period. Where no monthly withdrawal data were available, missing monthly data were filled with values equal to 75 percent of permitted withdrawal maximums. Missing discharge data were filled using the same method as withdrawals.

The discharges and withdrawals included in the simulation are presented in table 4. Isolated single-family residential discharges were not included in the streamflow simulation. Monthly-to-hourly disaggregation of water-use data was done by the HSPF model at the time of simulation. Inputs from point sources include water-quality constituent loads, discharge temperature, and rate of discharge. Point-source discharge-quality data, typically available as monthly or yearly values, were disaggregated to an hourly time step by dividing monthly or yearly values by the number of time steps in those periods during simulation.

Spatial Data

Spatial data input to the HSPF model are used primarily to define the structure and “fixed” characteristics of the model. The principal structural unit of the HSPF model is the hydrologic response unit (i.e. PERLND and IMPLND). Hydrologic-response units for the modeled basin were determined from analysis of digital spatial data consisting of land use, elevation, geology, soil association, and sanitary-sewer service area data. The digital spatial data were compiled from multiple sources by the Water Resources Agency for New Castle County for this study (Greig and others, 1998). These data were processed with a geographic information system (GIS) and compiled for model input. Fifteen land-use categories were delineated in the original digital database. These categories were simplified and reclassified into 10 pervious and 2 impervious land-use categories that were expected to have distinct nonpoint-source water-quality signatures (table 5). Impervious areas were not delineated digitally and were

Table 4. *Stream withdrawals and discharges of flow and ammonia and phosphorus loads included in the Hydrological Simulation Program–Fortran (HSPF) model of the Christina River subbasin, Pennsylvania, Maryland, and Delaware*

[Mgal/d, million gallons per day; lbs/d, pounds per day; IND, industrial; DW, drinking water supply; STP, sewage treatment plant; SWR, stormwater; NCW, non-contact cooling water; --, not applicable or no information]

Subbasin	Name	Type	Flow volume (Mgal/d)		1994-98 Average discharge load (lbs/d)	
			Capacity or flow limit	1994-98 Average[1]	Ammonia	Phos-phorus
	Withdrawals					
Main stem	Marvin Hershberger	IND	0.15	--	--	--
Main stem	United Water Delaware	DW	4.0	--	--	--
	Discharges					
West Branch	Highlands waste-water treatment plant	STP	.05	0.039	0.17	0.23
West Branch	Meadowview Utilities, Inc.	STP	.45	.33	4.19	1.48
Little Mill Creek	General Motors Assembly	SWR	--	.24	3.07	3.76
Little Mill Creek	DuPont Chestnut Run (outfalls 001 + 002)	SWR	--	.039	.19	.18
Main stem-tidal	Ciba-Geigy Corporation	NCW	--	--	--	--
Main stem-tidal	Boeing Corporation	SWR	--	--	--	--

[1] Average as estimated for model input.

Table 5. *Land-use categories used in the Hydrological Simulation Program–Fortran (HSPF) model of the Christina River subbasin, Pennsylvania, Maryland, and Delaware*

Land-use category for model		Description of land use
Pervious land area[1]	residential-septic	Includes all residential land not within a sewer service area
	residential-sewer	Includes all residential land within a sewer service area
	urban	Includes commercial, industrial, institutional, transportation uses
	agricultural-livestock	Predominantly mixed agricultural activities of dairy cows, row crop, pasture and other livestock operations
	agricultural-rowcrop	Predominantly row crop cultivation (corn, soybean, alfalfa), may include some hay or pasture
	agricultural-mushroom	Mushroom growing activities including compost preparation, mushroom house operations, spent compost processing
	open	Recreational and other open land not used for agriculture
	forested	Predominantly forested land
	wetlands/water	Wetlands and open water
	undesignated	Land use not defined
Impervious land area[2]	residential	Impervious residential land
	urban	Impervious commercial, industrial, and other urban land

[1] Pervious land area is designated as PERLND in model.

[2] Impervious land area is designated as IMPLND in model.

estimated as percentages of the total areas in residential and urban land uses. Areas of specific types of agriculture also were not available in digital form and were estimated from knowledge of the basin and non-digital information from conservation districts. The spatial distribution of the simplified pervious land-use categories derived from the original digital database is shown in figure 6. Areas of undesignated land use were considered to have characteristics of areas with open land use.

Agricultural land use was divided into three characteristic subtypes for the model. Agricultural-livestock land use identifies relatively small acreage farms with high animals-per-acre densities, limited pasture areas, and rowcrops. Small acreage dairy operations typify this land-use type. Agricultural-rowcrop land use identifies farms with lower animals-per-acre densities (typically beef cattle and horses) and substantial pasture and crop acreage. Agricultural-mushroom land use is the third type of agricultural land use delimited. Mushroom growing, which involves the preparation and use of large amounts of manure-based compost, is more prevalent in the Red Clay Creek and White Clay Creek subbasins than elsewhere in the Christina River Basin.

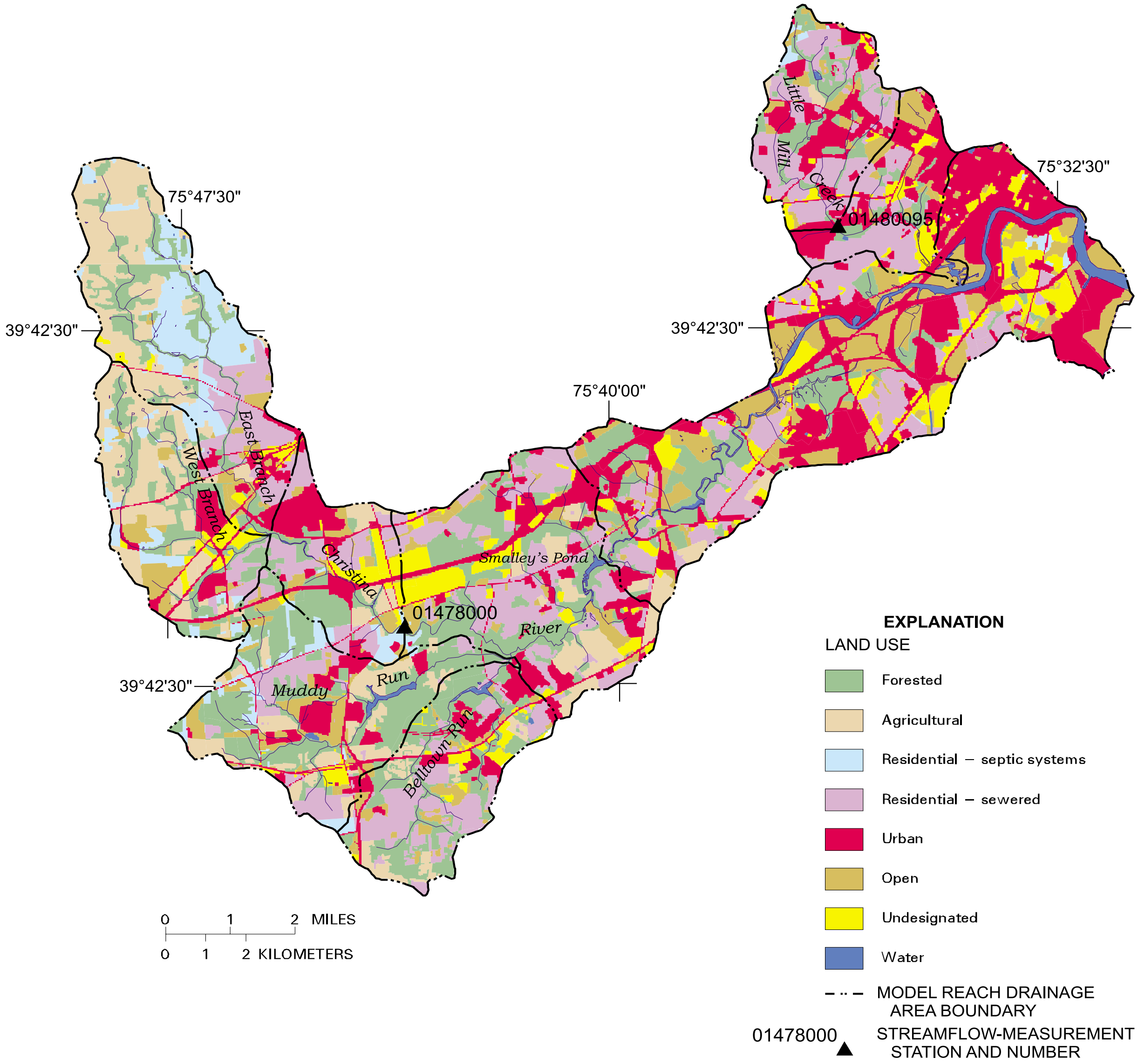


Figure 6. Generalized 1995 land-use map for the Christina River subbasin, Pennsylvania, Maryland, and Delaware (Land-use data from Greig and others, 1998).

Residential land use is distributed throughout the basin and is divided into two types: sewered and non-sewered. Sewered residential areas tend to have higher housing densities and are nearer to urban / suburban areas than non-sewered area. Non-sewered residential areas tend to have lower densities and are more rural. Urban land use in the basin generally is concentrated in the Coastal Plain in the vicinity of the Christina River. Other urban land use is in small boroughs and towns and along major roadways. Forested land is distributed throughout the basin and tends to be along stream channels, especially in the southern and northern parts of the basin (fig. 6).

Model-Calibration Data

Observed streamflow and water-quality data are needed to calibrate the hydrologic and water-quality components of the HSPF model, respectively. These data are available at streamflow-measurement stations (gages) and water-quality monitoring sites established in the basin for this study and for other purposes. The period of record and frequency of observations differ among these gages and monitoring locations. In general, fewer water-quality data are available than streamflow data.

Hydrologic Data

Data used for the hydrologic calibration was collected at two USGS streamflow-measurement stations operating in the Christina River subbasin during the 1994-98 simulation period (table 6; fig. 7) (James and others, 1996, 1997, 1998, 1999).

Table 6. *Streamflow-measurement stations in the Christina River subbasin, Pennsylvania, Maryland, and Delaware*

U.S. Geological Survey station identification number	Station name	Drainage area (square miles)	Period of record
01478000	Christina River at Coochs Bridge, Del.	20.5	4/43 - current
01480095	Little Mill Creek near Newport, Del.	5.24	10/90 - 9/95, 8/97-10/98

Streamflow data at all the sites were recorded at time steps smaller than the 1-hour time step used in the model. Because of the shorter time steps, no disaggregation was needed for the streamflow data. However, substantial periods of missing data exist in the hourly streamflow record. Relatively short periods (up to several days) of missing data were estimated, where possible, by interpolation or regression. During periods of relatively steady base flow, missing data were interpolated. During periods of rapidly changing flow (generally stormflow), missing data were estimated by linear regression. A regression equation was generated using data from the nearest upstream or downstream streamflow-measurement station, and which bounded the period of missing record. Long periods (up to a year or more) of missing data exist due to discontinuous station operation or loss of the data record. In these instances, no attempt was made to estimate the missing record. Periods of poor-quality data due to freezing conditions are few. As a result, these data were used as recorded except in the instances where data from a nearby streamflow-measurement station were not ice affected. In these cases, estimated daily values were pro-rated using hourly values from the nearby station.

Water-Quality Data

Water-quality data at stream-monitoring sites were used in model calibration. Water-quality data for the simulation period 1994-98 were collected by DNREC and USGS as part of several monitoring efforts in the Christina River subbasin (fig. 7). The period of record at monitoring sites varied from 1 to 5 or more years (table 7), and the sampling interval varied from hourly or less for storms to annually. The chemical analyses of samples collected as part of these monitoring efforts varied.

Two of the monitoring programs were designed specifically to assist in the current assessment of water quality in the Christina River Basin: (1) monthly and bi-monthly monitoring efforts were conducted by DNREC and PADEP from 1995 to 1998; and (2) a hydrologically based sampling scheme for nonpoint-source monitoring was done by USGS, PADEP, and DNREC in 1998. The monthly and bimonthly monitoring effort included analyses for metals, nutrients, suspended solids, and other constituents in samples collected at three stream sites (table 7) in the free-flowing part of the Christina River subbasin and was done to support

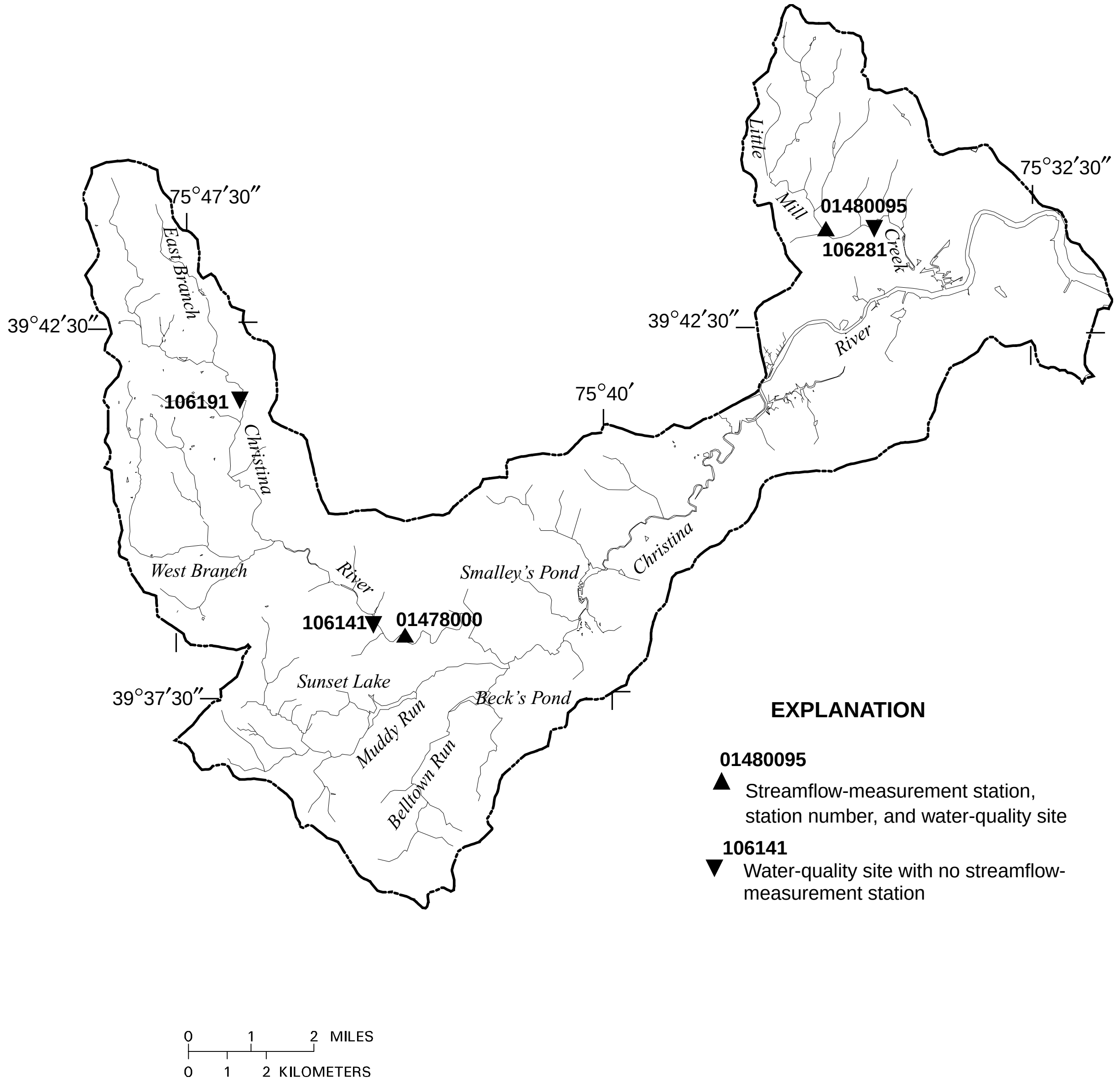


Figure 7. Streamflow-measurement stations and water-quality monitoring sites in the Christina River subbasin, Pennsylvania, Maryland, and Delaware.

an assessment of water quality during low-flow conditions and target point-source contributions. The hydrologically based sampling scheme included analyses for nutrients, suspended solids, and organic carbon at two sites in the Christina River subbasin (table 7) and nine sites elsewhere in the Christina River Basin (table 1) and was done to support an assessment of these constituents under base-flow and stormflow conditions throughout the year and assist in the evaluation of nonpoint-source contributions to the stream.

The nonpoint-source water-quality monitoring in 1997-98 in the Christina River Basin was designed to provide data on the concentrations and loads of nutrients and suspended solids seasonally under various hydrologic conditions for the whole of each of the four subbasins and for seven small areas predominantly covered by one land use. Samples were collected during four base-flow periods and up to six stormflow events. Continuous data collected at the nonpoint-source monitoring sites included streamflow and water temperature. In the Christina River subbasin, samples collected at the streamflow-measurement station, Little Mill Creek near Newport, Del. (01480095), provided information about water quality in a small subbasin predominantly covered by urban land use. Samples collected at the streamflow-measurement station, Christina River at Coochs Bridge, Del. (01478000), provided information about the water quality of a part of the Christina River subbasin covered by mixed land uses (about 28 percent of the drainage area). Samples collected in the six small subbasins predominantly covered by one land use (table 7) elsewhere in the Christina River Basin were used to provide information about the relation between land use and water quality. The predominant land uses in the small-basin sites include various types of residential, forested, agricultural, and urban land use. The small-basin data were used to develop transferable model parameters for specific land uses.

The stormflow and base-flow sampling periods were selected as representative of the range of seasonal, hydrologic, and land-use conditions in the basin. Timing for the six stormflow events was as follows: two storms in mid to late winter (February 4-5 and March 8-9, 1998), one storm in early spring after pre-planting tillage (May 2-3, 1998), one storm in late spring / early summer after planting of crops (June 12-13, 1998), one storm in mid-summer (July 8-9, 1998), and one storm in fall after harvest (October 8-9, 1998). Sampling was delayed because of dry conditions in the fall of 1997. In addition, because of the mild winter of 1998, there was no opportunity to collect samples from frozen-ground runoff and snowmelt events. Sampled storms resulted from precipitation events that ranged from about 0.4 to 3.3 in. For Brandywine Creek at Chadds Ford, Pa., these precipitation events resulted in peak flows with a 1-year or less recurrence interval. Base flow was sampled in January, April, July, and September 1998.

Table 7. *Water-quality monitoring sites in the nontidal Christina River subbasin during 1994-98*

[Abbreviations: --, no data; P, Pennsylvania Department of Environmental Protection; U, U.S. Geological Survey; D, Delaware Department of Natural Resources and Environmental Control; TSS, total suspended solids]

U.S. Geological Survey streamflow-measurement station number	State site number	Drainage area (square miles)	Location (predominant land use)	Monitoring agency	Period of record	Chemical analyses
Monthly and bi-monthly monitoring sites						
--	106191		Christina River, Delaware Rt 273 above Newark, Del.	P	1995-98	Nutrients, TSS
--	106141		Christina River, Road 26 at Old Baltimore Pike	P	1995-98	Nutrients, TSS
--	106281		Little Mill Creek at Atlantic Avenue	P	1995-98	Nutrients, TSS
Base flow and stormflow nonpoint-source monitoring small and whole basin sites						
01478000	--	20.5	Christina River at Coochs Bridge, Del. (mixed-whole basin)	U, P, D	1998	Nutrients, TSS
01480095	--	5.24	Little Mill Creek near Newport, Del. (urban basin)	U, P, D	1998	Nutrients, TSS

Base-flow and stormflow samples collected from January to October 1998 were analyzed for concentrations of dissolved and total nitrogen and phosphorus species and suspended solids (table 8). Other constituents, such as dissolved organic carbon (DOC) and chlorophyll *a*, and properties, such as chemical oxygen demand (COD) and biological oxygen demand (BOD), also were analyzed to better understand and simulate the chemical processes involving the fate and transport of nutrients. Chloride was measured to provide data on the concentrations of a conservative solute. Stormflow samples were collected by USGS and the University of Delaware. Base-flow samples were collected by PADEP and by DNREC. The DNREC laboratory in Dover, Del., performed all laboratory chemical analyses. Results of laboratory analyses for all stormflow and base-flow samples are listed in Appendix 1.

Table 8. *Constituents in nonpoint-source monitoring samples to be determined by laboratory chemical analysis[1], Christina River Basin, Pennsylvania, Maryland, and Delaware*

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; EPA. U.S. Environmental Protection Agency; STDMTD, Standard Methods (American Public Health Association, 1995)]

Constituent	STORET code	Method	Reporting limit (mg/L)
Required constituents or properties for all samples			
Ammonia nitrogen, dissolved	00608	EPA 350.1	0.004
Ammonia nitrogen, total	00610		.004
Kjeldahl nitrogen, dissolved	00623	EPA 351.2	.05
Kjeldahl nitrogen, total	00625		.05
Nitrite plus nitrate nitrogen, dissolved	00631	EPA 353.2	.05
Orthophosphorus, dissolved	00671	EPA 365.1	.005
Phosphorus, dissolved	00666	EPA 365.1	.005
Phosphorus, total	00665		.005
Chloride	00940	EPA 325.2	1
Specific conductance	90095	EPA 120.1	1 µS/cm
Total suspended-solids concentration	80154	EPA 160.2	1
Biological oxygen demand (BOD_{20})	00308	EPA 405.1	2.4
Dissolved organic carbon	00681	EPA 415.1	1
Chlorophyll-*a*[2]	70953	92 STDMTD	.001
Pheophytin		10200H	.002
Additional constituents-Main-stem sites			
Copper, dissolved	01040	EPA 220.2	.005
Copper, total	01042		.005
Lead, dissolved	01049	EPA 239.2	.003
Lead, total	01052		.003
Zinc, dissolved	01090	EPA 200.7	.010
Zinc, total	01092		.010
Chemical oxygen demand	00340	EPA 410.1, 410.2, 410.3	5.0
Total organic carbon	00680	EPA 415.1	1

[1] Specifications for analytical method, reporting limit, holding time, sample volume and preservation provided by the Delaware Department of Natural Resources and Environmental Control laboratory.

[2] First storm sampling event, all grab sampling events.

Two types of samples, discrete and composite, were collected by an automatic sampler during storm events. Discrete samples, collected at fixed-time intervals during the storm event, represent instantaneous concentrations. Composite samples can be used to estimate loads for a storm event. The automatic sampler was programmed prior to each storm event to start sampling at a pre-determined change in stage and to collect one series of fixed-interval discrete samples and another series of flow-weighted aliquots (250 milliliters each) for the composite sample. The fixed-interval series consisted of up to six 2-liter samples, collected from 1.5 to 3 hours apart. The flow-weighted series consisted of up to 48 250-milliliter samples. The intake for the automatic sampler was set in midstream and stage was determined by a transducer set in the stilling well and linked to the automatic sampler. Streams were assumed to be well mixed. The automatic sampler was programmed to collect a sample at fixed-time intervals and after each time that a pre-determined flow volume, calculated using an established rating between stage and streamflow, had passed by the monitoring site. Composite samples were obtained by mixing the series of flow-weighted aliquots. Because the automatic sampler was programmed in advance of storms for which the intensity and duration were unknown, the extent of the actual storm periods covered by samples varied.

The measured concentration of constituents in discrete storm samples was, in general, related to streamflow. The concentration of total suspended solids, total ammonia nitrogen plus organic-nitrogen, and total phosphorus tended to increase with increasing streamflow, whereas the concentration of dissolved nitrite plus nitrate nitrogen tended to decrease with increasing streamflow (figs. 8, 9). Concentrations of dissolved ammonia nitrogen and dissolved orthophosphate did not show a strong relation to streamflow.

Concentrations of suspended solids and nutrients in stream samples varied at the Christina River Basin nonpoint-source monitoring locations in relation to hydrologic conditions. Base-flow concentrations primarily are controlled by groundwater discharge and stormflow concentrations by runoff and interflow processes. The distribution of constituent concentrations under stormflow and base-flow conditions at the 11 nonpoint-source monitoring sites in the Christina River Basin are shown in figures 10-15. For all constituents, the range of concentrations was greater in the storm samples than in the base-flow samples, which primarily was due to the more highly variable meteorologic and hydrologic conditions affecting the storm samples. Concentrations of total suspended solids, total ammonia, and total phosphorus in stream samples were greater under stormflow conditions than under base-flow conditions (figs. 10, 13, and 15). Concentrations of dissolved nitrate in stream samples commonly were greater under base-flow conditions than under stormflow conditions (fig. 11). Concentrations of dissolved ammonia and orthophosphate were similar or, at some sites, tended to be slightly greater under stormflow conditions than base-flow conditions (figs. 12 and 14).

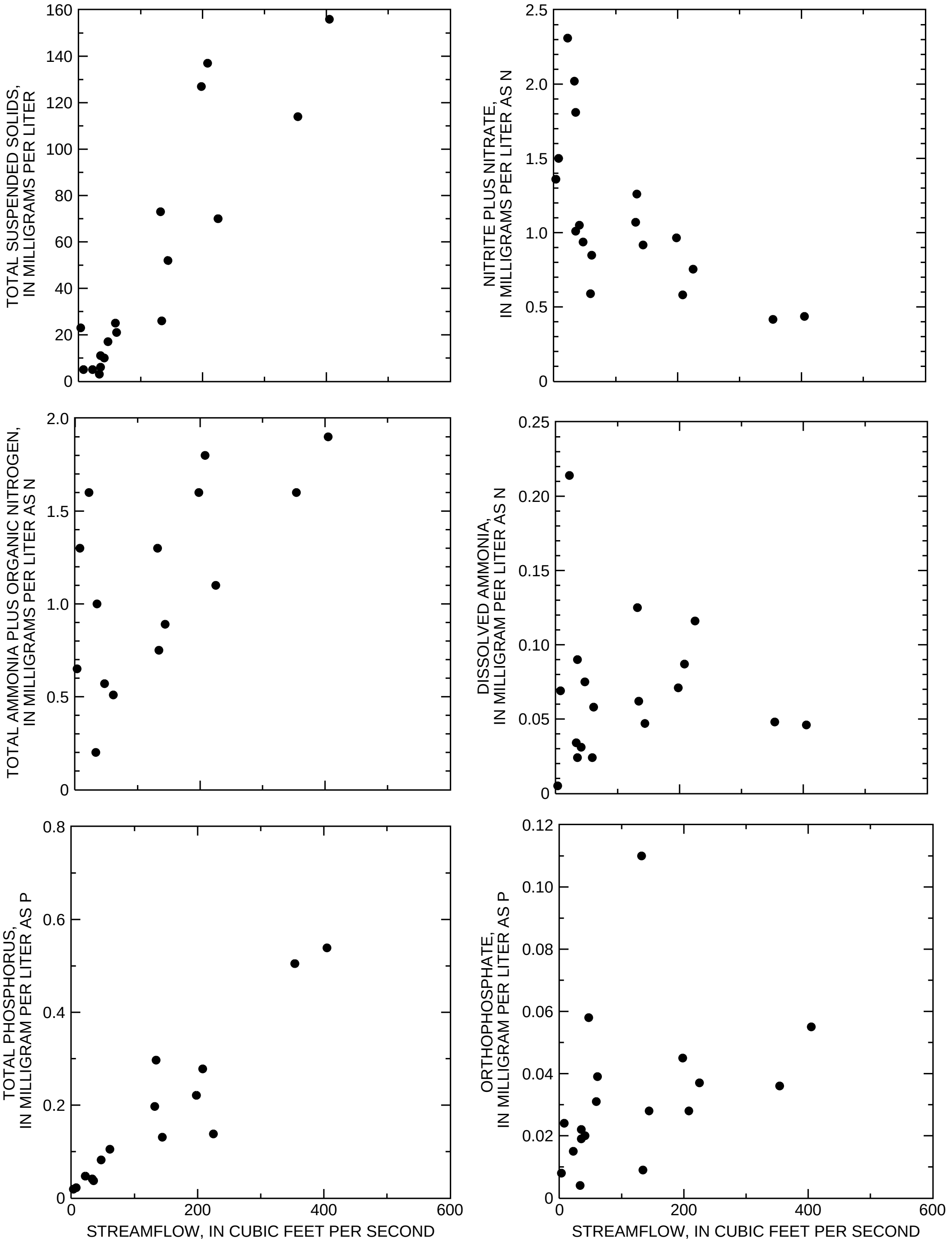


Figure 8. Relation between water-quality constituents and streamflow for stormflow and base-flow samples collected in 1998 at streamflow-measurement station 01478000, Christina River at Coochs Bridge, Del.

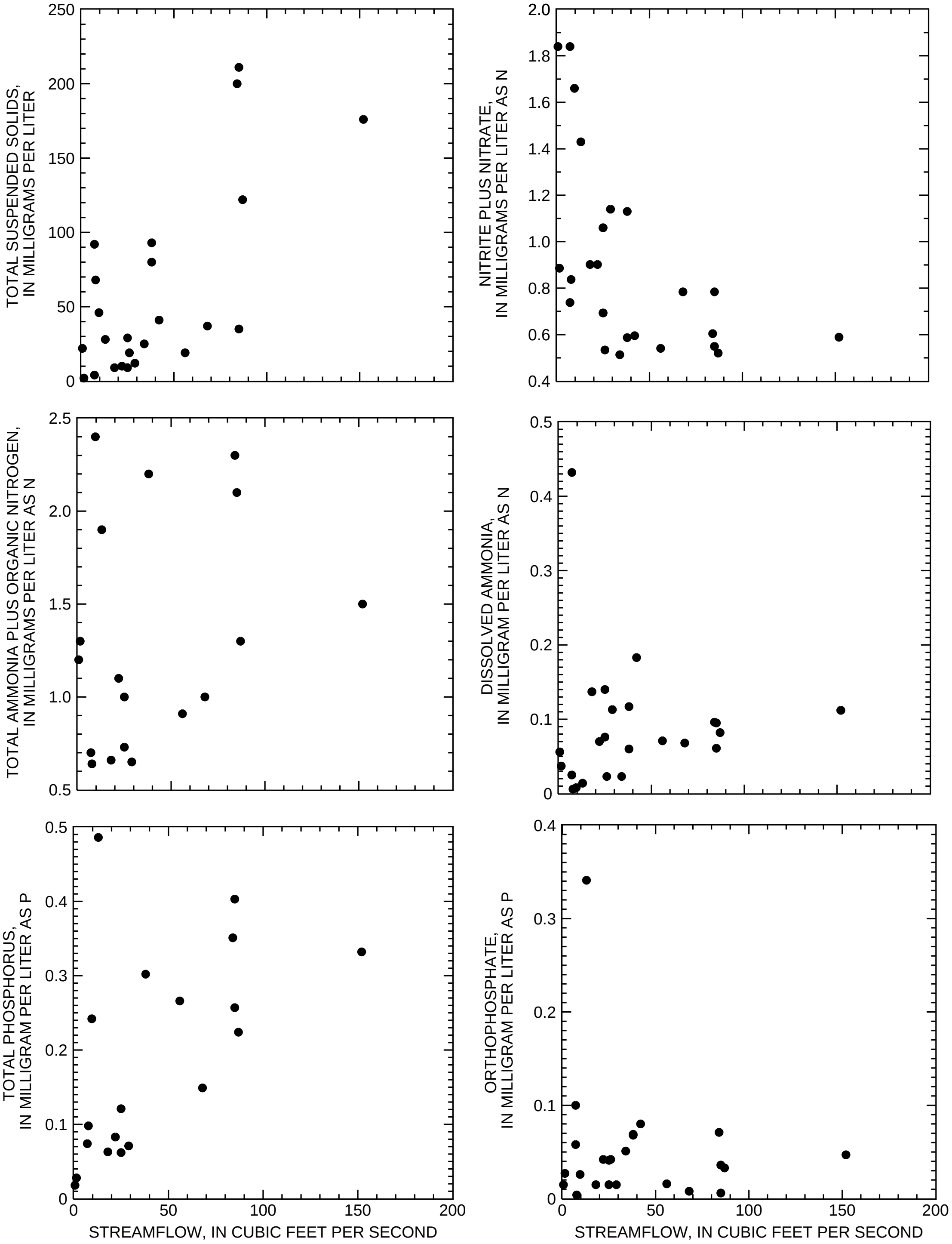
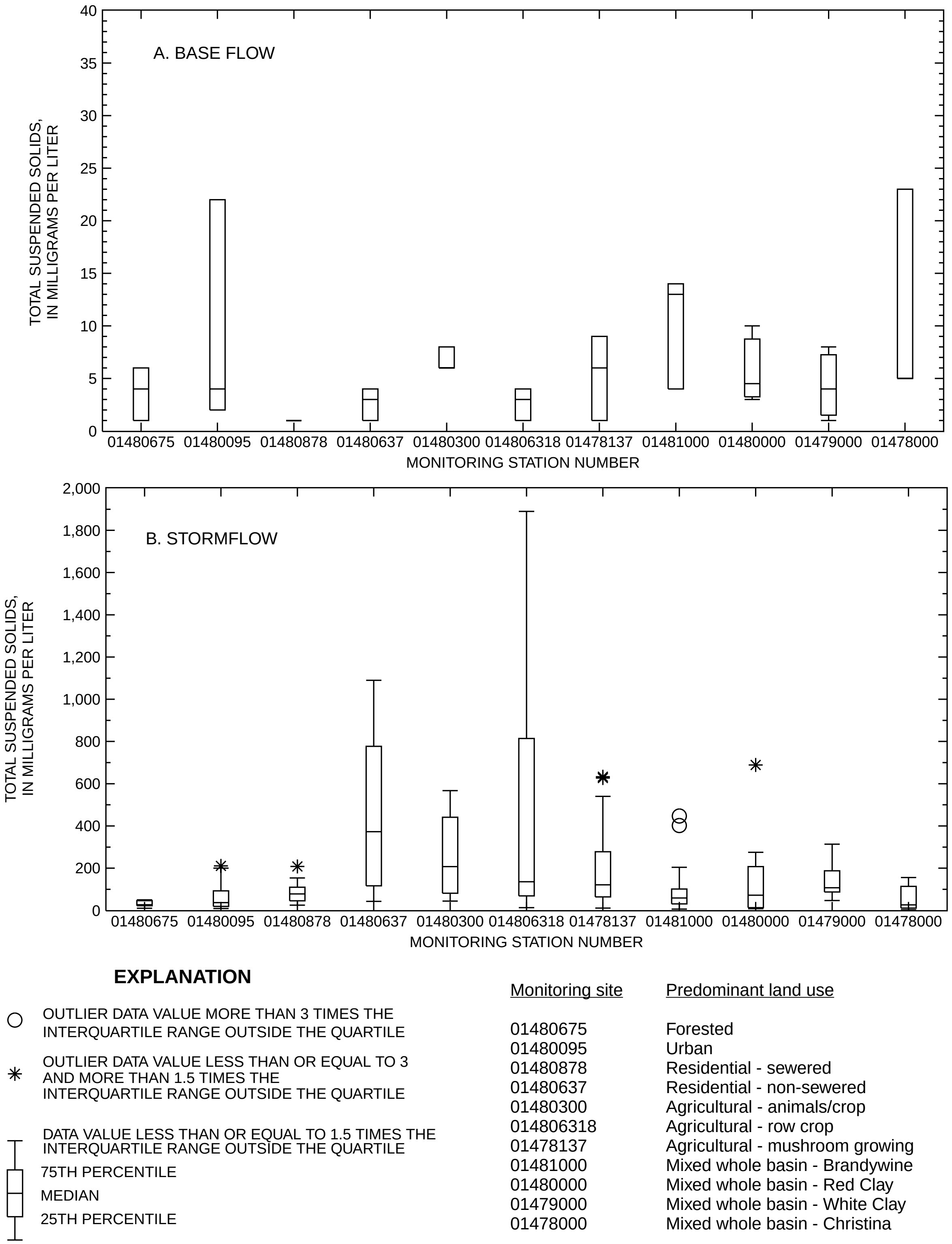
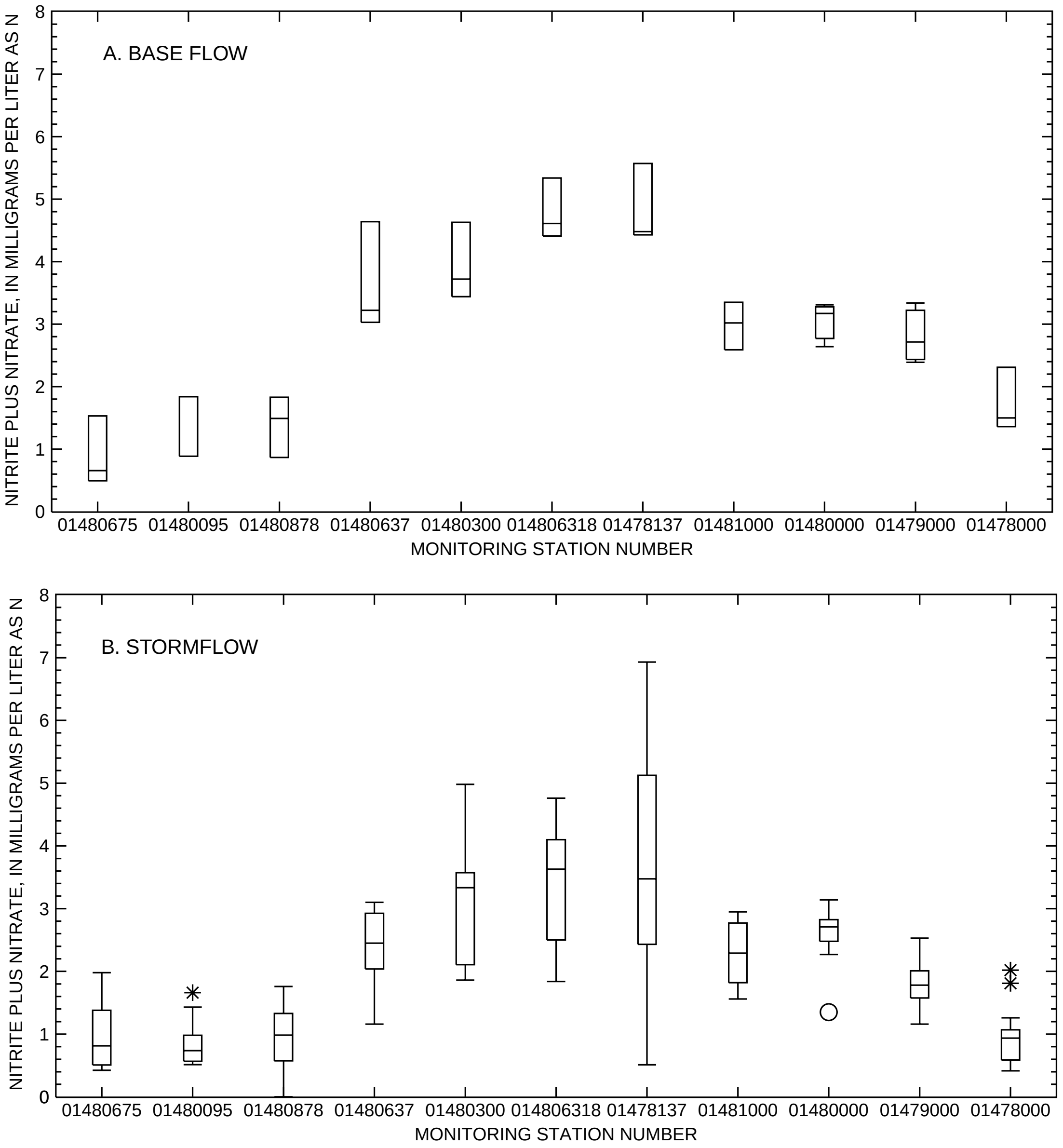


Figure 9. Relation between water-quality constituents and streamflow for stormflow and base-flow samples collected in 1998 at streamflow-measurement station 01480095, Little Mill Creek near Newport, Del.



Monitoring site	Predominant land use
01480675	Forested
01480095	Urban
01480878	Residential - sewered
01480637	Residential - non-sewered
01480300	Agricultural - animals/crop
014806318	Agricultural - row crop
01478137	Agricultural - mushroom growing
01481000	Mixed whole basin - Brandywine
01480000	Mixed whole basin - Red Clay
01479000	Mixed whole basin - White Clay
01478000	Mixed whole basin - Christina

Figure 10. Distribution of concentrations of suspended solids in samples collected under (A) base-flow and (B) stormflow conditions at the 11 nonpoint-source monitoring sites in the Christina River Basin during 1998. (See table 1 for description and figure 1 for location of monitoring sites.)



EXPLANATION

○ OUTLIER DATA VALUE MORE THAN 3 TIMES THE INTERQUARTILE RANGE OUTSIDE THE QUARTILE

✳ OUTLIER DATA VALUE LESS THAN OR EQUAL TO 3 AND MORE THAN 1.5 TIMES THE INTERQUARTILE RANGE OUTSIDE THE QUARTILE

DATA VALUE LESS THAN OR EQUAL TO 1.5 TIMES THE INTERQUARTILE RANGE OUTSIDE THE QUARTILE

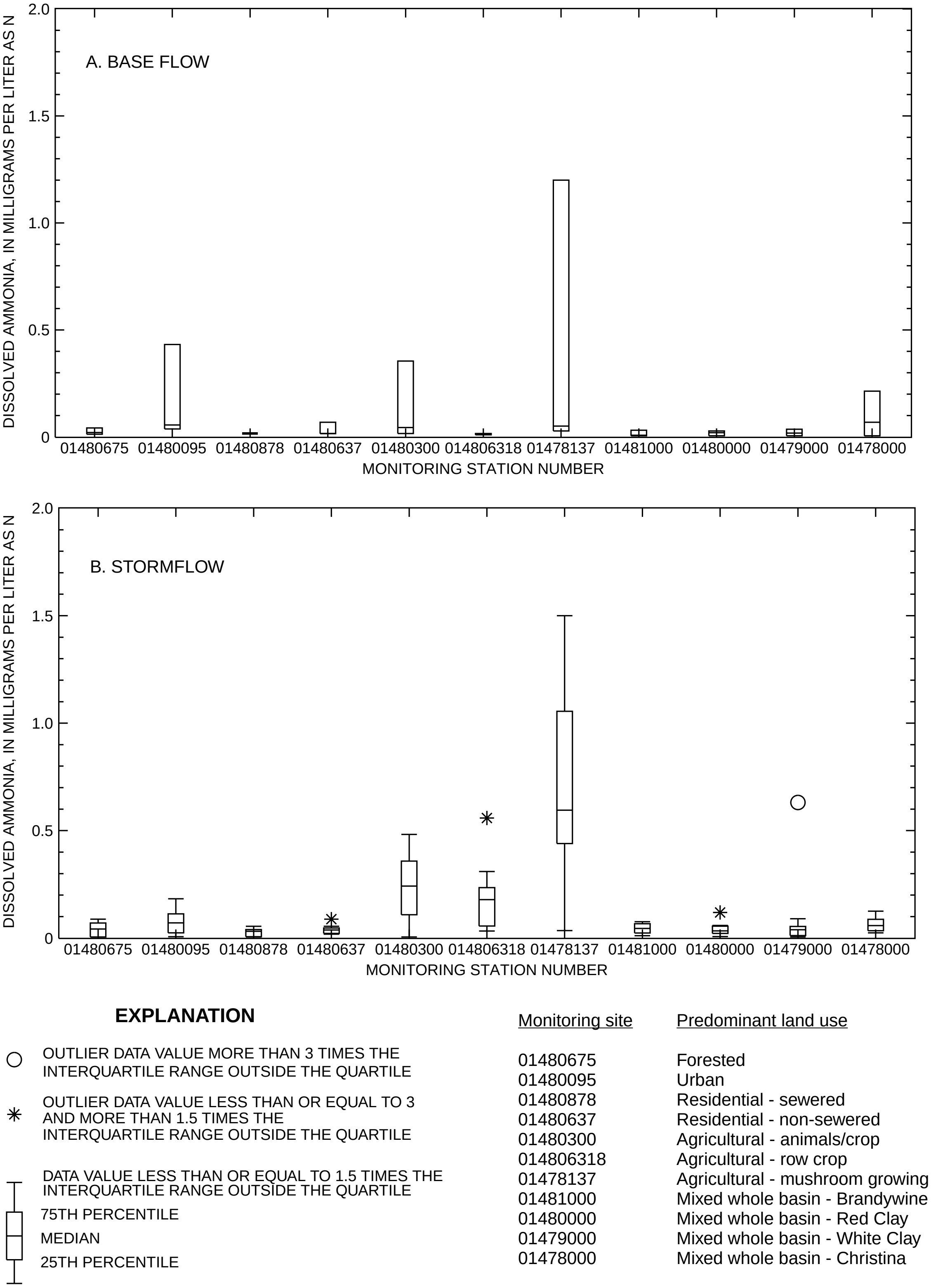
75TH PERCENTILE

MEDIAN

25TH PERCENTILE

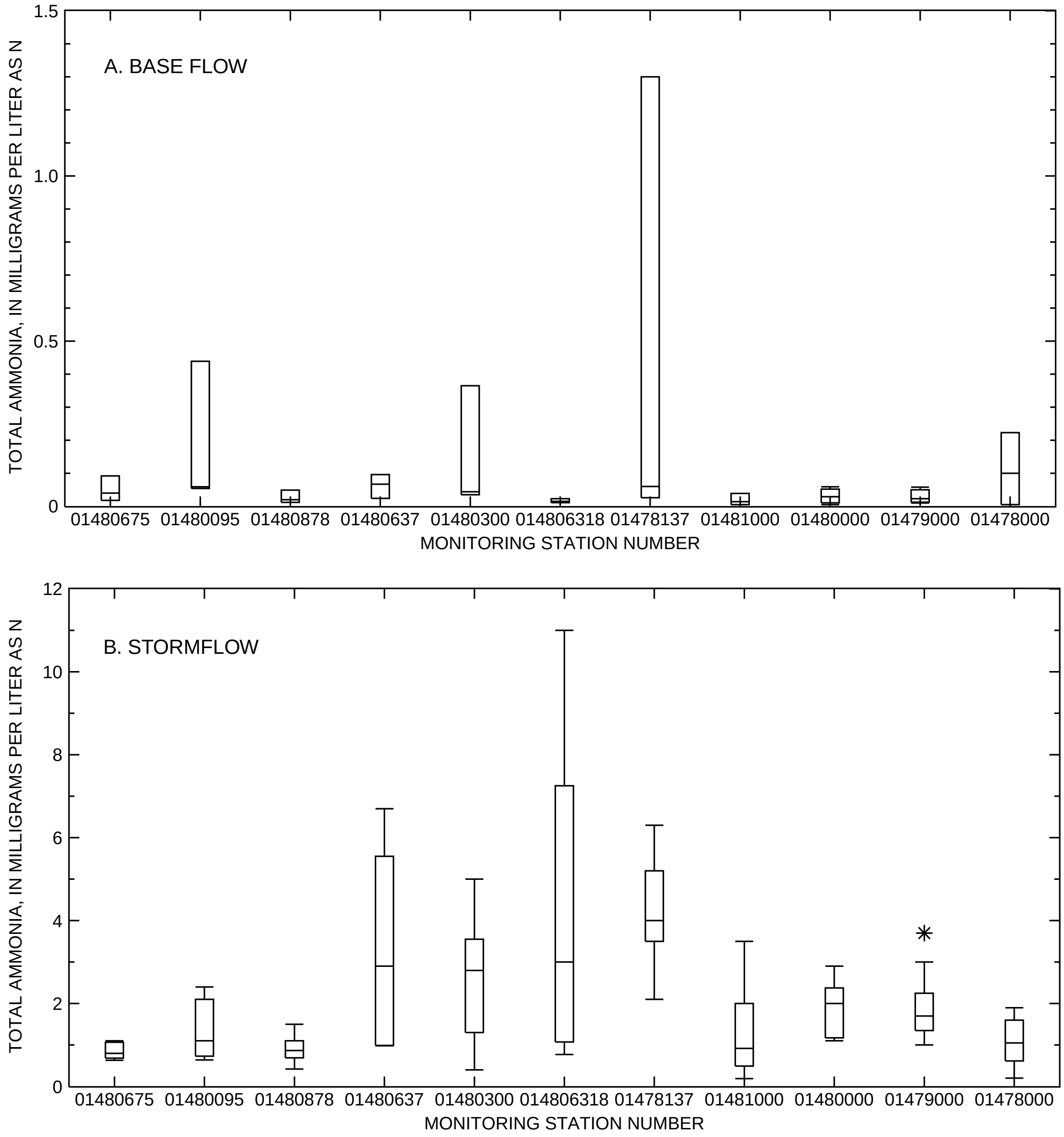
Monitoring site	Predominant land use
01480675	Forested
01480095	Urban
01480878	Residential - sewered
01480637	Residential - non-sewered
01480300	Agricultural - animals/crop
014806318	Agricultural - row crop
01478137	Agricultural - mushroom growing
01481000	Mixed whole basin - Brandywine
01480000	Mixed whole basin - Red Clay
01479000	Mixed whole basin - White Clay
01478000	Mixed whole basin - Christina

Figure 11. Distribution of concentrations of dissolved nitrite plus nitrate in samples collected under (A) base-flow and (B) stormflow conditions at the 11 nonpoint-source monitoring sites in the Christina River Basin during 1998. (See table 1 for description and figure 1 for location of monitoring sites.)



Monitoring site	Predominant land use
01480675	Forested
01480095	Urban
01480878	Residential - sewered
01480637	Residential - non-sewered
01480300	Agricultural - animals/crop
014806318	Agricultural - row crop
01478137	Agricultural - mushroom growing
01481000	Mixed whole basin - Brandywine
01480000	Mixed whole basin - Red Clay
01479000	Mixed whole basin - White Clay
01478000	Mixed whole basin - Christina

Figure 12. Distribution of concentrations of dissolved ammonia in samples collected under (A) base-flow and (B) stormflow conditions at the 11 nonpoint-source monitoring sites in the Christina River Basin during 1998. (See table 1 for description and figure 1 for location of monitoring sites.)



EXPLANATION

○ OUTLIER DATA VALUE MORE THAN 3 TIMES THE INTERQUARTILE RANGE OUTSIDE THE QUARTILE

✳ OUTLIER DATA VALUE LESS THAN OR EQUAL TO 3 AND MORE THAN 1.5 TIMES THE INTERQUARTILE RANGE OUTSIDE THE QUARTILE

DATA VALUE LESS THAN OR EQUAL TO 1.5 TIMES THE INTERQUARTILE RANGE OUTSIDE THE QUARTILE

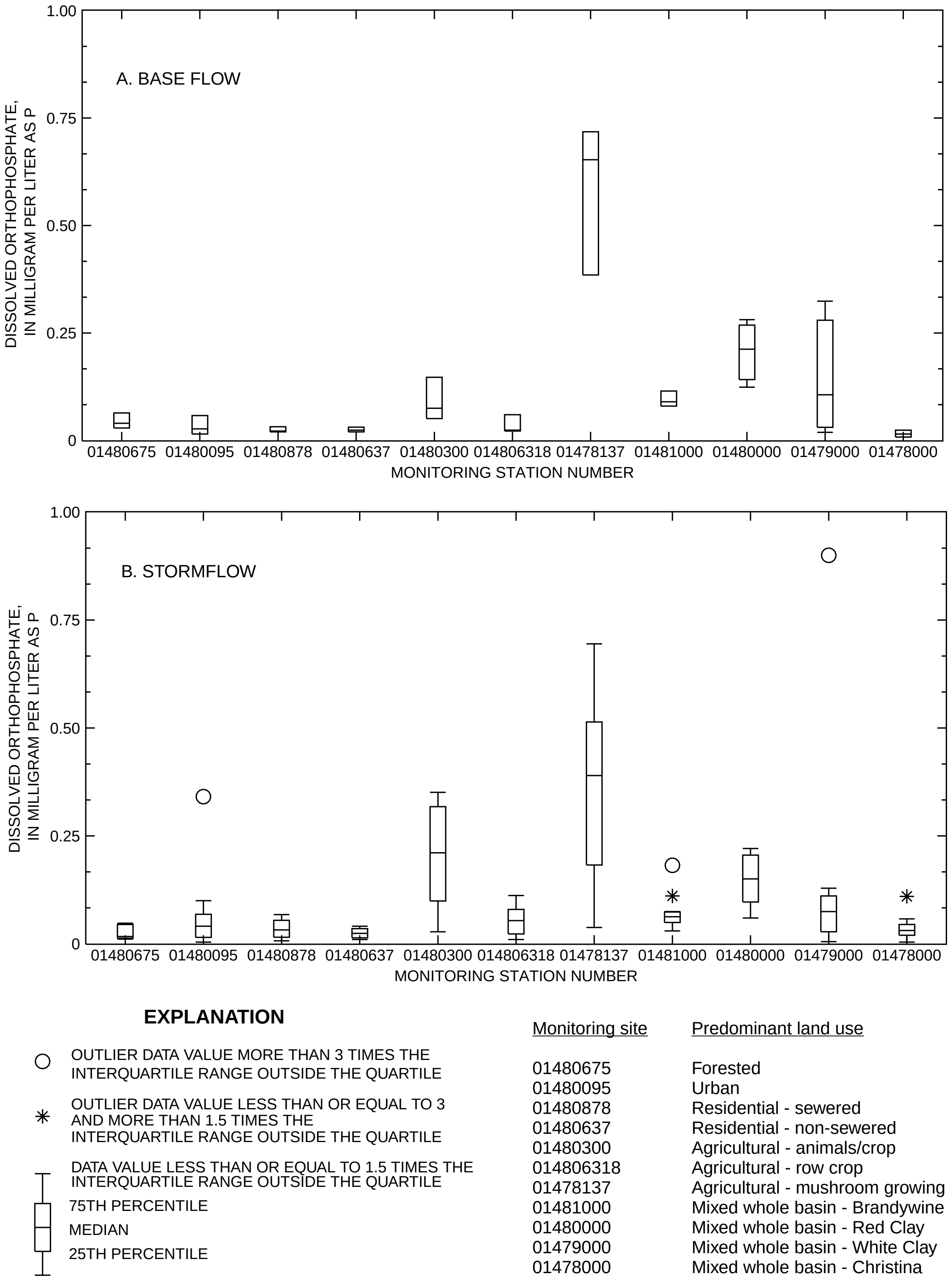
75TH PERCENTILE

MEDIAN

25TH PERCENTILE

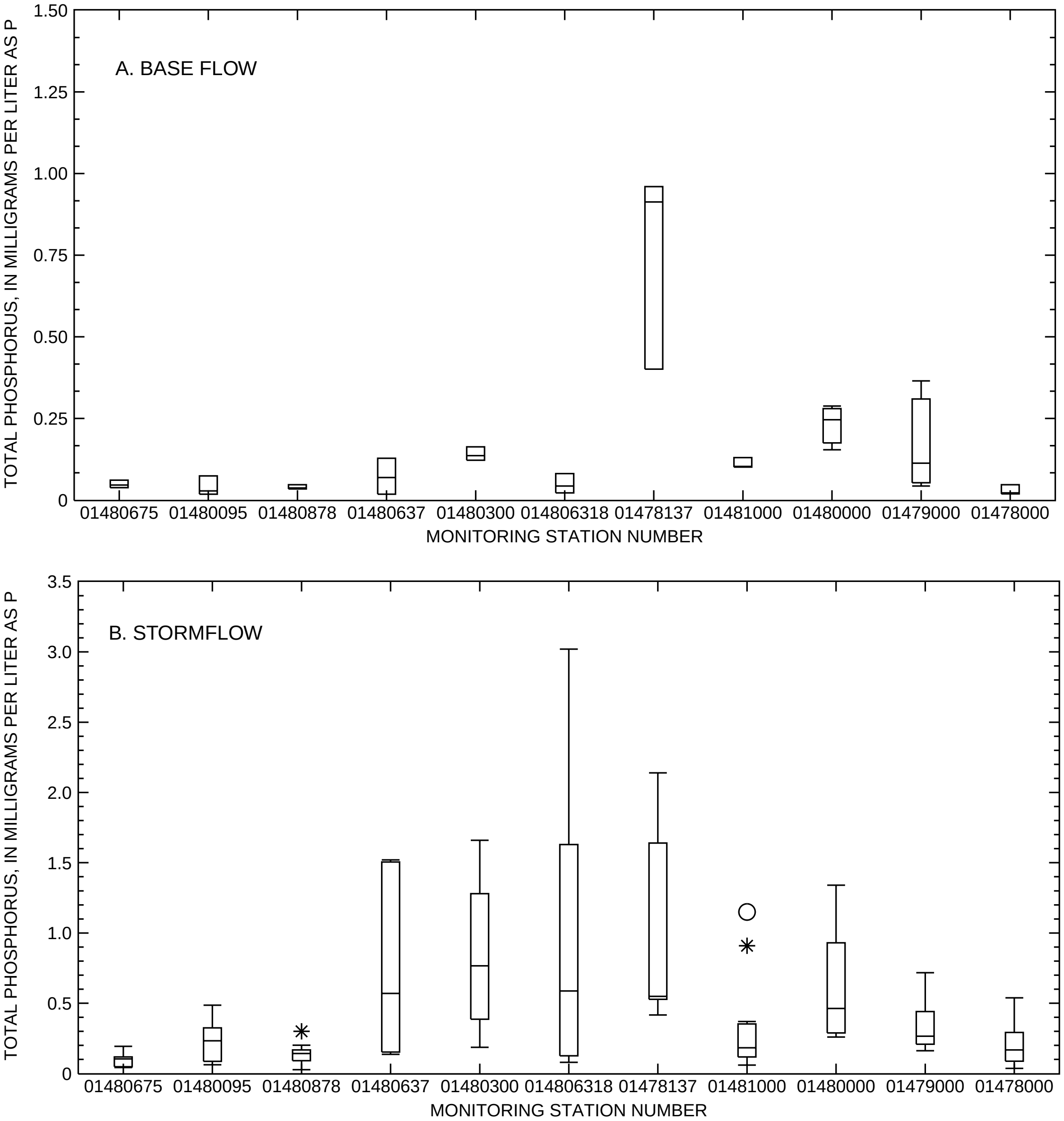
Monitoring site	Predominant land use
01480675	Forested
01480095	Urban
01480878	Residential - sewered
01480637	Residential - non-sewered
01480300	Agricultural - animals/crop
014806318	Agricultural - row crop
01478137	Agricultural - mushroom growing
01481000	Mixed whole basin - Brandywine
01480000	Mixed whole basin - Red Clay
01479000	Mixed whole basin - White Clay
01478000	Mixed whole basin - Christina

Figure 13. Distribution of concentrations of total ammonia in samples collected under (A) base-flow and (B) stormflow conditions at the 11 nonpoint-source monitoring sites in the Christina River Basin during 1998. (See table 1 for description and figure 1 for location of monitoring sites.)



Monitoring site	Predominant land use
01480675	Forested
01480095	Urban
01480878	Residential - sewered
01480637	Residential - non-sewered
01480300	Agricultural - animals/crop
014806318	Agricultural - row crop
01478137	Agricultural - mushroom growing
01481000	Mixed whole basin - Brandywine
01480000	Mixed whole basin - Red Clay
01479000	Mixed whole basin - White Clay
01478000	Mixed whole basin - Christina

Figure 14. Distribution of concentrations of dissolved orthophosphate in samples collected under (A) base-flow and (B) stormflow conditions at the 11 nonpoint-source monitoring sites in the Christina River Basin during 1998. (See table 1 for description and figure 1 for location of monitoring sites.)



EXPLANATION

○ OUTLIER DATA VALUE MORE THAN 3 TIMES THE INTERQUARTILE RANGE OUTSIDE THE QUARTILE

✳ OUTLIER DATA VALUE LESS THAN OR EQUAL TO 3 AND MORE THAN 1.5 TIMES THE INTERQUARTILE RANGE OUTSIDE THE QUARTILE

DATA VALUE LESS THAN OR EQUAL TO 1.5 TIMES THE INTERQUARTILE RANGE OUTSIDE THE QUARTILE

75TH PERCENTILE

MEDIAN

25TH PERCENTILE

Monitoring site	Predominant land use
01480675	Forested
01480095	Urban
01480878	Residential - sewered
01480637	Residential - non-sewered
01480300	Agricultural - animals/crop
014806318	Agricultural - row crop
01478137	Agricultural - mushroom growing
01481000	Mixed whole basin - Brandywine
01480000	Mixed whole basin - Red Clay
01479000	Mixed whole basin - White Clay
01478000	Mixed whole basin - Christina

Figure 15. Distribution of concentrations of total phosphorus in samples collected under (A) base-flow and (B) stormflow conditions at the 11 nonpoint-source monitoring sites in the Christina River Basin during 1998. (See table 1 for description and figure 1 for location of monitoring sites.)

Throughout the Christina River Basin, differences in water quality appear to be related to land use. Data from 1998 (Senior and Koerkle, 2003a; Senior and Koerkle, 2003b; this report) indicate that under stormflow conditions, concentrations of suspended solids, nitrate, dissolved and total ammonia, dissolved orthophosphate, and total phosphorus generally were higher at the sites in predominantly agricultural small subbasins than at sites in small subbasins with predominantly residential, urban, or forested land uses, with a few exceptions (figs. 10-15). Concentrations of dissolved nitrate and orthophosphate under base-flow conditions also commonly wefre higher at the sites in predominantly agricultural subbasins than at sites in subbasins with other land uses. Concentrations of suspended sediment, nitrate, and total phosphorus under base-flow and stormflow conditions were greater at the site in the predominantly non-sewered residential subbasin than at the sites in the predominantly forested, sewered residential, and urban subbasins. Although elevated ammonia and orthophosphate can be related to the land use, some of these constituents may be associated with discharge from sewage treatment plants or other point sources upstream of monitoring sites. Differences in water quality at monitoring sites on the main stems of the Brandywine Creek, Red Clay Creek, White Clay Creek, and Christina River (figs. 10-15) reflect differences in the land uses and point-source discharges in each major subbasin.

SIMULATION OF STREAMFLOW

Streamflow in the Christina River subbasin was simulated for the period October 1994 to October 29, 1998, or just over 4 years. Donigian and others (1984) suggest a 3-year to 5-year simulation period as optimal for HSPF because a greater variety of climatic conditions will be included.

The Christina River subbasin was divided into three segments, numbered 5, 8, and 9, for the model (fig. 16). Segments of the basin area were defined primarily on the basis of spatial distribution of precipitation and soils. Within each segment, the hydrologic response of land areas was assumed to differ principally by land use and soil type. Segment 5 includes the area underlain by soils developed on the crystalline rocks in the northwestern part of the subbasin. Segment 8 includes the area underlain by soils developed on unconsolidated sediments in the southwestern and central part of the subbasin. Segment 9 includes the area underlain by predominantly urban soils developed on both crystalline rocks and unconsolidated sediments. Precipitation input for the western model area (fig. 16) is based on data from the Newark University Farm NOAA meteorologic station and precipitation input for the central and eastern model area is based on data from the Wilmington Airport meteorologic station (fig. 3). The land-based hydrologic response in each segment was characterized spatially by sub-dividing the area into as many as 12 land-use categories consisting of 10 pervious and 2 impervious land-use types (table 9). These simplified land-use categories represent the predominant land uses in the 565-mi^2 Christina River Basin. Initial hydrologic-response parameters were assigned to the land-use categories and were modified as needed during model calibration. Parameters do not vary within a segment but may vary from segment to segment.

The amount of impervious land was calculated from the residential and urban pervious land uses using factors modified from Water Resource Agency for New Castle County values in Greig and others (1998). Because the HSPF model simulates no infiltration in impervious areas and some runoff from impervious areas such as roofs and roads does infiltrate, the amount of effectively impervious area is expected to be lower than impervious areas estimated by land-use maps. Thus, the amount of effectively impervious area was reduced from the amount of impervious area estimated from land-use maps. This type of modification has been employed in HSPF models in other study areas (Zarriello, 1999). The proportion of effectively impervious land was estimated as 10 percent in residential areas without sewers, 30 percent in residential areas with sewers, 50 percent for urban areas, and 10 percent for undesignated lands in sewered areas.

Nine RCHRES were specified for the Christina River subbasin model (fig. 16) of which seven were used in the model hydraulic simulations. RCHRES 8 and 9 were not included in the Christina River model simulations because of tidal influences. Of the RCHRES included in the model simulations, lengths ranged from 1.46 to 6.73 mi; the median length was 3.20 mi. Selection of RCHRES lengths was guided by the confluences of major tributaries, the location of calibration points, the location of dams and impoundments, and major changes in land use contributing to a stream reach. Reach lengths were measured from topographic maps. One RCHRES was in the West Branch, one RCHRES was in the East Branch, and

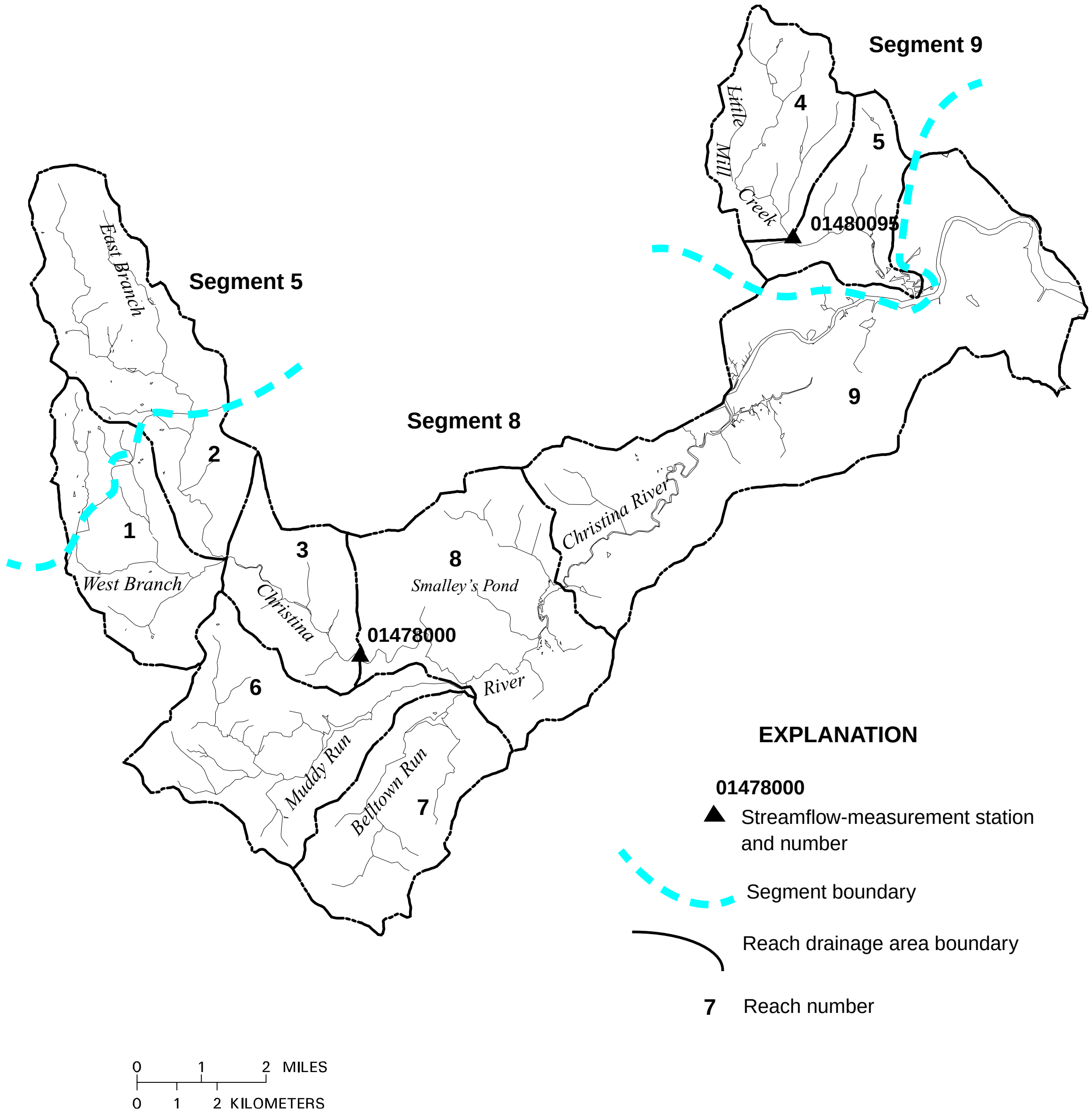


Figure 16. Location of segments, reach drainage areas, and stream reaches (RCHRES) delineated for Hydrological Simulation Program–Fortran (HSPF) model of the Christina River subbasin, Pennsylvania, Maryland and Delaware.

Table 9. *Reach number, length, drainage area, segment number, and percent of land-use category in drainage area for Christina River subbasin model*

[mi, miles; mi^2, square miles]

Reach number	Reach length (mi)	Reach drainage area (mi^2)	Segment number	Land-use category (percent of drainage area)											
				Residential - septic	Residential- sewer	Urban	Agricultural - livestock	Agricultural - row crop	Agricultural - mushroom	Forested	Open	Wetland.water	Undesignated	Impervious - residential	Impervious - urban
1	1.46	1.87	5	9.1	0	0.4	0	58.1	0	29.7	1.1	0	0.2	1.0	0.4
1	3.33	4.83	8	7.9	4.0	7.9	0	27.1	0	23.4	12.5	0	6.2	2.6	8.3
2	4.96	7.08	5	25.5	4.7	.3	0	41.1	0	21.7	.6	.1	1.0	4.8	.3
2	3.20	2.65	8	7.7	25.9	9.6	0	4.5	0	10.7	13.8	0	13.3	12.0	10.2
3	3.24	4.47	8	4.8	17.5	12.7	0	9.2	0	18.4	8.0	.2	9.0	8.0	13.5
4	4.65	5.37	9	1.5	28.1	12.8	0	1.4	0	18.3	9.2	.2	2.6	12.2	13.4
5	2.30	3.84	9	.1	20.9	17.6	0	0	0	8.7	15.2	1.1	9.3	8.9	25.6
6	6.73	8.64	8	6.0	8.8	6.6	0	15.5	0	38.4	10.6	1.1	1.8	4.5	6.8
7	2.08	6.37	8	.6	20.1	6.9	0	8.5	0	34.3	8.1	.8	4.7	8.7	7.4
8[1]	6.21	10.7	8	.2	19.3	8.4	0	10.4	0	27.0	7.0	.5	9.3	8.3	9.2
[1]9	15.09	21.9	8	.5	10.3	17.8	0	1.8	0	12.5	20.0	4.3	9.9	4.5	18.5
Total	53.25	77.7	--	4.6	13.7	10.8	0	11.9	0	21.6	11.6	1.6	6.5	6.4	11.4

[1] Reaches 8 and 9 not included in the hydraulic model simulation because the Christina River is tidally affected in these reaches.

seven were in the main stem and tributaries below the confluence of the East and West Branches. The main stem was divided into three reaches, with lower reach boundaries at a USGS streamflow-measurement station, Smalley's Pond dam, and the confluence with the Delaware River. The tributary Little Mill Creek was divided into two reaches, with the uppermost reach terminating at a USGS streamflow-measurement station and the lower reach ending at the Christina River confluence. The other reaches (RCHRES 6 and 7) were for the tributaries Muddy Run and Belltown Run, each of which has a dam. The area draining directly to each reach ranged from 3.84 to 21.9 mi^2, with differing amounts of the various land-use categories in each reach drainage area (table 9).

Snowfall, snow accumulation, and snow melt were simulated throughout the Christina River subbasin because hydrologic and meteorologic records indicated substantial snow, ice, and sub-freezing temperatures during the winter of 1995-96. In the coldest periods, channel icing occurred at the calibration sites. Only estimated daily streamflows were available during icing periods, which occurred in February 1995 (10 days) and in January and February 1996 (12 days). Hourly streamflow values for these periods are considered poor and published daily streamflows are reported as estimated.

Assumptions

The simulation of streamflow in the Christina River subbasin was done under the following assumptions: (1) inputs of hourly precipitation would be estimated reasonably well by disaggregated daily precipitation data; (2) the average precipitation over a given land segment would be represented adequately by weighted data from a single precipitation gage; and (3) a simplified set of PERLNDs and IMPLNDs would not unduly limit a satisfactory hydrologic calibration of the Christina River subbasin model.

Calibration

The basin hydrology model was calibrated using GenScn (Kittle and others, 1998), an interactive computer program for creating, analyzing, and comparing model simulations. HSPEXP (Lumb and others, 1994), a computer program that assists in calibration using an expert system, and the calibration guidelines in Donigian and others (1984) were employed to a limited extent because of incomplete streamflow record at the calibration sites. The model calibration effort was directed at the full range of observed streamflow with an emphasis on higher streamflows, because transport of many nonpoint source constituents is greatest at high flows. Prior to calibration, initial estimates of the hydrologic calibration parameters were determined. The initial values were derived from known watershed characteristics where possible, from parameters determined for calibrated HSPF models for the adjacent Brandywine and White Clay Creek Basins (Senior and Koerkle, 2003a; 2003b), from the HSPFParm database (Donigian and others, 1998), and from published sources such as Donigian and Davis (1978) and the U.S. Environmental Protection Agency (2000b). During calibration with GenScn, simulated streamflow is compared to observed streamflow through statistical and graphical methods. HSPEXP also uses statistical and graphical methods but includes default criteria for determination of a satisfactory hydrologic calibration (table 10) and lists suggestions as to which parameter(s) needs modification. The criteria are maximum allowable differences (errors) between observed and simulated streamflow expressed as percent error. These criteria are not fixed in HSPEXP and can be modified depending on the users' needs. Donigian and others (1984) offer the following error criteria for calibration: annual and monthly values less than 10 percent difference (Very Good); 10 to 15 percent difference (Good); 15 to 25 percent difference (Fair). Calibrated hydrologic parameter values are listed in the user-control input (UCI) for the Christina River subbasin model in Appendix 3.

The model was calibrated at gaged locations along the free-flowing sections of the Christina River main stem and Little Mill Creek tributary. Some drainage areas of the Christina River subbasin downstream from the streamflow-measurement station 01478000, Christina River at Coochs Bridge, Del., were simulated but not calibrated because no streamflow data were available in some locations and because the Christina River becomes tidal below Smalley's Pond. The HSPF does not simulate routing of water in tidal reaches. The period of calibration was October 1, 1994, to October 29, 1998.

Stormflow hydrograph calibration consisted of comparing stormflow volume, average simulated peak flows, and recession rates of selected storms with observed data in GenScn and HSPEXP and visual examination of simulated and observed stormflow hydrographs. Twenty-one storm events were selected from the October 1, 1994, to August 15, 1995, period for analysis in HSPEXP. Storms were selected using the following criteria as a guide: (1) total storm precipitation will be equal to 0.5 in. or more. The summary statistics—error in total storm volume, error in the mean of peak stormflows for all selected storms, and error in total summer storm volume—were calculated for selected stormflow periods collectively. For the Christina River at Coochs Bridge and Little Mill Creek sites, these statistics indicate simulation errors less than the default HSPEXP error criteria (table 10) except for the 50 percent lowest flows and summer storm volume at Little Mill Creek near Newport, Del. The statistics in table 10 for the Little Mill Creek site show undersimulation for total volume, high flows, and low flows. Having simulation errors in the same direction for these statistics simultaneously is normally indicative of an overall water balance error. In this case, the reporting of these statistics for a 10.5-month period while calibrating the model for best fit over a 4-year period resulted in the apparent short-term bias. The large summer storm volume error results from poor simulation of one of four storm events

Table 10. *Calibration criteria and errors for HSPF simulated streamflow at two streamflow-measurement stations in the Christina River Basin for the period October 1, 1994, through August 15, 1995*

	Calibration criteria, in percent[1]						
	Total volume	Low flow recession rate	50-percent lowest flows	10-percent highest flows	Storm peaks	Seasonal volume error	Summer storm volume error
	10.0	**0.03**	**10.0**	**15.0**	**20.0**	**30.0**	**50.0**
Calibration site[2]	**Calibration errors from HSPEXP, in percent**						
01478000	5.3	0.0	6.3	-1.0	16.7	12.2	14.2
01480095	-2.3	-.03	-16.1	-3.0	18.8	29.0	63.5

[1] Default criteria for satisfactory hydrologic calibration in HSPEXP.

[2] Streamflow-measurement station number.

selected for the statistic calculation. Observed storm volume for the July 28, 1995, storm was 610 percent greater than the simulated volume. Note that these statistics are not indicative of the errors for individual storm simulations.

In general, errors in individual storm simulations vary widely. The largest errors in the simulation of stormflow appear to result from incorrectly specified precipitation. Typically, a time discrepancy between the simulated and observed stormflow hydrographs has no effect on the HSPEXP error statistics except when the time shift moves the simulated hydrograph beyond the established storm event time boundaries. These boundaries are set at whole day increments (for individual storms) or seasonal periods (June, July, August for the summer). However, a time-shifted event can cause difficulties with water-quality calibrations; a temporal mismatch between observed and simulated streamflows produces a corresponding mismatch between observed and simulated water quality. Use of weighting of rainfall also has the potential to result in incorrectly specified rainfall for individual storm events. Stormflow simulations with the least error tended to result from storms that produced the most uniform rainfall distribution across a drainage basin. In the HSPF model for the adjacent Brandywine Creek Basin, errors in individual storm simulations tended to increase with decreasing drainage area (Senior and Koerkle, 2003a).

Time-series comparisons of simulated and observed daily mean streamflows at the streamflow-measurement stations on Christina River at Coochs Bridge and on Little Mill Creek near Newport, Del. (fig. 17), show good agreement except from May 1998 through August 1998. During that period, simulated base flows tend to be noticeably greater than observed base flows for the Coochs Bridge site and for the Little Mill Creek site. The spring and summer of 1998 was an unusually dry period with little ground-water recharge and strong evapotranspiration (ET) demand. In this instance, the model allocated more water to base-flow discharge rather than to satisfying (ET) demand. This effect is more pronounced at the Little Mill Creek site where greater urban land use reduced the effective ET demand, allowing greater base-flow discharge. Substantial periods of missing observed hourly streamflow data (October 1, 1995, to September 30, 1996, at Christina River at Coochs Bridge and August 20, 1995, to August 20, 1997, at Little Mill Creek near Newport) prevented comparison of simulated and observed hourly values over the complete simulation period. For the period of missing hourly streamflow data (October 1, 1995, to September 30, 1996), daily streamflow data were available for Christina River at Coochs Bridge (fig. 17).

Time-series comparisons of simulated and observed hourly streamflow at the nonpoint-source water-quality monitoring sites, Christina River at Coochs Bridge, Del., and Little Mill Creek near Newport, Del., are shown in figure 18 for the sampling period January 1 through October 29, 1998. Simulated low-flow conditions exceeded observed streamflow in the summer months of 1998 at both sites, with the greatest departure at the Little Mill Creek site. Summer storms also are oversimulated with the greatest oversimulation at the Little Mill Creek site. The more pronounced oversimulation of summer storms at the Little Mill Creek site is most likely due to underestimation of the effective impervious land area in the basin. Excess simulated base flow would also occur if effective impervious land area was too small.

Flow-duration curves of simulated and observed hourly streamflow for a limited portion of the simulation period show generally good agreement. The largest departures occur during peak stormflows at Christina River at Coochs Bridge, Del., and low flows at Little Mill Creek at Newport, Del. (fig. 19). These curves represent the longest period of continuous observed hourly streamflow data available for each site. This period includes 25 months of data for the Coochs Bridge site and 14 months of data for the Newport site.

Oversimulation of peak stormflow at the Coochs Bridge site resulted primarily for streamflows above 1,500 ft^3/s, which occurred no more than 0.1 percent of the time in the 25-month period. The oversimulation of low flows at the Newport site is prominent up to about 5 ft^3/s, which represents about 70 percent of the time in the 14-month period.

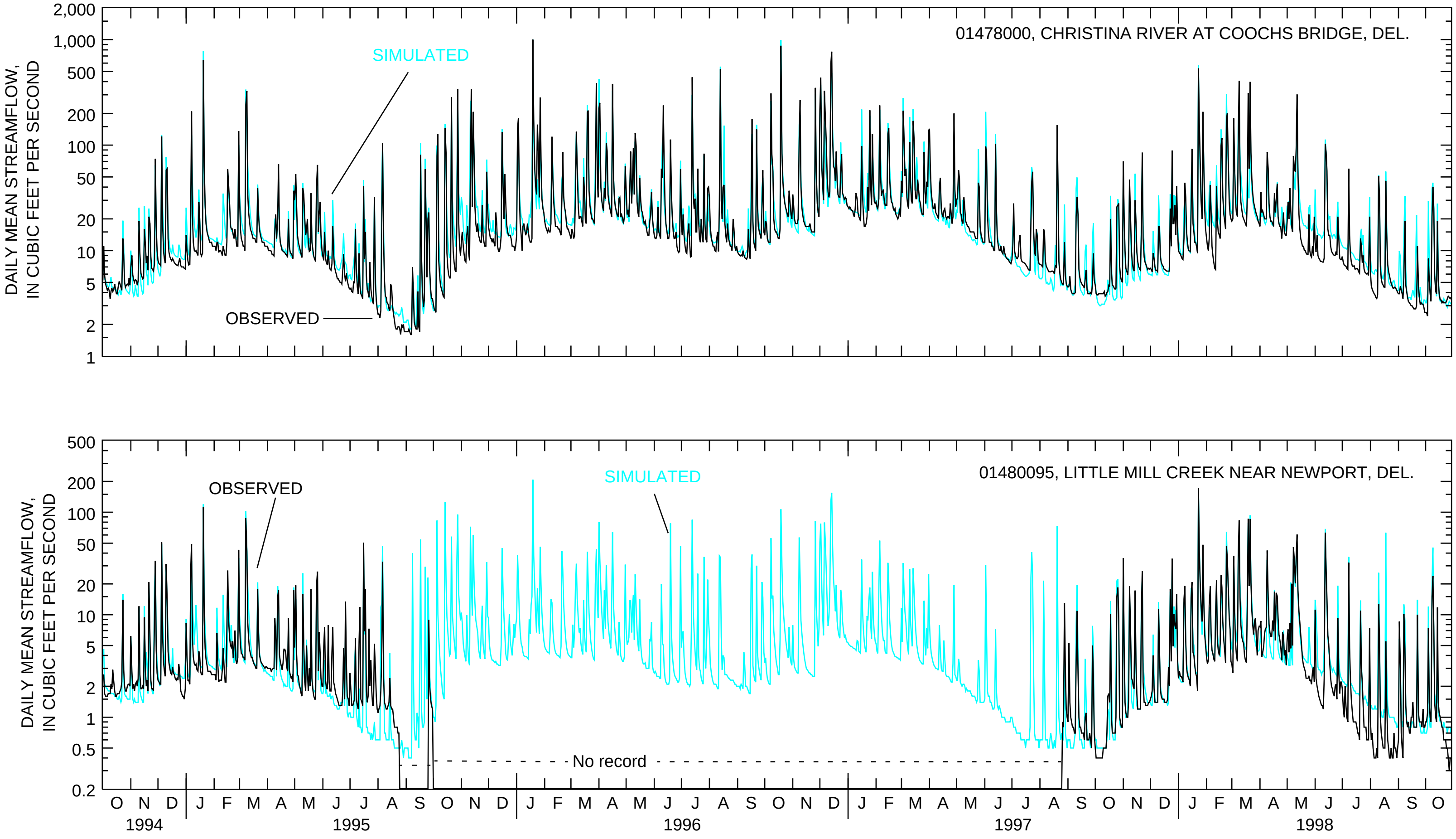


Figure 17. Simulated and observed daily mean streamflow at streamflow-measurement stations 01478000 Christina River at Coochs Bridge, Del. (top), and 01480095 Little Mill Creek near Newport, Del. (bottom), for the period October 1, 1994, through October 29, 1998.

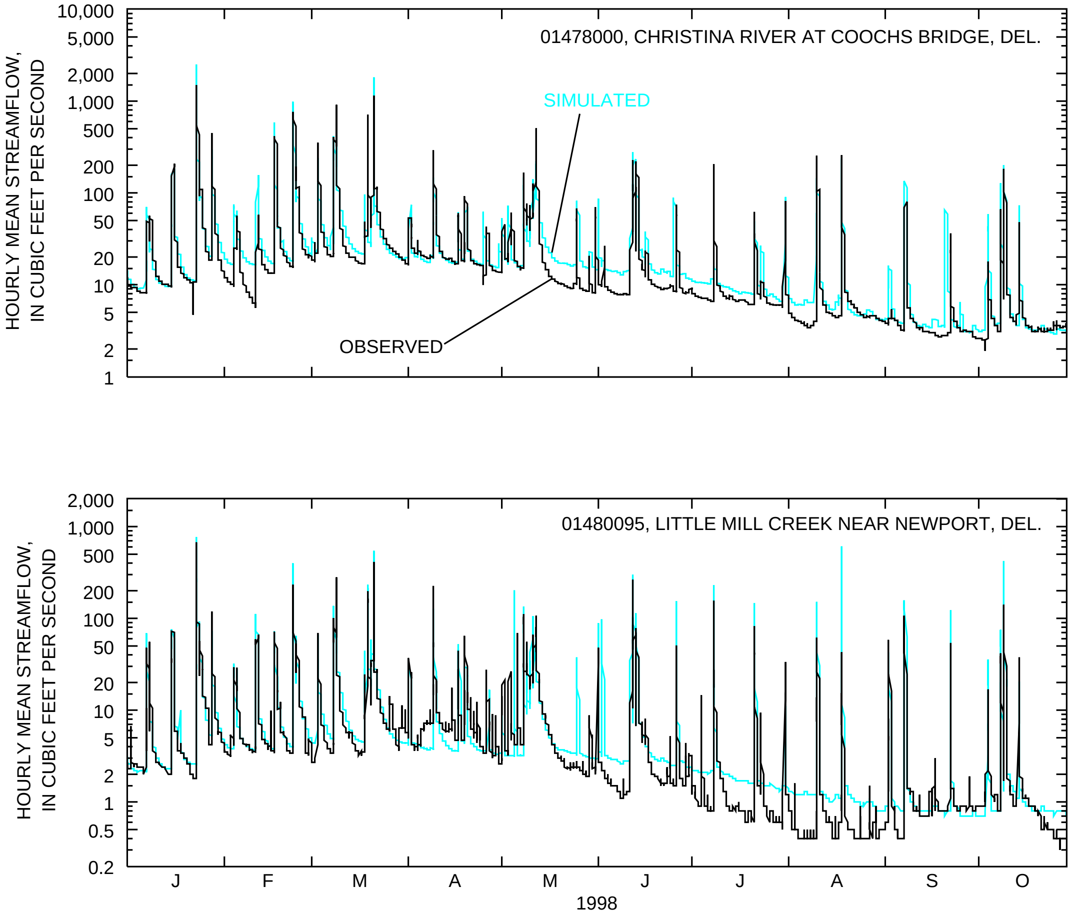


Figure 18. Simulated and observed hourly mean streamflow at the nonpoint-source water-quality monitoring sites in the Christina River subbasin, 01478000 Christina River at Coochs Bridge, Del. (top), and 01480095 Little Mill Creek near Newport, Del. (bottom), for the sampling period January 1 through October 29, 1998.

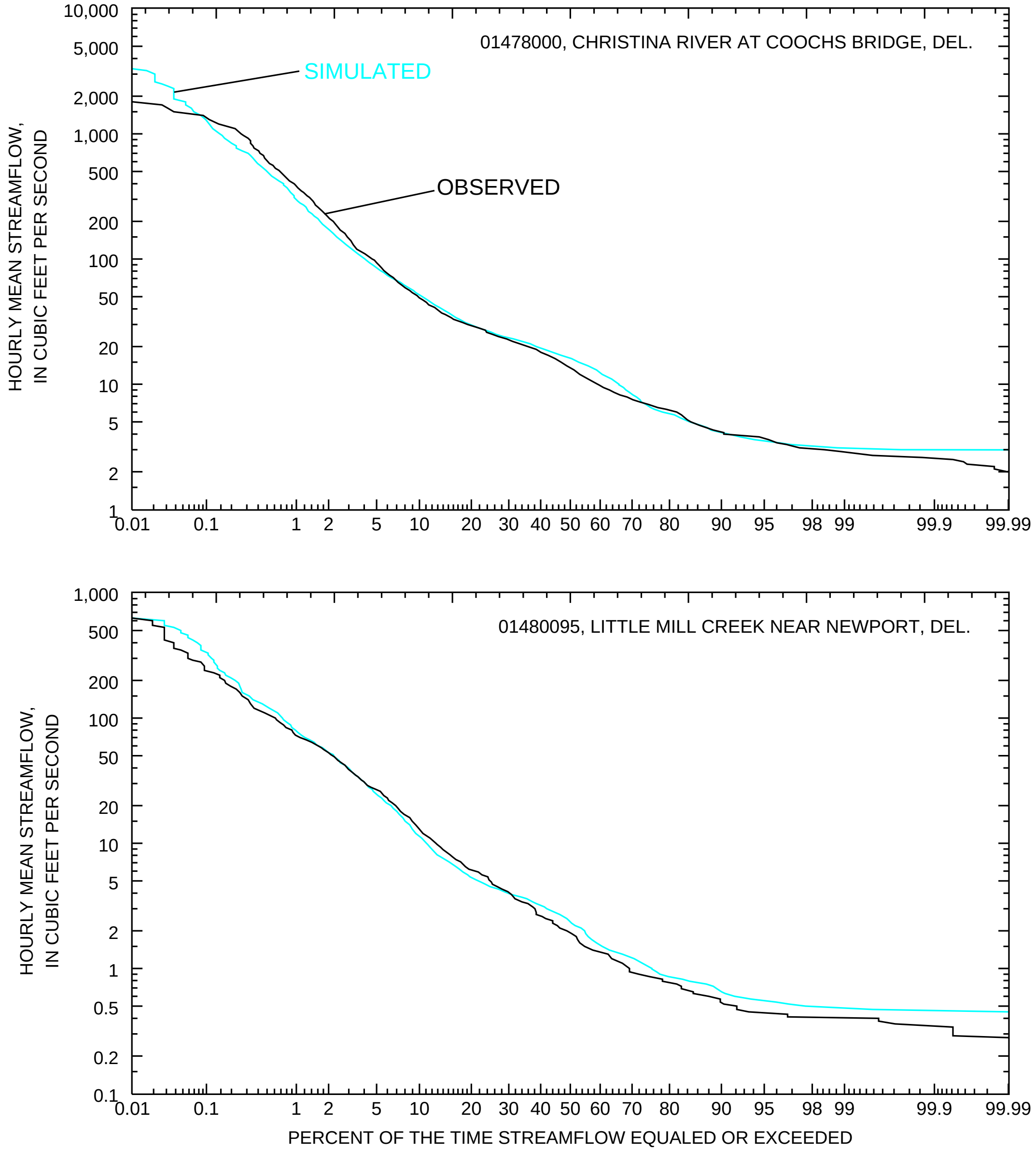


Figure 19. Duration curves of simulated and observed hourly mean streamflow for Christina River at Coochs Bridge, Del., for the period October 1, 1996, to October 29, 1998 (top), and for Little Mill Creek near Newport, Del. (bottom), for the period September 1, 1997, to October 29, 1998.

The model performance in simulating hourly and daily streamflow was evaluated at the two nonpoint-source water-quality monitoring sites for 1998, the year of stormflow and base-flow water-quality data collection, and at one site for the calibration period of 1994-98. Statistical measures of the hourly and daily streamflow comparison are listed in table 11. Correlation and model-fit efficiency coefficients for Christina River at Coochs Bridge site are lower than those for the Little Mill Creek near Newport site. Unlike the flow-duration comparisons, the statistics for one-to-one comparison of observed and simulated values (table 11) are affected by errors in the timing of storms. Because errors in the timing of precipitation and consequent storms commonly occur in shifts on the scale of hours, not days, they result in lower values of correlation and model-fit efficiency coefficients for hourly streamflow compared to those for daily streamflow (table 11). Errors in timing of precipitation on the scale of hours affect simulated stormflow in small drainage areas to a greater extent than simulated stormflow in large drainage areas because the time to peak for storms generally increases with basin size. The evaluation indicates that the model fit efficiency and correlation coefficients for Christina River at Coochs Bridge are similar and generally slightly better for the calibration period of 1994-98 than for 1998. Model-fit efficiency coefficients greater than 0.97 indicate an excellent calibration (Martin and others, 2000; James and Burgess, 1982). Simulated and observed streamflow statistics, in inches, for Christina River at Coochs Bridge, Del., are listed by year and for the entire 4-year period of simulation in table 12.

Table 11. *Statistics for comparison of observed and simulated hourly and daily mean streamflow at the two nonpoint-source water-quality monitoring sites (01480095 Little Mill Creek near Newport and 01478000 Christina River at Coochs Bridge), during the January - October 1998 nonpoint-source monitoring period and at one water-quality monitoring site (01478000 Christina River at Coochs Bridge), during the October 1994 - October 1998 calibration period in the Christina River subbasin*

Site	Streamflow, in cubic feet per second							
	Type of mean values	Number of values	Mean observed	Mean simulated	Mean error	Mean absolute error[1]	Correlation coefficient	Model-fit efficiency[2]
Nonpoint-source monitoring period, January - October 1998								
Little Mill Creek near Newport	hourly	7,248	7.70	7.94	-0.243	2.983	0.84	0.71
Little Mill Creek near Newport	daily	302	7.70	7.94	-.243	2.107	.95	.89
Christina River at Coochs Bridge	hourly	7,248	26.74	26.28	.462	11.717	.77	.52
Christina River at Coochs Bridge	daily	302	26.74	26.28	.462	8.769	.90	.73
Calibration period, October 1994 - October 1998								
Christina River at Coochs Bridge	daily	1,490	29.60	29.29	.310	8.154	.93	.85

[1] Mean absolute error = sum[|(simulated - observed)|/number of values].

[2] From Nash and Sutcliffe (1970) described in Wicklein and Schiffer (2002).

$$E = \left(\sum_{i=1}^{N} (Qoi - Qo)^2 - \sum_{i=1}^{N} (Qoi - Qsi)^2 \right) \Big/ \left(\sum_{i=1}^{N} (Qoi - Qo)^2 \right)$$

where

E is model-fit efficiency,

Qoi is the observed streamflow for time interval i,

Qo is the observed average streamflow for the time interval,

Qsi is the simulated streamflow for time interval i, and

N is the number of time intervals in the comparison period.

Table 12. *Observed and simulated streamflow for Christina River at Coochs Bridge, Del., 1994-98*

Year	Streamflow, in inches			Percentage difference[1]
	Simulated	Observed	Simulated - observed	
[2]1994	1.77	1.70	0.07	4.1
1995	14.8	13.9	.9	6.5
1996	30.8	33.1	-2.3	-6.9
1997	15.9	15.4	.5	3.2
[3]1998	14.1	14.2	-.1	-0.7
Total (1994-98)	77.4	78.3	-.9	-1.1

[1] 100 x (Simulated - Observed) / Observed.

[2] October 1 through December 31, 1994.

[3] Through October 29, 1998.

Errors in simulated streamflows exhibited a seasonal and climatic dependence. A plot of cumulative difference between simulated and observed streamflow for the Christina River at Coochs Bridge, Del. (fig. 20), shows that, overall, simulated streamflow agrees best with observed streamflow during the summer and fall months. Winter and spring periods show the greatest simulation error. Periods of good agreement between simulated and observed streamflow are displayed as a horizontal line with minor y-axis (vertical) fluctuations. Periods of poor agreement appear as larger vertical displacements. The y-axis value lists the total difference between simulated and observed streamflow volumes, in inches, from the beginning of the simulation period to the corresponding date on the x-axis scale. The winter of 1996-97 had the greatest snowfall accumulation and showed the largest change in cumulative error; simulated streamflow totals departed about -1.5 in. in the November-December 1996 period. A part of this loss was returned during the spring snowmelt. Cumulative error in simulated streamflow at Coochs Bridge remained within about +1 to -1.5 in. rainfall equivalent over the entire simulation period.

The volume of water leaving land areas (PERLNDs) and entering an HSPF model reach can be subdivided into surface runoff (SURO), interflow (IFWO), and active ground-water flow (AGWO). Impervious land segments (IMPLNDs), by definition, have only a surface runoff (SURO) pathway. For the Christina River at Coochs Bridge, the totals simulated for these components are 33.2 in. of surface runoff (44 percent of total flow), 12.8 in. of interflow (17 percent of total flow), and 29.6 in. of active ground-water flow (39 percent of total runoff).

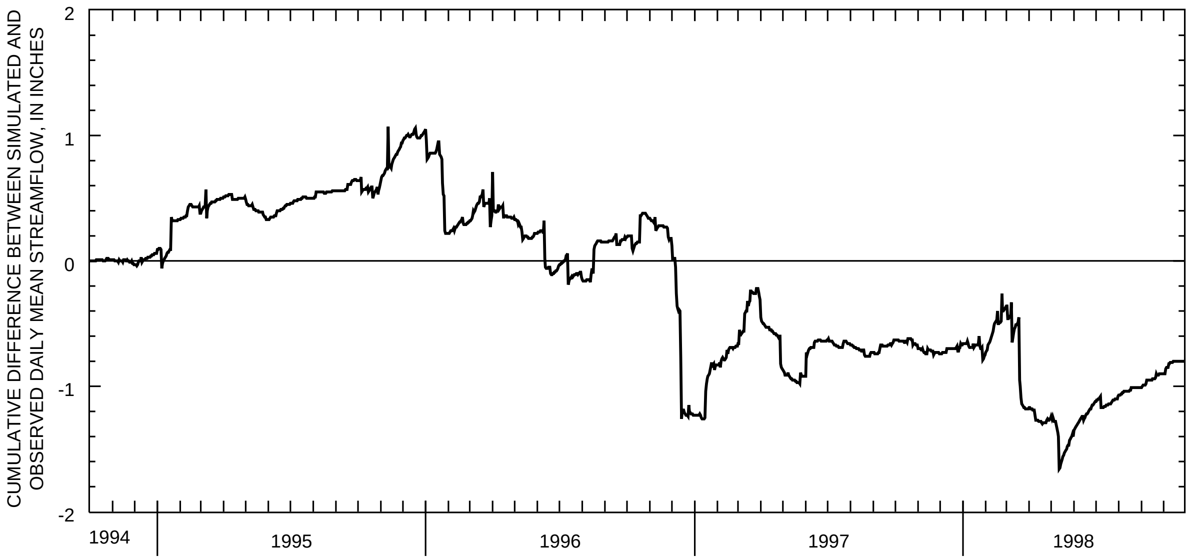


Figure 20. Cumulative difference between simulated and observed daily mean streamflow at streamflow-measurement station 01478000, Christina River at Coochs Bridge, Del., October 1, 1994, to October 29, 1998.

A well-calibrated HSPF model will satisfactorily simulate the proportioning of surface runoff, interflow, and ground-water components of the total volume of water leaving land areas and entering streams. Simulation of components of flow is important because the transport of contaminants in surface runoff, interflow, and ground water is affected by the amount and rate of water leaving the land through each process. As a check on the simulated proportion of base flow, a fixed-interval base-flow-separation technique (Sloto and Crouse, 1996; Pettyjohn and Henning, 1979) was applied to the simulated and observed streamflow record for the Coochs Bridge and Newport sites. Base-flow percentages determined by this technique were 51.3 and 46.9 percent for HSPF simulated streamflow and 45.9 and 44.4 percent for observed streamflow, respectively, at the Coochs Bridge and Newport sites. The fixed-interval base-flow-separation technique does not compute interflow as a separate component as does HSPF. Rather, interflow is divided between base flow and surface runoff in unknown proportions. The HSPF computed ground-water component (AGWO) plus interflow (IFWO) represented 54.7 and 47.0 percent, respectively, for the Coochs Bridge and Newport sites.

The partitioning of PERLND water among SURO, IFWO, and AGWO affects the stream hydrograph and, consequently, the simulation of nonpoint-source constituent transport (Fontaine and Jacomino, 1997). The monthly contributions from SURO, IFWO, and AGWO for a wetter-than-average year (1996) and a drier-than-average year (1997) at Coochs Bridge, Del., are presented in figure 21. Simulated surface runoff and interflow are greater in magnitude and represent a greater percent of simulated total runoff in the wet year, 1996, than in the dry year, 1997, as would be expected. In 1996 and 1997, SURO represented 14.4 and 5.7 in., respectively (47 and 36 percent, respectively), of the total runoff at Christina River at Coochs Bridge, Del.

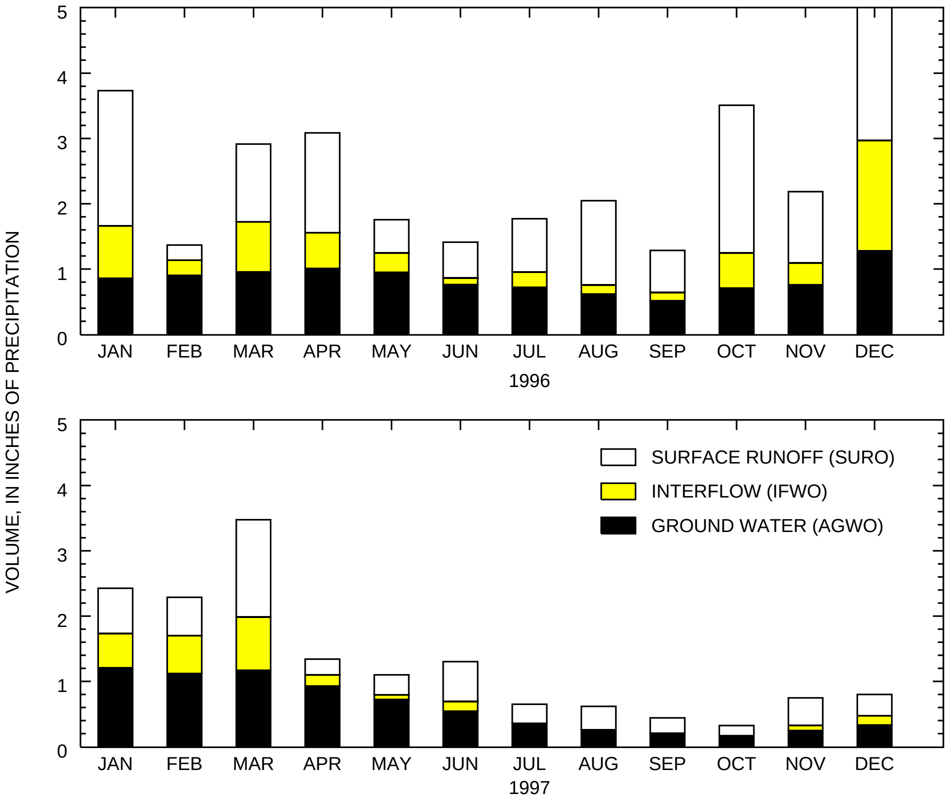


Figure 21. Simulated surface runoff, interflow, and ground-water (base-flow) monthly flow contributions from pervious land segments (PERLNDs) at the streamflow measurement station 01478000, Christina River at Coochs Bridge, Del., 1996-97.

Overall, the calibration of the hydrologic component of the HSPF model for the Christina River subbasin generally is balanced over the full range of observed streamflows, even though more emphasis was placed on high-flow simulation. As calibrated, the hydrologic component of the model nevertheless has limitations for the application of simulating water quality under stormflow conditions. These limitations, related primarily to the regionalization of distant point-source precipitation data, result in a larger range and magnitude of errors for the simulated hydrologic responses to individual storm events than for simulated streamflow at daily or longer time steps. Errors in hourly stormflow simulation are due in part to errors in hourly rainfall estimated by disaggregating daily values. Because of the dependence of certain water-quality characteristics on streamflow conditions, limitations in the hydrologic simulations will affect water-quality simulations, particularly during stormflow conditions at sites draining relatively small areas. In the HSPF model for the adjacent Brandywine Creek Basin, errors commonly were relatively greater at sites draining smaller areas (less than 10 mi^2) than at sites draining larger areas (more than 10 mi^2) (Senior and Koerkle, 2003a). Although the model is intended for high-flow simulations, base-flow water-quality data commonly constitute a large part of water-quality monitoring efforts. Therefore, users should be aware that the oversimulation of base-flow discharge may produce inflated estimates of base-flow constituent loads.

Sensitivity Analysis

A sensitivity analysis was performed to examine the influence of altering selected parameters on streamflow volume simulated by the Christina River subbasin HSPF model. For the analysis, parameters were altered one at a time. To a large extent, the relative sensitivities of the model simulation results to changes in individual parameters are determined by the algorithm in which the parameters are used. However, relative sensitivities also are influenced by the calibrated values of other parameters because of various degrees of interdependence. IMPLND and RCHRES parameters were not included in the sensitivity analysis because they proved to have minimal influence on streamflow volumes during the calibration process. Rather, variations in the timing of stormflow discharges are affected most by varying IMPLND and RCHRES parameters. The sensitivity analysis was limited to the period from October 1, 1994, to September 30, 1995, because HSPEXP will not calculate error statistics if data are missing. The missing 1996 water year observed mean hourly streamflow data thus prevented a longer analysis period.

Selected PERLND parameter values were multiplied by a factor prior to running a simulation while holding all other parameters constant. Typically, application of the multiplication factors resulted in doubling or halving the initial parameter value. In some instances, such as the lower zone evapotranspiration (LZETP) and ground-water recession (AGWRC) parameters, limitations on the range of allowable values prevented doubling or halving the values. In addition, the AGWRC parameter was only decreased because its calibrated value is close to the maximum allowable value. The response of simulated runoff characteristics is listed in table 13.

Total runoff volumes at the Coochs Bridge site show the greatest sensitivity to lower-zone storage (LZSN), upper-zone storage (UZSN), and to the active ground-water recession constant (AGWRC). These parameters influence simulated base flow and ET (UZSN to a lesser extent). Base flow and ET are the largest components of the hydrologic budget, together making up about 75 percent of the total budget.

The 10-percent highest flows are primarily sensitive to the lower zone storage (LZSN) and secondarily sensitive to AGWRC, infiltration (INFILT), and UZSN. These parameters determine the amount of water diverted from the total available for runoff. The 50-percent lowest flows are primarily sensitive to AGWRC and secondarily sensitive to INFILT. These parameters determine the discharge rate from and inflow to ground-water storage.

Seasonal runoff volumes are most sensitive to the active ground-water recession constant (AGWRC). Seasonal runoff volume refers to the differences between summer (June, July, and August) runoff volumes and winter (December, January, and February) runoff volumes. Secondary sensitivity is greatest for INFILT and LZSN. AGWRC determines how rapidly stream base flow diminishes over time after recharge to ground-water storage. Ground-water storage is controlled, in part, by infiltration and water loss to lower-zone storage and evapotranspiration. Recharge to ground-water storage typically exhibits seasonal-

Table 13. *Sensitivity analysis of modeled runoff characteristics at Christina River at Coochs Bridge, Del. (01478000), to variations in selected pervious land (PERLND) parameters for the period October 1, 1994, to September 30, 1995*

[AGWRC, active ground-water recession constant; INFILT, infiltration; LZSN, lower-zone storage; CEPSC, interception storage; UZSN, upper-zone storage; SLSUR, slope of overland flow; NSUR, Manning's n for overland flow; INTFW, interflow; IRC, interflow recession rate; LZETP, lower-zone evapotranspiration]

Parameter	Multiplier	Runoff errors (in percent)						Total inches			
		Total runoff volume	50-percent low flow	10-percent high flow	Seasonal runoff volume	Summer storm volume	Average stormflow peak	Total runoff	Surface runoff	Interflow	Total ET
Calibrated value	1	5.9	6.3	0.5	11.9	13.7	13.7	10.94	4.86	1.08	22.11
AGWRC	0.75	12	-57	17	62	-1.6	16	11.58	4.86	1.08	21.91
INFILT	2	7.5	28	-11	47	31	-4.9	11.11	4.14	0.87	21.78
INFILT	0.5	6	-18	16	24	-8.7	41	10.95	5.89	1.18	22.34
LZSN	2	-25	-26	-25	31	37	-9.1	7.74	4.07	0.52	23.04
LZSN	0.5	27	5.7	33	36	-19	47	13.11	6.03	2.18	20.94
CEPSC	2	2.8	-5.4	-.20	.50	11	14	10.62	4.86	1.06	22.54
CEPSC	0.5	7.7	13	.70	18	14	14	11.13	4.86	1.09	21.81
UZSN	2	-3.2	6.3	-15	36	30	-4.9	10.00	4.27	.73	22.84
UZSN	0.5	12	5.1	12	5.4	.70	30	11.61	5.32	1.46	21.61
SLSUR	2	6.1	5.7	1.3	11	12	16	10.96	4.93	1.05	22.10
SLSUR	0.5	5.8	6.3	-.40	12	15	12	10.93	4.79	1.11	22.13
NSUR	2	5.6	6.9	-1.1	14	17	9.6	10.91	4.71	1.15	22.14
NSUR	0.5	6.2	5.1	2.0	10	12	18	10.97	4.99	1.03	22.10
INTFW	2	6.5	5.7	0	10	21	-.80	11.00	4.27	1.80	22.08
INTFW	0.5	5.2	6.3	2.8	14	5.7	28	10.87	5.49	.28	22.16
IRC[1] [2]	2	5.0	17	-8.0	26	21	14	10.85	4.86	.99	22.11
IRC[1]	0.5	5.9	5.1	3.3	11	11	16	10.94	4.86	1.08	22.11
LZETP[1] [2]	1.25	4.3	2.6	-.8	12	15	14	10.77	4.82	1.04	22.82
LZETP[1]	0.75	8.5	11	2.6	11	11	16	11.21	4.93	1.15	21.29

[1] Included monthly entries.

[2] For IRC & LZETP, when increasing values in UCI file reached or exceeded 1, the value was input as .99 or .9.

ity. Stream base flow modeled with relatively high ground-water recession rates shows or even amplifies the seasonality in ground-water storage, whereas, base flow modeled with relatively low ground-water recession rates suppresses seasonal fluctuations in ground-water storage.

Summer storm volumes show primary sensitivity to LZSN and secondary sensitivity to INFILT. LZSN generally is not considered to have much influence over storm volumes. However, because HSPEXP calculates storm volumes over only whole 24-hour increments, storm volumes for short-duration events, which are more prevalent in the summer, will include more base flow. These base-flow periods are affected by the LZSN parameter.

Peak stormflows were most sensitive to LZSN, which determines the lower-zone storage. The percentage to which the lower-zone storage is filled directly affects the infiltration rate and, therefore, the water available for surface runoff. Peak stormflow was next most sensitive to INFILT, UZSN, and INTFW. INTFW diverts surface runoff into interflow storage. In addition to these PERLND parameters, peak stormflow also is affected by IMPLND parameters, if sufficient IMPLND area exists, and by RCHRES storages as defined in the F-TABLES, which specify relations between depth, surface area, reach volume, and outlflow. As with storm volumes, the choice of storms selected for inclusion into HSPEXP has a substantial effect on the reported peak-stormflow statistics.

Model Limitations

The final calibration of the hydrology component of the HSPF model for the Christina River subbasin satisfies most of the recommended calibration criteria but has limitations. These limitations can be classified as either errors in the input and calibration data or errors in the model structure. Errors in the input data may result from the measurement, interpolation, and extrapolation of precipitation and other climatic data, and discharge and withdrawal rates. Errors in calibration data include those involved in the actual measurement of streamflow or in the transcription of streamflow data. Measurement errors result from equipment malfunction, incorrect data transcription, and other problems, including the presence of ice in the stream channel at or near the measurement site. Specific information required to evaluate random or transitory measurement errors is generally unavailable. Interpolation errors can occur when data is disaggregated to smaller time steps. Extrapolation errors can occur when spatial variations and timing in data are lost by applying localized data to large areas.

Errors resulting from extrapolation, interpolation, and disaggregation of the precipitation data are probably the greatest limitation to achieving the best possible model calibration and simulations. Applying point location data from four raingages to the entire 54-mi^2 basin and disaggregating daily precipitation data to hourly data values introduces substantial errors; stormflow simulations, in particular, have errors in peak flows and total volumes regularly exceeding 100 percent. These errors will translate into the water-quality calibration of the model. In addition, temporal errors in stormflow simulations can be detrimental to the water-quality calibration even if stormflow peaks and volumes are well simulated. The overall effect of these errors is an increase in the average error as the time period of simulation is decreased. Other climatic data such as air temperature, solar radiation, and wind speed are subject to the same type of errors but are less influential factors than precipitation in the streamflow simulation.

Measurement errors in observed streamflow are known and corrected in some instances but unknown and roughly estimated in other instances such as ice-affected streamflow data. In many cases, corrections are limited to daily values and hourly data are left uncorrected or missing. Periods of missing hourly streamflow record were filled with estimated data for the model to calculate statistics. However, the errors associated with this estimated data are unknown. Estimated records are rated as poor and errors greater then 15 percent can be expected (Durlin and Schaffstall, 1999). Errors in observed streamflow data can be expected to affect the statistics used for calibration evaluation and, if severe, lead to incorrect selection of parameter values.

Errors in the model structure are mainly due to limited resolution of PERLND, IMPLND, and RCHRES spatial characteristics and incorrectly specified model parameters. In general, spatial errors result from the loss of local variation in spatial characteristics. Lack of data resolution and the need to limit the complexity of the model structure are the primary reasons for this loss. For example, in the Christina River subbasin model, the number of pervious land-use categories has been limited to 10. In actuality, more than 10 distinct land-use categories exist. Further, each of these PERLND categories is assigned individual calibration parameters that are selected to represent a composite average for that category. In addition, the effective impervious or IMPLND values may depart from the expected averages. For example, in predominantly urban areas such as the Little Mill Creek Basin, the effective impervious area is probably underestimated judging from the simulated streamflow hydrograph. Because of this spatial averaging, the model has limited capability to resolve responses from land uses with limited areal extent or that differ greatly from the average.

Many HSPF parameters are not expressed in terms of known physical behavior, making selection of parameter values somewhat ambiguous and may lead to incorrect specification. For example, the parameter AGWRC is not defined in terms of established ground-water hydrologic characteristics. Also, in the case of the parameter INFILT, published soil permeability values cannot be used directly but only as a guide. Verification of the proper selection of parameters occurs in the calibration process but a satisfactorily calibrated model can be produced with more than one combination of parameters.

SIMULATION OF WATER QUALITY

Suspended sediment and nutrients were simulated for the Christina River subbasin. The simulation included delivery of suspended sediment and nutrients from pervious and impervious land areas to stream reaches and transport and chemical reactions in the stream reaches. The instream simulation of nutrients requires information about stream temperature and dissolved oxygen, both of which were simulated using the model. Stream temperature is an important variable in determining water quality because temperature affects saturation levels of dissolved oxygen and rates of chemical reactions. Dissolved oxygen concentrations affect the extent of chemical reactions involving nutrients, such as nitrification. In HSPF, the simulation of water quality is based on and is an extension of the hydrologic simulation.

The simulation of water quality was undertaken with the following assumptions: (1) land-based contributions of sediment and nutrients could be simulated by a simplified set of land-use categories; (2) water quality could be represented by the condition where chemical transformation of nutrients are simulated explicitly in the stream channel but not in land processes; and (3) the contribution of sediment from bank erosion in the stream channel can be estimated by sediment from pervious land areas.

Calibration

Each land-use category is assigned parameters that affect interflow and ground-water temperature, sediment release, and nutrient contributions from land areas. Stream reaches are assigned parameters that affect the simulation of stream temperature, sediment transport, bed erosion and deposition, and chemical reactions in the stream channel. Individual parameters were adjusted until the simulated water quality was an acceptable match to observed water quality. The computer program GenScn (Kittle and others, 1998), a graphical interface to HSPF, was used for the water-quality calibration.

Suggested guidelines to evaluate sediment and water-quality calibration, including the nutrients nitrogen and phosphorus, in the HSPF model are given in percentage differences between observed and simulated monthly or annual values (table 14) (Donigian and others, 1984). Comparison of loads, rather than instantaneous concentrations, are considered more appropriate when evaluating water-quality simulations of nonpoint-source constituents (Donigian and others, 1984). Comparison of instantaneous concentrations may result in larger apparent differences between observed and simulated values than comparison of loads because of the effect of even small lags (errors) in the timing of storm events. In addition, simulation errors usually are larger for water-quality concentrations than for streamflow.

Table 14. *Suggested criteria to evaluate water-quality calibration for an Hydrological Simulation Program–Fortran (HSPF) model (from Donigian and others, 1984)*

[<, less than]

Constituent	Difference between observed and simulated monthly or annual values, in percent		
Quality of calibration	**Very good**	**Good**	**Fair**
Sediment	<15	15-25	25-35
Water quality (includes nitrogen and phosphorus)	<20	20-30	30-40

Water-quality calibration included stormflow and base-flow conditions. Because the hydrologic part of the model is integral to simulation of water quality, only well-simulated storms would, ideally, be used for calibration of suspended sediment and nutrients. In all cases, however, the simulated storm hydrograph does not replicate the observed storm hydrograph well, especially with respect to peak flows. Therefore, simulated concentrations of suspended sediment, nitrate, ammonia, and phosphorus cannot be expected to exactly replicate observed concentrations for all storms. Calibration was considered satisfactory when the general pattern of simulated streamflow and suspended sediment and nutrients was simulated and when, for better simulated storms, simulated concentrations and loads of suspended sediment and nutrients were within an order of magnitude of observed concentrations and loads. Individual storm errors considerably larger than the recommended criteria of 40 percent or less for monthly or annual values for fair to good water-quality calibration may occur and have little effect on the overall calibration (Donigian and others, 1984). Calibrated values for water-quality parameters are given in the UCI file for Christina River subbasin model (Appendix 3).

Monthly and annual load data were not available to assess calibration errors. Simulated and observed load data for five to six storms in 1998 were used to provide estimates of calibration accuracy. Loads were calculated from measured discharge and constituent concentrations in flow-weighted composite samples collected during storms. However, these limited data do not provide a long-term measure of the accuracy of the model and may include one or more poorly simulated storms or questionable laboratory analyses, which can have a large effect on the apparent accuracy of the model. The calibration error, calculated as (simulated-observed) / observed for the total flow volume or constituent load for the five storms sampled, is listed in table 15. Calibration errors for individual storms at the nonpoint-source monitoring site are listed and discussed in more detail in subsequent sections describing calibration of suspended sediment, nitrogen, and phosphorus. For many, but not all, of these storm events, loads of suspended sediment, nitrogen, and phosphorus were undersimulated when streamflow was undersimulated and oversimulated when streamflow was oversimulated. Dissolved constituents were simulated better than particulate constituents.

Water Temperature

Simulated streamwater temperature was calibrated against data collected at two streamflow-measurement stations in the Christina River subbasin where intermittent water-temperature data were available. Continuous observed water- temperature data were available for the periods January 21, 1998, to October 29, 1998, at the Coochs Bridge station and December 1, 1997, to October 29, 1998, at the Newport station. Intermittent observed instantaneous water-temperature data were available for the period October 1994 to October 1998 at the Coochs Bridge station. Comparisons of simulated and observed continuous daily mean water temperature at the two streamflow-measurement stations (fig. 22) show good agreement between simulated and observed water temperature over the observed range of 0 to 25°C except for the period of September and October 1998. During this period, simulated water temper-

Table 15. *Cumulative calibration errors in flow volume and constituent loads for selected storms in 1998 at two nonpoint-source monitoring sites in the Christina River subbasin, 01478000, Christina River at Coochs Bridge, Del., and 01480095, Little Mill Creek near Newport, Del.*

Site	Number of storms	Cumulative calibration error for selected storm simulations in 1998, in percent[1]						
		Streamflow volume	Suspended-sediment load	Nitrate load	Dissolved ammonia load	Particulate ammonia load	Dissolved ortho-phosphate load	Particulate phosphorus load[2]
Little Mill Creek near Newport, Del.	6	2	1	-38	-31	83	-51	-62
Christina River at Coochs Bridge, Del.	5	-2	102	5	21	-67	-33	-41

[1] Percentage calibration error = 100 × [(simulated-observed) / observed].

[2] One fewer storm was available for comparison because total phosphorus was not analyzed in the October 1998 storm.

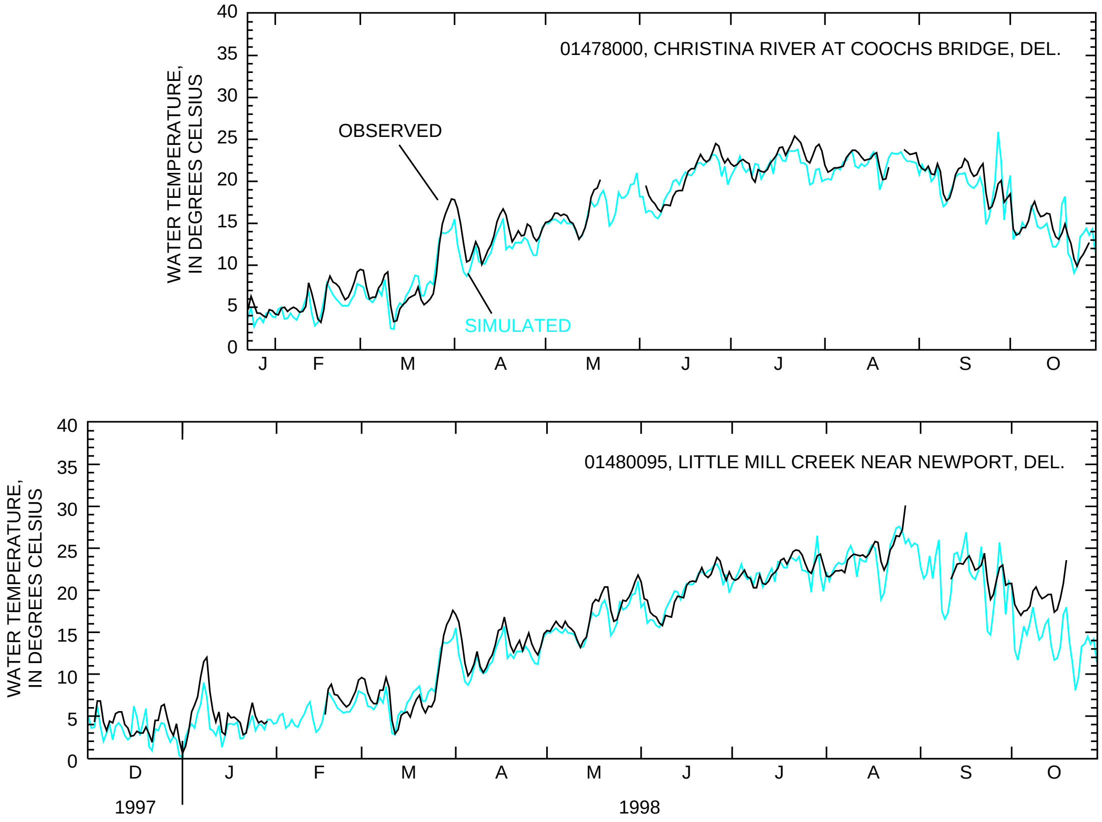


Figure 22. Simulated and observed daily mean water temperature at streamflow-measurement stations 01478000, Christina River at Coochs Bridge, Del., and 01480095, Little Mill Creek near Newport, Del.

atures fluctuated considerably more than observed water temperatures. This excessive fluctuation in simulated water temperatures appears to be the result of an instability in the HSPF model when water volume in a reach approaches the lower limits. During the late summer and early fall of 1998 after prolonged lack of rainfall, simulated streamflow decreased to the point of instability. Comparison of observed instantaneous water temperatures to simulated mean hourly water temperatures (fig. 23) also shows generally good agreement between simulated and observed values. Thirty-nine of 43 instantaneous measurements were within 4°C of the observed temperature. Because water temperature affects the rate of chemical reactions and biological processes involving nutrients in the stream, errors in the temperature simulation will affect calibration of the nutrient simulation to some extent.

Sediment

Calibration of suspended sediment in the stream channel largely is done by adjusting parameters affecting soil detachment, soil washoff, and soil scour processes for pervious land surfaces, solids build up and washoff processes for impervious land surfaces, and sediment transport in the channel, including deposition on and scour of the channel bottom controlled by setting shear stress regimes. Sediment in streams may be derived from land areas, streambanks, and beds. For the calibration, no net erosion of streambeds was assumed to occur over the simulation period and therefore the principal sources of sediment were assumed to be land areas and streambanks. Because the HSPF model does not include the process of bank erosion, sediment from streambanks was estimated by simulating scour in pervious land areas. Simulated concentrations of suspended sediment were evaluated against total suspended-solids data collected

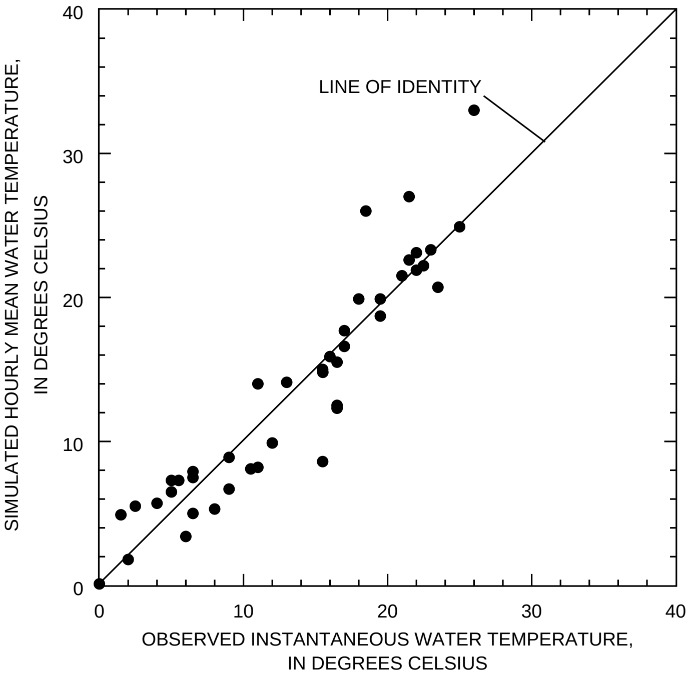


Figure 23. Simulated hourly mean and observed instantaneous water temperature at streamflow-measurement station 01478000, Christina River at Coochs Bridge, Del., October 1994–October 1998.

by USGS in 1998 at two nonpoint-source monitoring sites, 01480095, Little Mill Creek near Newport and 01478000, Christina River at Coochs Bridge, and data collected monthly and bi-monthly by DNREC from 1994-98 at sites in Delaware.

The results of suspended-sediment simulation at Little Mill Creek near Newport provide information about sediment yields from a predominantly urban drainage area. The results of suspended-sediment simulation at Christina River at Coochs Bridge provide a measure of the overall model accuracy on a basin-wide scale. Instantaneous concentrations of suspended solids were measured for six storms and four base-flow events in 1998. Reported concentrations of suspended solids (nonfilterable material) were considered estimates for suspended-sediment concentrations. Suspended-solids concentrations are not always accurate estimates of suspended-sediment concentrations and tend to be biased low, especially for conditions when sand-sized particles represent more than 25 percent of suspended sediment (Gray and others, 2000). When suspended solids are used as a surrogate for suspended-sediment concentrations, the resulting errors in load computations can be as large as several orders of magnitude (U.S. Geological Survey, 2000). As noted earlier, only well-simulated storms (simulation error less than 20 percent for storm peaks, for example) would, ideally, be used for calibration of suspended sediment. In many cases, storms were not well simulated. Observed and simulated streamflow and suspended sediment for the six sampled storms at Little Mill Creek near Newport and the five sampled storms at Christina River at Coochs Bridge are shown in figures 24 and 25. Streamflow is undersimulated and oversimulated for the sampled storms at the two sites. Some storms are not simulated well probably because of errors in the estimated hourly precipitation record. Simulated streamflow poorly replicates the occurrence of the May 1998 storm for Little Mill Creek near Newport and misses the July 1998 storm for Christina River at Coochs Bridge. For the storms that are relatively well simulated, the simulated hourly mean suspended-sediment concentrations range from less than, similar to, and greater than observed concentrations of suspended solids in discrete samples collected during those storms. The simulated sharp rise in suspended-sediment concentrations near

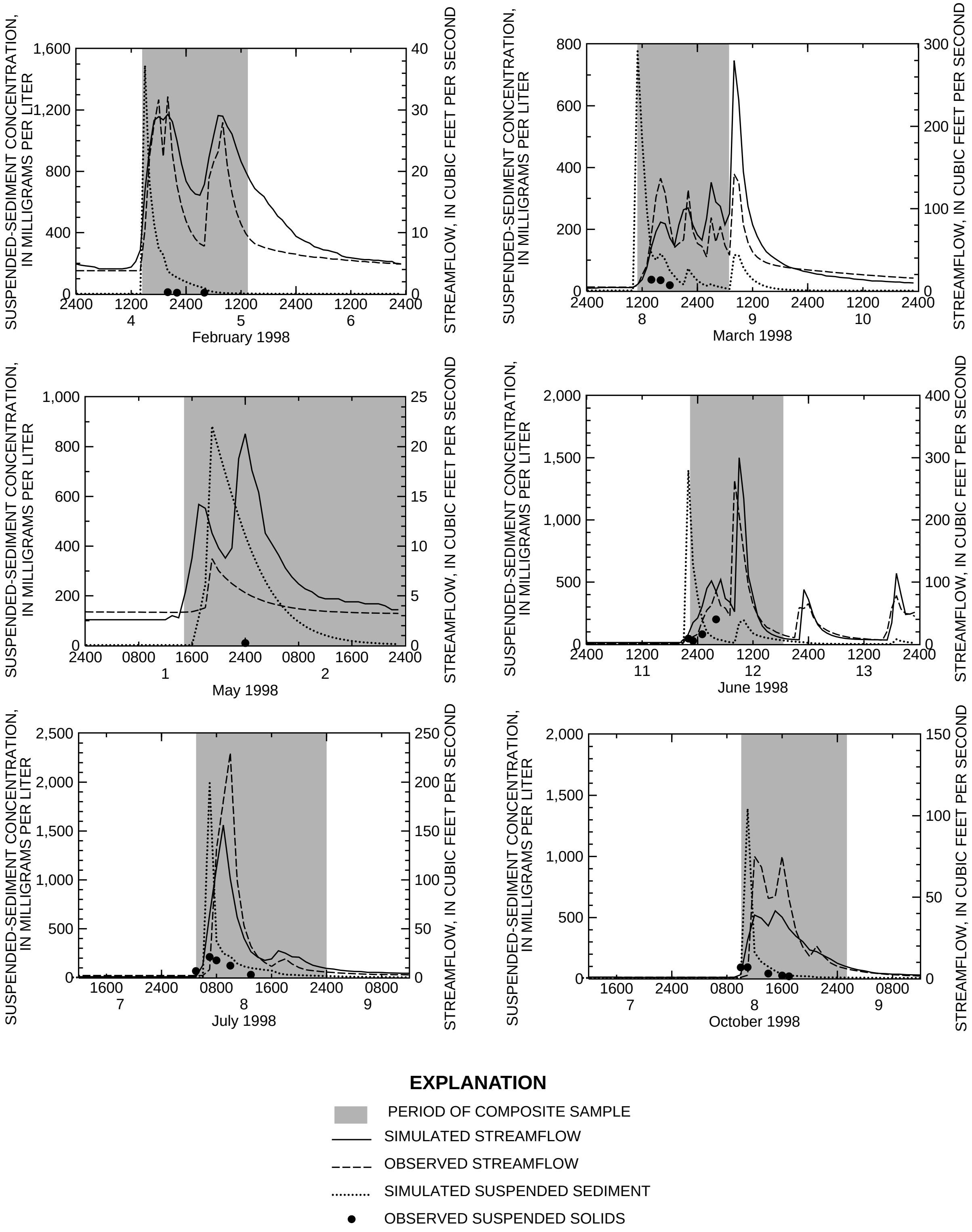


Figure 24. Simulated and observed streamflow and concentrations of suspended sediment and period of composite sample during six storms in 1998 at streamflow-measurement station 01480095, Little Mill Creek near Newark, Del.

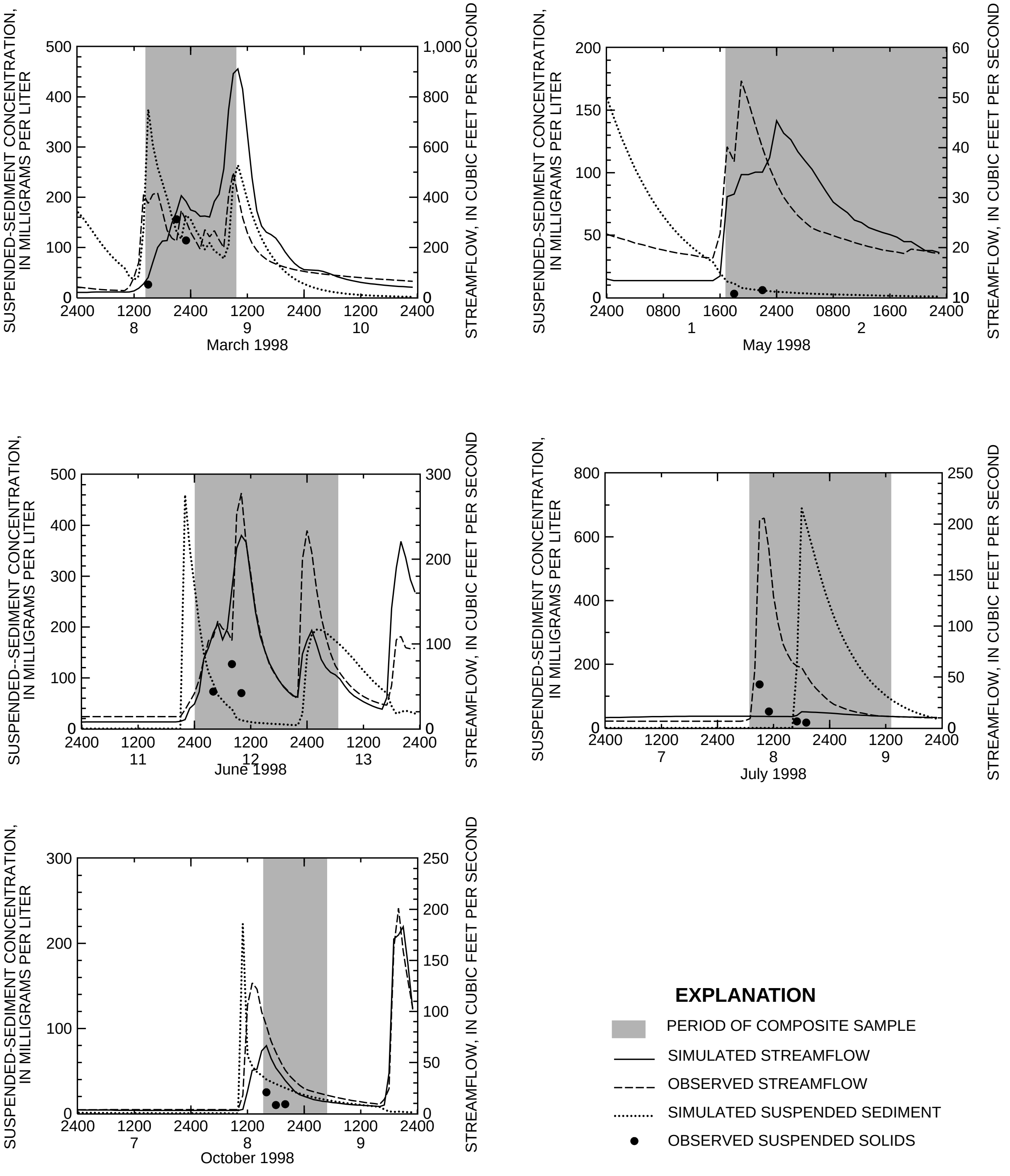


Figure 25. Simulated and observed streamflow and concentrations of suspended sediment and period of composite sample during five storms in 1998 at streamflow-measurement station 01478000, Christina River at Coochs Bridge, Del.

the beginning of the rise of streamflow in each storm is not supported by the few observed data for these periods, which may be due to errors in washoff simulation and (or) to in-stream scouring and hydraulic simulations.

Composite samples collected during storms at the two nonpoint-source monitoring sites in the Christina River subbasin in 1998 allow comparison of simulated and observed loads for the periods monitored. Peak flows were greatest in the March 1998 storm and least in the May 1998 storm (table 16). For the sampled storm periods, storm volume is under- and oversimulated and suspended-sediment loads tend to be oversimulated. For Little Mill Creek near Newport, the difference between observed and simulated streamflow ranged from -49 to 33 percent for individual storms and was 2 percent for the total of all storms. The difference between observed and simulated suspended-sediment loads ranged from -43 to 579 percent for individual storms and was 1 percent for the total of all storms. For Christina River at Coochs Bridge, the difference between observed and simulated streamflow ranged from -83 to 68 percent for individual storms and was -2 percent for the total of all storms. At that site, the difference between observed and simulated suspended-sediment loads ranged from -47 to 452 percent for individual storms and was 102 percent for the total of all storms.

Comparison of simulated and observed values (table 16) for about half of the storms sampled at the two sites indicates that when flow is undersimulated or oversimulated, loads of suspended sediment also are undersimulated or oversimulated, respectively. For example, in a case of oversimulation for the July 1998 storm at Little Mill Creek near Newport, the error was 13 percent for simulated streamflow and 43 percent for simulated suspended-sediment load. In a case of undersimulation for the July 1998 storm at Christina River at Cooches Bridge, the error was -83 percent for simulated streamflow and -47 percent for simulated suspended-sediment load. The error in simulated streamflow contributes to the overall error in simulated loads. The magnitude and sign of the percent error in streamflow can be compared to the magnitude and percent error in load to indicate whether

Table 16. *Simulated and observed streamflow and loads of suspended sediment for storms sampled in 1998 at the nonpoint-source monitoring sites 01480095, Little Mill Creek near Newport, Del., and 01478000, Christina River at Coochs Bridge, Del.*

[ft^3/s, cubic feet per second]

Dates of storm sampling	Peak discharge[1] (ft^3/s)	Streamflow (millions of cubic feet)			Suspended-sediment load (tons)		
		Simulated	Observed	Percentage difference[2]	Simulated	Observed	Percentage difference[2]
Little Mill Creek near Newport, Del.							
February 4-5	29.1	1.48	2.06	-23	8.52	2.06	313
March 8-9	132	4.79	4.99	-4	11.7	9.94	18
May 1-2	21.3	.51	1.00	-49	4.27	.63	579
June 11-12	264	5.67	4.94	15	25.8	45.2	-43
July 8-9	156	3.13	2.76	13	21.7	15.1	43
October 8-9	41.6	1.74	1.31	33	4.78	3.90	45
Total - all storms		17.3	17.1	2	76.7	76.3	1
Christina River at Coochs Bridge, Del.							
March 8-9	747	21.08	22.10	-5	111	46.1	142
May 1-3	45.4	3.60	2.14	68	.48	.40	18
June 11-13	228	12.58	10.53	19	28.9	13.3	116
July 8-9	206	.86	5.13	-83	7.88	14.8	-47
October 8-9	66.5	2.58	1.68	54	2.93	.53	452
Total - all storms		40.69	41.57	-2	151	75.1	102

[1] Peak mean hourly discharge during period of composite sampling.

[2] 100 × (simulated-observed)/observed.

water-quality concentrations are under- or over-simulated. The nonlinear relation between streamflow and sediment accounts for some of the differences in errors for streamflow and suspended-sediment simulations. Suspended-sediment simulation is dependent on accuracy of precipitation data and the flow simulation and has a large degree of variability.

Simulated concentrations of suspended sediment under base-flow conditions were within a factor of 10 of observed concentrations for half of the samples at the two nonpoint-source monitoring sites (fig. 26). For all base-flow samples, streamflow was well simulated, as shown in figure 26. Differences larger than an order of magnitude between observed suspended solids and simulated suspended-sediment concentrations were associated with an April 1998 sample at Little Mill Creek near Newport and September 1998 samples at both sites. The April 1998 sample was collected the day after a storm and a lag in the simulated storm peak resulted in an incorrect lag in the simulated suspended-sediment peak concentrations. No large storms occurred before the collection of the September 1998 samples, but unexpectedly, the highest observed concentrations of suspended solids were in samples collected during the lowest base-flow conditions in September 1998 at the two sites and the source of error for simulated suspended sediment is unknown or possibly related to sample collection or processing.

Instantaneous loads, calculated from measured streamflows at two USGS streamflow-measurement stations and suspended-solids concentrations in grab samples collected monthly or bimonthly by DNREC near those stations also were used to evaluate model calibration. Differences in location of sample-collection site and streamflow-measurement site may result in inaccurate characterization of water quality at the streamflow-measurement location. Therefore, the comparison of simulated and observed concentrations and loads must be considered to have substantial amounts of uncertainty. Samples were collected at the DNREC site Christina River at Old Baltimore Pike, which is upstream of the streamflow-measurement station 01478000, Christina River at Coochs Bridge. Samples also were collected at the DNREC site Little Mill Creek at Atlantic Avenue, which is downstream of the streamflow-measurement station 01480095, Little Mill Creek near Newport. However, because of a large stormwater discharge outfall between the

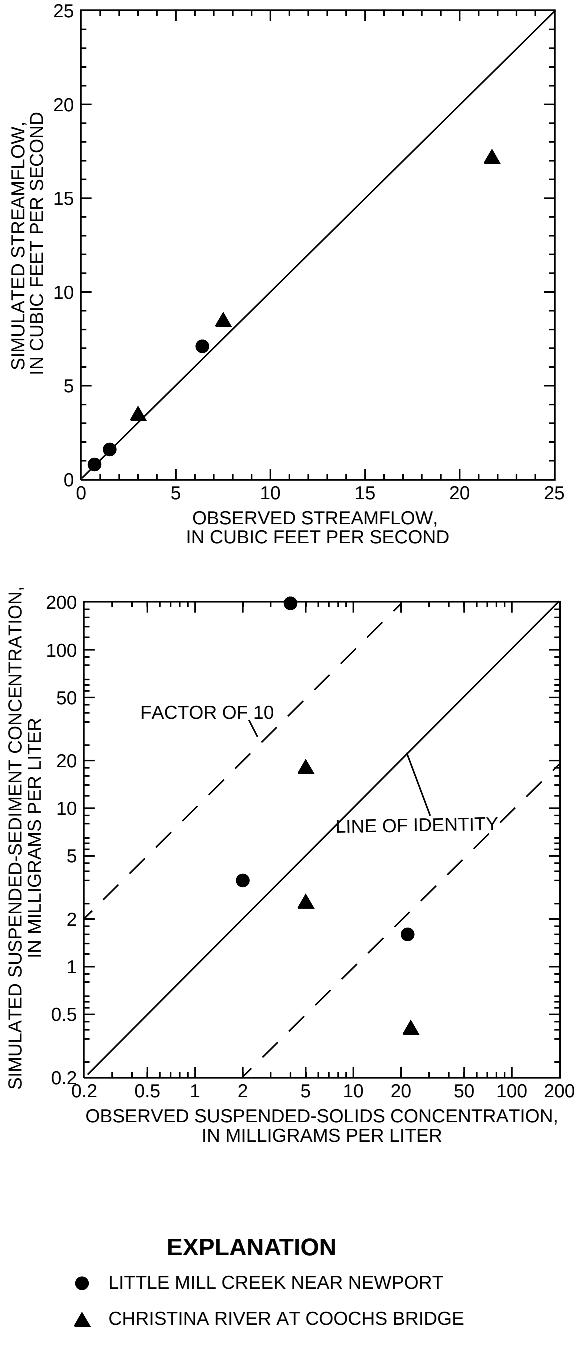


Figure 26. Simulated hourly mean streamflow and suspended-sediment concentrations and observed instantaneous streamflow and total suspended-solids concentrations under base-flow conditions at monitoring site 01480095, Little Mill Creek near Newport, Del., and 01478000, Christina River at Coochs Bridge, Del., 1998.

streamflow-measurement station and the DNREC sampling site at Atlantic Avenue, the DNREC samples may not be representative of water-quality upstream of the stormwater discharge outfall during stormflow conditions. The instantaneous streamflows were fairly well simulated at the Christina River at Coochs Bridge site (fig. 27), with a median difference between simulated and observed streamflows of 12 percent. At the Christina River at Coochs Bridge site, many simulated suspended-sediment instantaneous loads were within an order of magnitude (or factor of 10) of observed loads of suspended solids, and in some cases, were two or more orders of magnitude larger or smaller than observed loads (fig. 27). Most of the grab samples were collected from October 1994 through October 1998 under moderate to low-flow conditions, although a few samples were collected under relatively high-flow conditions. The median percent difference between simulated suspended-sediment loads and observed suspended-solids loads was -80 percent at streamflow-measurement station 01478000 and -8 percent at streamflow-measurement station 01480095. Although data on monthly and annual loads of suspended sediment are not available, the median of instantaneous loads at the these stations provides an estimate of the adequacy of the sediment calibration as worse than ‘fair’ to ‘good’ using guidelines described by Donigian and others (1984).

In summary, the quality of the suspended-sediment calibration ranges from less than ‘fair’ (more than 35 percent error) to ‘good’ (15-25 percent error) for individual storms using criteria from Donigian and others (1984). Simulated instantaneous suspended-sediment loads estimated at one long-term fixed time-interval site commonly were within one order of magnitude of observed loads of suspended solids but were sometimes different by larger amounts. These results indicate the range of variability that might be expected in simulating individual storms or instantaneous values. Additional apparent sources of error may be associated with the use of total suspended-solids concentration as a surrogate for suspended-sediment concentration, which can underestimate the suspended sediment by up to several orders of magnitude, especially for sediment loads with greater than 25 percent sand-sized particles. Comparison of the observed and simulated suspended-sediment concentration duration curves in the HSPF model for the adjacent Brandywine Creek subbasin suggests that over relatively long time periods (5 years or more), the model results are statistically similar to observed data (Senior and Koerkle, 2003a). This would also be the expected case in the Christina River subbasin.

Simulated yields of sediment differ by land use and vary with precipitation from year to year (table 17). Simulated yields of sediment by land use were similar in the three segments (tables 17 and 18) and are within the ranges reported for equivalent land-use types by Dunne and Leopold (1978, p. 520-522). Most of the simulated sediment yield was from agricultural land-use areas. Using pervious-land scour as an estimate of bank erosion, the average simulated amount of sediment removed by scour for the years 1994-97 differed among land uses and ranged from 0 to 13 percent of the total sediment yield. The highest percentage of sediment yield produced by scour was in urban and sewered residential land uses (median values of 8 and 5 percent, respectively) and the lowest was in forested and wetland land uses (median values of 0 percent). In areas of agricultural land use, the range of average simulated scour (bank erosion) was about 1 to 3 percent of total sediment yield for 1994-97 and appears to be slightly lower or similar to estimates obtained elsewhere. In a study of sediment sources in two agricultural basins in the United Kingdom, bank erosion was estimated to contribute about 10 percent or less of the sediment yield (Russell and others, 2001).

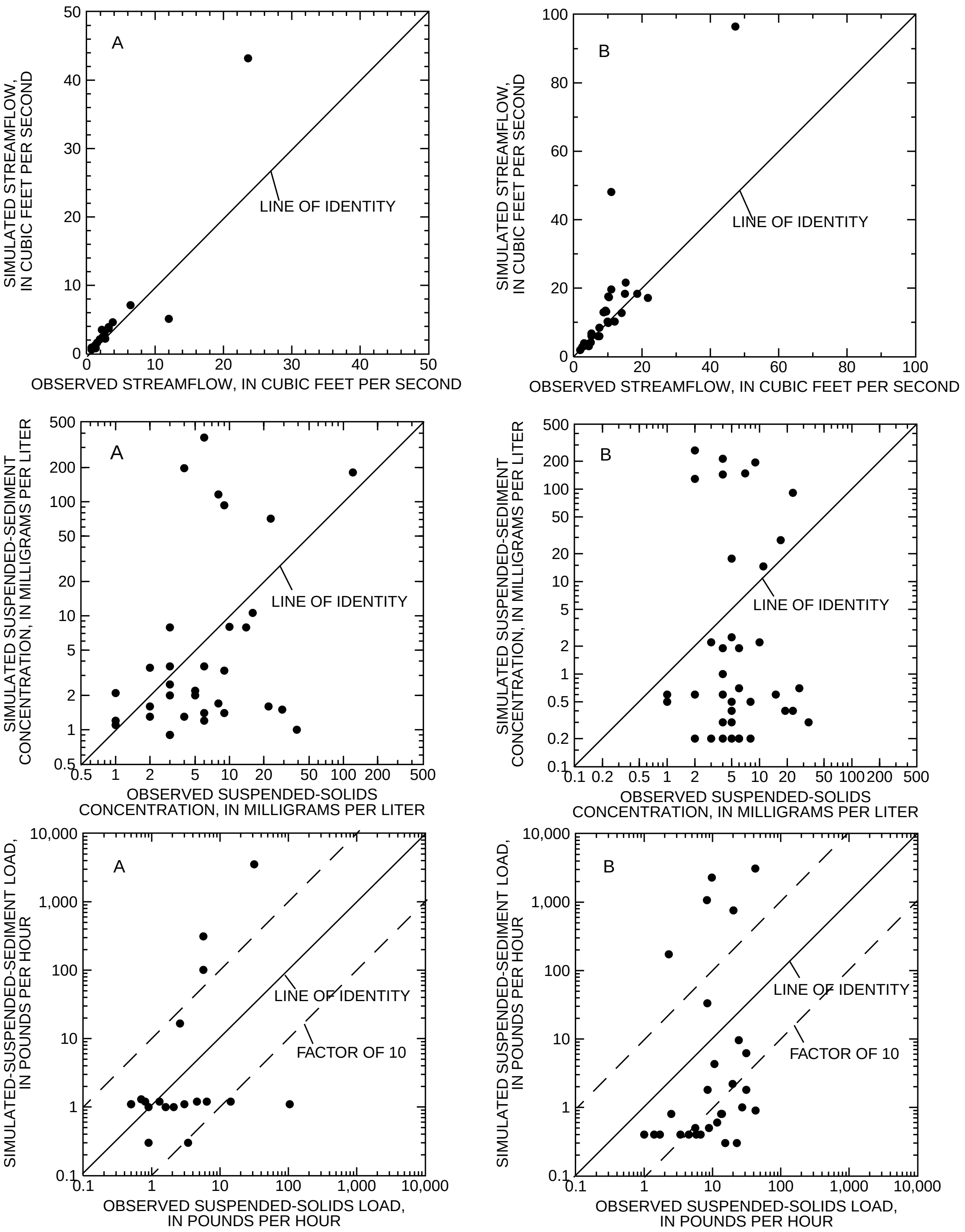


Figure 27. Comparison of simulated hourly mean streamflow, suspended-sediment concentrations and suspended-sediment loads to observed instantaneous streamflow, total suspended-solids concentrations and hourly mean suspended-sediment loads at streamflow-measurement stations (A) 01480095, Little Mill Creek near Newport, Del., and (B) 01478000, Christina River at Coochs Bridge, Del., October 1994–October 1998. Observed suspended-solids data for Little Mill Creek at Atlantic Avenue and Christina River at Old Baltimore Pike from Delaware Department of Natural Resources and Environmental Control were used to estimate observed suspended-sediment concentrations at near Newport and Coochs Bridge stations.

Table 17. *Observed annual precipitation and simulated annual sediment yields by land use for three segments of Hydrological Simulation Program–Fortran (HSPF) model for Christina River subbasin, 1995-97*

	Year				
	Segment	**1995**	**1996**	**1997**	**1995-97 average**
Precipitation (inches)	5,8	38.1	56.9	34.7	43.2
Simulated sediment yield (tons per acre per year) by land-use category[1]					
Residential - unsewered	5	.15	.389	.035	.191
Residential - sewered	5	.203	.524	.047	.258
Urban	5	.427	.704	.073	.401
Agricultural - animal/crop	5	1.46	2.44	.586	1.495
Agricultural - row crop	5	1.44	2.43	.563	1.478
Agricultural - mushroom	5	1.44	2.45	.489	1.460
Forested	5	.052	.153	.012	.072
Open	5	.216	.550	.0496	.272
Wetlands/water	5	.003	.009	.001	.004
Undesignated	5	.214	.547	.049	.270
Impervious - residential	5	.113	.118	.118	.116
Impervious - urban	5	.657	.682	.68	.673
Simulated sediment yield (tons per acre per year) by land-use category[1]					
Residential - unsewered	8	.181	.338	.037	.185
Residential - sewered	8	.258	.471	.053	.261
Urban	8	.500	.576	.060	.379
Agricultural - animal/crop	8	1.52	2.32	.547	1.462
Agricultural - row crop	8	1.51	2.3	.524	1.445
Agricultural - mushroom	8	1.54	2.32	.492	1.451
Forested	8	.007	.132	.011	.050
Open	8	.263	.477	.054	.265
Wetlands/water	8	.003	.007	.0004	.003
Undesignated	8	.262	.477	.054	.264
Impervious - residential	8	.113	.118	.118	.116
Impervious - urban	8	.656	.681	.682	.673
Precipitation (inches)	9	38.0	49.7	26.5	38.1
Simulated sediment yield (tons per acre per year) by land-use category[1]					
Residential - unsewered	9	.142	.124	.00184	.089
Residential - sewered	9	.358	.223	.00479	.195
Urban	9	.482	.289	.0092	.260
Agricultural - animal/crop	9	1.05	.903	.0133	.655
Agricultural - row crop	9	1.04	.854	.0116	.635
Agricultural - mushroom	9	1.11	1.01	.0215	.714
Forested	9	.0057	.007	.00003	.004
Open	9	.181	.155	.00245	.113
Wetlands/water	9	.00065	.00056	.000005	.000
Undesignated	9	.178	.153	.00233	.111
Impervious - residential	9	.117	.113	.114	.115
Impervious - urban	9	.679	.656	.662	.666

[1] In pervious areas, unless noted.

Table 18. *Observed annual precipitation and simulated average annual sediment yield by land use for pervious and impervious land areas in three segments of Hydrological Simulation Program–Fortran (HSPF) model for Christina River subbasin, 1995-97*

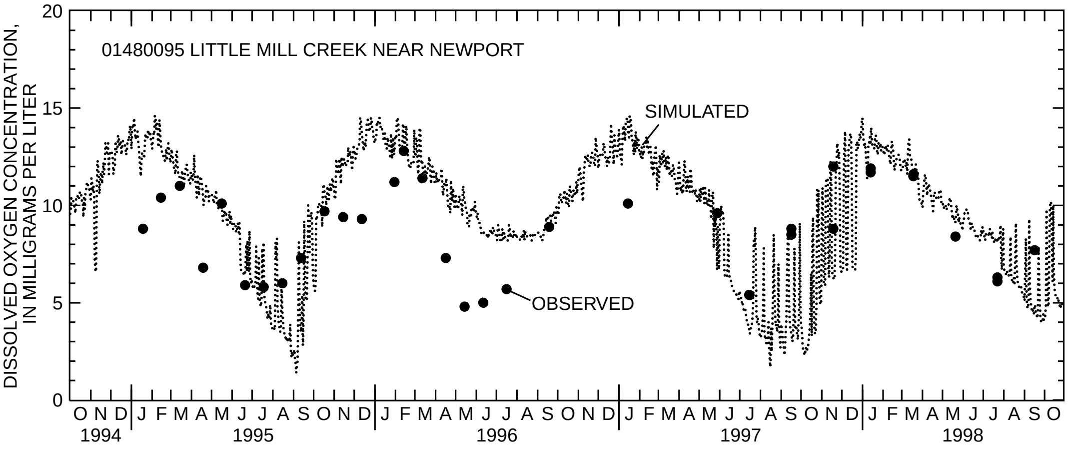
	1995-97 Average			
	Segment 5	Segment 8	Segment 9	Average of all segments
Precipitation (inches)	43.2	43.2	38.1	41.5
Average sediment yield (tons per acre per year) by land-use category[1]				
Residential - unsewered	.191	.185	.089	.155
Residential - sewered	.258	.261	.195	.238
Urban	.401	.379	.260	.347
Agricultural - animals / crops	1.50	1.46	.655	1.20
Agricultural - row crop	1.48	1.45	.635	1.19
Agricultural - mushroom	1.46	1.45	.714	1.21
Forested	.072	.050	.004	.042
Open	.272	.265	.113	.216
Wetlands / water	.004	.003	.000	.003
Undesignated	.270	.264	.111	.215
Impervious - residential	.116	.116	.115	.116
Impervious - urban	.673	.673	.666	.671

[1] In pervious areas, unless noted.

Dissolved Oxygen and Biochemical Oxygen Demand

Dissolved oxygen and biochemical oxygen demand (BOD) must be simulated to simulate nutrients in the stream. The simulation of dissolved oxygen included the in-stream effects of air and water temperature, reaeration, advection, and algal activity (photosynthesis and respiration). Oxygen concentrations were simulated in land-surface runoff and were fixed in interflow and ground water. Dissolved-oxygen concentration data collected intermittently near two streamflow-measurement stations in the Christina River subbasin were used to evaluate the dissolved-oxygen simulation. To reproduce the temporal pattern of diurnal fluctuations in dissolved oxygen concentrations observed at three continuous monitoring sites on the Brandywine Creek, simulation of plankton was needed (Senior and Koerkle, 2003a) and, therefore, simulation of periphyton and phytoplankton was included in the water-quality modeling for the Christina River subbasin. The simulation of BOD from nonpoint sources included transport of BOD from land to streams and in-stream processes of BOD decay, settling, and advection. Concentrations of BOD in the soil (sediment), interflow, and ground water were fixed in amounts that differed by land use. Estimates of BOD in soil, interflow, and ground water were derived from an HSPF model of the Pautuxent River Basin in northeastern Maryland (Stephen Preston, U.S. Geological Survey, written commun., 1995). BOD concentration data from the analysis of grab and composite stream samples collected at the nonpoint-source monitoring site were used to evaluate the BOD simulation.

The general pattern of seasonal changes in dissolved oxygen concentrations was simulated by the model with varying degrees of accuracy, as shown in figure 28 for the data collected near the streamflow-measurement stations 01480095, Little Mill Creek near Newport, Del., and 01478000, Christina River at Coochs Bridge, Del. The monthly DNREC water-quality data were collected near, but not at, the streamflow-measurement stations and therefore may not accurately represent water quality at those stations. Simulated concentrations of dissolved oxygen tended to be higher than observed concentrations at Christina River at Coochs Bridge, especially in the summer months (fig. 28). The diurnal fluctuation in concentrations of dissolved oxygen attributed to processes of algal photosynthesis and respiration becomes more pronounced in the summer months than at other times of the year.



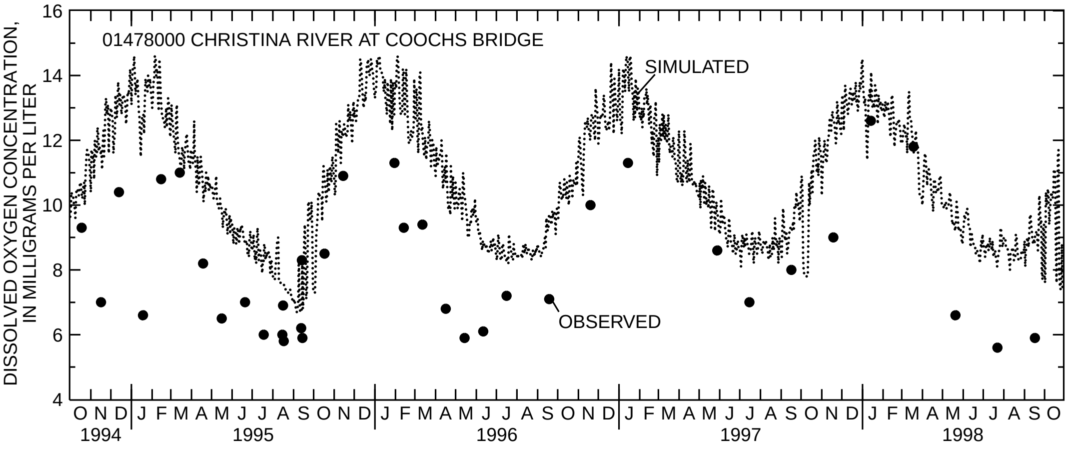


Figure 28. Simulated daily mean dissolved oxygen concentrations at streamflow-measurement stations 01480095, Little Mill Creek near Newport, Del., and observed instantaneous dissolved-oxygen concentrations at water-quality monitoring site 106281, Little Mill Creek at Atlantic Avenue (top), and simulated daily mean dissolved oxygen concentrations at streamflow-measurement station 01478000, Christina River at Coochs Bridge, Del., and observed instantaneous dissolved oxygen concentrations at water-quality monitoring site 106141, Christina River at Old Baltimore Pike (bottom), October 1994–October 1998. (Water-quality data from Delaware Department of Natural Resources and Environmental Control.)

At Little Mill Creek near Newport, the difference between simulated hourly mean and observed instantaneous oxygen concentrations (measured at Little Mill Creek at Atlantic Avenue) ranged from -59 to 86 percent [100 x (simulated - observed)/observed] and the average difference was 13 percent for 35 observations made from October 1994 through October 1998. At Christina River at Coochs Bridge, the difference between simulated hourly mean and observed instantaneous oxygen concentrations (measured upstream at Old Baltimore Pike) ranged from -19 to 71 percent and the average difference was 33 percent for 37 observations made from October 1994 through October 1998. These results indicate that dissolved oxygen concentration tends to be slightly to moderately oversimulated at the Little Mill Creek near Newport and Christina River at Coochs Bridge sites (fig. 29).

The simulation of phytoplankton in the Christina River subbasin was evaluated using chlorophyll-*a* concentration data for grab samples collected under base-flow conditions in 1998 as part of the nonpoint-source monitoring at two sites and over a range of hydrologic conditions in 1994-98 as part of state monthly monitoring at two streamflow-measurement stations in Delaware. Evaluation of the limited data collected and simulated results under base-flow conditions indicates that concentrations of chlorophyll *a* are undersimulated at both sites and the undersimulation is more pronounced at the Christina River at Coochs Bridge site than at the Little Mill Creek near Newport site (fig. 30). Although the model apparently fails to adequately simulate chlorophyll *a* at the Coochs Bridge site in particular, observed concentrations at that site typically were low (8 mg/L or less), and the performance of the model in simulating nutrient concentrations probably is not affected to a great extent by undersimulation of in-stream algal processes. The relative amounts of undersimulation at the two sites also are shown by the larger amount of data collected under state monitoring at nearby locations (fig. 30). The highest concentration of chlorophyll *a* was measured in the samples at the two sites collected under the highest flow conditions of all samples and may include chlorophyll *a* from sources (such as periphyton) disturbed by high-flow conditions.

Samples for BOD analysis were collected under stormflow and base-flow conditions in 1998 at the two nonpoint-source monitoring sites, 01480095, Little Mill Creek near Newport, Del.,

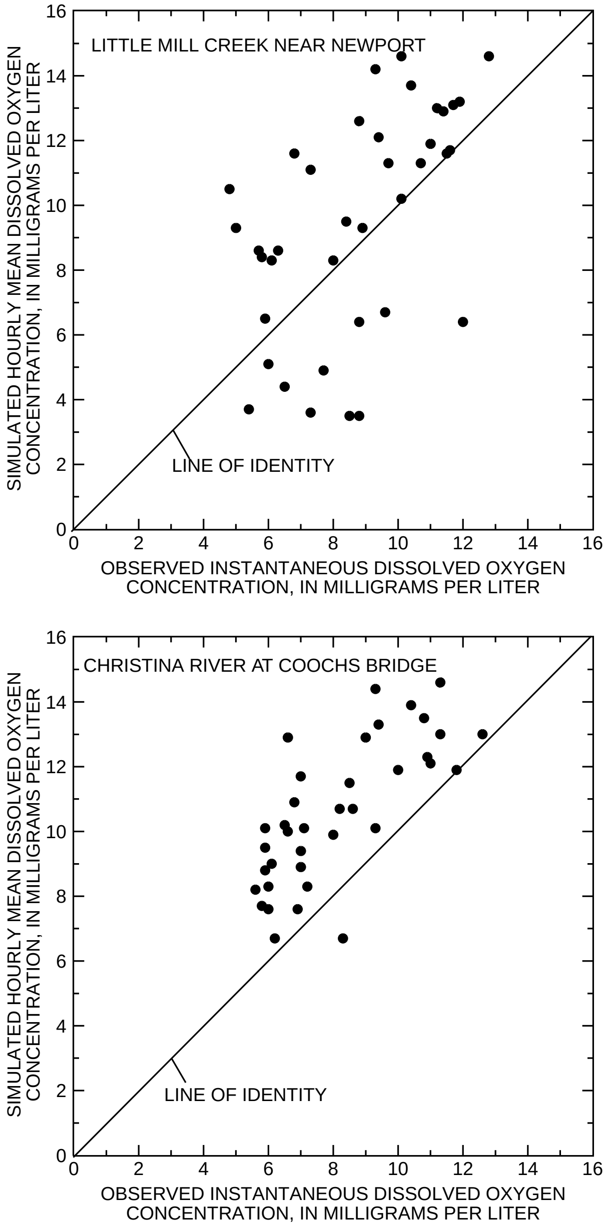


Figure 29. Simulated hourly mean dissolved oxygen concentrations at streamflow-measurement stations 01480095, Little Mill Creek near Newport, Del. (top), and observed instantaneous dissolved oxygen concentrations at water-quality monitoring site 106281, Little Mill Creek at Atlantic Avenue (top), and simulated hourly mean dissolved oxygen concentration at streamflow-measurement station 01478000 Christina River at Coochs Bridge, Del., and observed instantaneous dissolved oxygen concentrations at water-quality monitoring site 106141, Christina River at Old Baltimore Pike (bottom), October 1994–October 1998. (Water-quality data from Delaware Department of Natural Resources and Environmental Control.)

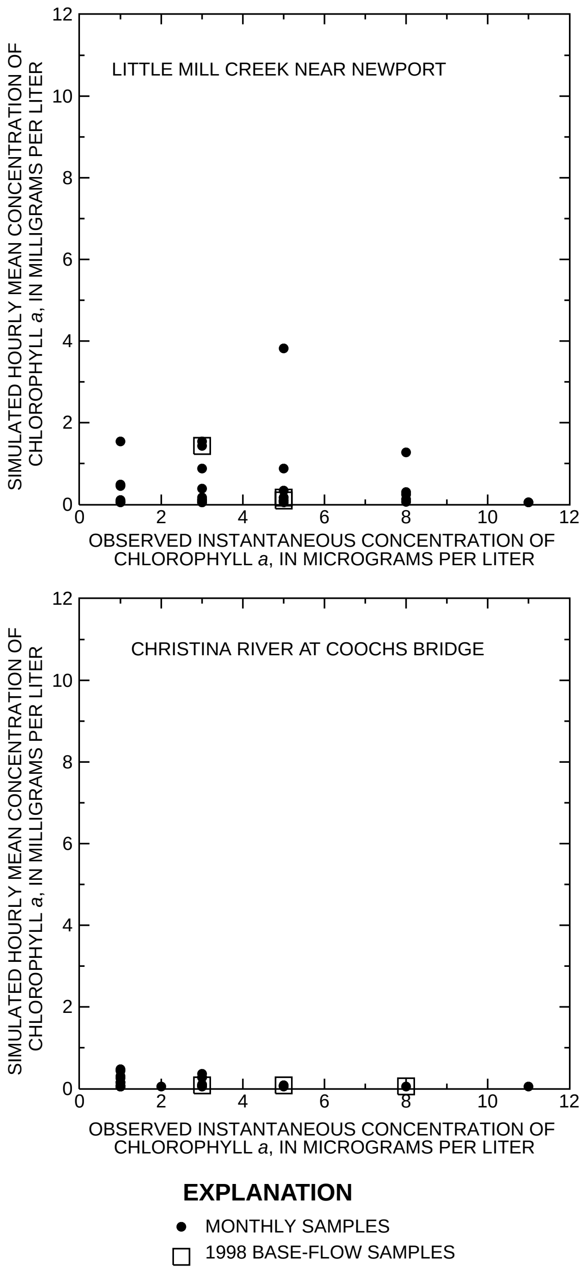


Figure 30. Simulated hourly mean chlorophyll-*a* concentrations at streamflow-measurement stations 01480095, Little Mill Creek near Newport, Del., and observed instantaneous dissolved oxygen concentrations at water-quality monitoring site 106281, Little Mill Creek at Atlantic Avenue (top), and simulated hourly mean chlorophyll-*a* concentrations at streamflow-measurement station 01478000, Christina River at Coochs Bridge, Del., and observed instantaneous chlorophyll-*a* concentrations at water-quality monitoring site 106141, Christina River at Old Baltimore Pike (bottom), October 1994–October 1998. (Water-quality data from Delaware Department of Natural Resources and Environmental Control.)

and 01478000, Christina River at Coochs Bridge, Del. Comparison of simulated and observed BOD loads under stormflow conditions indicates that BOD is undersimulated often when stormflow is undersimulated and often oversimulated when stormflow is oversimulated for storms at the two sites (table 19). Errors in BOD simulation may result in undersimulation or oversimulation of BOD decay and consequent oxygen depletion. The amount of oxygen in the stream reach can affect the extent of nitrification and denitrification reactions. No bias in the simulation of BOD under base-flow conditions was apparent for the limited number of samples (fig. 31). Concentrations of BOD in some of the samples collected in 1998 under base-flow conditions were reported as less than the detection level of 2.4 mg/L (fig. 31).

Concentration data in grab samples collected monthly by DNREC near two streamflow-measurement stations under a range of hydrologic conditions also were used to evaluate the simulation of BOD. As noted earlier, most of the samples were collected under moderate or base-flow conditions. The DNREC water-quality data were collected near but not at the streamflow-measurement stations and therefore may not accurately represent water quality at those stations. The average difference between simulated and observed BOD concentrations was -15 percent for Little Mill Creek and 5 percent for Christina River at Coochs Bridge (fig. 31). This pattern of differences between simulated and observed concentrations is the converse of the dissolved oxygen simulation. Apparent error trends in BOD and dissolved oxygen simulations may result in part from the inverse relation between these constituents. Errors in load estimates of BOD from point sources and nonpoint sources may contribute to overall errors of BOD in-stream concentrations.

Overall, the simulation of oxygen-related constituents results in ‘fair’ estimates of dissolved oxygen concentrations that are needed for the in-stream simulation of nutrients. Errors in the simulation of BOD and plankton affect the simulation of in-stream dissolved oxygen concentrations. Undersimulation of BOD would result in oversimulation of dissolved oxygen. Undersimulation of plankton could result in the undersimulation of dissolved oxygen during the day, when photosynthesis occurs, and oversimulation of dissolved oxygen during the night, when respiration processes are dominant. Further, undersimulation of plankton could affect the simulations of in-stream concentra-

Table 19. *Simulated and observed streamflow and loads of biochemical oxygen demand for storms sampled in 1998 at the two nonpoint-source monitoring sites, 01480095, Little Mill Creek near Newport, Del., and 01478000, Christina River at Coochs Bridge, Del.*

[BOD, biochemical oxygen demand; ft^3/s, cubic feet per second]

Dates of storm sampling	Peak discharge[1] (ft^3/s)	Streamflow (millions of cubic feet)			BOD load (tons)		
		Simulated	Observed	Percentage difference[2]	Simulated	Observed	Percentage difference[2]
Little Mill Creek near Newport, Del.							
February 4-5	29.1	1.48	2.06	-23	0.70	0.41	73
March 8-9	132	4.79	4.99	-4	.84	.93	-9
May 1-2	21.3	.51	1.00	-49	.13	.15	-12
June 11-12	264	5.67	4.94	15	1.35	1.05	29
July 8-9	156	3.13	2.76	13	1.53	.63	143
October 8-9	41.6	1.74	1.31	33	.81	.21	291
Total - all storms		17.3	17.1	2	5.37	3.27	59
Christina River at Coochs Bridge, Del.							
March 8-9	747	21.08	22.10	-5	2.81	4.05	-31
May 1-3	45.4	3.60	2.14	68	.62	.38	65
June 11-13	228	12.58	10.53	19	1.71	4.66	-63
July 8-9	206	.86	5.13	-83	.21	.81	-74
October 8-9	66.5	2.58	1.68	54	.56	.44	29
Total - all storms		40.69	41.57	-2	5.91	10.3	-43

[1] Peak mean hourly discharge during period of composite sampling.

[2] 100 × (simulated-observed)/observed.

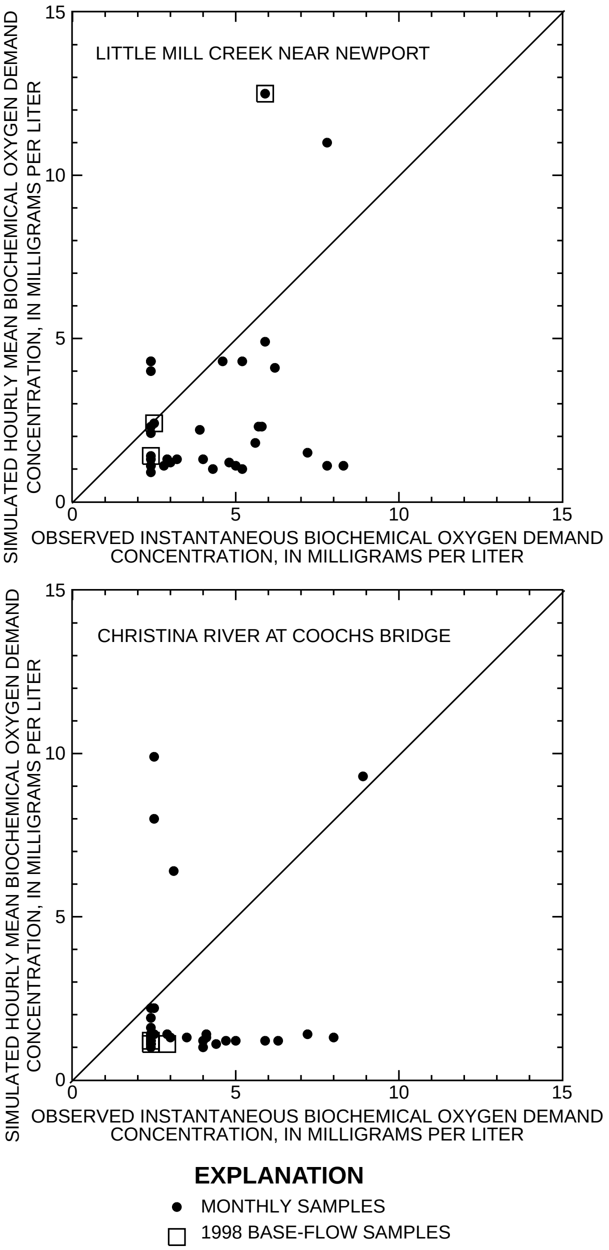


Figure 31. Simulated hourly mean biochemical oxygen demand concentrations at streamflow-measurement station 01480095, Little Mill Creek near Newport, Del., and observed instantaneous 20-day biochemical oxygen demand concentrations at water-quality monitoring site 106281, Little Mill Creek at Atlantic Avenue (top), and simulated hourly mean biochemical oxygen demand concentrations at streamflow-measurement station 01478000, Christina River at Coochs Bridge, Del., and observed instantaneous 20-day biochemical oxygen demand concentrations at water-quality monitoring site 106141, Christina River at Old Baltimore Pike (bottom), October 1994–October 1998. (Water-quality data from Delaware Department of Natural Resources and Environmental Control.)

tions of nutrients, especially ammonia and orthophosphate, by undersimulating nutrient uptake and release.

Nitrogen

Two inorganic species of nitrogen, nitrate and ammonia, were simulated. Nitrogen loads from point and nonpoint sources were included in the simulation. Loads from point-source discharges were estimated from reported average monthly data for input on an hourly time step to the model. For most point-source discharges, nitrate was estimated from reported ammonia loads using the ratios specified in USEPA, Region 3 (2000a) and nitrite was assumed to be negligible. The ratio of nitrate to ammonia in point-source effluent used for model data sets was 0.84 for small wastewater treatment plants (WWTPs), 314 for advanced secondary treatment type 1 WWTPs, 157 for advanced secondary treatment type 2 WWTPs, and 0.21 for industrial discharges. In the Christina River subbasin, all WWTPs were considered small plants (U.S. Environmental Protection Agency, 2000a). For nonpoint sources, concentrations of nitrate and ammonia in sediment (soil), interflow, and ground water were estimated as fixed concentrations that differed by land use. Nitrate was assumed to be transported solely in the dissolved form. Ammonia was assumed to be transported in dissolved and adsorbed forms.

Water-quality data from the nonpoint-source monitoring stations, 01480095 Little Mill Creek near Newport, Del., and 01478000 Christina River at Coochs Bridge, Del., were used in the calibration of concentrations of dissolved nitrate and dissolved and particulate ammonia nitrogen in stormflow and base flow. Simulated and observed concentrations of dissolved nitrate are shown in figure 32 for one of the better simulated storms out of the storms sampled at each the two nonpoint-source monitoring sites. Composite samples were collected for six storms at Little Mill Creek near Newport and five storms at Christina River at Coochs Bridge and the number of discrete samples varied at each site for the storms sampled in 1998. Observed and simulated nitrate concentrations generally decrease as streamflow increases during storms (fig. 32).

Data from composite stormflow samples collected in 1998 were used in the calculation of loads of dissolved nitrate and dissolved and particulate

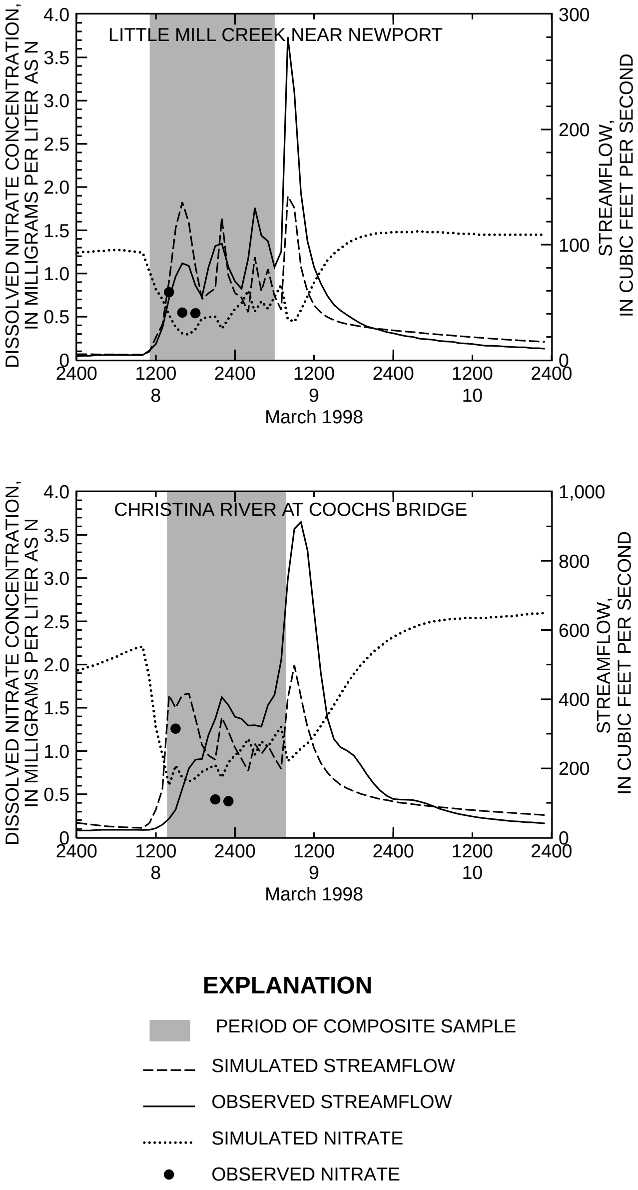


Figure 32. Simulated and observed streamflow and concentrations of dissolved nitrate and period of composite sample for one of the better simulated storms in 1998 at each of the streamflow-measurement stations 01480095, Little Mill Creek near Newark, Del., and 01478000, Christina River at Coochs Bridge, Del.

ammonia nitrogen. Calculated loads served as the observed values in overall evaluation of nitrogen transport during storms.

Simulated and observed streamflow and load data for dissolved nitrate for sampled storm events are presented in table 20. For the sampled storm periods, nitrate loads were undersimulated at Little Mill Creek near Newport and under- and oversimulated at Christina River at Coochs Bridge. For some storms at each of the two sites, streamflow volume and nitrate loads were undersimulated. At Little Mill Creek near Newport, the difference between observed and simulated streamflow ranged from -49 to 33 percent for individual storms and was 2 percent for the total of all storms, and the difference between observed and simulated nitrate loads ranged from -12 to -65 percent for individual storms and was -38 percent for the total of all storms. The error in simulated streamflow contributes to the overall error in simulated loads. The magnitude and sign of the percent error in streamflow can be compared to the magnitude and percent error in load to indicate whether water-quality concentrations are under- or oversimulated. At Christina River at Coochs Bridge, the difference between observed and simulated streamflow ranged from -83 to 68 percent for individual storms and was -2 percent for the total of all storms. The difference between observed and simulated nitrate loads ranged from -54 to 88 percent for individual storms and was 5 percent for the total of all storms. Using an approach described in the section on simulation of suspended sediment, the cumulative error in the simulated nitrate component of load, adjusted for the cumulative error in simulated streamflow, is 39 percent for the Little Mill Creek near Newport site and 7 percent for the Christina River at Coochs Bridge site. At both monitoring sites, the undersimulation of nitrate may be related to errors in estimating contributions of nitrate from point sources in additions to those associated with nitrate from nonpoint sources.

Simulated concentrations of dissolved nitrate in base flow were within 1.2 mg/L or 65 percent of observed concentrations at the nonpoint-source monitoring sites near Newport and at Coochs Bridge (fig. 33). Streamflow was well simulated for all base-flow samples, as shown in figure 26. The monitoring sites at Little Mill Creek near Newport and Christina River at Coochs Bridge are downstream of point-source discharges that can affect concentrations of nitrate and other constitu-

Table 20. *Simulated and observed streamflow and loads of dissolved nitrate, dissolved ammonia, and particulate ammonia for storms sampled in 1998 at the two nonpoint-source monitoring sites, 01480095, Little Mill Creek near Newport, Del., and 01478000, Christina River at Coochs Bridge, Del.*

[ft^3/s, cubic feet per second]

Dates of storm sampling	Peak discharge[1] (ft^3/s)	Streamflow (millions of cubic feet)			Nitrate load (pounds as nitrogen)			Dissolved ammonia load (pounds as nitrogen)			Particulate ammonia load (pounds as nitrogen)		
		Simulated	Observed	Percentage difference[2]	Simulated	Observed	Percentage difference[2]	Simulated	Observed	Percentage difference[2]	Simulated	Observed	Percentage difference[2]
Little Mill Creek near Newport, Del.													
February 4-5	29.1	1.48	2.06	-23	76.6	120	-36	7.30	12.6	-42	1.23	1.33	8
March 8-9	132	4.79	4.99	-4	146	165	-12	8.94	20.8	-57	.75	.32	138
May 1-2	21.3	.51	1.00	-49	34.9	58	-40	2.86	.75	279	.73	.44	-65
June 11-12	264	5.67	4.94	15	81.7	232	-65	16.3	38.1	-57	2.75	[3] 0	--
July 8-9	156	3.13	2.76	13	77.8	112	-31	16.6	14.3	16	4.20	1.40	201
October 8-9	41.6	1.74	1.31	33	37.3	47.4	-21	9.03	1.73	421	.83	2.23	-63
Total - all storms		17.3	17.1	2	454	735	-38	61.0	88.3	-31	10.5	5.72	83
Christina River at Coochs Bridge, Del.													
March 8-9	747	21.08	22.10	-5	1,153	820	41	48.3	72.0	-35	5.37	25.1	-79
May 1-3	45.4	3.60	2.14	68	409	217	88	26.5	4.99	430	.08	1.08	-93
June 11-13	228	12.58	10.53	19	437	672	-35	49.3	31.3	58	2.60	[3] 0	--
July 8-9	206	.86	5.13	-83	130	283	-54	8.03	11.4	-29	1.77	3.57	-50
October 8-9	66.5	2.58	1.68	54	63.2	100	37	15.2	[4] .27	5,624	.33	[5] .85	-61
Total - all storms		40.69	41.57	-2	2,191	2,091	5	147	122	21	10.1	30.6	-67

[1] Peak mean hourly discharge during period of composite sampling.

[2] 100 × (simulated-observed)/observed.

[3] Reported concentration of total ammonia was less than that for dissolved ammonia.

[4] Estimated dissolved ammonia concentration from reported concentrations of <0.005 mg/L as N dissolved ammonia by assuming 0.5 times the reporting level (0.0025 mg/L as N) for dissolved ammonia.

[5] Estimated particulate ammonia concentration from reported concentrations of 0.011 mg/L as N total ammonia and <0.005 mg/L as N dissolved ammonia by assuming 0.5 times the reporting level (0.0025 N mg/L) for dissolved ammonia.

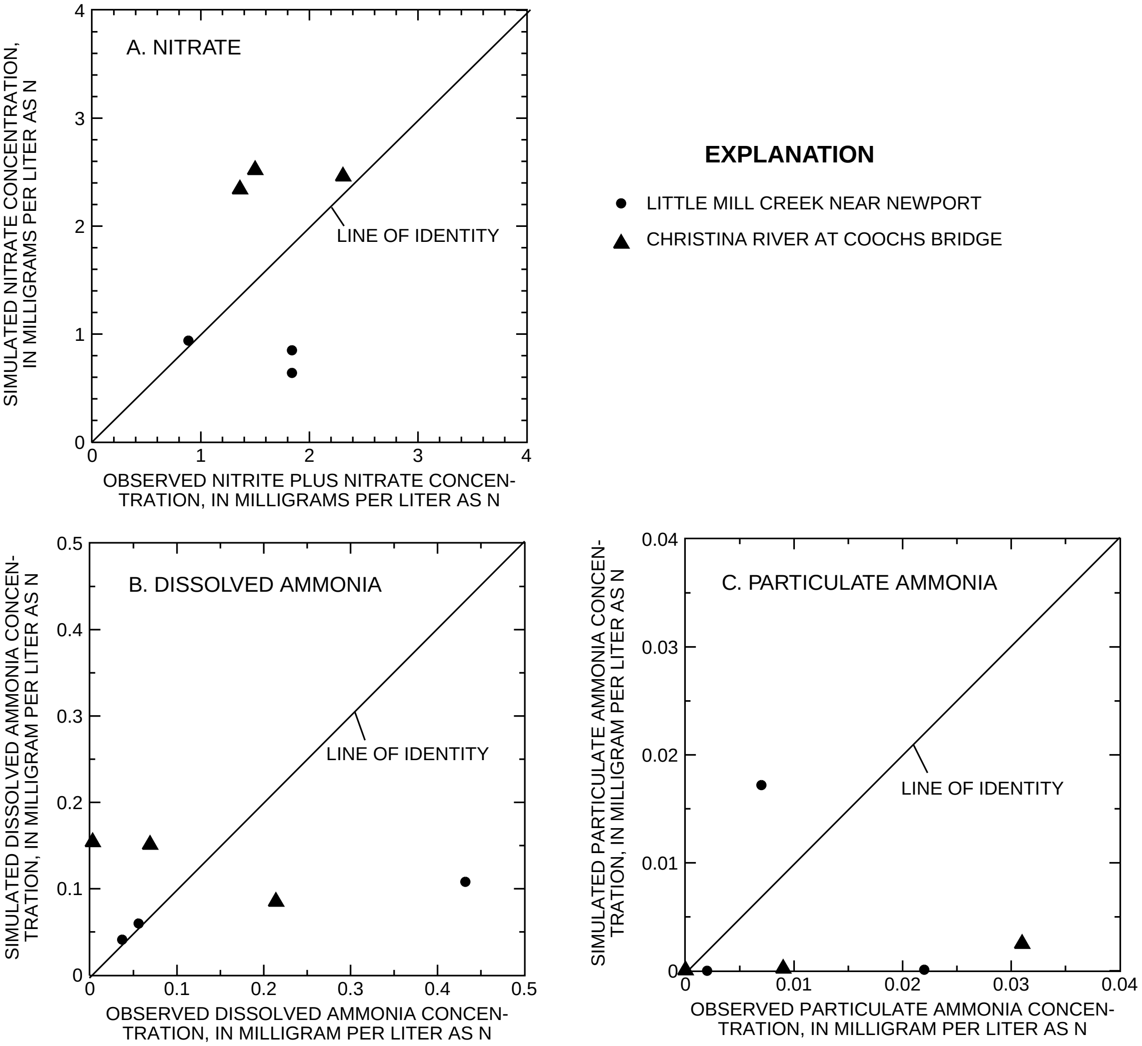


Figure 33. Simulated and observed concentrations of (A) nitrate, (B) dissolved ammonia, and (C) particulate ammonia during base-flow conditions in 1998 at streamflow-measurement stations 01480095, Little Mill Creek near Newport, Del. and 01478000, Christina River at Coochs Bridge, Del.

ents. Observed hourly concentrations of nitrate for sewage treatment plant discharges were not available but were interpolated from reported average monthly concentrations of ammonia assuming a constant ratio of nitrate to ammonia. The ratio of nitrate to ammonia in effluent probably fluctuates through time.

Concentration data for grab samples collected by DNREC near two streamflow-measurement stations under a range of hydrologic conditions also were used to evaluate the simulation of nitrate. Both of the sites are downstream of point-source discharges. As noted earlier, most of the samples were collected under moderate or base-flow conditions. Simulated concentrations generally were similar or somewhat higher than observed nitrate concentrations at Christina River at Coochs Bridge and were similar or somewhat lower at Little Mill Creek near Newport (fig. 34). The median difference between simulated and observed nitrate concentrations was 63 percent for Christina River at Coochs Bridge and -20 percent for Little Mill Creek near Newport. Errors in load estimates of nitrate from point sources and non-point sources and in-stream processes may contribute to overall errors of in-stream nitrate concentrations. Errors in streamflow simulations (fig. 27) contribute to overall error in load simu-

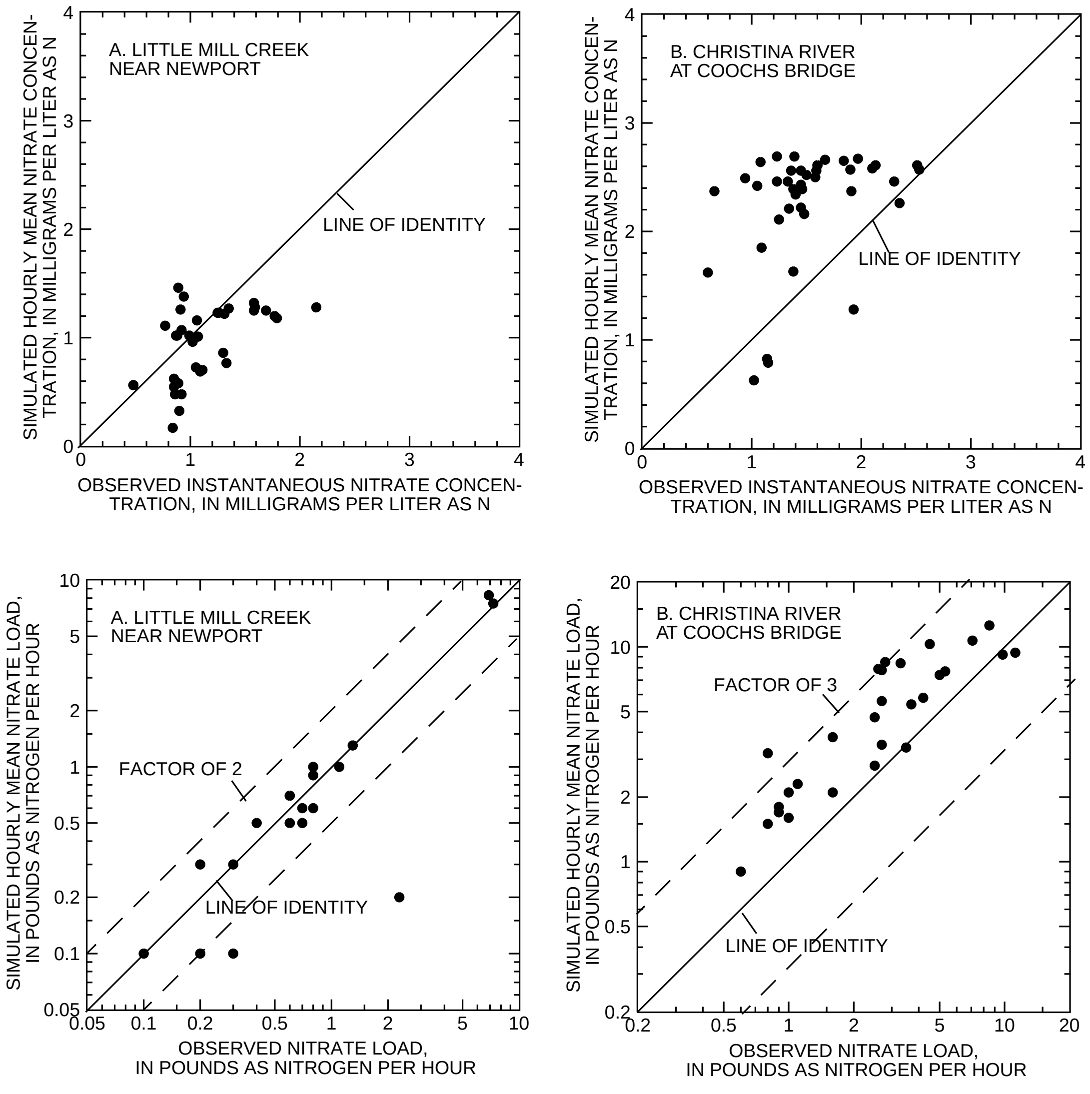


Figure 34. Simulated hourly mean nitrate concentrations and loads at streamflow-measurement stations (A) 01480095, Little Mill Creek near Newport, Del., and (B) 01478000, Christina River at Coochs Bridge, Del., and observed instantaneous nitrate concentrations and loads at water-quality monitoring sites (A) 106281, Little Mill Creek at Atlantic Avenue and (B) 106141, Christina River at Old Baltimore Pike, October 1994–October 1998. Observed loads calculated from observed concentrations at water-quality monitoring sites and streamflow at streamflow-measurement stations. (Water-quality data from Delaware Department of Natural Resources and Environmental Control.)

lations at the two sites. Simulated nitrate loads generally were within a factor of 2 or less of observed loads at Little Mill Creek near Newport and within a factor of 3 of observed loads at Christina River at Coochs Bridge.

At the Christina River at Coochs Bridge site, there is an apparent bias (high) in the nitrate concentration and load simulation that may be caused by errors in point-source and nonpoint-source contributions. Comparison of 1994-98 DNREC monitoring data collected at Christina River at Rt. 273, a site that is upstream of the West Branch Christina River confluence and therefore upstream of point-source discharges, and simulated nitrate concentrations for reach 2 of the model indicates that nitrate concentrations also may be oversimulated in reach 2. The Christina River at Rt. 273 site (DNREC monitoring site 106191) is not located at the bottom of reach 2 and therefore may not represent water quality for the entire reach 2. The Rt. 273 site excludes some drainage area of reach 2 that is urbanized land, which yields relatively small amounts of nitrate and thus results in diluting in-stream nitrate concentrations. The median difference between nitrate concentrations simulated for reach 2 and observed at Christina River at Rt. 273 (DNREC monitoring site 106191) is about 20 percent. The apparent oversimulation of nitrate concentrations in reach 2 probably accounts for some but not all of the oversimulation of nitrate at Christina River at Coochs Bridge.

Simulated concentrations of dissolved and particulate ammonia were compared to observed concentrations of dissolved and particulate ammonia in stormflow and base-flow conditions where observed particulate ammonia concentrations were calculated by subtracting dissolved ammonia concentrations from total ammonia concentrations. Review of 1998 nonpoint-source monitoring data indicates that, on average, dissolved ammonia represents about 80 percent of total ammonia concentrations for samples collected at Little Mill Creek near Newport and Christina River at Coochs Bridge.

Simulated and observed concentrations of dissolved and particulate ammonia for one of the better simulated storms of the six storms sampled at each of the two nonpoint-source monitoring sites, Little Mill Creek near Newport and Christina River at Coochs Bridge, are shown in figures 35 and 36. Simulated water quality for all storms at both sites are shown in Appendix 2. Observed and

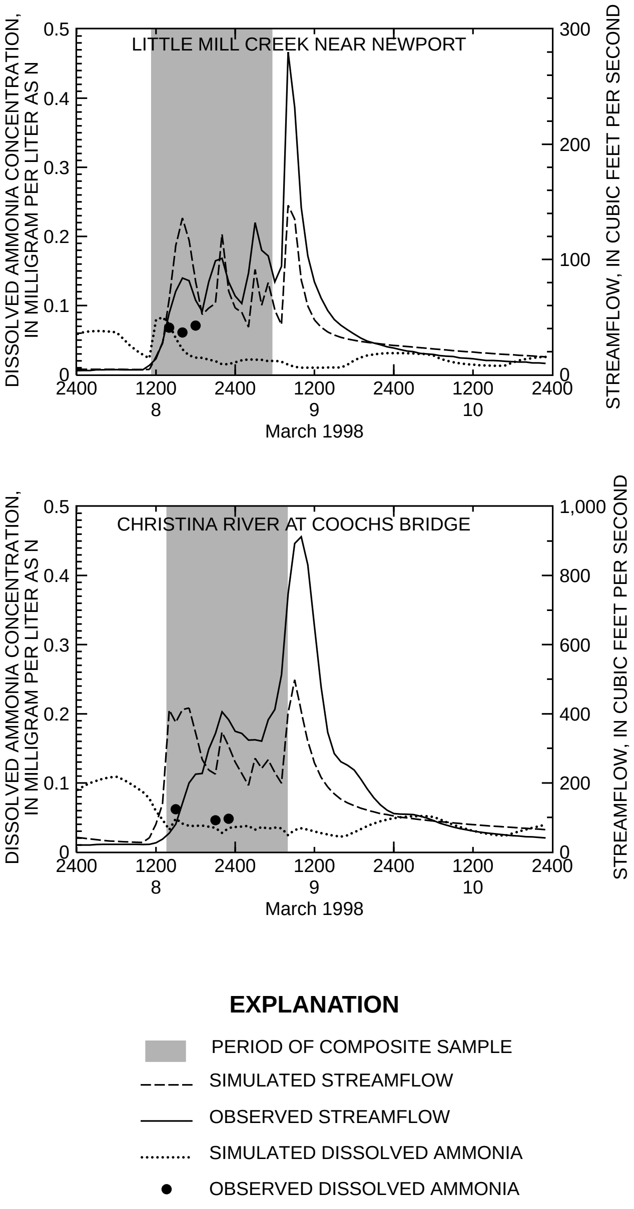


Figure 35. Simulated and observed streamflow and concentrations of dissolved ammonia and period of composite sample for one of the better simulated storms in 1998 at each of the streamflow-measurement stations 01480095, Little Mill Creek near Newark, Del., and 01478000, Christina River at Coochs Bridge, Del.

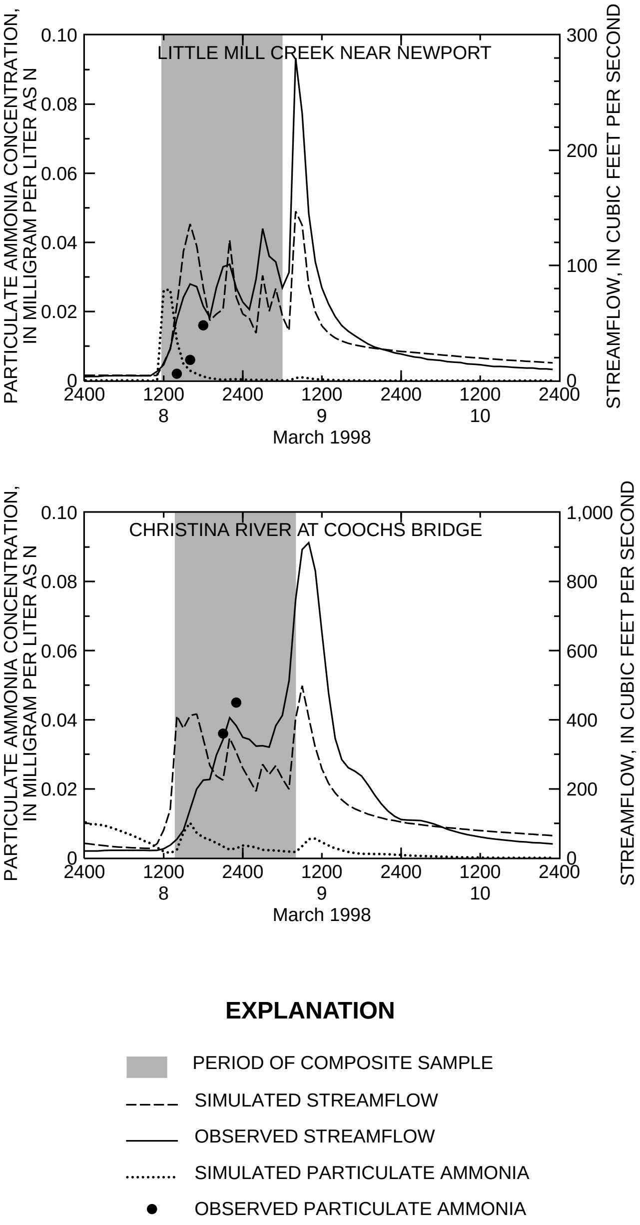


Figure 36. Simulated and observed streamflow and concentrations of particulate ammonia and period of composite sample for one of the better simulated storms in 1998 at each of the streamflow-measurement stations 01480095, Little Mill Creek near Newark, Del., and 01478000, Christina River at Coochs Bridge, Del.

simulated concentrations of dissolved ammonia appear to decrease slightly as streamflow increases during the March storm (fig. 35). Observed and simulated concentrations of particulate ammonia appear to increase as streamflow increases during the March storm (fig. 36). Though the general range of observed dissolved and particulate ammonia concentrations during storms are simulated by the model, errors or differences between observed and simulated concentrations are apparent. Errors or differences between observed and simulated particulate ammonia concentrations are due in part to errors in flow, suspended-sediment simulation, and timing of rainfall for storms. In addition, the available nonpoint-source monitoring data are insufficient to calibrate the effects of phytoplankton on in-stream dissolved ammonia concentrations, and the phytoplankton simulation is a source of error for the dissolved ammonia simulation.

Data from composite stormflow samples collected in 1998 were used in the calculation of loads of dissolved nitrate and dissolved and particulate ammonia nitrogen. Calculated loads served as the observed values in overall evaluation of nitrogen transport during storms. Simulated and observed streamflow and loads of dissolved and particulate ammonia nitrogen for storm events occurring in 1998 are presented in table 20. Observed loads of dissolved ammonia commonly were greater than observed loads of particulate ammonia except for one storm in October 1998, for which the particulate ammonia was greater than the dissolved ammonia load. The analytical results for the ammonia concentrations in the October composite storm sample are questionable, however.

For the sampled storm periods, dissolved ammonia loads were under- and oversimulated at Little Mill Creek near Newport and at Christina River at Coochs Bridge (table 20). Particulate ammonia loads tended to be oversimulated at Little Mill Creek and undersimulated at Christina River at Coochs Bridge. The error in simulated streamflow contributes to the overall error in simulated loads. The magnitude and sign of the percent error in streamflow can be compared to the magnitude and percent error in load to indicate whether water-quality concentrations for load computations are under- or oversimulated. At Little Mill Creek near Newport, the difference between observed and simulated streamflow ranged from -49 to 33 percent for individual storms and was 2 percent for the total of all storms; the difference between observed and simulated dissolved ammonia loads ranged from -57 to 421 percent for individual storms and was -31 percent for the total of all storms; and the difference between observed and simulated particulate ammonia loads ranged from -65 to 201 percent for individual storms and was 83 percent for the total of all storms. At Christina River at Coochs Bridge, the difference between observed and simulated streamflow ranged from -83 to 68 percent for individual storms and was -2 percent for the total of all storms, the difference between observed and simulated dissolved ammonia loads ranged from -35 to 5,624 percent for individual storms and was 21 percent for the total of all storms; and the difference between observed and simulated particulate ammonia loads ranged from -93 to -50 percent for individual storms and was -67 percent for the total of all storms. Using an approach described in the section on simulation of suspended sediment, the cumulative error in the simulated dissolved ammonia component of load, adjusted for the cumulative error in simulated streamflow, is -32 percent for the Little Mill Creek near Newport site and 23 percent for the Christina River at Coochs Bridge site. The cumulative error in the simulated particulate ammonia component of load, adjusted for the cumulative error in simulated streamflow, is 81 percent for the Little Mill Creek near Newport site and -66 percent for the Christina River at Coochs Bridge site.

At both monitoring sites, the over- and undersimulation of dissolved ammonia may be related to analytical errors and errors in estimating contributions of ammonia from point sources in addition to those associated with ammonia from nonpoint sources. The undersimulation of particulate ammonia may be related to errors in partitioning from dissolved to sorbed phases and to errors in sediment transport. Using monthly or yearly annual load criteria (Donigian and others, 1984), the dissolved and particulate ammonia calibration ranges from ‘fair’ to worse than ‘fair’ for individual storms.

Simulated concentrations of dissolved ammonia under base-flow conditions were different than observed concentrations by -0.324 to 0.151 mg/L as nitrogen (N) at the two nonpoint-source monitoring sites (fig. 33). The median difference between simulated and observed ammonia concentrations for base-flow samples was about 9 percent. As noted previously, streamflow was well simulated for all base-flow samples (fig. 26). The errors in simulation of dissolved ammonia at the Little Mill Creek near Newport and Christina River at Coochs Bridge sites under base-flow conditions may be related to the lack of temporal resolution in estimated ammonia concentrations in point-source discharges upstream and to inadequate simulation of in-stream processes that include ammonia uptake and release by algae. Mean hourly ammonia loads for point-source discharges were estimated from reported average monthly ammonia values; however, hourly values probably vary within each month. Simulated concentrations of particulate ammonia were less than 0.001 mg/L as N at both sites, except for the April 1998 value at Little Mill Creek near Newport, and generally were less than the observed concentrations of particulate ammonia, which ranged from 0.0 to 0.03 mg/L as N.

Concentration data for grab samples collected by DNREC near two streamflow-measurement stations under a range of hydrologic conditions also were used to evaluate the simulation of total ammonia. The Christina River sites at Coochs Bridge and Little Mill Creek near Newport sites are downstream from point-source discharges. As noted earlier, most of the samples were collected under moderate or base-flow conditions. Ammonia concentrations are not well simulated. The median difference between simulated and observed total ammonia concentrations was 57 percent for Christina River at Coochs Bridge and 37 percent for Little Mill Creek near Newport. Errors in load estimates of nitrate from point sources and nonpoint sources and in-stream processes may contribute to overall errors in in-stream ammonia concentrations. Errors in streamflow simulations (fig. 37) contribute to overall error in load simulations at the two sites. Simulated total ammonia loads generally were within a factor of 5 or less of observed loads at Little Mill Creek near Newport and within a factor of 10 of observed loads at Christina River at Coochs Bridge. Ammonia tends to be oversimulated at both sites.

Overall, the nitrate and dissolved and particulate ammonia simulation under base-flow and stormflow conditions generally appears to represent the observed patterns of ammonia concentrations in response to flow conditions and defined land uses. Dissolved ammonia storm loads and base-flow concentrations tend to be oversimulated at the two monitoring sites (Little Mill Creek near Newport and Christina River at Coochs Bridge) that are downstream from several point-source discharges and this oversimulation may be partly

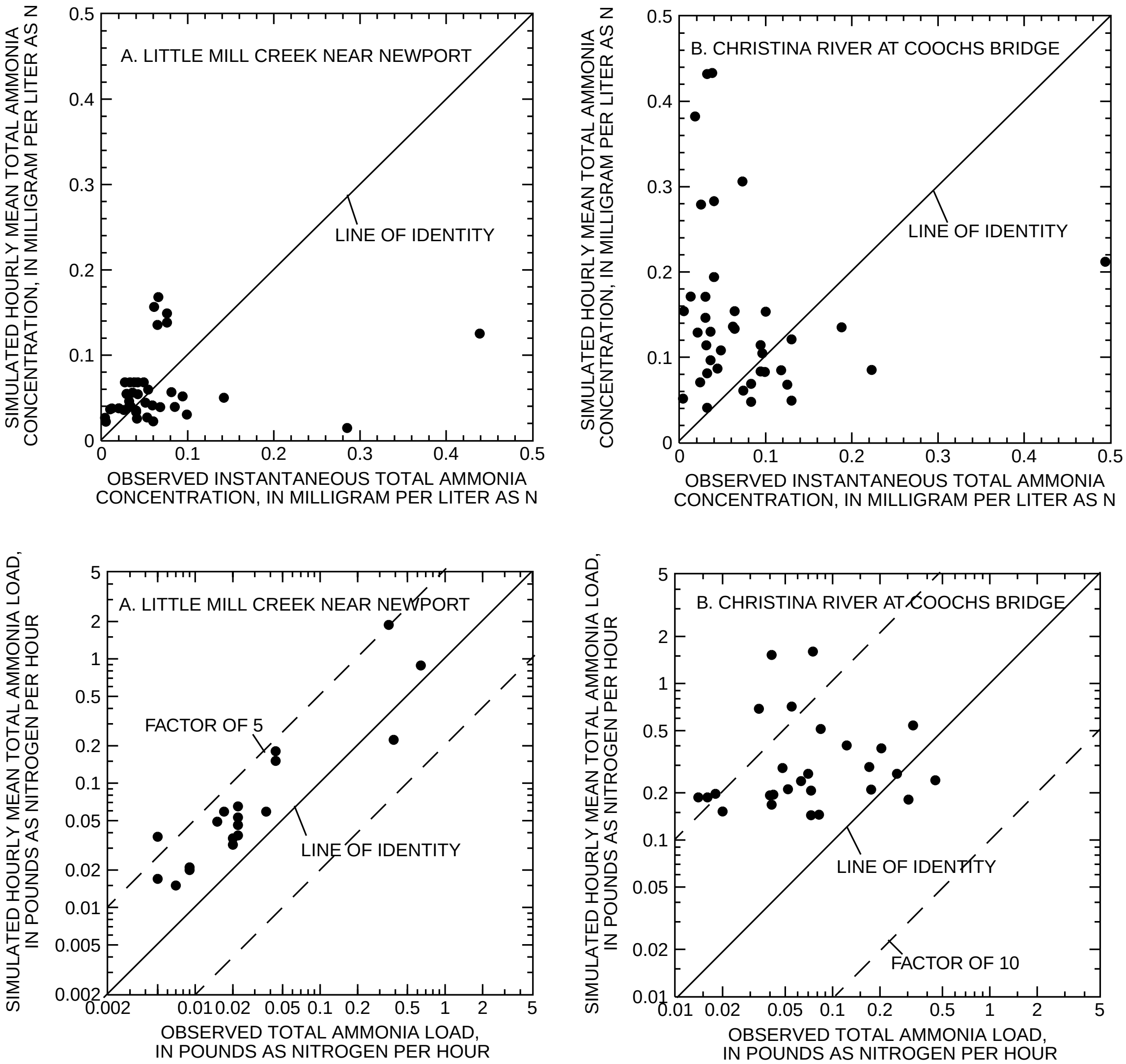


Figure 37. Simulated hourly mean total ammonia concentrations and loads at streamflow-measurement stations (A) 01480095, Little Mill Creek near Newport, Del., and (B) 01478000, Christina River at Coochs Bridge, Del., and observed instantaneous total ammonia concentrations and loads at water-quality monitoring sites (A) 106281, Little Mill Creek at Atlantic Avenue and (B) 106141, Christina River at Old Baltimore Pike, October 1994–October 1998. (Observed loads calculated from observed concentrations at water-quality monitoring sites and streamflow at streamflow-measurement stations. Water-quality data from Delaware Department of Natural Resources and Environmental Control.)

related to inaccurate characterization of ammonia uptake upstream of the sampling site and (or) inadequate characterization of ammonia in discharges. Commonly, errors expressed in percent are greater for particulate ammonia simulation than for dissolved ammonia simulation and are greater for the ammonia simulation than the nitrate simulation. Of the nitrogen species simulated, nitrate represents the greatest amount and particulate ammonia represents the least amount of the inorganic nitrogen load. In storms, nitrate loads are an order of magnitude greater than dissolved ammonia loads and two orders of magnitude greater than particulate ammonia loads (table 20).

Simulated annual yields of nitrogen varied by land use. Annual yields of nitrate and ammonia are presented per land-use category per segment in tables 21 and 23 and mean yields of nitrate and ammonia for the simulation period are presented per land-use category per segment in tables 22 and 24. For most land uses, simulated nitrate yields generally were at least one order of magnitude greater than simulated total ammonia yields.

Table 21. *Observed annual precipitation and simulated annual nitrate yields by land use for the three segments of the Hydrological Simulation Program–Fortran (HSPF) model for Christina River subbasin, 1995-97*

	Year				
	Seg-ment	1995	1996	1997	1995-97 average
Precipitation (inches)	5, 8	38.1	56.9	34.7	43.2
Simulated annual nitrate yield (pounds as nitrogen per acre per year) by land-use category[1]					
Residential - unsewered	5	6.46	14.7	9.2	10.12
Residential - sewered	5	3.46	7.92	4.73	5.37
Urban	5	3.66	7.91	4.69	5.42
Agricultural - animal/crop	5	13.6	28.6	16.8	19.7
Agricultural - row crop	5	11.8	24.9	14.3	17.0
Agricultural - mushroom	5	16.9	36.4	21.6	25.0
Forested	5	.684	1.63	1.06	1.13
Open	5	2.39	5.34	3.14	3.62
Wetlands/water	5	.744	2.02	1.42	1.40
Undesignated	5	2.36	5.39	3.16	3.64
Impervious - residential	5	2.02	2.06	2.03	2.04
Impervious - urban	5	2.02	2.06	2.03	2.04
Simulated annual nitrate yield (pounds as nitrogen per acre per year) by land-use category[1]					
Residential - unsewered	8	6.69	13.7	7.73	9.37
Residential - sewered	8	3.65	7.40	4.02	5.02
Urban	8	3.84	7.27	3.98	5.03
Agricultural - animal/crop	8	14.9	28.5	15.6	19.7
Agricultural - row crop	8	13.1	24.9	13.4	17.1
Agricultural - mushroom	8	17.7	34.2	18.6	23.5
Forested	8	.815	1.79	1.02	1.21
Open	8	2.47	4.98	2.69	3.38
Wetlands/water	8	.995	2.49	1.48	1.66
Undesignated	8	2.48	5.00	2.70	3.39
Impervious - residential	8	2.00	2.07	2.03	2.03
Impervious - urban	8	2.00	2.07	2.03	2.03
Precipitation (inches)	9	35.7	45.4	25.6	35.6
Simulated annual nitrate yield (pounds as nitrogen per acre per year) by land-use category[1]					
Residential - unsewered	9	7.07	13.6	5.27	8.65
Residential - sewered	9	3.83	7.16	2.71	4.57
Urban	9	3.89	7.08	2.68	4.55
Agricultural - animal/crop	9	14.2	25.6	9.74	16.51
Agricultural - row crop	9	12.1	21.8	8.18	14.0
Agricultural - mushroom	9	17.5	32.4	12.2	20.7
Forested	9	.743	1.5	.699	.981
Open	9	2.47	4.65	1.78	2.97
Wetlands/water	9	.934	1.97	.919	1.27
Undesignated	9	2.48	4.68	1.79	2.98
Impervious - residential	9	2.01	1.97	1.94	1.97
Impervious - urban	9	2.01	1.97	1.94	1.97

[1] In pervious areas, unless noted.

Table 22. *Observed annual precipitation and simulated average annual nitrate yield by land use for pervious and impervious land areas in the three segments of the Hydrological Simulation Program–Fortran (HSPF) model for Christina River subbasin, 1995-97*

	1995-97 Average			
	Segment 5	**Segment 8**	**Segment 9**	**Average of all segments**
Precipitation (inches)	43.2	43.2	35.6	40.7
Simulated annual nitrate yield (pounds as nitrogen per acre per year) by land-use category[1]				
Residential - unsewered	10.1	9.37	8.65	9.38
Residential - sewered	5.37	5.02	4.57	4.99
Urban	5.42	5.03	4.55	5.00
Agricultural - animals / crops	19.7	19.7	16.5	18.6
Agricultural - row crop	17.0	17.1	14.0	16.1
Agricultural - mushroom	25.0	23.5	20.7	23.1
Forested	1.13	1.21	.981	1.11
Open	3.62	3.38	2.97	3.32
Wetlands / water	1.40	1.66	1.27	1.44
Undesignated	3.64	3.39	2.98	3.34
Impervious - residential	2.04	2.03	1.97	2.01
Impervious - urban	2.04	2.03	1.97	2.01

[1] In pervious areas, unless noted.

Table 23. *Observed annual precipitation and simulated annual total ammonia yields by land use for the three segments of the Hydrological Simulation Program–Fortran (HSPF) model for Christina River subbasin, 1995-97*

		Year			
	Seg-ment	1995	1996	1997	1995-97 average
Precipitation (inches)	5, 8	38.1	56.9	34.7	43.2
Simulated annual total ammonia yield (pounds as nitrogen per acre per year) by land-use category[1]					
Residential - unsewered	5	.082	.199	.079	.120
Residential - sewered	5	.046	.110	.043	.066
Urban	5	.066	.122	.045	.078
Agricultural - animal/crop	5	.624	1.06	.305	.663
Agricultural - row crop	5	.404	.704	.214	.441
Agricultural - mushroom	5	2.23	3.86	.901	2.33
Forested	5	.017	.042	.028	.029
Open	5	.069	.162	.074	.102
Wetlands/water	5	.012	.036	.023	.024
Undesignated	5	.069	1.63	.075	.591
Impervious - residential	5	.362	.364	.363	.363
Impervious - urban	5	.416	.42	.419	.418
Simulated annual total ammonia yield (pounds as nitrogen per acre per year) by land-use category[1]					
Residential - unsewered	8	.091	.179	.068	.113
Residential - sewered	8	.052	.1	.038	.063
Urban	8	.074	.106	.039	.073
Agricultural - animal/crop	8	.504	.794	.231	.510
Agricultural - row crop	8	.28	.454	.147	.294
Agricultural - mushroom	8	1.55	2.39	.598	1.51
Forested	8	.021	.046	.027	.031
Open	8	.075	.148	.065	.096
Wetlands/water	8	.016	.043	.024	.028
Undesignated	8	.076	.148	.065	.096
Impervious - residential	8	.364	.352	.363	.360
Impervious - urban	8	.407	.405	.420	.411
Precipitation (inches)	9	35.7	45.4	25.6	35.6
Simulated annual total ammonia yield (pounds as nitrogen per acre per year) by land-use category[1]					
Residential - unsewered	9	.070	.123	.041	.078
Residential - sewered	9	.197	.212	.023	.144
Urban	9	.286	.242	.023	.184
Agricultural - animal/crop	9	.603	.92	.051	.525
Agricultural - row crop	9	.589	.874	.049	.504
Agricultural - mushroom	9	.679	1.01	.173	.621
Forested	9	.02	.041	.018	.026
Open	9	.093	.107	.04	.080
Wetlands/water	9	.015	.033	.014	.021
Undesignated	9	.092	.084	.040	.072
Impervious - residential	9	.364	.352	.354	.357
Impervious - urban	9	.417	.405	.410	.411

[1] In pervious areas, unless noted.

Table 24. *Observed annual precipitation and simulated average annual total ammonia yield for pervious and impervious land areas in the three segments of the Hydrological Simulation Program–Fortran (HSPF) model for Christina River subbasin, 1995-97*

	1995-97 Average			
	Segment 5	Segment 8	Segment 9	Average of all segments
Precipitation (inches)	43.2	43.2	35.6	40.7
Average annual total ammonia yield (pounds per acre per year) by land-use category[1]				
Residential - unsewered	.120	.113	0.078	.109
Residential - sewered	.066	.063	.144	.063
Urban	.078	.073	.184	.072
Agricultural - animals / crops	.663	.510	.525	.504
Agricultural - row crop	.441	.294	.504	.324
Agricultural - mushroom	2.33	1.51	.621	1.73
Forested	.029	.031	.026	.030
Open	.102	.096	.080	.094
Wetlands / water	.024	.028	.021	.025
Undesignated	.591	.096	.072	.257
Impervious - residential	.363	.360	.357	.360
Impervious - urban	.418	.411	.411	.413

[1] In pervious areas, unless noted.

Phosphorus

The model was used to simulate inorganic phosphorus, where dissolved and adsorbed orthophosphate are considered to be the principal dissolved and particulate inorganic phosphorus species. Phosphorus loads from point and nonpoint sources are included in the simulation. Loads from point-source discharges were estimated from reported monthly average values for input on an hourly time step to the model. For nonpoint sources, dissolved and particulate phosphorus were estimated at fixed concentrations in sediment (soil), interflow, and ground water that differed by land use. Phosphorus was assumed to be transported in dissolved and adsorbed forms from the land surface and in the stream channel. For 1998 data collected at the Christina River at Coochs Bridge and Little Mill Creek near Newport nonpoint-source monitoring stations under a range of flow conditions, dissolved orthophosphate represented on average about 30 to 35 percent of total phosphorus.

Water-quality data from the nonpoint-source monitoring stations, Little Mill Creek near Newport and Christina River at Coochs Bridge, were used to assess the calibration of dissolved and particulate (adsorbed) orthophosphate. Observed concentrations of particulate orthophosphate were estimated by subtracting concentrations of dissolved phosphorus from concentrations of total phosphorus and assuming the difference was particulate orthophosphate.

Simulated and observed concentrations of dissolved and particulate orthophosphate are shown in figures 38 and 39 for one of the better simulated storms of the six storms sampled at each of the nonpoint-source monitoring sites, Little Mill Creek near Newport and Christina River at Coochs Bridge. Simulated water quality for all storms at both sites is shown in Appendix 2. Samples from the October 1998 storm were not analyzed for total phosphorus and therefore particulate phosphorus concentrations could not be estimated. Observed concentrations of dissolved and particulate orthophosphate generally appeared to increase as streamflow increased during the March 1998 storm (figs. 38 and 39). This general pattern of observed dissolved and particulate orthophosphate concentrations during storms appears to be simulated by the model for most storms (Appendix 2).

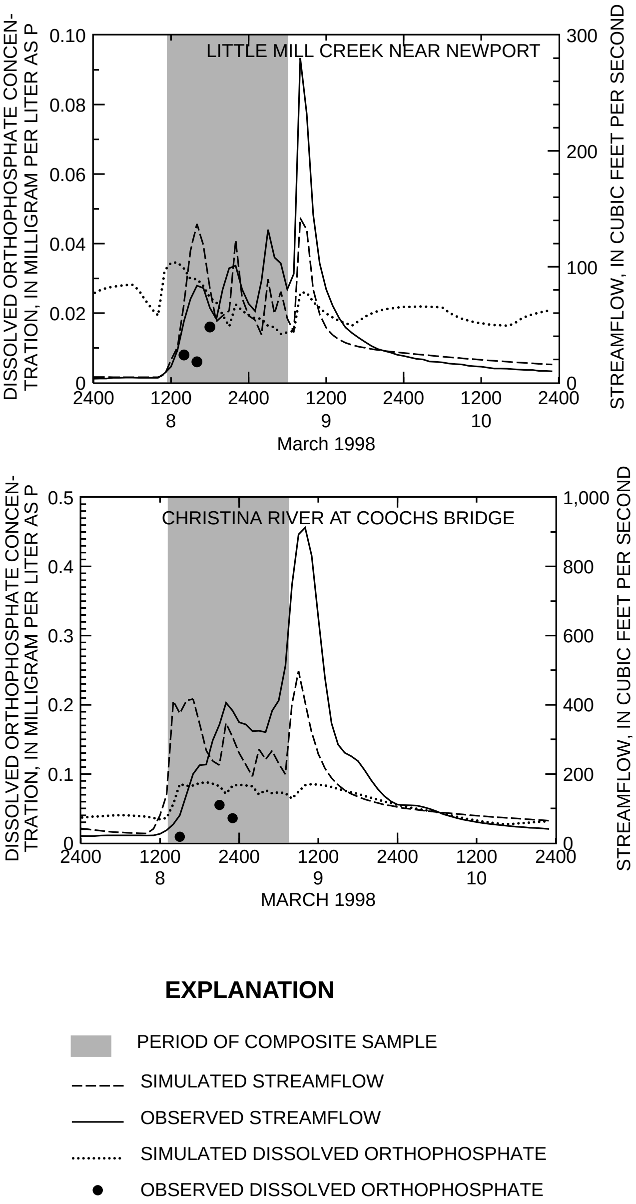


Figure 38. Simulated and observed streamflow and concentrations of dissolved orthophosphate and period of composite sample for one of the better simulated storms in 1998 at each of the streamflow-measurement stations, 01480095, Little Mill Creek near Newark, Del., and 01478000, Christina River at Coochs Bridge, Del.

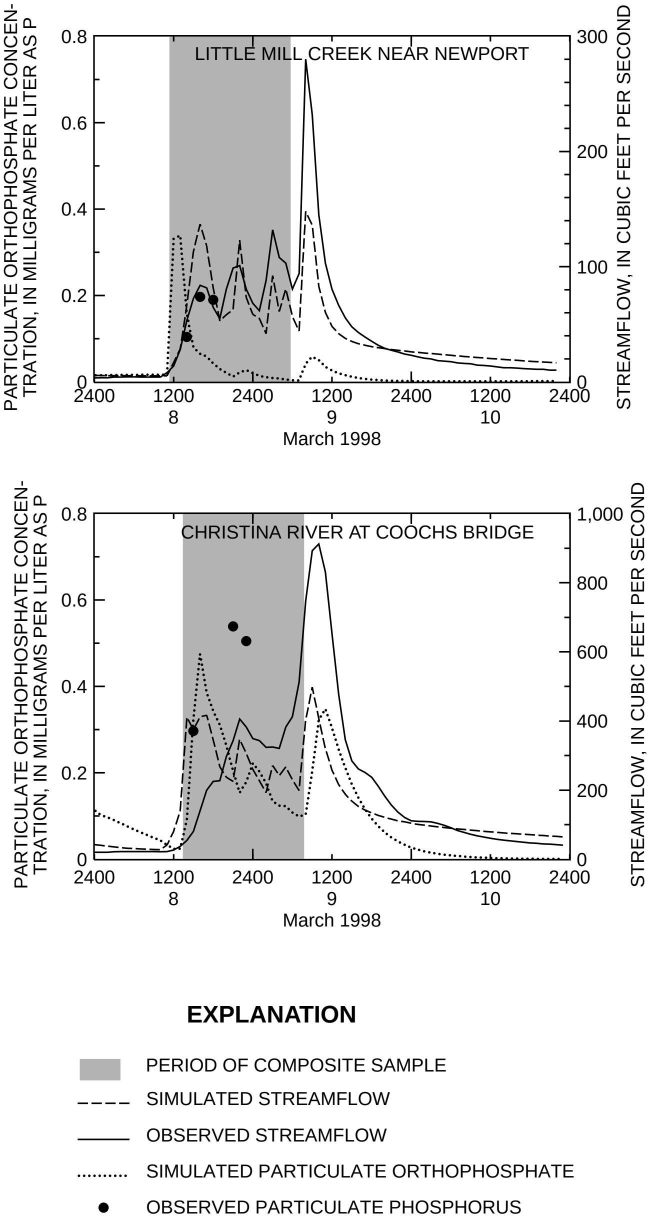


Figure 39. Simulated and observed streamflow and concentrations of particulate orthophosphate and period of composite sample for one of the better simulated storms in 1998 at each of the streamflow-measurement stations 01480095, Little Mill Creek near Newark, Del., and 01478000, Christina River at Coochs Bridge, Del.

Data from composite stormflow samples collected in 1998 were used in the calculation of loads of dissolved orthophosphate and particulate orthophosphate. Calculated loads served as the observed values in the evaluation of overall phosphorus transport during storms. Simulated and observed streamflow and loads of dissolved and particulate orthophosphate for storm events occurring in 1998 are presented in table 25. Observed loads of particulate orthophosphate commonly were greater than observed loads of dissolved orthophosphate. For one small storm in May 1998, dissolved orthophosphate loads were greater than particulate orthophosphate loads. Dissolved and particulate orthophosphate loads tended to be undersimulated when flow was undersimulated, with the exception of the March 1998 storm.

For the sampled storm periods, dissolved and particulate orthophosphate loads were under- and oversimulated at Little Mill Creek near Newport and at Christina River at Coochs Bridge. The error in simulated streamflow contributes to the overall error in simulated loads. The magnitude and sign of the percent error in streamflow can be compared to the magnitude and percent error in load to indicate whether water-quality concentrations for load computations are under- or oversimulated. At Little Mill Creek near Newport, the difference between observed and simulated streamflow ranged from -56 to 43 percent for individual storms and was 3 percent for the total of all storms; the difference between observed and simulated dissolved orthophosphate loads ranged from -82 to 168 percent for individual storms and was -51 percent for the total of all storms; and the difference between observed and simulated particulate orthophosphate loads ranged from -86 to 256 percent for individual storms and was -62 percent for the total of all storms (table 25). At Christina River at Coochs Bridge, the difference between observed and simulated streamflow ranged from -83 to 68 percent for individual storms and was -2 percent for the total of all storms; the difference between observed and simulated dissolved orthophosphate loads ranged from -72 to 365 percent for individual storms and was -34 percent for the total of all storms; and the difference between observed and simulated particulate orthophosphate loads ranged from -86 to 46 percent for individual storms and was -41 percent for the total of all storms. Using an approach described in the section on simulation of suspended sediment, the cumulative error in the simulated dissolved orthophosphate

Table 25. *Simulated and observed streamflow and loads of dissolved and particulate orthophosphate for storms sampled in 1998 at the nonpoint-source monitoring sites 01480095, Little Mill Creek near Newport, Del., and 01478000, Christina River at Coochs Bridge, Del.*

[ft^3/s, cubic feet per second; Sim., simulated; Obs., observed; diff., difference; na, not applicable; nd, not done]

Dates of storm sampling	Peak flow[1] (ft^3/s)	Streamflow (millions of cubic feet)			Dissolved orthophosphate load (pounds as phosphorus)			Particulate orthophosphate load (pounds as phosphorus)		
		Sim.	Obs.	Percent diff.[2]	Sim.	Obs.	Percent diff.[2]	Sim.	Obs.	Percent diff.[2]
Little Mill Creek near Newport, Del.										
February 4-5	29.1	1.37	2.06	-32	5.53	2.06	168	14.3	4.00	256
March 8-9	132	4.80	4.99	-4	11.2	8.52	32	15.2	82.3	-82
May 1-2	21.3	.44	1.00	-56	6.25	7.67	-18	.35	2.52	-86
June 11-12	264	5.78	4.94	17	12.1	69.3	-82	31.9	112	-72
July 8-9	156	3.28	2.76	19	8.03	5.77	39	34.5	53.6	-36
October 8-9	41.6	1.87	1.31	43	4.52	3.47	30	na	nd	na
Total - all storms		17.5	17.1	3	47.7	96.8	-51	96.1	255	-62
Christina River at Coochs Bridge, Del.										
March 8-9	747	21.08	22.10	-5	102	204	-50	286	512	-44
May 1-3	45.4	3.60	2.14	68	7.82	2.02	286	.54	3.91	-86
June 11-13	228	12.58	10.53	19	37.1	17.3	114	70.0	47.9	46
July 8-9	206	.86	5.13	-83	2.08	7.46	-72	10.2	57.1	-82
October 8-9	66.5	2.58	1.68	54	5.43	1.16	365	na	nd	na
Total - all storms		40.69	41.57	-2	155	232	-33	367	621	-41

[1] Peak mean hourly discharge during period of composite sampling.

[2] 100 x (observed-simulated)/observed.

component of load, adjusted for the cumulative error in simulated streamflow, is -52 percent for the Little Mill Creek near Newport site and 32 percent for the Christina River at Coochs Bridge site. The cumulative error in the simulated particulate orthophosphate component of load, adjusted for the cumulative error in simulated streamflow, is -63 percent for the Little Mill Creek near Newport site and -40 percent for the Christina River at Coochs Bridge site.

At both monitoring sites, some errors may be associated with estimated contributions of phosphorus from point sources in addition to those associated with simulated orthophosphate from nonpoint sources. The greater undersimulation of particulate orthophosphate compared to dissolved orthophosphate may be related to errors in partitioning from dissolved to sorbed phases and to errors in sediment transport. Using monthly or yearly annual load criteria (Donigian and others, 1984), the dissolved and particulate orthophosphate calibration ranges from ‘good’ to worse than ‘fair’ for individual storm loads and ‘fair’ to worse than ‘fair’ for the cumulative storms loads.

Simulated concentrations of dissolved orthophosphate under base-flow conditions in 1998 generally were greater than or similar to observed concentrations at the nonpoint-source monitoring sites Christina River at Coochs Bridge and Little Mill Creek near Newport (fig. 40). The difference between observed and simulated dissolved orthophosphate for base-flow conditions was greater for samples collected at Little Mill Creek near Newport than for samples collected at Christina River at Coochs Bridge, and the median percent difference for all samples was about 110 percent. As noted previously, streamflow was well simulated for all base-flow samples (fig. 26). Simulated concentrations of particulate orthophosphate under base-flow conditions generally were similar or less than observed concentrations, except for the April 1998 value at Little Mill Creek near Newport, which was oversimulated due to probable errors in storm simulation prior to that sample. The median difference between observed and simulated particulate orthophosphate for samples collected under base-flow conditions at both sites was -48 percent (low).

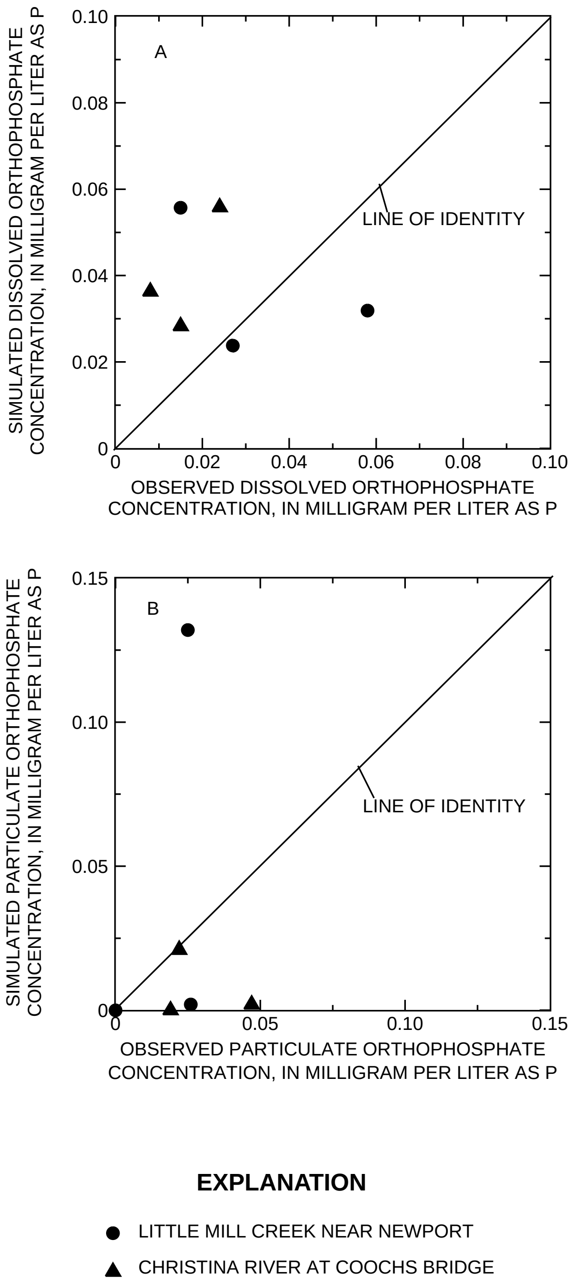


Figure 40. Simulated and observed concentrations of (A) dissolved orthophosphate and (B) particulate orthophosphate during base-flow conditions in 1998 at streamflow-measurement stations 01480095, Little Mill Creek near Newport, Del., and 01478000, Christina River at Coochs Bridge, Del.

Data collected by DNREC near two streamflow-measurement stations under a range of hydrologic conditions also were used to evaluate the simulation of dissolved orthophosphate. Both of the sites are downstream of point-source discharges. As noted earlier, most of the samples were collected under moderate or base-flow conditions. Dissolved orthophosphate concentrations generally were oversimulated at both sites (fig. 41). The median difference between simulated and observed dissolved orthophosphate concentrations was 380 percent for Christina River at Coochs Bridge and 110 percent for Little Mill Creek near Newport. Errors in load estimates of dissolved orthophosphate from point sources and nonpoint sources and in-stream processes may contribute to overall errors in in-stream orthophosphate concentrations. Simulated dissolved orthophosphate loads generally were within a factor of 5 or less of observed loads at Little Mill Creek near Newport and within a factor of 10 of observed loads at Christina River at Coochs Bridge.

Overall, the dissolved and particulate orthophosphate simulation under base flow and stormflow conditions generally appears to represent the observed patterns of phosphorus concentrations in response to flow conditions and defined land uses. In most storms, observed particulate orthophosphate loads commonly were from 2 to 10 times greater than observed dissolved orthophosphate loads (table 25). Observed orthophosphate loads generally were greater than simulated orthophosphate loads in stormflow at the two nonpoint-source monitoring sites, and appeared to be greater than simulated loads for moderate or base-flow conditions as determined by state monitoring data collected nearby.

Simulated annual yields of phosphorus varied by land use. Simulated yields of total orthophosphate (dissolved plus adsorbed or particulate orthophosphate) are presented per land-use category per segment per year in table 26 and mean yields of total orthophosphate for the simulation period are presented per land-use category per segment in table 27.

Sensitivity Analysis

Sensitivity analyses for the water-quality component of the HSPF model for the Christina River subbasin were not done for the Christina River subbasin model. Results of analyses done for the other subbasins in the Christina River Basin indicate that the model sensitivities to changes in selected parameters for the Christina River subbasin model should be similar to model sensitivities to changes in these parameters for the other models. General results of the sensitivity analyses for the other subbasins are discussed below.

Calibration of water temperature is specified by 13 parameters: 5 are for pervious land surfaces, 2 are for impervious land surfaces, and 6 are for stream reaches. For water-temperature simulation, the model is more sensitive to parameters in the reach modules than parameters in pervious and impervious modules. Water temperature in a reach is modeled as a function of the variables: upstream flow and land surface inflow temperatures, air temperature, and various radiation, conduction, and convection gains or losses. Of these variables, radiation, conduction, and convection gains and losses have calibration parameters. Although no formal sensitivity analysis was done for parameters affecting water temperature, through the calibration process, simulated water temperatures were found to be sensitive most to the parameters CFSAEX, the solar radiation correction factor, and KCOND, the conduction-convection coefficient. Daily high temperatures are affected by CFSAEX and nighttime low temperatures by KCOND. In combination, CFSAEX and KCOND also influence daily mean water temperature.

The simulated sediment yield from pervious and impervious land areas is dependent on parameters affecting soil detachment, soil scour, and soil or sediment washoff and is sensitive to parameters affecting soil detachment (KRER, JRER), soil washoff (KSER, JSER), and soil scour processes (KGER, JGER) for pervious land surfaces, and solids build up (ACCSDP, REMDSP) and washoff processes for impervious land surfaces (KEIM, JEIM). Sediment washoff or transport capacity is dependent on surface runoff (SURO) and, therefore, the hydrologic component of the simulation. In addition, calibration of suspended sediment in the stream channel is sensitive to parameters controlling shear stress regimes (TAUD, TAUS) that determine deposition on and scour of the channel bottom.

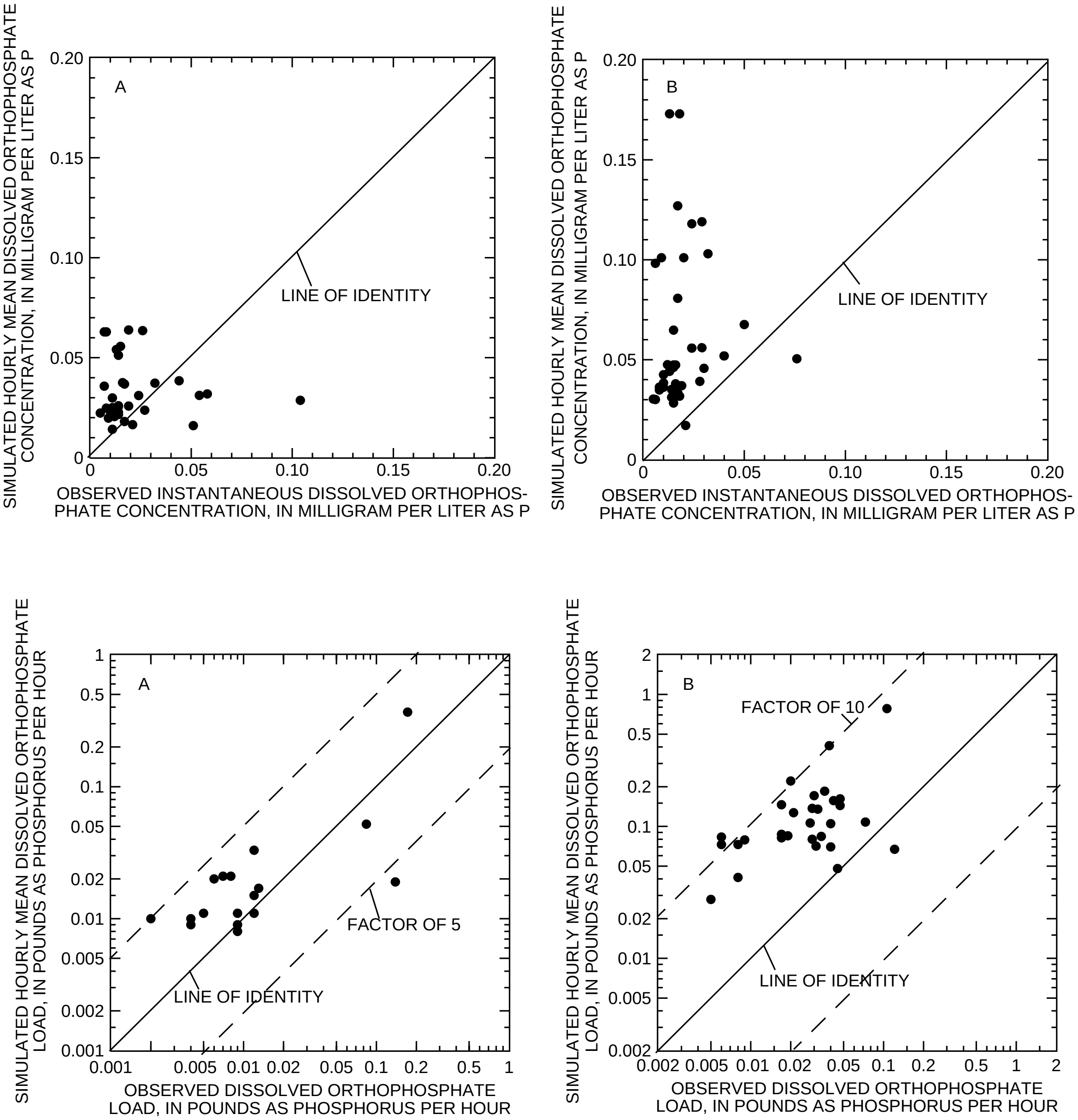


Figure 41. Simulated hourly mean dissolved orthophosphate concentrations and loads at streamflow-measurement stations (A) 01480095, Little Mill Creek near Newport, Del., and (B) 01478000, Christina River at Coochs Bridge, Del., and observed instantaneous dissolved orthophosphate concentrations and loads at water-quality monitoring sites (A) 106281, Little Mill Creek at Atlantic Avenue and (B) 106141, Christina River at Old Baltimore Pike, October 1994–October 1998. (Observed loads calculated from observed concentrations at water-quality monitoring sites and streamflow at streamflow-measurement stations. Water-quality data from Delaware Department of Natural Resources and Environmental Control.)

Table 26. *Observed annual precipitation and simulated annual total (dissolved plus adsorbed) orthophosphate yields by land use for the three segments of the Hydrological Simulation Program–Fortran (HSPF) model for Christina River subbasin, 1995-97*

		Year			
	Seg-ment	1995	1996	1997	1995-97 average
Precipitation (inches)	5, 8	38.1	56.9	34.7	43.2
Simulated annual total orthophosphate yield (pounds as phosphorus per acre per year) by land-use category[1]					
Residential - unsewered	5	.13	.324	.085	.180
Residential - sewered	5	.16	.399	.092	.217
Urban	5	.279	.471	.104	.285
Agricultural - animal/crop	5	5.8	9.62	2.42	5.947
Agricultural - row crop	5	5.71	9.58	2.34	5.877
Agricultural - mushroom	5	19.8	33.6	6.96	20.120
Forested	5	.0092	.023	.014	.015
Open	5	.187	.471	.065	.241
Wetlands/water	5	.006	.018	.012	.012
Undesignated	5	.185	.469	.064	.239
Impervious - residential	5	.29	.313	.298	.300
Impervious - urban	5	.771	.805	.796	.791
Simulated annual total orthophosphate yield (pounds as phosphorus per acre per year) by land-use category[1]					
Residential - unsewered	8	.149	.287	.076	.171
Residential - sewered	8	.191	.358	.085	.211
Urban	8	.323	.397	.092	.271
Agricultural - animal/crop	8	6.04	9.23	2.26	5.843
Agricultural - row crop	8	6	9.16	2.17	5.777
Agricultural - mushroom	8	21.3	32	6.98	20.093
Forested	8	.011	.025	.014	.017
Open	8	.223	.408	.064	.232
Wetlands/water	8	.008	.022	.012	.014
Undesignated	8	.223	.408	.064	.232
Impervious - residential	8	.288	.314	.298	.300
Impervious - urban	8	.77	.804	.797	.790
Precipitation (inches)	9	35.7	45.4	25.6	35.6
Simulated annual total orthophosphate yield (pounds as phosphorus per acre per year) by land-use category[1]					
Residential - unsewered	9	.091	.144	.038	.091
Residential - sewered	9	.165	.219	.04	.141
Urban	9	.213	.231	.042	.162
Agricultural - animal/crop	9	2.46	3.8	.117	2.126
Agricultural - row crop	9	2.41	3.62	.111	2.047
Agricultural - mushroom	9	9.55	14.3	.407	8.086
Forested	9	.01	.02	.009	.013
Open	9	.09	.119	.016	.075
Wetlands/water	9	.008	.016	.007	.010
Undesignated	9	.09	.117	.016	.074
Impervious - residential	9	.28	.284	.272	.279
Impervious - urban	9	.757	.743	.771	.757

[1] In pervious areas, unless noted.

Table 27. *Observed annual precipitation and simulated average annual total orthophosphate yield by land use for pervious and impervious land areas in the three segments of the Hydrological Simulation Program–Fortran (HSPF) model for Christina River subbasin, 1995-97*

	1995-97 Average			
	Segment 5	**Segment 8**	**Segment 9**	**Average of all segments**
Precipitation (inches)	43.2	43.2	35.6	40.7
Simulated annual total orthophosphate yield (pounds as phosphorus per acre per year) by land-use category[1]				
Residential - unsewered	.180	.171	.091	.147
Residential - sewered	.217	.211	.141	.190
Urban	.285	.271	.162	.239
Agricultural - animals / crops	5.95	5.84	2.13	4.64
Agricultural - row crop	5.88	5.78	2.05	4.57
Agricultural - mushroom	20.1	20.1	8.09	16.1
Forested	.015	.017	.013	.015
Open	.241	.232	.075	.183
Wetlands / water	.012	.014	.010	.012
Undesignated	.239	.232	.074	.182
Impervious - residential	.300	.300	.279	.293
Impervious - urban	.791	.790	.757	.779

[1] In pervious areas, unless noted.

The simulated yields of nitrate, ammonia, and orthophosphate from pervious land areas are dependent on parameters affecting sediment yield except those controlling sediment scour processes. Nitrate yields are less affected than ammonia and phosphorus by changes in sediment yield because the model, as set up, simulates surface-runoff and ground-water transport of these constituents from land areas to streams in different relative amounts. The largest amounts of nitrate from land areas enter the streams through ground-water discharge (AGWO). The largest amounts of ammonia and orthophosphate from most land areas enter streams with sediment in surface runoff (SURO). The difference in transport mechanisms is supported by studies that indicate nitrate commonly leaches from soils to ground water more readily than ammonia and phosphorus (Guo and others, 2001) and that the majority of nitrate and phosphorus yields in nearby basins are in base flow and stormflow, respectively (Lietman, 1997).

The simulated yields of nitrate, ammonia, and phosphate from pervious and impervious land areas also are dependent on parameters affecting concentrations of the constituent on detached soil or sediment (POTFW) and in interflow (IFLW-CONC) and ground water (GRND-CONC). The parameters affecting interflow and ground-water concentrations affect nitrate yields more than yields of ammonia and orthophosphate because of differences in the main mechanisms that deliver these nutrients to the streams. Consequently, changes to parameters affecting concentrations of nutrients on detached soil (POTFW) affect yields of ammonia and orthophosphate more than nitrate.

Model Limitations

The simulation of water-quality constituent concentrations and loads is dependent on the output of the hydrologic portion of the model. Thus the accuracy of the water-quality simulations will be limited by the hydrologic model. In addition, the water-quality calibration was based on relatively few available observed water-quality data; therefore, compared to a calibration with many water-quality data points, greater uncertainty is associated with this simulation of water quality and assessment of the model performance is more difficult.

The water-quality simulation used model parameters that were obtained from calibration of models in adjacent basins of various sizes and may not be wholly representative of land uses in the Christina River subbasin. Simulation of concentrations of suspended sediment, nitrate, ammonia, and phosphorus for individual storms or short periods of time may not be well simulated by the model because of hydrologic limitations related to accuracy of rainfall data. The timing and intensity of rainfall affect detachment processes for soil and soil-related constituents and transport of the solids from land to streams. The simulation of sediment was calibrated using measured concentrations of suspended solids in samples collected at one point in the stream. However, these point samples may not accurately represent mean suspended-sediment concentrations for the entire cross section in stream reaches that are not well mixed. Simulation of water quality may be less accurate for ungaged areas of the subbasin downstream of the streamflow-measurement station used for calibration (01478000 Christina River at Coochs Bridge) because of unknown spatial differences in hydrologic response. For example, most of the ungaged areas in the subbasin are underlain by soils developed on the Coastal Plain with substantially different infiltration and storage characteristics from the Piedmont area. Also, much of the ungaged area has a shallow water table and drains directly to tidal sections of the Christina River.

The simulation of the nutrients, including nitrogen and phosphorus, also included the biological processes of algal plankton and benthic algal nutrient uptake and release but not the role of zooplankton. Thus the magnitude of diurnal fluctuations in concentrations of dissolved oxygen due to processes of in-stream photosynthesis and respiration may not be fully characterized by the simulation. The simulation of in-stream nutrient concentrations is further affected by the quality and quantity of information about nutrients in discharge from point sources. For example, although the model is run on an hourly time step, data on point-source discharges generally are available as monthly mean values for ammonia, and contributions of phosphorus. Nitrate discharges are extrapolated from reported ammonia. The model, as configured, is better used to estimate loads of nonpoint-source nutrients from land areas than to predict concentrations after considerable in-stream transport and residence time at downstream sites.

The simulation of particulate orthophosphate was calibrated to an estimated value, calculated as observed total phosphorus minus observed dissolved phosphorus. This difference, however, may include forms of phosphorus other than orthophosphate. Because the model as configured only simulates orthophosphate, particulate phosphorus that includes other forms of phosphorus may be undersimulated.

Overall, the model represents streamflow and general water-quality conditions in the Christina River Basin to a reasonable degree. Over long periods of time (months to years) the model appears to be fairly accurate for streamflow. However short-term simulations and simulations of storms are less accurate. The sparseness of water-quality data renders rigorous evaluation of the long-term and short-term performance of the water-quality component of the model simulation difficult. Nevertheless, it is expected that the simulation of water quality is more accurate over long periods than short periods, such as individual storms. Therefore, given the model structure, assumptions, and approach, the best applications of the model are long-term predictions of nonpoint-source contributions to water quality.

OVERVIEW OF CHRISTINA RIVER BASIN MODELS

Separate HSPF models were developed for each of the four main subbasins of the Christina River Basin, including Brandywine Creek, White Clay Creek, Red Clay Creek (Senior and Koerkle 2003a; 2003b; 2003c), and the Christina River subbasin itself (fig. 1). The HSPF models for the main subbasins of the Christina River Basin were developed as part of a basin-wide effort to simulate nonpoint-source contributions of suspended sediment and nutrients. Data for calibration was collected at sites throughout the Christina River Basin and included at least one site in each main subbasin in the nonpoint-source monitoring in 1998. The models can be used separately for each of the subbasins and for the Christina River Basin as whole.

Calibration

Calibration of the HSPF model for each subbasin followed slightly different approaches based on the location and number of streamflow-measurement stations and water-quality monitoring sites in each subbasin. In most subbasins, the hydrologic calibration was done in a downstream order. For the Brandywine Creek model, primary hydrologic calibration was done using data from seven streamflow-measurement stations on the West Branch, East Branch, and main stem Brandywine Creek and less emphasis was placed on the hydrologic calibration of the four small tributary subbasins with nonpoint-source monitoring sites. For the White Clay Creek model, the data used for hydrologic calibration included streamflow measurements from a station on the main stem of Red Clay Creek in an area adjacent to the White Clay Creek subbasin and streamflow measurements from three stations on the main stem of White Clay Creek, with some calibration adjustments using data from a headwaters tributary subbasin (Trout Run). This approach to calibration of the Brandywine Creek and White Clay Creek models resulted in a more satisfactory hydrologic calibration of the overall basin than of smaller subbasin areas less than 10 to 20 mi^2. Similar hydrologic calibration results would be expected for the Red Clay Creek model. For the Red Clay Creek model, no small tributary subbasins had streamflow-measurement stations and the hydrologic calibration was done using data from three streamflow-measurement stations on the main stem of Red Clay Creek. For the Christina River subbasin model, much of the stream is tidal and the hydrologic-calibration data came from streamflow-measurement stations on the main stem and a tributary that drain relatively small areas (less than 25 mi^2) in separate parts of the Christina River subbasin. The overall accuracy of the hydrologic calibrations at the two sites in the Christina River subbasin are similar.

Water-quality data from the small subbasins with nonpoint-source monitoring sites, which are predominantly of one major land use, were used to calibrate the water-quality component of land-based nonpoint-source contributions. Five of the seven small subbasins with nonpoint-source monitoring sites were in the Brandywine Creek drainage area, one in the White Clay Creek drainage area, and one (Little Mill Creek, described in this report) in the Christina River drainage area. The five nonpoint-source monitoring sites in the Brandywine Creek subbasin were located to assess water quality associated with two types of agricultural (row crop and mixed animal/crop), two types of residential (sewered and septic systems), and forested land uses. Model water-quality parameters from these five land uses were transferred with minor modifications to models for White Clay Creek, Red Clay Creek, and Christina River subbasins. Model water-quality parameters from the agricultural land use of mushroom-growing were developed for the White Clay Creek model and transferred to the Red Clay Creek model. Despite the limitations of the hydrologic calibration of the small subbasins with nonpoint-monitoring sites in the Brandywine Creek and White Clay Creek models, the transfer of the water-quality model parameters appeared to result in reasonable water-quality simulations in the other subbasin models.

Simulated Sediment and Nutrient Yields

Simulated yields of suspended sediment and nutrients differed by land use and in some cases by soil type. In general, in each of the modeled subbasins, Brandywine Creek, White Clay Creek, Red Clay Creek, and the Christina River itself, simulated suspended-sediment yields were larger from agricultural land than from other land uses. Simulated average annual sediment and nutrient yields for 1995-97 from the various land uses in the four subbasins are presented in tables 28-31. Yields tended to increase in relation to increases in precipitation because ground-water discharge and surface runoff commonly were greater in wet years than in dry years. Average annual precipitation for 1995-97 was greatest in the Brandywine Creek subbasin and least in the Christina River subbasin, indicating a spatial trend of a north to south decrease in precipitation for the 1995-97 period.

Table 28. *Observed annual precipitation and simulated average annual sediment yield by land use for pervious and impervious land areas in segments of Hydrological Simulation Program–Fortran (HSPF) model for the Brandywine Creek, Red Clay Creek, White Clay Creek, and Christina River subbasins, 1995-97*

	Subbasin average, 1995-97			
	Brandywine Creek average of four segments	**White Clay Creek average of three segments**	**Red Clay Creek average of three segments**	**Christina River average of three segments**
Precipitation (inches)	50.51	45.91	45.86	40.68
Simulated average annual sediment yield (tons per acre per year) by land-use category[1]				
Residential - unsewered	.218	.192	.232	.146
Residential - sewered	.261	.271	.287	.222
Urban	.418	.404	.381	.340
Agricultural - animals/crops	1.67	1.76	1.88	1.18
Agricultural - row crop	1.67	1.69	1.83	1.16
Agricultural - mushroom	1.23	2.39	2.10	1.18
Forested	.067	.047	.060	.041
Open	.217	.259	.263	.201
Wetlands/water	.050	.005	.007	.003
Undesignated	.226	.260	.258	.198
Impervious - residential	.114	.201	.198	.114
Impervious - urban	1.124	.795	.785	.665

[1] In pervious areas, unless noted.

Table 29. *Observed annual precipitation and simulated average annual nitrate yield by land use for pervious and impervious land areas in segments of Hydrological Simulation Program–Fortran (HSPF) model for the Brandywine Creek, Red Clay Creek, White Clay Creek, and Christina River subbasins, 1995-97*

	Subbasin average, 1995-97			
	Brandywine Creek average of four segments	**White Clay Creek average of three segments**	**Red Clay Creek average of three segments**	**Christina River average of three segments**
Precipitation (inches)	50.51	45.91	45.86	40.68
Simulated average annual nitrate yield (pounds as nitrogen per acre per year) by land-use category[1]				
Residential - unsewered	17.25	14.28	12.66	9.38
Residential - sewered	9.02	7.55	6.73	4.99
Urban	9.07	7.62	6.66	5.00
Agricultural - animals/crops	32.14	27.2	24.3	18.6
Agricultural - row crop	29.46	24.5	19.0	16.1
Agricultural - mushroom	40.81	33.1	29.2	23.1
Forested	1.80	1.47	1.39	1.11
Open	6.46	5.08	4.62	3.32
Wetlands/water	1.58	1.78	1.53	1.44
Undesignated	6.16	5.09	4.62	3.39
Impervious - residential	2.07	2.04	2.03	2.01
Impervious - urban	2.07	2.04	2.03	2.01

[1] In pervious areas, unless noted.

Table 30. *Observed annual precipitation and simulated average annual total ammonia yield by land use for pervious and impervious land areas in segments of Hydrological Simulation Program–Fortran (HSPF) model for the Brandywine Creek, Red Clay Creek, White Clay Creek, and Christina River subbasins, 1995-97*

	Subbasin average, 1995-97			
	Brandywine Creek average of four segments	**White Clay Creek average of three segments**	**Red Clay Creek average of three segments**	**Christina River average of three segments**
Precipitation (inches)	50.51	45.91	45.86	40.68
Simulated average annual total ammonia yield (pounds as nitrogen per acre per year) by land-use category[1]				
Residential - unsewered	.172	.152	.149	.101
Residential - sewered	.108	.085	.080	.088
Urban	.102	.095	.086	.107
Agricultural - animals / crops	.835	.758	.720	.508
Agricultural - row crop	.676	.584	.470	.391
Agricultural - mushroom	.435	3.40	2.97	1.40
Forested	.045	.040	.037	.028
Open	.157	.134	.124	.087
Wetlands / water	.025	.030	.026	.023
Undesignated	.155	.134	.124	.248
Impervious - residential	.361	.372	.371	.360
Impervious - urban	.499	.432	.430	.413

[1] In pervious areas, unless noted.

Table 31. *Observed annual precipitation and simulated average annual total orthophosphate yield by land use for pervious and impervious land areas in segments of Hydrological Simulation Program–Fortran (HSPF) model for the Brandywine Creek, Red Clay Creek, White Clay Creek, and Christina River subbasins, 1995-97*

	Subbasin average, 1995-97			
	Brandywine Creek average of four segments	**White Clay Creek average of three segments**	**Red Clay Creek average of three segments**	**Christina River average of three segments**
Precipitation (inches)	50.51	45.91	45.86	40.68
Simulated average annual total orthophosphate yield (pounds as phosphorus per acre per year) by land-use category[1]				
Residential - unsewered	.210	.210	.222	.147
Residential - sewered	.215	.252	.251	.190
Urban	.272	.312	.291	.239
Agricultural - animals / crops	10.5	6.99	7.50	4.64
Agricultural - row crop	9.10	6.71	7.31	4.57
Agricultural - mushroom	14.8	32.6	29.0	16.1
Forested	.029	.020	.029	.015
Open	.256	.245	.245	.183
Wetlands / water	.120	.015	.013	.012
Undesignated	.263	.245	.241	.182
Impervious - residential	.367	.401	.400	.293
Impervious - urban	1.88	.912	.903	.779

[1] In pervious areas, unless noted.

Model Applications

The HSPF model for the Christina River was developed to assist in the assessment of suspended sediment and nutrient loads from nonpoint sources to streams. The model load estimates may be used as part of an ongoing total maximum daily load (TMDL) assessment for the Christina River Basin to indicate the possible location and magnitude of load reductions that might be needed to maintain or improve water quality where impaired. These load estimates are based on the land-use conditions during the period of calibration and do not reflect the effects of best management practices put in place after 1998.

The models can be used to estimate loads from individual basins for the purposes of evaluating relative and absolute contributions of suspended sediment, nitrogen, and phosphorus. This information may be helpful in assessing areas that appear to generate elevated nonpoint-source loads of these constituents. For example, simulated total loads and loads per acre in 1995 for selected headwater areas are listed for the Brandywine Creek, White Clay Creek, and Red Clay Creek subbasins (Senior and Koerkle, 2003a; 2003b; 2003c). Precipitation in 1995 was similar to the long-term average, and yields in that year might be assumed to be similar to average.

The HSPF model for the Christina River Basin can be used to compare simulated loads in the Christina River Basin and adjacent basins, where monitoring data are limited, to loads calculated from extensive observed data in nearby basins to the west that drain to the Chesapeake Bay. Evaluation of monitoring data from these nearby basins indicates a positive correlation between the percentage of land in agricultural use and calculated yields of nitrate, ammonia, phosphorus, and suspended sediment (Langland and others, 1995). Similar relations are indicated by results of the HSPF model for the Brandywine Creek, White Clay Creek, and Red Clay Creek (Senior and Koerkle, 2003a; 2003b; 2003c), and the Christina River subbasins. Comparison of simulated and calculated yields suggests that these models provide reasonable estimates of nonpoint-source yields (figs. 42 and 43).

The HSPF model for the Christina River Basin also can be used to compare simulated loads from land-based nonpoint sources to reported loads from point-source discharges to streams in the basin. For example, total nitrate, ammonia, and orthophosphate loads as estimated by the HSPF models for the drainage area above selected streamflow-measurement stations near the bottom of the main subbasins (Brandywine Creek, White Clay Creek, Red Clay Creek, and the Christina River) are listed with estimated and reported loads from point-source discharges to the streams in table 32. For phosphorus in table 32, the reported point source loads are for total phosphorus and the simulated nonpoint-source loads are for total orthophosphate, which would be a minimum estimate for total phosphorus. The simulated loads shown in table 32 are for the entire Christina River Basin for the 4-year period (October 1994-October 1998) and represent a range of hydrologic conditions. Total loads of nitrate, ammonia, and orthophosphate tend to decrease with decreasing subbasin area. Yields (or loads per acre) of sediment and nutrients are less for the Christina River subbasin than for other subbasins.

The relative proportion of nonpoint-source and point-source contributions differs by constituent and by subbasin. The White Clay Creek subbasin had the least amount of point-source loads relative to nonpoint-source loads of the four subbasins modeled. Simulated nitrate loads from nonpoint sources were about twice the estimated nitrate loads from point sources for Brandywine Creek and more than 30 times greater than estimated nitrate loads from point sources in the other subbasins (table 32). Simulated ammonia loads from nonpoint sources were about twice the estimated ammonia loads from point sources for Brandywine Creek, Red Clay Creek, and Christina River and more than 30 times greater than estimated ammonia loads from point sources for White Clay Creek. Simulated phosphorus loads from nonpoint sources were about 2 times greater than estimated phosphorus loads from point sources for the Christina River, 13 times greater for Brandywine Creek, 26 times greater for Red Clay Creek, and almost 100 times greater than estimated phosphorus loads from point sources for White Clay Creek.

The HSPF models for the Christina River Basin may be used as a predictive tool to estimate loads under statistically identified flow conditions, such as those based on some period of record. For example, expected average or baseline constituent loads from the whole basin or selected subbasins in the Christina River Basin could be estimated for base flow or stormflow conditions by selecting simulation periods corresponding to periods of

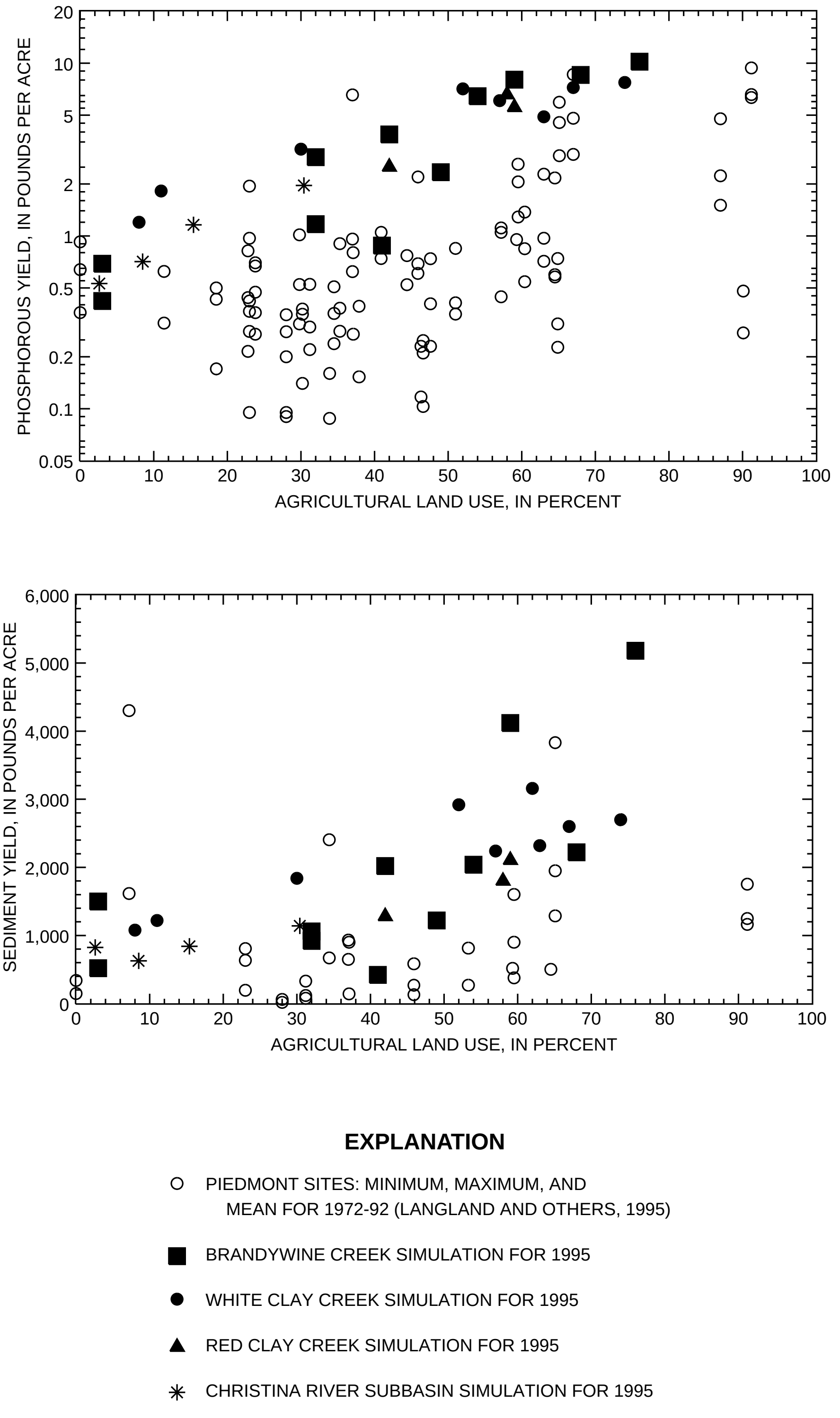


Figure 42. Sediment and phosphorus yields in relation to percent agricultural land use as calculated from observed data for subbasins in the Chesapeake Bay Watershed and as simulated by Hydrological Simulation Program–Fortran (HSPF) model for selected subbasins in the Brandywine Creek, White Clay Creek, Red Clay Creek, and Christina River Basins.

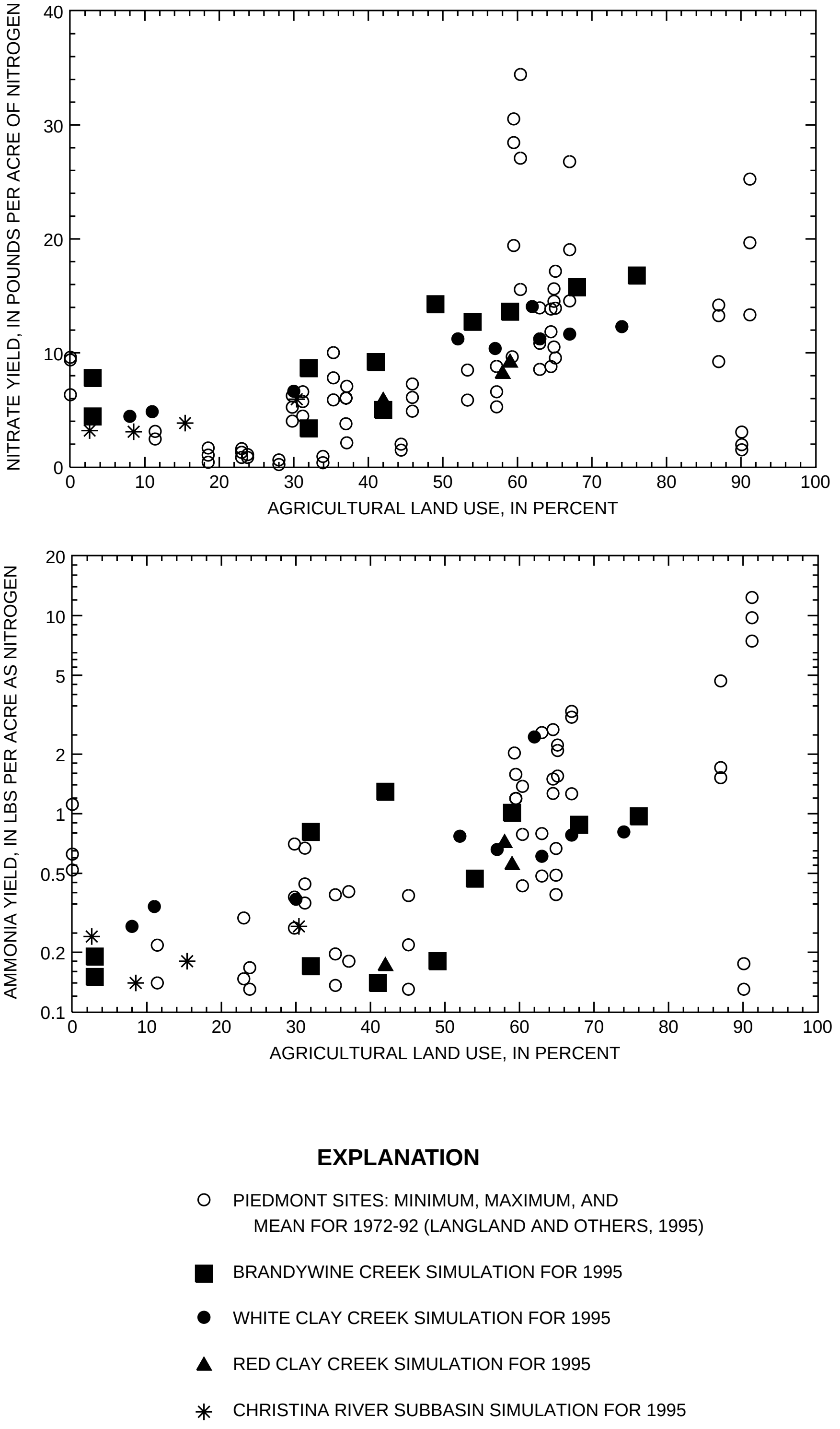


Figure 43. Yields of nitrate and ammonia in relation to percent agricultural land use as calculated from observed data for subbasins in the Chesapeake Bay Watershed and as simulated by Hydrological Simulation Program–Fortran (HSPF) model for selected subbasins in the Brandywine Creek, White Clay Creek, Red Clay Creek, and Christina River Basins.

Table 32. *Total simulated nonpoint-source and estimated point-source loads of nitrate, ammonia, and phosphorus for the 4-year period October 1, 1994, through September 30, 1998, Christina River Basin*

	Drainage area (square miles)	Total load, 1994-98, in tons		
		Nitrate[1]	Ammonia	Phosphorus[2]
Brandywine Creek[3]	314			
Nonpoint source		5,860	123	1,470
Point source		3,390	55	112
White Clay Creek[4]	89.1			
Nonpoint source		1,414	54	455
Point source		3.5	4	4.7
Red Clay Creek[5]	52.4			
Nonpoint source		696	29	266
Point source		25	30	13
Christina River[6]	20.9			
Nonpoint source		198	5.0	43
Point source		2.6	3.1	1.2

[1] Estimated for point sources from reported ammonia loads.

[2] Estimated by simulated total orthosphosphate for nonpoint sources.

[3] Reported point-source discharges and simulated nonpoint-source loads for drainage area above 01481500, Brandywine Creek at Wilmington Del.

[4] Reported point-source discharges and simulated nonpoint-source loads for drainage area above 01479000, White Clay Creek near Newark, Del.

[5] Reported point-source discharges and simulated nonpoint-source loads for drainage area above 01480015, Red Clay Creek near Stanton, Del.

[6] Reported point-source discharges and simulated nonpoint-source loads for drainage area above 01478000, Christina River at Coochs Bridge, Del.

normal precipitation. In addition, loads for events associated with statistical recurrence intervals such as the 25-year storm or 100-year flood could be estimated by selecting simulation periods where the hydrologic record indicates events of these magnitudes have occurred.

The transport pathways from land to stream for nonpoint-source contaminants differ by constituent. In the Christina River models, the majority of nitrate enters the stream through ground-water discharge and the majority of ammonia and orthophosphate enters the stream through surface runoff and interflow. This information may be useful to water-resources managers in devising strategies to reduce loads from nonpoint sources. For example, the HSPF model for the Christina River subbasin can be used to quantify the amount of nutrients that entered the stream in ground water or runoff. For the October 1994 through October 1998 simulation period, the model estimated that about 60 percent of the nitrate load from nonpoint sources (land areas) above the Christina River at Coochs Bridge, Del., entered the stream through ground-water discharge. Further, the model estimates only about 20 percent of ammonia and 2 percent of orthophosphate entered the stream through ground-water discharge in the drainage area above Coochs Bridge, and the balance of these constituents entered the stream in interflow and surface-water runoff.

Successful application of the Christina River Basin HSPF models to future scenarios or periods of record other than the calibration period will be best supported if the model is calibrated to a broad range of representative hydrologic conditions. The Christina River Basin models generally were calibrated to a range of streamflows that covered all but the more extreme high-flow and low-flow periods (Senior and Koerkle, 2003a; 2003b; 2003c). For example, comparison of the simulated and observed daily mean streamflow duration curves for the simulation period at station 01478000, Christina River at Coochs Bridge, Del., to the observed daily mean streamflow duration curve for the 58-year period October 1, 1943, to September 30, 2001 (fig. 44), shows generally good agreement. Daily mean streamflows greater than 1,000 ft^{3}/s did not occur in the simulation period, so that above that value, the duration curves for the simulation period are extrapolations and should not be directly compared with the duration curve for the period of record. Daily mean streamflows greater than 1,000 ft^{3}/s occurred less than 0.1 percent of the time during the 58-year period of record at

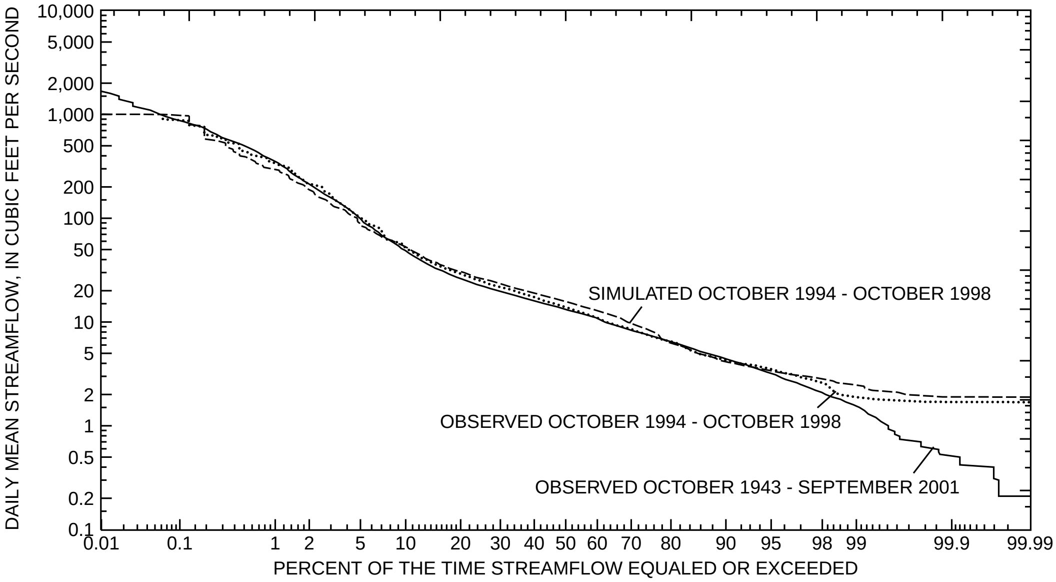


Figure 44. Duration curves of observed daily mean streamflow for the period October 1, 1943, to September 30, 2001, and of observed and simulated daily mean streamflow for the period of simulation, October 1, 1994, to October 29, 1998, at 01478000, Christina River at Coochs Bridge, Del.

Christina River at Coochs Bridge. The highest streamflows generally produce the largest loads of suspended constituents, but they are also infrequent events. Below about 1.5 ft^3/s, duration curves for the simulation period and 58-year period of record do show substantial departure. Thus, the performance of the model simulations at these low flows, estimated to occur 2 percent of the time, is unknown; however, the transport of suspended nonpoint-source constituents can be expected to be negligible during these infrequent occurrences.

Limitations and Uncertainty

Model use should consider calibration approaches and limitations of data. Because the model was calibrated for relatively large drainage areas, the model should not be expected to predict well the hydrologic response and water quality for drainage areas of less than 10 to 20 mi^2. In addition, because the model was calibrated with water-quality parameters transferred between one or more subbasins, the models may not necessarily characterize differences related to variations in land use and loading rates within the Christina River Basin.

Limited water-quality data were available to calibrate and assess the water-quality simulation, especially during storm or high-flow conditions. Substantial uncertainty is associated with the water-quality simulations due to limited monitoring data, and for main-stem sites downstream of point-source discharges, lack of daily or hourly discharge information. Nevertheless, estimates of model uncertainty for stormflow and base-flow conditions were obtained from the 1998 nonpoint-source monitoring data. Figures 45-47 are boxplots that show the range in ratios of simulated to observed stormflow volume and constituent loads for sampled storms in 1998. The ratio of simulated to observed flow or loads for a perfect simulation with neither a positive or negative bias would be equal to 1.0. A dotted line equal to 1.0 is shown on the figures as a reference to evaluate the degree to which simulated values are greater or smaller than observed values. The median value indicates the central tendency of the simulation and the box and whiskers diagram shows the range of values outside the median. The box includes 50 percent of the data and the whiskers include 80 percent of the data (between the 90th and 10th percentiles).

Data are grouped into main-stem and subbasin sites. The main-stem sites include the streamflow-measurement stations near the bottom of the free-flowing sections of Brandywine Creek, Red Clay Creek, White Clay Creek, and Christina River and drain relatively large areas with a variety of different land uses. The subbasin sites include the nonpoint-source monitoring sites in drainage areas predominantly covered by one of seven land uses. Simulated stream volumes or constituent loads for individual sites within the main stem and subbasin groups may be more similar to observed stream volumes or constituent loads shown for the groupings as a whole.

The range in ratios of simulated to observed stormflow volume and suspended sediment and nutrient loads commonly is smaller for main-stem sites than subbasin sites (figs. 45-47). For stormflow volume, differences in main-stem and subbasin simulated to observed ratios are partly a consequence of the greater emphasis that was placed on the hydrologic calibration of main-stem sites than of small subbasin sites. The model simulations for stormflow volume at main-stem sites appear to have little positive or negative bias compared to a slight negative bias (undersimulation) at the subbasin sites (fig. 45). The median ratio of simulated to observed stormflow volume for main-stem sites is near 1.0 and for subbasin sites is about 0.8.

The errors in water-quality load simulations commonly will be larger than streamflow simulations because simulation errors include those associated with water-quality and streamflow simulations. For suspended sediment, the median ratios of simulated to observed loads is near 1.0 for main-stem and subbasin sites, indicating little bias in the simulations. However, the range in ratios of simulated to observed suspended-sediment loads is larger than the range in ratio of simulated to observed stormflow volumes. For nitrate, the median ratios of simulated to observed loads is about 0.7 for main-stem and subbasin sites, indicating undersimulation. The range in ratio of simulated to observed nitrate loads is not as large as that for sediment loads and suggests that uncertainty in simulated nitrate is less than that for suspended sediment.

For dissolved ammonia, the median ratios of simulated to observed loads was about 2.0 for main-stem sites and 0.4 for subbasin sites (fig. 46). These results indicate that dissolved ammonia

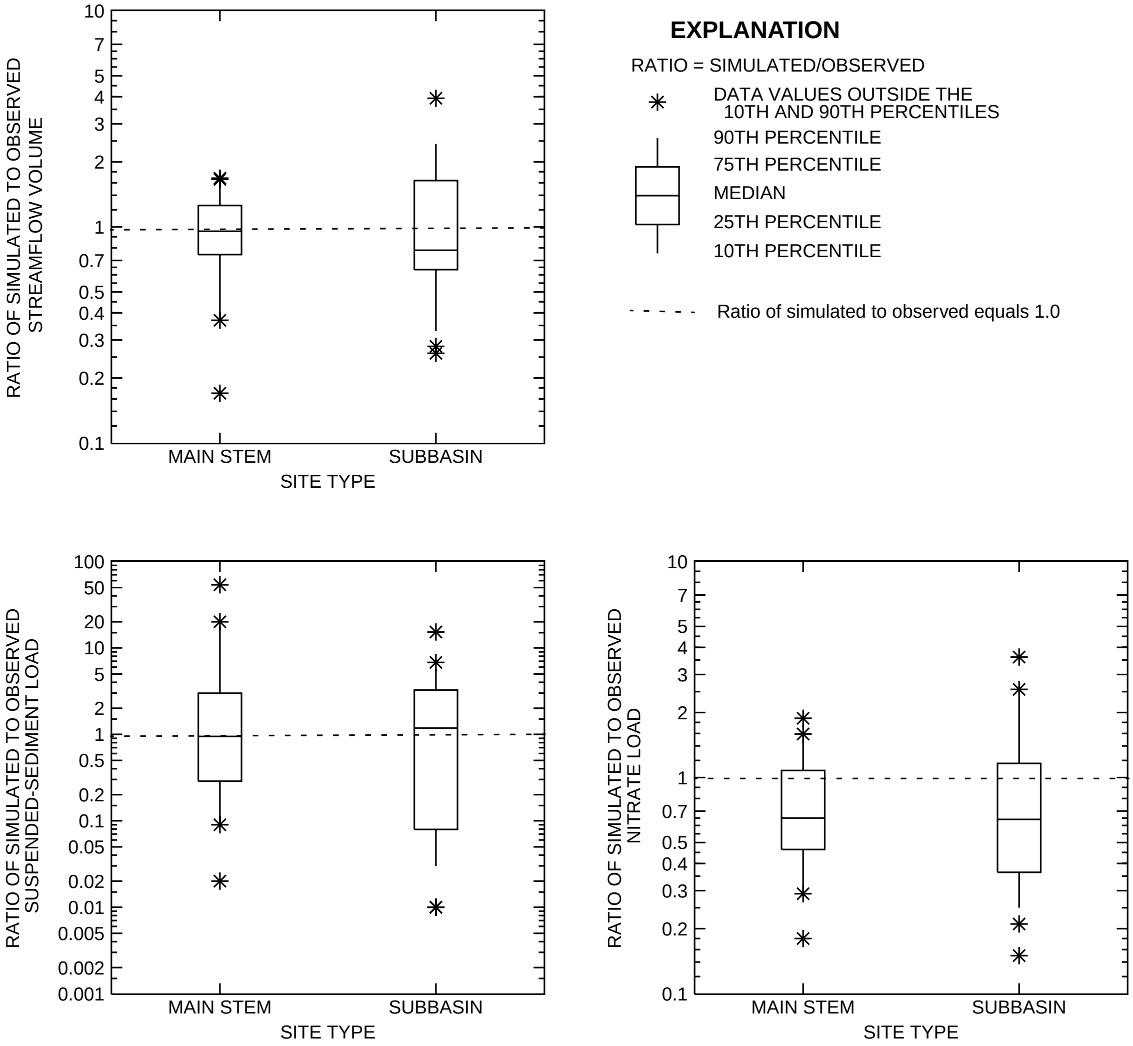


Figure 45. Boxplots showing ratio of simulated to observed streamflow, suspended-sediment loads, and nitrate loads for sampled storms in 1998 at four main-stem sites and seven subbasin sites in the Christina River Basin.

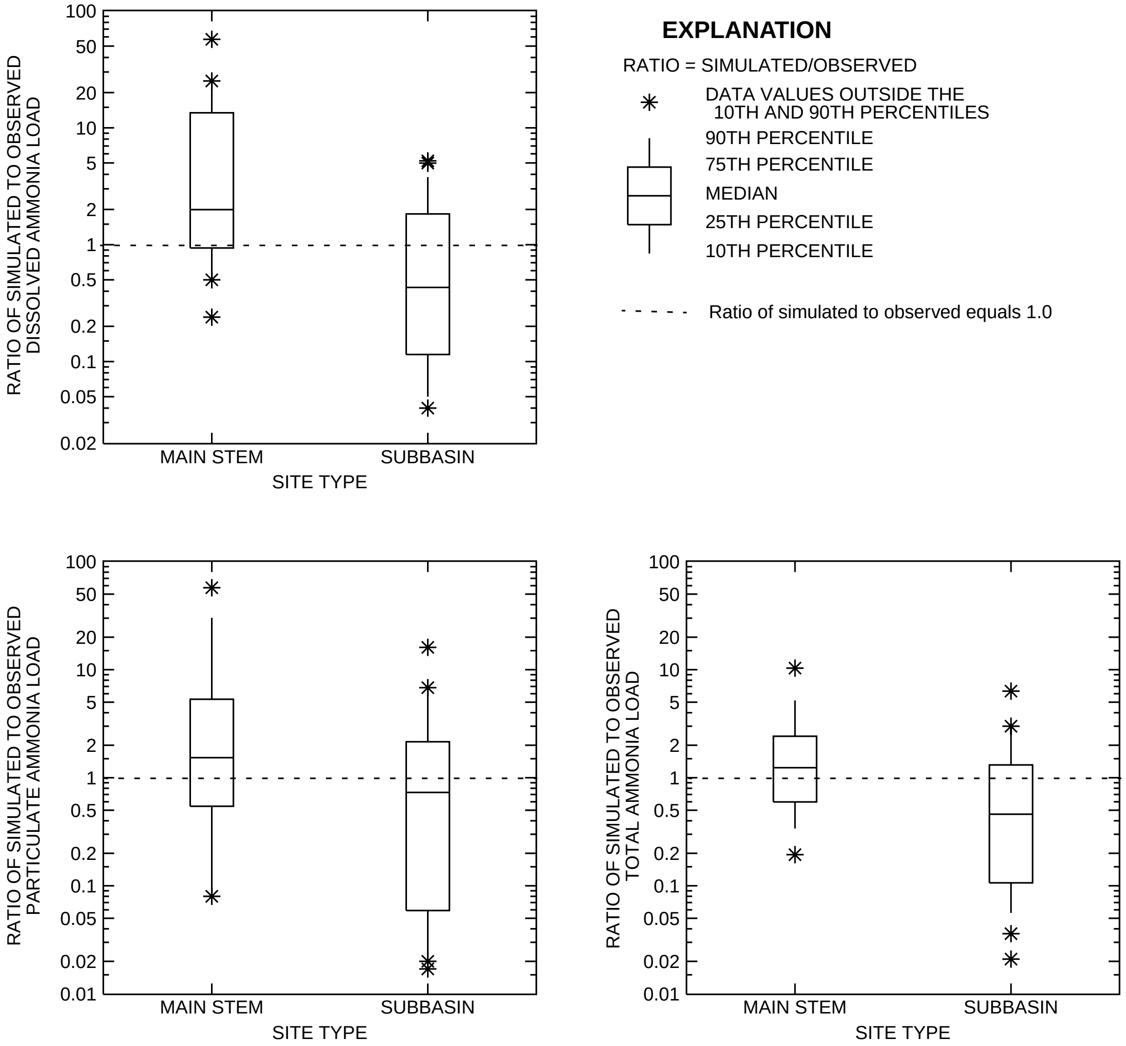


Figure 46. Boxplots showing ratio of simulated to observed dissolved ammonia, particulate ammonia, and total ammonia loads for sampled storms in 1998 at four main-stem sites and seven subbasin sites in the Christina River Basin.

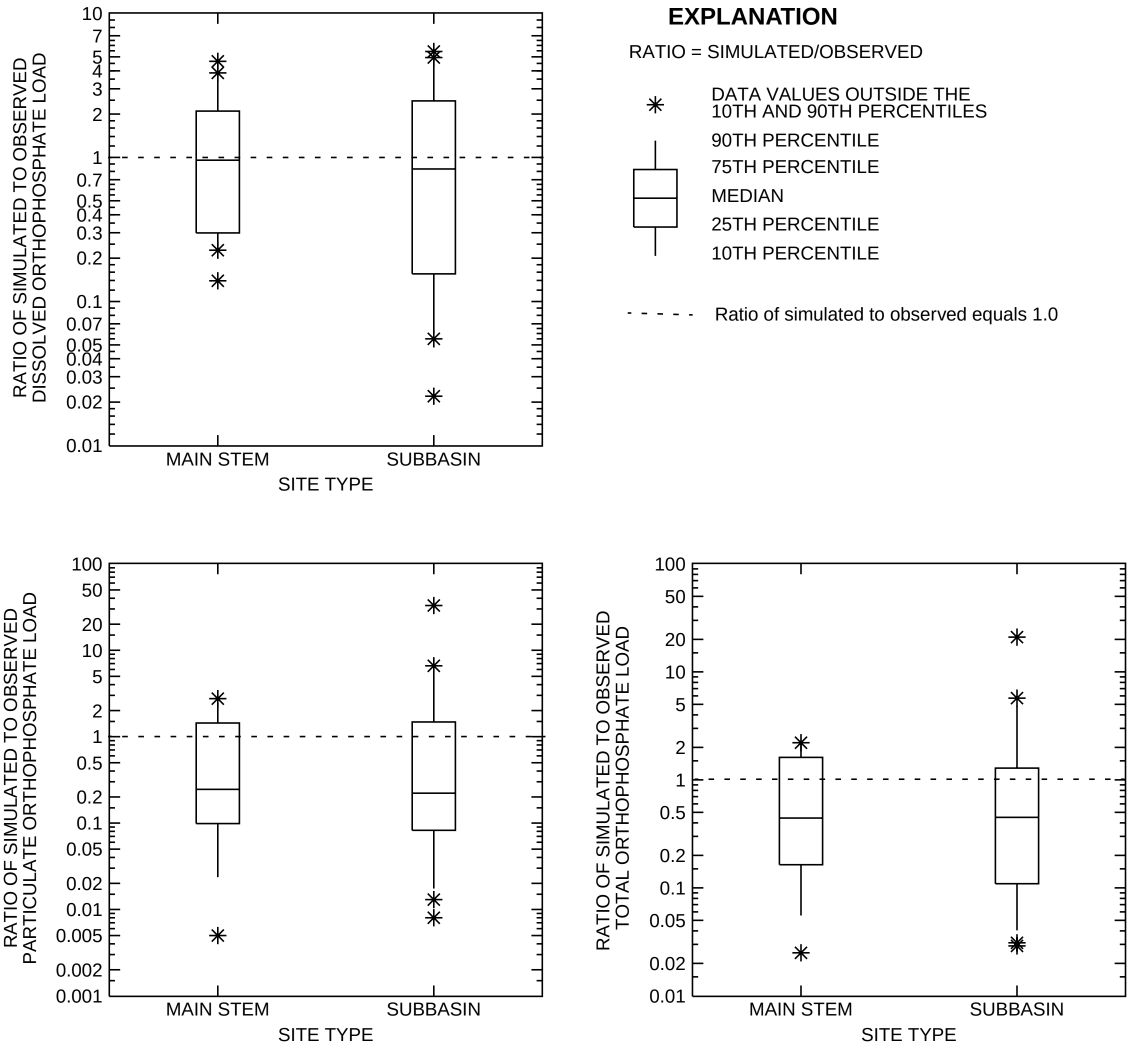


Figure 47. Boxplots showing ratio of simulated to observed dissolved orthophosphate, particulate orthophosphate, and total orthophosphate loads for sampled storms in 1998 at four main-stem sites and seven subbasin sites in the Christina River Basin.

tended to be oversimulated at main-stem sites and undersimulated at subbasin sites. The oversimulation of dissolved ammonia at main-stem sites may be related to errors in estimated point-source discharges of ammonia and (or) in-stream processing of nutrients. For particulate ammonia, the median ratios of simulated to observed loads is about 1.5 for main-stem sites and 0.7 for subbasin sites, and for total ammonia (dissolved plus particulate), the median ratios of simulated to observed loads was about 1.2 for main-stem sites and 0.5 for subbasin sites (fig. 46). The range of ratios of simulated to observed loads was smaller for total ammonia than for dissolved or particulate ammonia. This result may indicate that a source of model error may be associated with the simulated partitioning of ammonia between the dissolved and particulate phases.

For dissolved orthophosphate, the median ratios of simulated to observed loads was about 0.95 for main-stem sites and 0.85 for subbasin sites, indicating little bias in the simulation (fig. 47). For particulate orthophosphate, the median ratios of simulated to observed loads was about 0.25 for main-stem and subbasin sites, indicating undersimulation. The apparent undersimulation of particulate orthophosphate may be due to forms of phosphorus other than adsorbed orthophosphate in the total phosphorus analyzed by the laboratory. For total orthophosphate (dissolved plus particulate), the median ratios of simulated to observed loads was about 0.6 for main-stem and subbasin sites. The range of ratios of simulated to observed loads for total orthophosphate was similar to that for particulate orthophosphate because much of stormload orthophosphate was in the particulate phase. However, the median of simulated to observed ratios for total orthophosphate was closer to 1.0 than the median of simulated to observed ratios for particulate orthophosphate and probably was due to the superior simulation of the dissolved component of orthophos-phate (fig. 47).

Uncertainty associated with the simulation under base-flow conditions can be estimated from boxplots that show the range in ratios of simulated to observed stormflow and constituent loads in base-flow samples collected in 1998 (fig. 48). Under base-flow conditions, dissolved nutrient loads are larger than particulate nutrient loads and only dissolved loads are plotted in figure 48. In the base-flow samples collected in 1998 at nonpoint-source monitoring sites in the Christina River Basin, the dissolved ammonia load represented on average about 75 percent of the total ammonia load and the dissolved orthophosphate load represented on average about 65 percent of the total phosphorus load. In general, simulated streamflow and nutrient loads were more similar to observed streamflow and nutrient loads at the subbasin sites than at the main-stem sites. The median ratios of simulated hourly mean to observed instantaneous streamflow and dissolved nutrients were closer to 1.0 for the subbasin sites than for the main-stem sites (fig. 48). Differences in the apparent accuracy of nutrient simulation at the two types of sites may result in part from errors in estimating point-source discharges that affect water quality at the main-stem site and in part from a slighter greater bias in streamflow simulation at the main-stem sites than at the subbasin sites. No bias was apparent for the simulation of nitrate, dissolved ammonia, and dissolved orthophosphate loads at the subbasin sites under base-flow conditions. Nitrate and dissolved ammonia tended to be oversimulated at the main-stem sites under base-flow conditions.

SUMMARY AND CONCLUSIONS

The Christina River Basin drains 565 mi^2 in Pennsylvania and Delaware and is used for recreation, drinking water supply, and support of aquatic life. The Christina River Basin includes the major subbasins of Brandywine Creek (327 mi^2), White Clay Creek (89 mi^2), Red Clay Creek (54 mi^2), and the Christina River (76 mi^2). Monitoring data indicate that water quality in some parts of the Christina River Basin is impaired and does not support designated uses of the stream. A water-quality management strategy developed by a group of local, county, State, and Federal agencies to address water-quality problems included a modeling component to evaluate the effects of point and nonpoint-source contributions of nutrients and suspended sediment on stream water quality. The model selected for the nonpoint-source evaluation was Hydrological-Simulation Program–Fortran (HSPF). The HSPF model for the Christina River Basin was constructed and calibrated by the USGS in cooperation with the Delaware River Basin Commission, Delaware Department of Natural Resources and Environmental Control (DNREC), and Pennsylvania Department of Environmental Protection (PADEP) and consists of four independent models, one for each of the four main subbasins. Reports describing the HSPF model for each subbasin were pre-

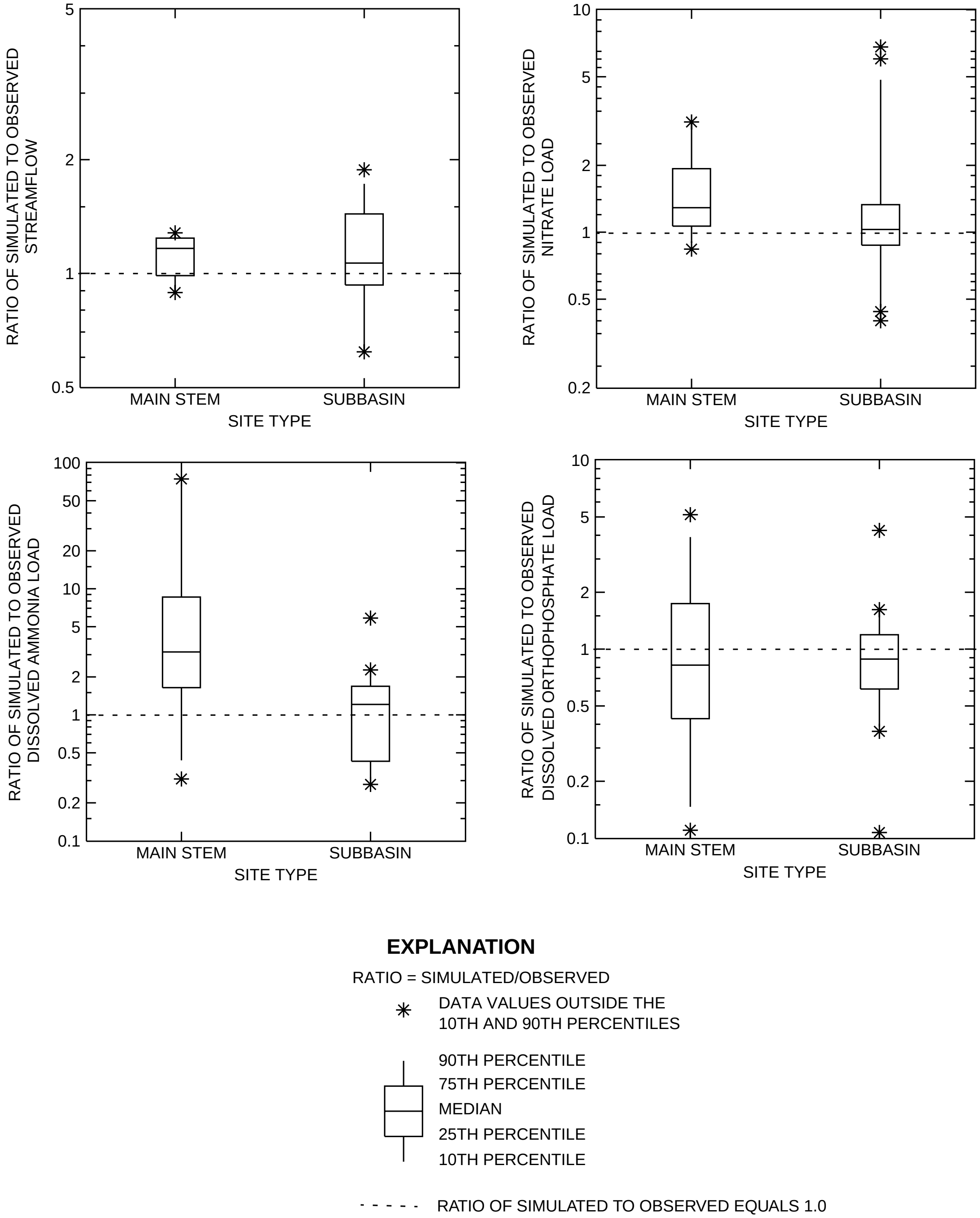


Figure 48. Boxplots showing ratio of simulated mean hourly to observed instantaneous streamflow, nitrate, dissolved ammonia, and dissolved orthophosphate loads for base-flow periods in 1998 at four main stem sites and seven subbasin sites in the Christina River Basin.

pared. This report describes the HSPF model for the Christina River subbasin and provides an overview of all four subbasin models.

The USGS also developed and executed a monitoring plan to collect water-quality data in each of the four main subbasins and in small areas predominantly covered by one land use for model calibration. Under this plan, stormflow and base-flow samples were collected during 1998 at two sites in the Christina River subbasin and nine sites elsewhere in the Christina River Basin. Seven of the eleven monitored stream sites in the Christina River Basin drained areas ranging in size from 0.6 to 18.7 mi^2 that were predominantly covered by one land use: mixed animal and row-crop agricultural; row-crop agricultural; mushroom-growing agricultural; forested; sewered residential; un-sewered residential; or urban. The nonpoint-source monitoring site at the streamflow-measurement station 01480095, Little Mill Creek near Newport, Del., had a drainage area of about 5.4 mi^2 where the land use is predominantly urban. The nonpoint-source monitoring site at the streamflow-measurement station 01478000, Christina River at Coochs Bridge, Del., was a few miles upstream of the tidal part of the Christina River and had a drainage area of about 21 mi^2 where the land use is mixed. Water samples were analyzed for dissolved and total nutrients and suspended solids. Because suspended-sediment data were not available, suspended-solids data were used as a surrogate for suspended-sediment data. The monitoring data indicated that suspended solids and total phosphorus concentrations were higher in stormflow than in base-flow samples whereas dissolved nitrate concentrations tended to be higher in base-flow than in stormflow samples.

The HSPF model for the Christina River subbasin was used to simulate streamflow, suspended sediment, and several species of the nutrients nitrogen and phosphorus. For the model, the subbasin was subdivided into nine reaches draining areas that ranged from 3.8 to 21.9 mi^2. Hydrologic routing was not simulated for the three reaches containing an impoundment (Belltown Run, Muddy Run, Smalley's Pond) and the one tidal reach below Smalley's Pond. Ten different pervious land uses and 2 impervious land uses were selected for simulation. Land-use areas were determined from 1995 land-use data. The predominant land uses in the Christina River subbasin were residential, urban, forested, and agricultural.

The hydrologic component of the model was run at an hourly time step and calibrated using streamflow data from two USGS streamflow-measurement stations for the period of October 1, 1994, through October 29, 1998. Daily precipitation data from one National Oceanic and Atmospheric Administration (NOAA) meteorologic station near the western part of Christina River subbasin and hourly precipitation-intensity data from one NOAA meteorologic station to the southeast of the subbasin were used for model input. The difference between observed and simulated streamflow volume ranged from -2.3 to 5.3 percent for a 10-month period at the two calibration sites. Annual differences between observed and simulated streamflow generally were greater than the overall error. For example, at streamflow-measurement station 01478000, Christina River at Coochs Bridge, Del. (drainage area of 20.9 mi^2), annual differences between observed and simulated streamflow ranged from -6.9 to 6.5 percent and the overall error for the 4-year period was -1.1 percent (-0.9 in.). At the two streamflow-measurement stations, calibration errors for total flow volume, low-flow-recession rate, 50-percent lowest flows, 10-percent highest flows, storm peaks and other seasonal measures generally were within recommended criteria for a satisfactory calibration. Much of the error in simulating storm events on an hourly time step can be attributed to uncertainty in the rainfall data.

Model parameters affecting water quality were taken, with minor adjustments, from calibrated HSPF models for the adjacent Brandywine Creek, White Clay Creek, and Red Clay Creek subbasins, where data were available to calibrate inputs from specific land uses. The calibration of water-quality components of the Christina River subbasin model was assessed using monitoring data collected at two USGS streamflow-measurement stations with variable periods ending October 1998. Both stations were downstream of point-source discharges. The date for the start of water-quality monitoring ranged from October 1994 to January 1998. Suspended-solids data collected during monitoring were used as estimates for suspended sediment. Fewer data were available for water-quality calibration than for streamflow calibration. Simulated cumulative loads of suspended sediment, nitrate, dissolved and particulate ammonia, and dissolved orthophosphate and particulate phosphorus were within an order of magnitude or less of observed loads for storms sampled in 1998 at the nonpoint-source monitoring sites. Simulation errors for grab samples collected by state agencies near the two streamflow-measurement stations were larger and may be due in part to differences in water quality at the sampling locations. Errors in ammonia simulation apparently were greater than errors in nitrate and orthophosphate simulation. Some error could be related to variability in point-source discharges upstream of monitoring sites. The error in water-quality loads typically was larger than the error in simulated stormflows, which was included in the water-quality error. Error in simulation of dissolved constituents generally was less than the error in simulation of particulate constituents. In storms, particulate phosphorus loads generally were greater than dissolved orthophosphate loads, and nitrate loads were about one order of magnitude greater than dissolved ammonia loads and two orders of magnitude greater than particulate ammonia loads.

Simulated yields of suspended sediment, nitrate, and ammonia for land uses in the Christina River subbasin were similar to yields simulated for those land uses in adjacent basins and to yields calculated from monitoring data for subbasins in the nearby Chesapeake Bay drainage. Yields (expressed in pounds per acre) of these constituents tended to increase as the percent of agricultural land increased. Nutrient yields generally were smaller in the Christina River subbasin than in the other subbasins because of the differences in land uses. The Christina River subbasin had proportionately more urban and residential land and less agricultural land than the White Clay, Red Clay, and Brandywine Creek subbasins.

Users of the Christina River Basin HSPF models should be aware of model limitations and consider the following when predictive scenarios are desired: duration curves suggest the model simulates streamflow reasonably well when measured over a broad range of conditions and time although streamflow and the corresponding water-quality for individual storm events may not be well simulated; streamflow duration curves for the simulation period compare well with duration curves for the longer periods of record, such as the 55.5-year period ending in 1998 at Christina River at Coochs Bridge, Del., and include all but the extreme high-flow and low-flow events; calibration for water quality was based on limited data, with the effect of increasing uncertainty in the water-quality simulation. Given these limitations, the model may be considered appropriate for simulating streamflow and water-quality concentrations and yields over relatively long periods of time, such as the 5-year period used for model calibration.

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APPENDIX 1

STORMFLOW AND BASE-FLOW WATER QUALITY

Table 1. *Results of laboratory analysis of stormflow samples collected at two sites in the Christina River subbasin, 1998*

Date	Time	Ending date	Ending time	AGENCY ANALYZING SAMPLE (CODE NUMBER) (00028)	AGENCY COLLECTING SAMPLE (CODE NUMBER) (00027)	ELEV. OF LAND SURFACE DATUM (FT. ABOVE NGVD) (72000)	DISCHARGE, IN CUBIC FEET PER SECOND (00060)	DISCHARGE, INST. CUBIC FEET PER SECOND (00061)	DRAINAGE AREA (SQ. MI.) (81024)	SPECIFIC CONDUCTANCE LAB (US/CM) (90095)	CHLORIDE, DISSOLVED (MG/L AS CL) (00940)	RESIDUE TOTAL AT 105 DEG. C, SUSPENDED (MG/L) (00530)	NITROGEN, AMMONIA DISSOLVED (MG/L AS N) (00608)
01480095 LITTLE MILL CREEK NEAR NEWPORT, DE (LAT 39 43 54N LONG 075 36 14W)													
FEB 1998													
04...	1415	19980205	1313	10003	1028	--	24	--	5.24	227	27.0	34	.104
04...	2106	--	--	10003	1028	--	--	29	5.24	270	40.0	12	.113
04...	2306	--	--	10003	1028	--	--	25	5.24	222	29.0	9	.140
05...	0506	--	--	10003	1028	--	--	18	5.24	203	25.0	9	.137
MAR													
08...	1129	19980309	0629	10003	1028	--	78	--	5.24	136	13.6	63	.066
08...	1545	--	--	10003	1028	--	--	68	5.24	169	20.3	37	.068
08...	1745	--	--	10003	1028	--	--	85	5.24	140	15.5	35	.061
08...	1945	--	--	10003	1028	--	--	56	5.24	141	14.8	19	.071
MAY													
01...	1536	19980503	0055	10003	1028	--	11	--	5.24	246	30.5	20	.012
02...	0104	--	--	10003	1028	--	--	22	5.24	217	25.1	10	.070
JUN													
11...	2302	--	--	10003	1028	--	--	9.6	5.24	265	34.0	46	.008
11...	2302	19980612	1829	10003	1028	--	75	--	5.24	113	10.5	290	.122
12...	0032	--	--	10003	1028	--	--	13	5.24	291	43.3	28	.014
12...	0202	--	--	10003	1028	--	--	38	5.24	191	25.2	80	.117
12...	0502	--	--	10003	1028	--	--	84	5.24	108	10.1	200	.096
JUL													
08...	0647	--	--	10003	1028	--	--	7.8	5.24	290	34.9	68	.006
08...	0647	19980709	0034	10003	1028	--	45	--	5.24	452	10.2	173	.082
08...	0816	--	--	10003	1028	--	--	85	5.24	174	17.8	211	.095
08...	0946	--	--	10003	1028	--	--	152	5.24	86	6.1	176	.112
08...	1116	--	--	10003	1028	--	--	87	5.24	96	7.4	122	.082
08...	1416	--	--	10003	1028	--	--	25	5.24	112	7.5	29	.076
OCT													
08...	1128	--	--	10003	1028	--	--	7.2	5.24	271	33.0	92	.025
08...	1128	19981009	0118	10003	1028	--	27	--	5.24	158	18.0	80	.021
08...	1258	--	--	10003	1028	--	--	38	5.24	159	17.0	93	.060
08...	1558	--	--	10003	1028	--	--	42	5.24	160	15.0	41	.183
08...	1728	--	--	10003	1028	--	--	34	5.24	159	18.0	25	.023
08...	1858	--	--	10003	1028	--	--	26	5.24	161	17.0	19	.023
01478000 CHRISTINA RIVER AT COOCHS BRIDGE, DE (LAT 39 38 14N LONG 075 43 40W)													
MAR 1998													
08...	1305	19980309	0921	10003	1028	25.54	305	--	20.50	112	14.2	66	.053
08...	1650	--	--	10003	1028	25.54	--	134	20.50	186	24.6	26	.062
08...	2250	--	--	10003	1028	25.54	--	405	20.50	106	12.9	156	.046
09...	0050	--	--	10003	1028	25.54	--	354	20.50	93	11.0	114	.048
MAY													
01...	1710	19980503	0820	10003	1028	25.54	21	--	20.50	219	31.3	6	.037
01...	1933	--	--	10003	1028	25.54	--	33	20.50	259	35.0	3	.034
01...	2333	--	--	10003	1028	25.54	--	35	20.50	259	37.5	6	.090
JUN													
11...	2344	19980613	0806	10003	1028	25.54	94	--	20.50	133	15.3	40	.047
12...	0544	--	--	10003	1028	25.54	--	132	20.50	117	17.6	73	.125
12...	0944	--	--	10003	1028	25.54	--	198	20.50	163	13.2	127	.071
12...	1144	--	--	10003	1028	25.54	--	225	20.50	99	10.8	70	.116
JUL													
08...	0840	19980709	0316	10003	1028	25.54	76	--	20.50	143	16.3	91	.035
08...	1040	--	--	10003	1028	25.54	--	208	20.50	156	10.9	137	.087
08...	1240	--	--	10003	1028	25.54	--	144	20.50	150	17.4	52	.047
08...	1840	--	--	10003	1028	25.54	--	61	20.50	123	11.3	21	.058
08...	2040	--	--	10003	1028	25.54	--	47	20.50	127	11.8	17	.075
OCT													
08...	1536	19981009	0415	10003	1028	25.54	65	--	20.50	171	25.0	10	<.005
08...	1736	--	--	10003	1028	25.54	--	59	20.50	116	18.0	25	.024
08...	1936	--	--	10003	1028	25.54	--	41	20.50	188	29.0	10	.031
08...	2136	--	--	10003	1028	25.54	--	35	20.50	186	26.0	11	.024

Table 1. *Results of laboratory analysis of stormflow samples collected at two sites in the Christina River subbasin, 1998—Continued*

Date	NITRO- GEN,AM- MONIA + ORGANIC DIS. (MG/L AS N) (00623)	NITRO- GEN,AM- MONIA + ORGANIC TOTAL (MG/L AS N) (00625)	NITRO- GEN, AMMONIA TOTAL (MG/L AS N) (00610)	NITRO- GEN, NO2+NO3 DIS- SOLVED (MG/L AS N) (00631)	PHOS- PHORUS DIS- SOLVED (MG/L AS P) (00666)	ORTHO- PHOS- PHATE, DIS- SOLVED (MG/L AS P) (00671)	PHOS- PHORUS TOTAL (MG/L AS P) (00665)	CARBON, ORGANIC DIS- SOLVED (MG/L AS C) (00681)	CARBON, ORGANIC TOTAL (MG/L AS C) (00680)	OXYGEN DEMAND, BIOCHEM CARBON. 20 (MG/L) (80087)	OXYGEN DEMAND, CHEM- ICAL (HIGH LEVEL) (MG/L) (00340)
01480095 LITTLE MILL CREEK NEAR NEWPORT, DE (LAT 39 43 54N LONG 075 36 14W)											
FEB 1998											
04...	.30	.56	.115	.989	.027	.017	.060	7.0	--	6.7	13
04...	.56	.65	.122	1.14	.024	.015	.071	7.0	--	6.5	22
04...	.43	.73	.187	1.06	.029	.015	.062	7.0	--	8.2	18
05...	.54	.66	.144	.902	.031	.015	.063	9.0	--	9.2	18
MAR											
08...	.55	1.3	.067	.524	.062	.027	.323	7.0	--	5.9	11
08...	.41	1.0	.070	.784	.045	.008	.149	5.0	--	4.1	<1
08...	.63	M	.067	.549	.060	.006	.257	7.0	--	3.4	<1
08...	.70	.91	.087	.541	.076	.016	.266	6.0	--	5.8	<1
MAY											
01...	.86	.93	.019	.923	.122	.122	.162	8.0	6.0	4.7	<1
02...	.82	1.1	.086	.902	.033	.042	.083	7.0	7.0	2.8	<1
JUN											
11...	1.4	2.4	.033	1.66	.050	.026	.242	13.0	--	13	--
11...	.86	3.5	.115	.744	.289	.222	.649	10.0	--	6.7	--
12...	1.3	1.9	.048	1.43	.408	.341	.486	12.0	--	8.1	--
12...	1.1	2.2	.146	1.13	.111	.068	.302	10.0	--	8.7	--
12...	.61	2.3	.097	.604	.132	.071	.351	8.0	--	5.3	--
JUL											
08...	.19	.64	.017	.837	.007	.004	.098	5.0	--	5.6	--
08...	.18	1.7	.090	.643	.010	.033	.317	9.0	--	7.2	--
08...	.12	2.1	.105	.784	.018	.036	.403	7.0	--	8.2	--
08...	.17	1.5	.115	.589	.019	.047	.332	7.0	--	6.3	--
08...	.18	1.3	.091	.520	.030	.033	.224	6.0	--	4.9	--
08...	.55	1.0	.077	.693	.086	.041	.121	9.0	--	4.2	--
OCT											
08...	--	--	.041	.738	--	.100	--	7.0	--	M	--
08...	--	--	.048	.574	--	.042	--	7.0	--	5.0	--
08...	--	--	.087	.587	--	.069	--	8.0	--	5.3	--
08...	--	--	.158	.595	--	.080	--	8.0	--	4.9	--
08...	--	--	.037	.513	--	.051	--	9.0	--	5.9	--
08...	--	--	.042	.534	--	.042	--	8.0	--	5.0	--
01478000 CHRISTINA RIVER AT COOCHS BRIDGE, DE (LAT 39 38 14N LONG 075 43 40W)											
MAR 1998											
08...	.84	1.3	.071	.587	.150	.146	.517	9.0	7.0	8.2	20
08...	.48	.75	.061	1.26	.065	.009	.297	6.0	4.0	3.8	5
08...	.71	1.9	.082	.436	.086	.055	.539	8.0	--	6.5	12
09...	.96	1.6	.093	.416	.095	.036	.505	9.0	11.0	5.0	30
MAY											
01...	.77	.87	.045	1.61	.015	.008	.044	6.0	6.0	5.6	<1
01...	.23	.20	.036	2.02	.033	.004	.041	3.0	2.0	<2.4	<1
01...	.65	1.0	.093	1.81	.034	.019	.037	5.0	6.0	<2.4	<1
JUN											
11...	.77	1.2	.042	1.01	.128	.026	.200	12.0	12.0	5.0	<1
12...	.91	1.3	.144	1.07	.115	.110	.197	10.0	12.0	5.8	20
12...	.74	1.6	.085	.965	.053	.045	.221	11.0	11.0	<2.4	12
12...	.60	1.1	.101	.754	.069	.037	.138	10.0	12.0	4.9	5
JUL											
08...	.35	1.3	.046	.871	.008	.023	.184	9.0	8.0	14	22
08...	.45	1.8	.088	.581	.028	.028	.278	8.0	7.0	6.7	51
08...	.38	.89	.052	.917	.017	.028	.131	7.0	5.0	4.8	6
08...	.43	.51	.064	.848	.021	.039	.105	6.0	5.0	4.0	21
08...	.46	.57	.241	.937	.020	.058	.082	7.0	5.0	3.9	25
OCT											
08...	--	--	.011	.939	--	.011	--	8.0	8.0	5.8	<1
08...	--	--	.043	.589	--	.031	--	7.0	9.0	3.5	6
08...	--	--	.036	1.05	--	.020	--	6.0	8.0	3.1	<1
08...	--	--	.027	1.01	--	.022	--	7.0	8.0	3.7	<1

Remark codes used in this report:
< -- Less than
M -- Presence verified, not quantified

Table 2. *Results of laboratory analysis of base-flow samples collected at two sites in the Christina River subbasin, 1998*

Date	Time	AGENCY ANA- LYZING SAMPLE (CODE NUMBER) (00028)	AGENCY COL- LECTING SAMPLE (CODE NUMBER) (00027)	ELEV. OF LAND SURFACE DATUM (FT. ABOVE NGVD) (72000)	DIS- CHARGE, INST. CUBIC FEET PER SECOND (00061)	DRAIN- AGE AREA (SQ. MI.) (81024)	OXYGEN, DIS- SOLVED (MG/L) (00300)	PH WATER WHOLE FIELD (STAND- ARD UNITS) (00400)	SPE- CIFIC CON- DUCT- ANCE (US/CM) (00095)	TEMPER- ATURE WATER (DEG C) (00010)	ANC WATER UNFLTRD FET FIELD MG/L AS CACO3 (00410)	CHLO- RIDE, DIS- SOLVED (MG/L AS CL) (00940)	RESIDUE TOTAL AT 105 DEG. C, SUS- PENDED (MG/L) (00530)
01480095 LITTLE MILL CREEK NEAR NEWPORT, DE (LAT 39 43 54N LONG 075 36 14W)													
APR 1998 27...	0933	10003	1028	--	7.2	5.24	10.7	6.8	241	1.3	43	27.6	4
JUL 23...	1157	10003	1028	--	1.5	5.24	8.0	7.2	246	24.2	55	30.0	2
SEP 15...	1026	10003	1028	--	.70	5.24	6.5	7.3	339	23.4	74	47.0	22
01478000 CHRISTINA RIVER AT COOCHS BRIDGE, DE (LAT 39 38 14N LONG 075 43 40W)													
APR 1998 27...	1007	10003	1028	25.54	22	20.50	10.3	6.7	234	1.3	31	31.8	5
JUL 23...	1009	10003	1028	25.54	7.5	20.50	7.0	6.8	222	24.3	41	30.0	5
SEP 15...	1411	10003	1028	25.54	3.0	20.50	8.6	7.3	286	23.7	51	47.0	23

Date	NITRO- GEN, AMMONIA DIS- SOLVED (MG/L AS N) (00608)	NITRO- GEN,AM- MONIA + ORGANIC DIS. (MG/L AS N) (00623)	NITRO- GEN,AM- MONIA + ORGANIC TOTAL (MG/L AS N) (00625)	NITRO- GEN, AMMONIA TOTAL (MG/L AS N) (00610)	NITRO- GEN, NO2+NO3 DIS- SOLVED (MG/L AS N) (00631)	PHOS- PHORUS DIS- SOLVED (MG/L AS P) (00666)	ORTHO- PHOS- PHATE, DIS- SOLVED (MG/L AS P) (00671)	PHOS- PHORUS TOTAL (MG/L AS P) (00665)	CARBON, ORGANIC DIS- SOLVED (MG/L AS C) (00681)	CARBON, ORGANIC TOTAL (MG/L AS C) (00680)	OXYGEN DEMAND, BIOCHEM CARBON. 20 (MG/L) (80087)	OXYGEN DEMAND, CHEM- ICAL (HIGH LEVEL) (MG/L) (00340)	PHEO- PHYTIN PHYTO- PLANK- TON, ACID M. (UG/L) (32218)
01480095 LITTLE MILL CREEK NEAR NEWPORT, DE (LAT 39 43 54N LONG 075 36 14W)													
APR 1998 27...	.432	.55	.70	.439	1.84	.049	.058	.074	8.0	9.0	5.9	39	<2.00
JUL 23...	.037	.59	1.3	.059	.886	<.005	.027	.028	5.0	5.0	<2.4	14	<2.00
SEP 15...	.056	.84	1.2	.054	1.84	.018	.015	.018	4.0	3.0	2.5	7	3.00
01478000 CHRISTINA RIVER AT COOCHS BRIDGE, DE (LAT 39 38 14N LONG 075 43 40W)													
APR 1998 27...	.214	1.4	1.6	.223	2.31	.013	.015	.047	6.0	6.0	2.9	32	3.00
JUL 23...	.069	.84	1.3	.100	1.50	<.005	.024	.022	7.0	6.0	<2.4	18	<2.00
SEP 15...	<.005	.38	.65	<.005	1.36	.014	.008	.019	4.0	4.0	<2.4	6	7.00

Date	CHLORO- HPYLL A PHYTO- PLANK- TON ACID M. (UG/L) (32211)
01480095 LITTLE MILL CREEK NEAR NEWPORT, DE (LAT 39 43 54N LONG 075 36 14W)	
APR 1998 27...	5.00
JUL 23...	5.00
SEP 15...	3.00
01478000 CHRISTINA RIVER AT COOCHS BRIDGE, DE (LAT 39 38 14N LONG 075 43 40W)	
APR 1998 27...	3.00
JUL 23...	5.00
SEP 15...	8.00

0Remark codes used in this report:

< -- Less than

APPENDIX 2

SIMULATED STORMFLOW AND WATER QUALITY FOR SAMPLED STORMS IN 1998

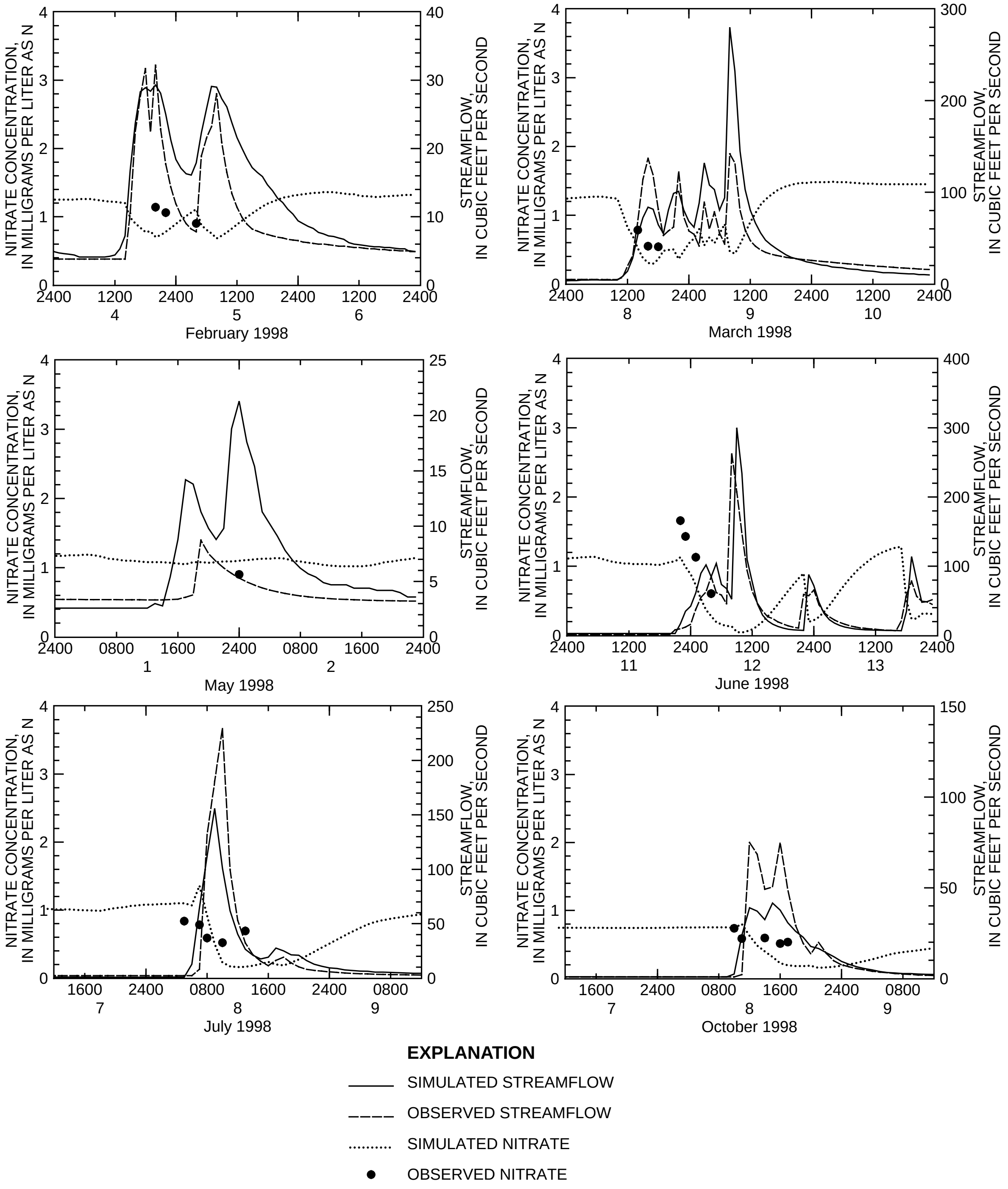

Figure 1. Simulated and observed streamflow and concentrations of dissolved nitrate during six storms in 1998 at streamflow-measurement station 01480095, Little Mill Creek near Newport, Del.

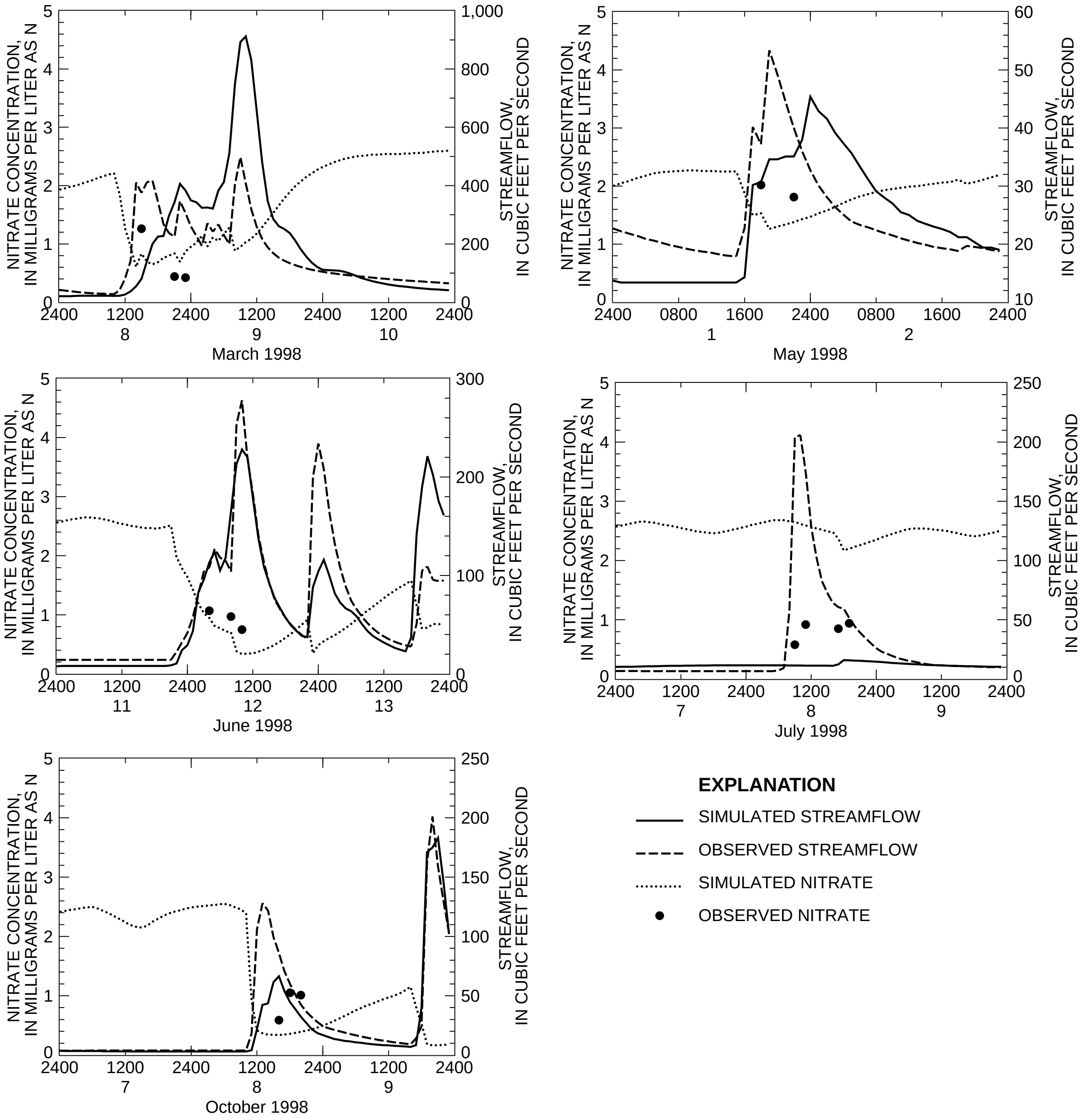

Figure 2. Simulated and observed streamflow and concentrations of dissolved nitrate during five storms in 1998 at streamflow-measurement station 01478000, Christina River at Coochs Bridge, Delaware.

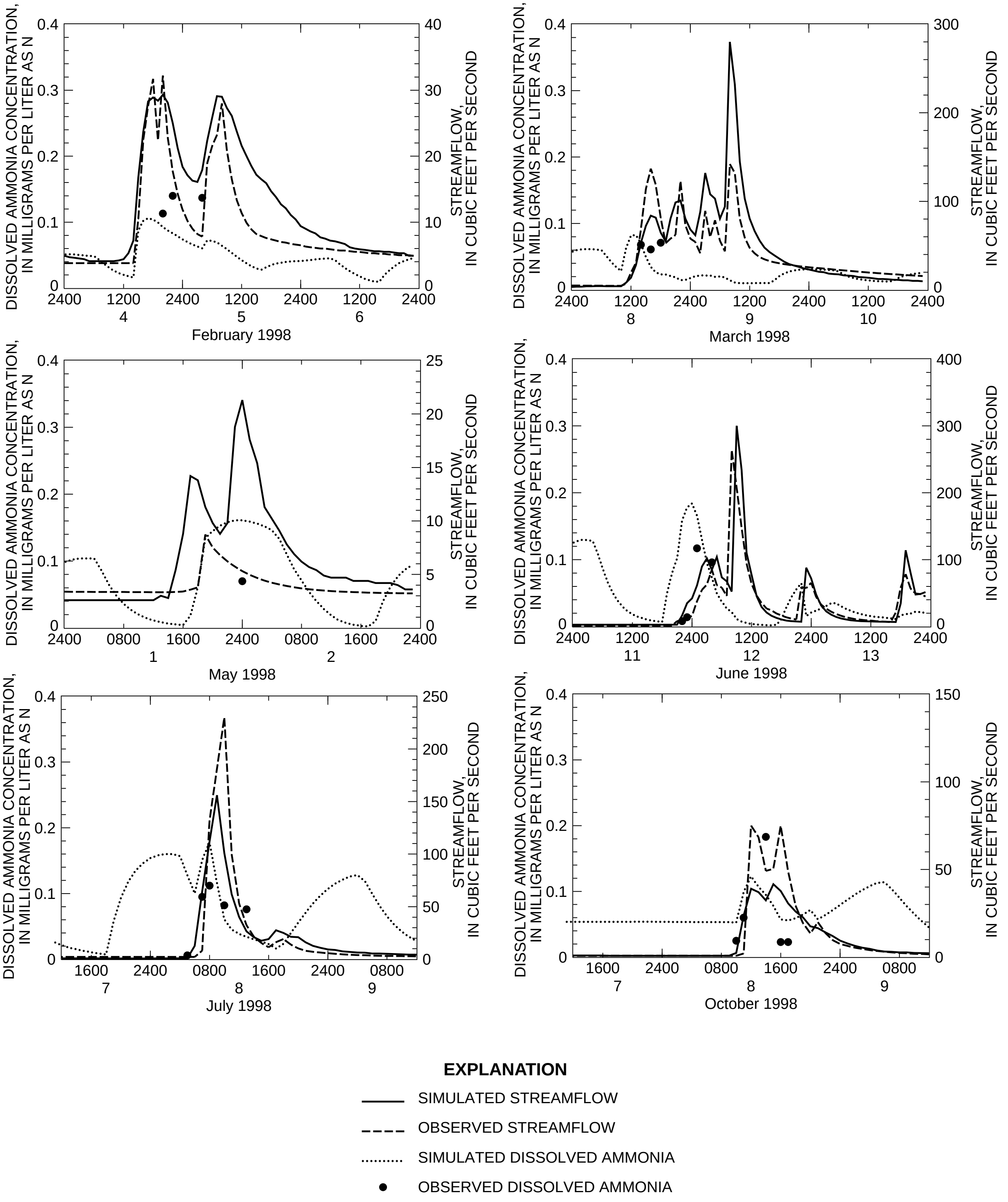

Figure 3. Simulated and observed streamflow and concentrations of dissolved ammonia during six storms in 1998 at streamflow-measurement station 01480095, Little Mill Creek near Newport, Del.

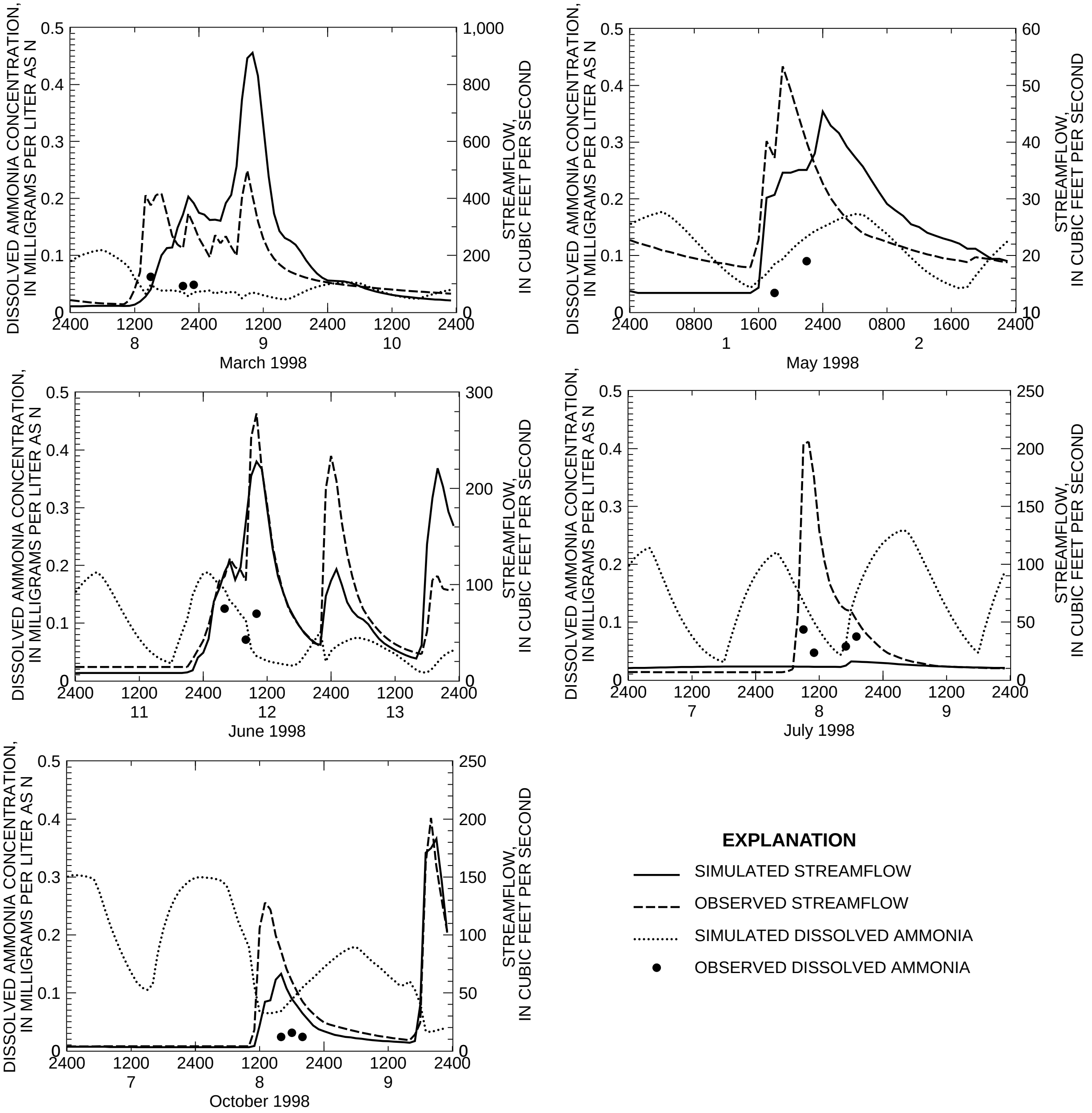

Figure 4. Simulated and observed streamflow and concentrations of dissolved ammonia during five storms in 1998 at streamflow-measurement station 01478000, Christina River at Coochs Bridge, Delaware.

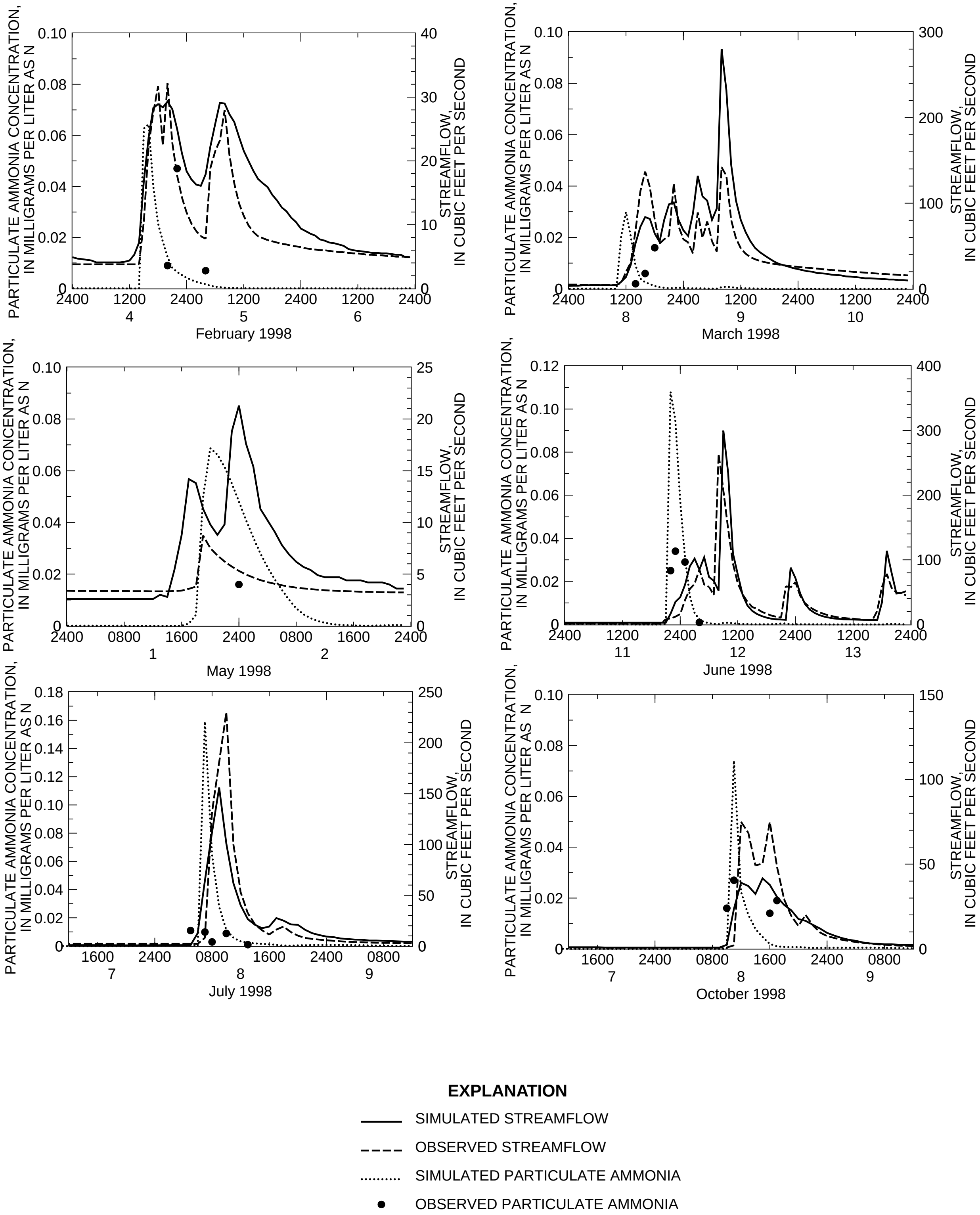

Figure 5. Simulated and observed streamflow and concentrations of particulate ammonia during six storms in 1998 at streamflow-measurement station 01480095, Little Mill Creek near Newport, Del.

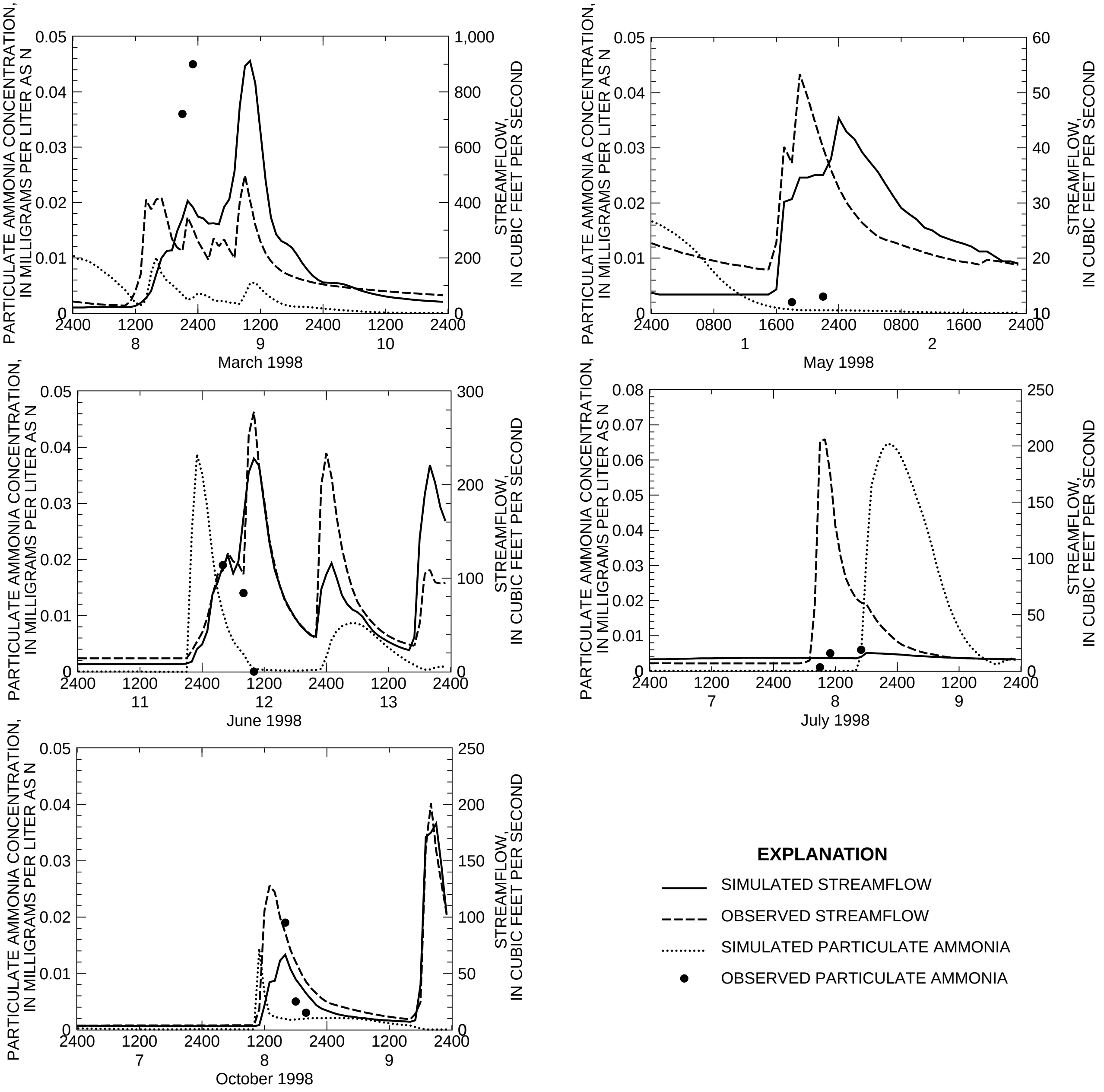

Figure 6. Simulated and observed streamflow and concentrations of particulate ammonia during five storms in 1998 at streamflow-measurement station 01478000, Christina River at Coochs Bridge, Delaware.

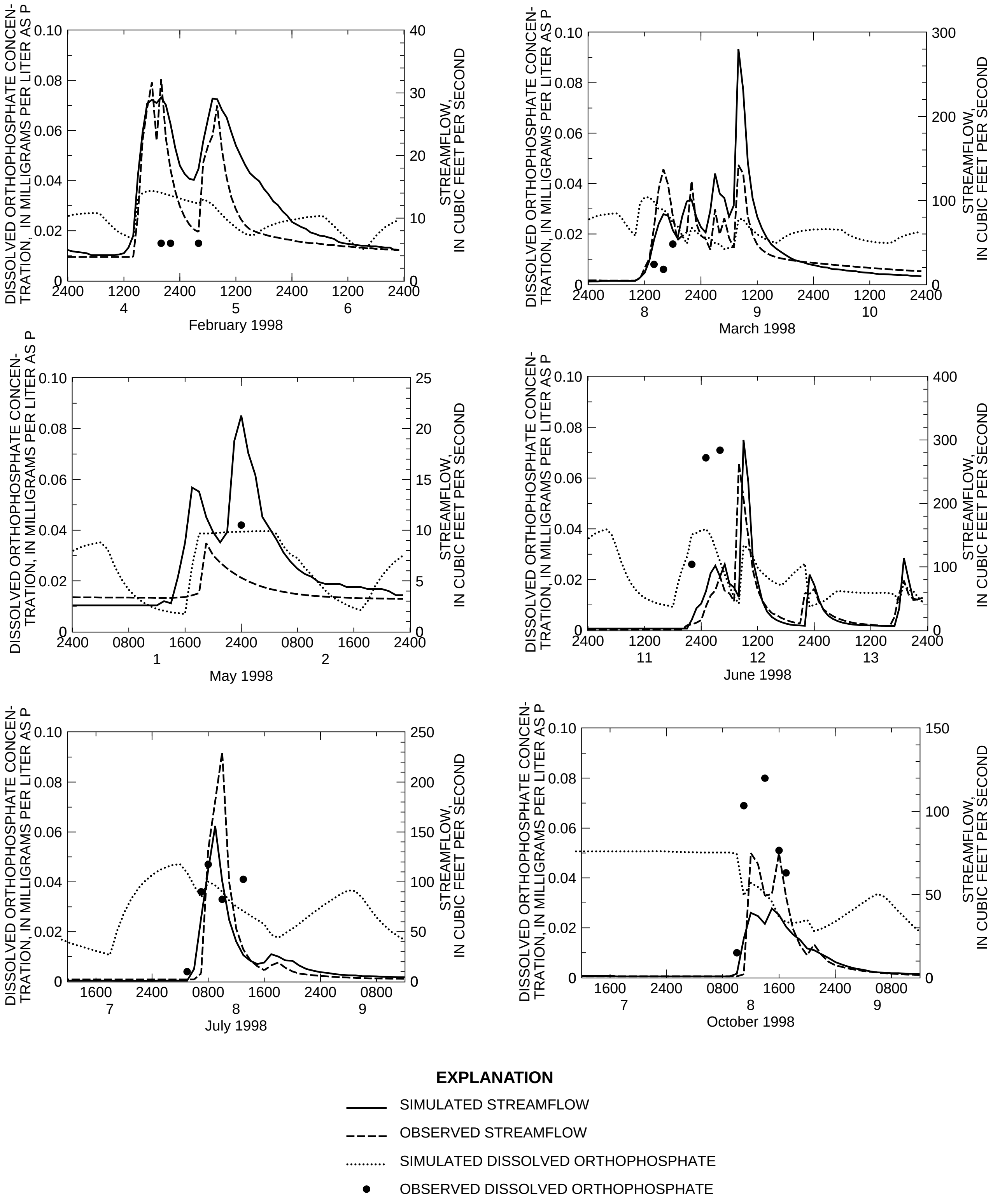

Figure 7. Simulated and observed streamflow and concentrations of dissolved orthophosphate during six storms in 1998 at streamflow-measurement station 01480095, Little Mill Creek near Newport, Del.

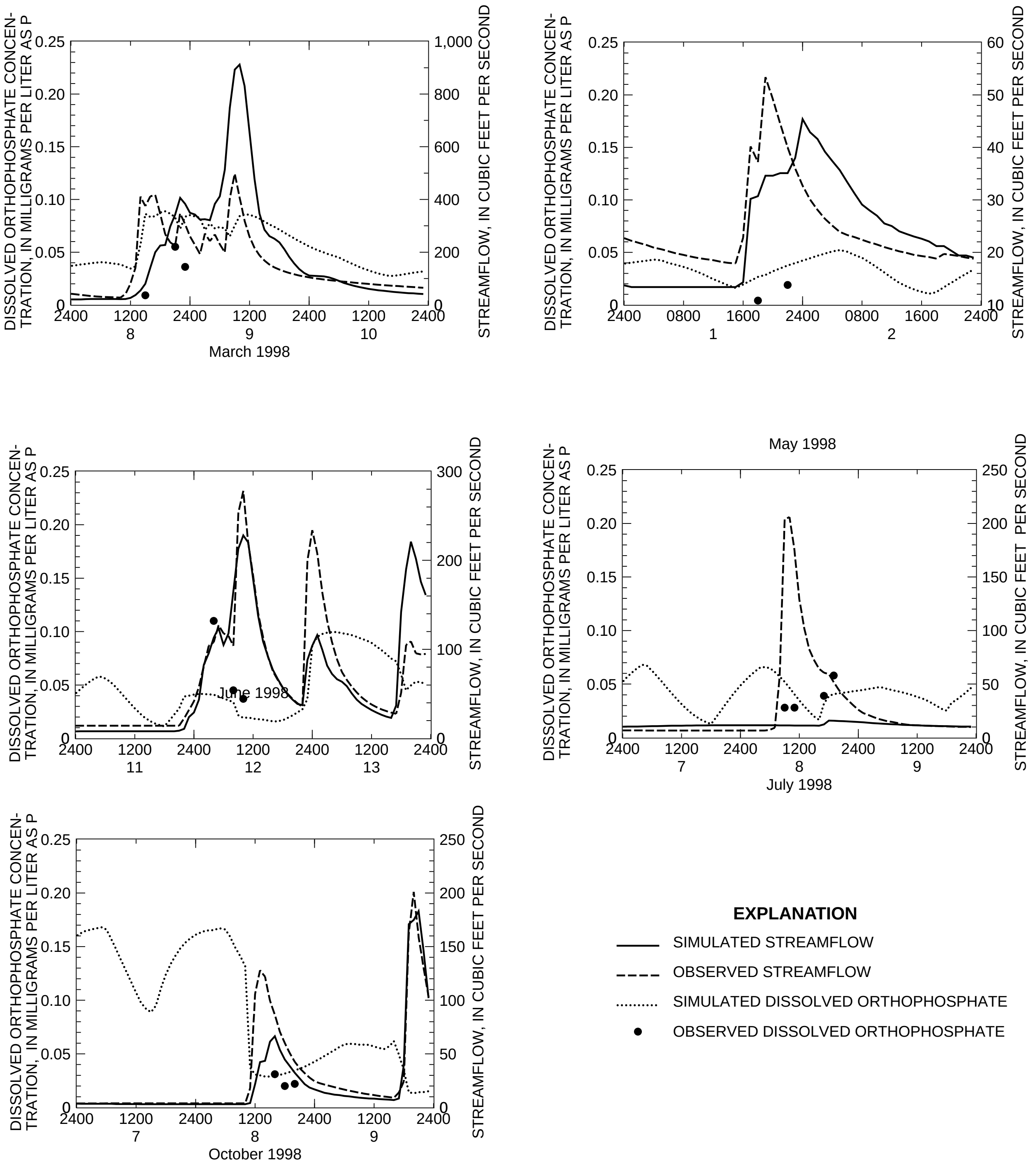

Figure 8. Simulated and observed streamflow and concentrations of dissolved orthophosphate during five storms in 1998 at streamflow-measurement station 01478000, Christina River at Coochs Bridge, Delaware.

APPENDIX 3

USER CONTROL FILE

```
RUN
GLOBAL
CHRISTINA RIVER HYDROLOGY - BASE SCENARIO - ALL SEGMENTS
  START       1994 10  1  0  0  END    1998 10 29 24  0
  RUN INTERP OUTPUT LEVEL    3    2
  RESUME     0 RUN     1                   UNIT SYSTEM     1
END GLOBAL

FILES
<type>  <UN#>***<------------fname--------------------------------------------->
WDM        26   christin.wdm
MESSU      25   christin.ech
           90   christin.out
END FILES

OPN SEQUENCE
    INGRP              INDELT  1:00
      PERLND     502
      PERLND     503
      PERLND     504
      PERLND     505
      PERLND     506
      PERLND     507
      PERLND     508
      PERLND     509
      PERLND     510
      PERLND     511
      IMPLND     501
      IMPLND     502
      PERLND     802
      PERLND     803
      PERLND     804
      PERLND     805
      PERLND     806
      PERLND     807
      PERLND     808
      PERLND     809
      PERLND     810
      PERLND     811
      IMPLND     801
      IMPLND     802
      RCHRES       1
      RCHRES       2
      RCHRES       3
      GENER        1
      GENER        2
      COPY        11
      COPY       200
      RCHRES       6
      RCHRES       7
      PERLND     902
      PERLND     903
      PERLND     904
      PERLND     905
      PERLND     906
      PERLND     907
      PERLND     908
      PERLND     909
      PERLND     910
      PERLND     911
      IMPLND     901
      IMPLND     902
      RCHRES       4
      GENER        3
      GENER        4
      COPY        12
      COPY       300
      RCHRES       5
      COPY       400
      COPY       500

    END INGRP

END OPN SEQUENCE

PERLND
  ACTIVITY
    #    # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC   ***
  502  911    1    1    1    1    1    1    1    0    0    0    0    0
  END ACTIVITY

  PRINT-INFO
    #    # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC *********
  502  911    5    5    5    5    5    5    5    0    0    0    0    0    0   12
  END PRINT-INFO

  GEN-INFO
    #    #      NAME          NBLKS  UCI   IN  OUT ENGL METR  ***
  502     RESIDENTIAL-SEPTIC      1    1    1    1   90    0
  503     RESIDENTIAL-SEWER       1    1    1    1   90    0
  504     COMMERCIAL/INDUSTRY     1    1    1    1   90    0
  505     AGRICULTURAL-COWS       1    1    1    1   90    0
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  506     AGRICULTURAL-CROPS      1    1    1    1   90    0
  507     AGRICULTURAL-MUSHROOM   1    1    1    1   90    0
  508     FOREST                  1    1    1    1   90    0
  509     OPEN LAND               1    1    1    1   90    0
  510     WETLANDS, WATER         1    1    1    1   90    0
  511     undesignated use        1    1    1    1   90    0
  802     RESIDENTIAL-SEPTIC      1    1    1    1   90    0
  803     RESIDENTIAL-SEWER       1    1    1    1   90    0
  804     COMMERCIAL/INDUSTRY     1    1    1    1   90    0
  805     AGRICULTURAL-COWS       1    1    1    1   90    0
  806     AGRICULTURAL-CROPS      1    1    1    1   90    0
  807     AGRICULTURAL-MUSHROOM   1    1    1    1   90    0
  808     FOREST                  1    1    1    1   90    0
  809     OPEN LAND               1    1    1    1   90    0
  810     WETLANDS, WATER         1    1    1    1   90    0
  811     undesignated use        1    1    1    1   90    0
  902     RESIDENTIAL-SEPTIC      1    1    1    1   90    0
  903     RESIDENTIAL-SEWER       1    1    1    1   90    0
  904     COMMERCIAL/INDUSTRY     1    1    1    1   90    0
  905     AGRICULTURAL-COWS       1    1    1    1   90    0
  906     AGRICULTURAL-CROPS      1    1    1    1   90    0
  907     AGRICULTURAL-MUSHROOM   1    1    1    1   90    0
  908     FOREST                  1    1    1    1   90    0
  909     OPEN LAND               1    1    1    1   90    0
  910     WETLANDS, WATER         1    1    1    1   90    0
  911     undesignated use        1    1    1    1   90    0
  END GEN-INFO

**** AIR TEMPERATURE ****

  ATEMP-DAT
               ELDAT    AIRTMP ***
    #    #      (ft)   (deg F) ***
  502  511     225.0      53.6
  802  811       0.0      53.6
  902  911      25.0      53.6
  END ATEMP-DAT

**** SNOW ****

  ICE-FLAG
*** <PLS > ICEFG
*** #    #
  502  911    1
  END ICE-FLAG

  SNOW-PARM1
*** <PLS >       LAT     MELEV     SHADE    SNOWCF    COVIND
*** #    #     (deg)      (ft)                          (in)
  502  511     39.71      300.      0.20       1.0      0.50
  802  811     39.71       75.      0.20       1.0      0.50
  902  911     39.70      100.      0.20       1.0      0.50
  END SNOW-PARM1

  SNOW-PARM2
*** <PLS >     RDSCN     TSNOW    SNOEVP    CCFACT    MWATER    MGMELT
*** #    #              (degF)                                (in/day)
  502  511      0.08      32.0      0.05      0.60      0.50     0.010
  802  811      0.08      32.0      0.05      0.60      0.50     0.021
  902  911      0.08      32.0      0.05      0.60      0.50     0.021
  END SNOW-PARM2

**** HYDROLOGY ****

  PWAT-PARM1
*** <PLS >                   Flags
*** x -  x CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE IFFC
  502         1    0    0    1    0    0    0    1    1    1
  503         1    0    0    1    0    0    0    1    1    1
  504         1    0    0    1    0    0    0    1    1    1
  505         1    0    0    1    0    0    0    1    1    1
  506         1    0    0    1    0    0    0    1    1    1
  507         1    0    0    1    0    0    0    1    1    1
  508         1    0    0    1    0    0    0    1    1    1
  509         1    0    0    1    0    0    0    1    1    1
  510         1    0    0    0    0    0    0    1    0    1
  511         1    0    0    1    0    0    0    1    1    1
  802         1    0    0    1    0    0    0    1    1    1
  803         1    0    0    1    0    0    0    1    1    1
  804         1    0    0    1    0    0    0    1    1    1
  805         1    0    0    1    0    0    0    1    1    1
  806         1    0    0    1    0    0    0    1    1    1
  807         1    0    0    1    0    0    0    1    1    1
  808         1    0    0    1    0    0    0    1    1    1
  809         1    0    0    1    0    0    0    1    1    1
  810         1    0    0    0    0    0    0    1    0    1
  811         1    0    0    1    0    0    0    1    1    1
  902         1    0    0    1    0    0    0    1    1    1
  903         1    0    0    1    0    0    0    1    1    1
  904         1    0    0    1    0    0    0    1    1    1
  905         1    0    0    1    0    0    0    1    1    1
  906         1    0    0    1    0    0    0    1    1    1
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  907         1    0    0    1    0    0    0    1    1    1
  908         1    0    0    1    0    0    0    1    1    1
  909         1    0    0    1    0    0    0    1    1    1
  910         1    0    0    0    0    0    0    1    0    1
  911         1    0    0    1    0    0    0    1    1    1
  END PWAT-PARM1

  PWAT-PARM2
***  <PLS>    FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
***  x - x                (in)   (in/hr)      (ft)              (1/in)   (1/day)
  502              0.0     8.000     0.070     150.0    0.1837     0.000     0.985
  503              0.0     8.000     0.070     150.0    0.2095     0.000     0.985
  504              0.0     8.000     0.070     150.0    0.1502     0.000     0.985
  505              0.0     8.000     0.080     150.0    0.1591     0.000     0.985
  506              0.0     8.000     0.080     150.0    0.1591     0.000     0.985
  507              0.0     8.000     0.070     150.0    0.1591     0.000     0.985
  508              0.0     8.000     0.090     150.0    0.2025     0.000     0.985
  509              0.0     8.000     0.070     150.0    0.1672     0.000     0.985
  510              0.0     8.000     0.100     150.0    0.1235     0.000     0.985
  511              0.0     8.000     0.070     150.0    0.1143     0.000     0.985
  802              0.0     4.000     0.030     150.0    0.0977     0.000     0.986
  803              0.0     4.000     0.030     150.0    0.0706     0.000     0.986
  804              0.0     4.000     0.030     150.0    0.0798     0.000     0.986
  805              0.0     4.000     0.040     150.0    0.0626     0.000     0.986
  806              0.0     4.000     0.040     150.0    0.0626     0.000     0.986
  807              0.0     4.000     0.030     150.0    0.0626     0.000     0.986
  808              0.0     4.000     0.060     150.0    0.1014     0.000     0.986
  809              0.0     4.000     0.030     150.0    0.0689     0.000     0.986
  810              0.0     4.000     0.100     150.0    0.0683     0.000     0.986
  811              0.0     4.000     0.030     150.0    0.0599     0.000     0.986
  902              0.0     4.500     0.030     200.0    0.1062     0.000     0.980
  903              0.0     4.500     0.030     200.0    0.1078     0.000     0.980
  904              0.0     4.500     0.030     200.0    0.1382     0.000     0.980
  905              0.0     4.500     0.040     200.0    0.1253     0.000     0.980
  906              0.0     4.500     0.040     200.0    0.1253     0.000     0.980
  907              0.0     4.500     0.030     200.0    0.1253     0.000     0.980
  908              0.0     4.500     0.080     200.0    0.0536     0.000     0.980
  909              0.0     4.500     0.030     200.0    0.1819     0.000     0.980
  910              0.0     4.500     0.100     200.0    0.0857     0.000     0.980
  911              0.0     4.500     0.030     200.0    0.1244     0.000     0.980
  END PWAT-PARM2

  PWAT-PARM3
***  <PLS>    PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
***  x - x   (deg F)   (deg F)
  502  509      40.0      36.0       2.0       2.0     0.010     0.035     0.000
  510           40.0      36.0       2.0       2.0     0.010     0.035     0.300
  511           40.0      36.0       2.0       2.0     0.010     0.035     0.000
  802  809      40.0      36.0       2.0       2.0     0.000     0.010     0.000
  810           40.0      36.0       2.0       2.0     0.000     0.010     0.500
  811           40.0      36.0       2.0       2.0     0.000     0.010     0.000
  902  909      40.0      36.0       2.0       2.0     0.000     0.015     0.000
  910           40.0      36.0       2.0       2.0     0.000     0.015     0.500
  911           40.0      36.0       2.0       2.0     0.000     0.015     0.000
  END PWAT-PARM3

  PWAT-PARM4
*** <PLS >     CEPSC      UZSN      NSUR     INTFW       IRC     LZETP
*** x -  x      (in)      (in)                       (1/day)
  502          0.050     0.700      0.35       0.9     0.500     0.600
  503          0.050     0.700      0.30       0.9     0.500     0.600
  504          0.050     0.600      0.25       0.9     0.500     0.600
  505          0.050     0.400      0.20       0.9     0.500     0.700
  506          0.050     0.400      0.30       0.9     0.500     0.700
  507          0.050     0.600      0.30       0.9     0.500     0.600
  508          0.100     1.000      0.35       0.9     0.500     0.800
  509          0.050     0.600      0.30       0.9     0.500     0.600
  510          0.050     1.000      0.05       0.9     0.500     0.900
  511          0.050     0.600      0.30       0.9     0.500     0.600
  802          0.050     0.800      0.35       1.3     0.500     0.600
  803          0.050     0.800      0.30       1.3     0.500     0.600
  804          0.050     0.700      0.25       1.3     0.500     0.600
  805          0.050     0.400      0.20       1.3     0.500     0.700
  806          0.050     0.400      0.30       1.3     0.500     0.700
  807          0.050     0.600      0.30       1.3     0.500     0.600
  808          0.100     1.100      0.35       1.3     0.500     0.800
  809          0.050     0.700      0.30       1.3     0.500     0.600
  810          0.050     1.000      0.05       1.3     0.500     0.900
  811          0.050     0.700      0.30       1.3     0.500     0.600
  902          0.050     0.800      0.35       2.5     0.500     0.600
  903          0.050     0.800      0.30       2.5     0.500     0.600
  904          0.050     0.700      0.25       2.5     0.500     0.600
  905          0.050     0.400      0.20       2.5     0.500     0.700
  906          0.050     0.400      0.30       2.5     0.500     0.700
  907          0.050     0.600      0.30       2.5     0.500     0.600
  908          0.100     1.200      0.35       2.5     0.500     0.800
  909          0.050     0.700      0.30       2.5     0.500     0.600
  910          0.050     1.000      0.05       2.5     0.500     0.900
  911          0.050     0.700      0.30       2.5     0.500     0.600
  END PWAT-PARM4

  MON-INTERCEP
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*** <PLS >  Interception storage capacity at start of each month (in)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  502  504 .040 .040 .060 .080 .100 .100 .100 .100 .080 .060 .040 .040
  505  507 .030 .030 .030 .030 .060 .090 .110 .110 .110 .080 .070 .030
  508      .040 .040 .070 .110 .140 .160 .160 .150 .120 .090 .050 .040
  509  511 .040 .040 .060 .080 .100 .100 .100 .100 .080 .060 .050 .040
  802  804 .040 .040 .060 .080 .100 .100 .100 .100 .080 .060 .040 .040
  805  807 .030 .030 .030 .030 .060 .090 .110 .110 .110 .080 .070 .030
  808      .040 .040 .070 .110 .140 .160 .160 .150 .120 .090 .050 .040
  809  811 .040 .040 .060 .080 .100 .100 .100 .100 .080 .060 .050 .040
  902  904 .040 .040 .060 .080 .100 .100 .100 .100 .080 .060 .040 .040
  905  907 .030 .030 .030 .030 .060 .090 .110 .110 .110 .080 .070 .030
  908      .040 .040 .070 .110 .140 .160 .160 .150 .120 .090 .050 .040
  909  911 .040 .040 .060 .080 .100 .100 .100 .100 .080 .060 .050 .040
  END MON-INTERCEP

  MON-UZSN
*** <PLS >  Upper zone storage at start of each month  (inches)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  505  506 .400 .400 .400 .430 .450 .450 .400 .400 .400 .400 .400 .400
  805  806 .400 .400 .400 .430 .450 .450 .400 .400 .400 .400 .400 .400
  905  906 .400 .400 .400 .430 .450 .450 .400 .400 .400 .400 .400 .400
  END MON-UZSN

  MON-IRC
***
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  502  911  0.4  0.4  0.5  0.5  0.5  0.5  0.5  0.5  0.6  0.6  0.7  0.4
  END MON-IRC

  MON-LZETPARM
*** <PLS >  Lower zone evapotranspir parm at start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  502  507  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.1  0.3  0.5  0.7
  508       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.2  0.4  0.6  0.8
  509  511  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.1  0.3  0.5  0.7
  802  807  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.1  0.3  0.5  0.7
  808       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.2  0.4  0.6  0.8
  809  811  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.1  0.3  0.5  0.7
  902  907  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.0  0.3  0.7  0.7
  908       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.0  0.4  0.8  0.8
  909  911  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.0  0.3  0.7  0.7
  END MON-LZETPARM

  PWAT-STATE1
***  <PLS>  PWATER state variables (in)
***  x - x      CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
  502            0.0       0.0       .70       0.0       8.0       0.8       0.0
  503            0.0       0.0       .70       0.0       8.0       0.8       0.0
  504            0.0       0.0       .60       0.0       8.0       0.8       0.0
  505            0.0       0.0       .40       0.0       8.0       0.8       0.0
  506            0.0       0.0       .40       0.0       8.0       0.8       0.0
  507            0.0       0.0       .60       0.0       8.0       0.8       0.0
  508            0.0       0.0      1.00       0.0       8.0       0.8       0.0
  509            0.0       0.0       .60       0.0       8.0       0.8       0.0
  510            0.0       0.0       .90       0.0       8.0       0.8       0.0
  511            0.0       0.0       .60       0.0       8.0       0.8       0.0
  802            0.0       0.0       .80       0.0       4.0       0.7       0.0
  803            0.0       0.0       .80       0.0       4.0       0.7       0.0
  804            0.0       0.0       .70       0.0       4.0       0.7       0.0
  805            0.0       0.0       .40       0.0       4.0       0.7       0.0
  806            0.0       0.0       .40       0.0       4.0       0.7       0.0
  807            0.0       0.0       .70       0.0       4.0       0.7       0.0
  808            0.0       0.0      1.10       0.0       4.0       0.7       0.0
  809            0.0       0.0       .70       0.0       4.0       0.7       0.0
  810            0.0       0.0       .90       0.0       4.0       0.7       0.0
  811            0.0       0.0       .70       0.0       4.0       0.7       0.0
  902            0.0       0.0       .90       0.0       5.5       0.8       0.0
  903            0.0       0.0       .90       0.0       5.5       0.8       0.0
  904            0.0       0.0       .90       0.0       5.5       0.8       0.0
  905            0.0       0.0       .40       0.0       5.5       0.8       0.0
  906            0.0       0.0       .40       0.0       5.5       0.8       0.0
  907            0.0       0.0       .90       0.0       5.5       0.8       0.0
  908            0.0       0.0      1.20       0.0       5.5       0.8       0.0
  909            0.0       0.0       .90       0.0       5.5       0.8       0.0
  910            0.0       0.0       .90       0.0       5.5       0.8       0.0
  911            0.0       0.0       .90       0.0       5.5       0.8       0.0
  END PWAT-STATE1

  SED-PARM1
*** <PLS >  Sediment parameters 1
*** x -  x  CRV VSIV SDOP
  502  911    1    0    1
  END SED-PARM1

  SED-PARM2
*** <PLS >      SMPF      KRER      JRER     AFFIX     COVER      NVSI
*** x -  x                               (/day)           lb/ac-day
  502  503     1.000     0.500     2.000     0.010     0.000     1.000
  504          1.000     0.500     2.000     0.010     0.000     1.000
  505  506     1.000     0.520     2.000     0.010     0.000     1.000
  507          1.000     0.520     2.000     0.010     0.000     1.000
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  508         1.000     0.450     2.000     0.002     0.000     2.000
  509         1.000     0.500     2.000     0.010     0.000     2.000
  510         1.000     0.400     2.000     0.002     0.000     2.000
  511         1.000     0.500     2.000     0.010     0.000     2.000
  802  803    1.000     0.450     2.000     0.010     0.000     1.000
  804         1.000     0.450     2.000     0.010     0.000     1.000
  805  806    1.000     0.500     2.000     0.010     0.000     1.000
  807         1.000     0.500     2.000     0.010     0.000     1.000
  808         1.000     0.400     2.000     0.002     0.000     2.000
  809         1.000     0.450     2.000     0.010     0.000     2.000
  810         1.000     0.400     2.000     0.002     0.000     2.000
  811         1.000     0.450     2.000     0.010     0.000     2.000
  902  903    1.000     0.450     2.000     0.010     0.000     1.000
  904         1.000     0.450     2.000     0.010     0.000     1.000
  905  907    1.000     0.450     2.000     0.010     0.000     1.000
  908         1.000     0.400     2.000     0.002     0.000     2.000
  909         1.000     0.450     2.000     0.010     0.000     2.000
  910         1.000     0.400     2.000     0.002     0.000     2.000
  911         1.000     0.450     2.000     0.010     0.000     2.000
  END SED-PARM2

  SED-PARM3
*** <PLS >  Sediment parameter 3
*** x -  x      KSER      JSER      KGER      JGER
  502         0.120     1.800     0.007     2.000
  503         0.160     1.800     0.010     2.000
  504         0.300     1.800     0.030     2.000
  505  506    1.650     1.800     0.025     2.000
  507         1.800     1.800     0.025     2.000
  508         0.080     1.800     0.000     2.000
  509         0.160     1.800     0.004     2.000
  510         0.005     1.800     0.000     2.000
  511         0.160     1.800     0.004     2.000
  802         0.100     2.000     0.005     2.000
  803         0.140     2.000     0.010     2.000
  804         0.285     2.000     0.020     2.000
  805  806    1.600     2.000     0.015     2.000
  807         1.500     2.000     0.015     2.000
  808         0.080     2.000     0.000     2.000
  809         0.140     2.000     0.004     2.000
  810         0.005     2.000     0.000     2.000
  811         0.140     2.000     0.004     2.000
  902         0.180     2.000     0.006     2.000
  903         0.450     2.000     0.012     2.000
  904         0.750     2.000     0.030     2.000
  905  907    1.800     2.000     0.020     2.000
  908         0.100     2.000     0.000     2.000
  909         0.200     2.000     0.010     2.000
  910         0.008     2.000     0.000     2.000
  911         0.200     2.000     0.010     2.000
  END SED-PARM3

  MON-COVER
*** <PLS >  Monthly values for erosion related cover
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  502  504 0.90 0.90 0.90 0.91 0.93 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  505  507 0.50 0.45 0.00 0.00 0.10 0.50 0.75 0.93 0.93 0.85 0.70 0.55
  508      0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97
  509      0.90 0.90 0.90 0.90 0.92 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  510      0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97
  511      0.90 0.90 0.90 0.90 0.92 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  802  804 0.90 0.90 0.90 0.91 0.93 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  805  807 0.50 0.45 0.00 0.00 0.10 0.50 0.75 0.93 0.93 0.85 0.70 0.55
  808      0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97
  809      0.90 0.90 0.90 0.90 0.92 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  810      0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97
  811      0.90 0.90 0.90 0.90 0.92 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  902  904 0.90 0.90 0.90 0.91 0.93 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  905  907 0.50 0.45 0.00 0.00 0.10 0.50 0.75 0.93 0.93 0.85 0.70 0.55
  908      0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97
  909      0.90 0.90 0.90 0.90 0.92 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  910      0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97
  911      0.90 0.90 0.90 0.90 0.92 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  END MON-COVER

  SED-STOR
*** <PLS >  Detached sediment storage (tons/acre)
*** x -  x      DETS
  502  911    0.4000
  END SED-STOR

  PSTEMP-PARM1
*** <PLS >  Flags for section PSTEMP
*** x -  x SLTV ULTV LGTV TSOP
  502  911    1    1    0    1
  END PSTEMP-PARM1

  PSTEMP-PARM2
PERLND ***      ASLT      BSLT     ULTP1     ULTP2     LGTP1     LGTP2
  502  911      32.0      0.50      32.0      0.90      54.0       0.0
  END PSTEMP-PARM2
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  MON-ASLT
PERLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  502  911 32.9 35.3 37.9 42.7 46.9 52.6 55.0 54.3 51.4 46.3 40.5 36.6
  END MON-ASLT

  MON-BSLT
PERLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  502  911 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23
  END MON-BSLT

  MON-ULTP1
PERLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  502  911 40.0 41.0 43.0 46.0 48.6 52.8 56.8 57.8 53.5 48.8 45.0 42.0
  END MON-ULTP1

  MON-ULTP2
PERLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  502  911 0.10 0.10 0.10 0.10 0.10 0.10 0.10 0.10 0.10 0.10 0.10 0.10
  END MON-ULTP2

  PSTEMP-TEMPS
PERLND ***     AIRTC     SLTMP     ULTMP     LGTMP
  502  911      50.0      60.0      57.0      53.0
  END PSTEMP-TEMPS

  PWT-PARM2
PERLND ***      ELEV     IDOXP     ICO2P     ADOXP     ACO2P
  502  511      250.      8.80         0      8.80         0
  802  811       75.      8.80         0      8.80         0
  902  911      150.      8.80         0      8.80         0
  END PWT-PARM2

  MON-IFWDOX
PERLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  502  911 11.0 10.0 10.0 10.0 9.00 7.00 6.00 6.00 7.00 9.00 10.0 11.0
  END MON-IFWDOX

  MON-GRNDDOX
PERLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  502  911 11.0 10.0 10.0 10.0 9.00 7.00 6.00 6.00 7.00 9.00 10.0 11.0
  END MON-GRNDDOX

  PWT-TEMPS
PERLND ***     SOTMP     IOTMP     AOTMP
  502  911       60.       57.       53.
  END PWT-TEMPS

  PWT-GASES
PERLND ***     SODOX     SOCO2     IODOX     IOCO2     AODOX     AOCO2
  502  911       8.8         0       8.8         0       8.8         0
  END PWT-GASES
*** Water Quality Constituents N and P ***
  NQUALS
    #    # NQAL  ***
  502  911    5
  END NQUALS

  QUAL-PROPS
    #    #<--QUALID-->    QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC  ***
  502  911         NO3     LBS    1    2    0    0    0    1    4    1    4
  END QUAL-PROPS

  QUAL-INPUT
    #    #     SQO   POTFW   POTFS   ACQOP  SQOLIM   WSQOP    IOQC    AOQC  ***
  502       0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  503       0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  504       0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  505       0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  506       0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  507       0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  508       0.100      1.      1.  0.0137  0.2500   0.500      1.      1. ***
  509       0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  510       0.100      1.      1.  0.0137  0.2500   0.500      1.      1. ***
  511       0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  902       0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  903       0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  904       0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  905       0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  906       0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  907       0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  908       0.100      1.      1.  0.0137  0.2500   0.500      1.      1. ***
  909       0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  910       0.100      1.      1.  0.0137  0.2500   0.500      1.      1. ***
  911       0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  802       0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  803       0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  804       0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  805       0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  806       0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  807       0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  808       0.100      1.      1.  0.0137  0.2500   0.500      1.      1. ***
  809       0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
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810        0.100      1.      1.  0.0137  0.2500   0.500      1.      1. ***
811        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
END QUAL-INPUT

MON-POTFW
          Potency factors for NO3 (lb NO3-N/ton sediment)             ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
502       1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5
902       1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5
802       1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5
503       1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4
903       1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4
803       1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4
504       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
904       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
804       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
505       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
905       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
805       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
506       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
906       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
806       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
507       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
907       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
807       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
508        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
908        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
808        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
509        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
909        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
809        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
510        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
910        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
810        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
511        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
911        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
811        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
END MON-POTFW

MON-IFLW-CONC
          Interflow concentration of NO3-N (mg/l)                     ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
502       3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
902       3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
802       3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
503       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
903       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
803       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
504       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
904       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
804       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
505       6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0
905       6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0
805       6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0
506       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
906       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
806       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
507       8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0
907       8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0
807       8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0
508      .400 .400 .400 .350 .350 .300 .300 .250 .300 .300 .350 .400
908      .400 .400 .400 .350 .350 .300 .300 .250 .300 .300 .350 .400
808      .400 .400 .400 .350 .350 .300 .300 .250 .300 .300 .350 .400
509       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
909       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
809       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
510      .700 .680 .600 .570 .530 .470 .430 .360 .430 .500 .570 .640
910      .700 .680 .600 .570 .530 .470 .430 .360 .430 .500 .570 .640
810      .700 .680 .600 .570 .530 .470 .430 .360 .430 .500 .570 .640
511       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
911       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
811       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
END MON-IFLW-CONC

MON-GRND-CONC
          Active groundwater concentration of NO3-N (mg/l)            ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
502       3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
902       3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
802       3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
503       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
903       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
803       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
504       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
904       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
804       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
505       6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0
905       6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0
805       6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0
506       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
906       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
806       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
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507       8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0
907       8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0
807       8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0
508      .400 .400 .400 .350 .350 .300 .300 .250 .300 .300 .350 .400
908      .400 .400 .400 .350 .350 .300 .300 .250 .300 .300 .350 .400
808      .400 .400 .400 .350 .350 .300 .300 .250 .300 .300 .350 .400
509       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
909       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
809       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
510      .700 .680 .600 .570 .530 .470 .430 .360 .430 .500 .570 .640
910      .700 .680 .600 .570 .530 .470 .430 .360 .430 .500 .570 .640
810      .700 .680 .600 .570 .530 .470 .430 .360 .430 .500 .570 .640
511       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
911       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
811       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
END MON-GRND-CONC

QUAL-PROPS
  #    #<--QUALID-->    QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC  ***
502  911         NH4     LBS    1    2    0    0    0    1    4    1    4
END QUAL-PROPS

MON-POTFW
          Potency factors for NH4 (lb NH4-N/ton sediment)             ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
502       .24  .24  .24  .24  .24  .24  .24  .24  .24  .24  .24  .24
902       .24  .24  .24  .24  .24  .24  .24  .24  .24  .24  .24  .24
802       .24  .24  .24  .24  .24  .24  .24  .24  .24  .24  .24  .24
503       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
903       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
803       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
504       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
904       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
804       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
505       .40  .40  .40  .40  .40  .40  .40  .40  .40  .40  .40  .40
905       .40  .40  .40  .40  .40  .40  .40  .40  .40  .40  .40  .40
805       .30  .30  .30  .30  .30  .30  .30  .30  .30  .30  .30  .30
506       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
906       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
806       .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15
507       1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5
907       1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5
807       .95  .95  .95  .95  .95  .95  .95  .95  .95  .95  .95  .95
508      .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002
908      .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002
808      .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002
509       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
909       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
809       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
510      .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002
910      .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002
810      .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002
511       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
911       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
811       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
END MON-POTFW

MON-IFLW-CONC
          Interflow concentration of NH4-N (mg/l)                     ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
502      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
902      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
802      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
503      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
903      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
803      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
504      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
904      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
804      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
505      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
905      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
805      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
506      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
906      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
806      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
507      .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100
907      .150 .150 .150 .150 .150 .150 .150 .150 .150 .150 .150 .150
807      .080 .080 .080 .080 .080 .080 .080 .080 .080 .080 .080 .080
508      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
908      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
808      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
509      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
909      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
809      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
510      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
910      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
810      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
511      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
911      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
811      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
END MON-IFLW-CONC
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MON-GRND-CONC
          Active groundwater concentration of NH4-N (mg/l)            ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
502      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
902      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
802      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
503      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
903      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
803      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
504      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
904      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
804      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
505      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
905      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
805      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
506      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
906      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
806      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
507      .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060
907      .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060
807      .050 .050 .050 .050 .050 .050 .050 .050 .050 .050 .050 .050
508      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
908      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
808      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
509      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
909      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
809      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
510      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
910      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
810      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
511      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
911      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
811      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
END MON-GRND-CONC

QUAL-PROPS
  #    #<--QUALID-->    QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC  ***
502  911         PO4     LBS    1    2    0    0    0    1    4    1    4
END QUAL-PROPS

MON-POTFW
          Potency factors for PO4 (lb PO4-P/ton sediment)             ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
502       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
902       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
802       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
503       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
903       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
803       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
504       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
904       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
804       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
505       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
905       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
805       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
506       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
906       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
806       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
507       14.  14.  14.  14.  14.  14.  14.  14.  14.  14.  14.  14.
907       14.  14.  14.  14.  14.  14.  14.  14.  14.  14.  14.  14.
807       14.  14.  14.  14.  14.  14.  14.  14.  14.  14.  14.  14.
508      .010 .010 .010 .010 .010 .025 .035 .035 .025 .010 .010 .010
908      .010 .010 .010 .010 .010 .025 .035 .035 .025 .010 .010 .010
808      .010 .010 .010 .010 .010 .025 .035 .035 .025 .010 .010 .010
509       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8
909       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8
809       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8
510      .020 .020 .020 .020 .020 .025 .035 .035 .035 .020 .020 .020
910      .020 .020 .020 .020 .020 .025 .035 .035 .025 .020 .020 .020
810      .020 .020 .020 .020 .020 .025 .035 .035 .025 .020 .020 .020
511       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8
911       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8
811       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8
END MON-POTFW

MON-IFLW-CONC
          Interflow concentration of PO4-P (mg/l)                     ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
502      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
902      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
802      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
503      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
903      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
803      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
504      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
904      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
804      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
505      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
905      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
805      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
506      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
906      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
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806      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
507      .120 .120 .120 .120 .120 .120 .120 .120 .120 .120 .120 .120
907      .120 .120 .120 .120 .120 .120 .120 .120 .120 .120 .120 .120
807      .120 .120 .120 .120 .120 .120 .120 .120 .120 .120 .120 .120
508      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
908      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
808      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
509      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
909      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
809      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
510      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
910      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
810      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
511      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
911      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
811      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
END MON-IFLW-CONC

MON-GRND-CONC
          Active groundwater concentration of PO4-P (mg/l)            ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
502      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
902      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
802      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
503      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
903      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
803      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
504      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
904      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
804      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
505      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
905      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
805      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
506      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
906      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
806      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
507      .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060
907      .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060
807      .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060
508      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
908      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
808      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
509      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
909      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
809      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
510      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
910      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
810      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
511      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
911      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
811      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
END MON-GRND-CONC

QUAL-PROPS
  #    #<--QUALID-->    QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC  ***
502  911         BOD      LBS    1    2    0    0    0    1    4    1    4
END QUAL-PROPS

MON-POTFW
          Potency factors for BOD (lb BOD/ton sediment)            ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
502       25.  25.  25.  25.  25.  25.  25.  25.  25.  25.  25.  25.
902       25.  25.  25.  25.  25.  25.  25.  25.  25.  25.  25.  25.
402       25.  25.  25.  25.  25.  25.  25.  25.  25.  25.  25.  25.
503       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
903       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
803       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
504       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
904       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
804       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
505       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
905       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
805       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
506       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
906       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
806       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
507       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
907       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
807       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
508       8.5  8.5  8.5  8.5  8.5  5.5  5.5  5.5  5.5  8.5  8.5  8.5
908       8.5  8.5  8.5  8.5  8.5  5.5  5.5  5.5  5.5  8.5  8.5  8.5
808       8.5  8.5  8.5  8.5  8.5  5.5  5.5  5.5  5.5  8.5  8.5  8.5
509       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
909       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
809       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
510       8.5  8.5  8.5  8.5  8.5  5.5  5.5  5.5  5.5  8.5  8.5  8.5
910       8.5  8.5  8.5  8.5  8.5  5.5  5.5  5.5  5.5  8.5  8.5  8.5
810       8.5  8.5  8.5  8.5  8.5  5.5  5.5  5.5  5.5  8.5  8.5  8.5
511       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
911       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
811       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
END MON-POTFW
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MON-IFLW-CONC
          Interflow concentration of BOD (mg/l)                       ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
502       .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65
902       .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65
802       .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65
503        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
903        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
803        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
504        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
904        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
804        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
505        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
905        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
805        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
506        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
906        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
806        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
507        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
907        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
807        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
508        .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5
908        .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5
808        .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5
509        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
909        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
809        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
510        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
910        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
810        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
511        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
911        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
811        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
END MON-IFLW-CONC

MON-GRND-CONC
          Active groundwater concentration of BOD (mg/l)              ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
502       .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65
902       .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65
802       .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65
503        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
903        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
803        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
504        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
904        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
804        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
505        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
905        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
805        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
506        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
906        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
806        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
507        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
907        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
807        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
508        .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5
908        .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5
808        .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5
509        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
909        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
809        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
510        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
910        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
810        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
511        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
911        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
811        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
END MON-GRND-CONC

QUAL-PROPS
  #    #<--QUALID-->    QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC  ***
502  911        ORGN     LBS    1    1    0    0    0    1    4    1    4
END QUAL-PROPS

MON-POTFW
          Potency factors for ORGN (lb ORGN/ton sediment)             ***
502       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
902       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
802       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
503       1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3
903       1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3
803        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
504        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
904        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
804        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
505       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
905       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
805       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
506       3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0
306       3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0
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  806       3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0
  507       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
  907       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
  807       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
  508       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  908       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  808       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  509       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  909       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  809       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  510       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  910       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  810       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  511       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  911       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  811       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  END MON-POTFW

  MON-IFLW-CONC
            Interflow concentration of ORGN (mg/l)                      ***
    #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
  502       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  902       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  802       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  503        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  903        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  803        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  504        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  904        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  804        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  505        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  905        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  805        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  506        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  906        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  806        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  507        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  907        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  807        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  508        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  908        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  808        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  509       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  909       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  809       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  510        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
  910        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
  810        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
  511       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  911       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  811       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  END MON-IFLW-CONC

  MON-GRND-CONC
            Active groundwater concentration of ORGN (mg/l)             ***
    #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
  502  811  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15
  END MON-GRND-CONC

END PERLND

IMPLND
  ACTIVITY
    #    # ATMP SNOW IWAT  SLD  IWG IQAL   ***
  501  902    1    1    1    1    1    1
  END ACTIVITY

  PRINT-INFO
    #    # ATMP SNOW IWAT  SLD  IWG IQAL PIVL  PYR  ***
  501  902    5    5    5    5    5    5    0   12
  END PRINT-INFO

  GEN-INFO
    #    #      NAME            UCI   IN  OUT ENGL METR  ***
  501     ROADS,BUILDING-resid    1    1    1   90    0
  502     ROADS,BUILDING-urban    1    1    1   90    0
  801     ROADS,BUILDING-resid    1    1    1   90    0
  802     ROADS,BUILDING-urban    1    1    1   90    0
  901     ROADS,BUILDING-resid    1    1    1   90    0
  902     ROADS,BUILDING-urban    1    1    1   90    0
  END GEN-INFO

**** AIR TEMPERATURE ****

  ATEMP-DAT
               ELDAT    AIRTMP ***
    #    #      (ft)   (deg F) ***
  501  502     225.0      53.6
  801  802       0.0      53.6
  901  902      25.0      53.6
  END ATEMP-DAT
```

```
**** SNOW ****

  ICE-FLAG
*** <ILS > ICEFG
*** #    #
  501  902    1
  END ICE-FLAG

  SNOW-PARM1
*** <ILS >       LAT     MELEV     SHADE    SNOWCF    COVIND
*** #    #     (deg)      (ft)                          (in)
  501  502     39.71      300.      0.20       1.0      0.50
  801  802     39.71       75.      0.20       1.0      0.50
  901  902     39.70      100.      0.20       1.0      0.50
  END SNOW-PARM1

  SNOW-PARM2
*** <ILS >     RDSCN     TSNOW    SNOEVP    CCFACT    MWATER    MGMELT
*** #    #              (degF)                                (in/day)
  501  502      0.08      32.0      0.05      0.60      0.50     0.050
  801  802      0.08      32.0      0.05      0.60      0.50     0.050
  901  902      0.08      32.0      0.05      0.60      0.50     0.050
  END SNOW-PARM2

**** HYDROLOGY ****

  IWAT-PARM1
*** <ILS >        Flags
*** x -  x CSNO RTOP  VRS  VNN RTLI
  501  802    1    1    1    0    0
  901  902    1    1    1    0    0
  END IWAT-PARM1

  IWAT-PARM2
*** <ILS >      LSUR     SLSUR      NSUR     RETSC
*** x -  x      (ft)                          (in)
  501          150.0     0.197      0.07       0.0
  502          150.0     0.150      0.05       0.0
  801          150.0     0.084      0.07       0.0
  802          150.0     0.080      0.05       0.0
  901          150.0     0.110      0.07       0.0
  902          150.0     0.138      0.05       0.0
  END IWAT-PARM2

  IWAT-PARM3
*** <ILS >    PETMAX    PETMIN
*** x -  x   (deg F)   (deg F)
  501  902      40.0      35.0
  END IWAT-PARM3

  MON-RETN
*** <ILS >  Retention storage capacity at start of each month (in)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  501  802  .03  .03  .04  .04  .04  .06  .06  .06  .04  .04  .04  .03
  901  902  .08  .08  .08  .08  .10  .12  .15  .15  .12  .10  .08  .08
  END MON-RETN

  IWAT-STATE1
*** <ILS >  IWATER state variables (inches)
*** x -  x      RETS      SURS
  501  902       0.0       0.0
  END IWAT-STATE1

  SLD-PARM1
*** <ILS >     Flags
*** x -  x VASD VRSD SDOP
  501  902    0    0    1
  END SLD-PARM1

  SLD-PARM2
IMPLND ***      KEIM      JEIM    ACCSDP    REMSDP
  501            1.0       1.2    0.0006      0.08
  502            1.0       1.2    0.0035      0.08
  801            1.0       1.2    0.0006      0.08
  802            1.0       1.2    0.0035      0.08
  901            1.0       1.2    0.0006      0.08
  902            1.0       1.2    0.0035      0.08
  END SLD-PARM2

  SLD-STOR
IMPLND ***      SLDS
  501  902      0.05
  END SLD-STOR

  IWT-PARM1
*** <ILS >  Flags for section IWTGAS
*** x -  x WTFV CSNO
  501  902    1    1
  END IWT-PARM1

*** WATER QUALITY CONSTITUENTS ***
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  NQUALS
    #    # NQAL  ***
  501  502    4
  901  902    4
  801  802    4
  END NQUALS

  QUAL-PROPS
    #    #<--QUALID-->    QTID  QSD VPFW  QSO  VQO  ***
  501  502         NO3     LBS    0    0    1    0
  901  902         NO3     LBS    0    0    1    0
  801  802         NO3     LBS    0    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
    #    #     SQO   POTFW   ACQOP  SQOLIM   WSQOP  ***
  501  502   0.050          0.0060  0.4000   0.500
  901  902   0.050          0.0060  0.4000   0.500
  801  802   0.050          0.0060  0.4000   0.500
  END QUAL-INPUT

  QUAL-PROPS
    #    #<--QUALID-->    QTID  QSD VPFW  QSO  VQO  ***
  501  502         NH4     LBS    1    0    1    0
  901  902         NH4     LBS    1    0    1    0
  801  802         NH4     LBS    1    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
    #    #     SQO   POTFW   ACQOP  SQOLIM   WSQOP  ***
  501  502   0.020     0.1  0.0010  0.1200   0.500
  901  902   0.020     0.1  0.0010  0.1200   0.500
  801  802   0.020     0.1  0.0010  0.1200   0.500
  END QUAL-INPUT

  QUAL-PROPS
    #    #<--QUALID-->    QTID  QSD VPFW  QSO  VQO  ***
  501  502         PO4     LBS    1    0    1    0
  901  902         PO4     LBS    1    0    1    0
  801  802         PO4     LBS    1    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
    #    #     SQO   POTFW   ACQOP  SQOLIM   WSQOP  ***
  501        0.010     1.2  0.0006  0.0090   0.500
  502        0.010     1.0  0.0004  0.0090   0.500
  901        0.010     1.2  0.0006  0.0090   0.500
  902        0.010     1.0  0.0004  0.0090   0.500
  801        0.010     1.2  0.0006  0.0090   0.500
  802        0.010     1.0  0.0004  0.0090   0.500
  END QUAL-INPUT

  QUAL-PROPS
    #    #<--QUALID-->    QTID  QSD VPFW  QSO  VQO  ***
  501  502         BOD     LBS    0    0    1    0
  901  902         BOD     LBS    0    0    1    0
  801  802         BOD     LBS    0    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
    #    #     SQO   POTFW   ACQOP  SQOLIM   WSQOP  ***
  501  502   1.900          0.3600  9.0000   0.500
  901  902   1.900          0.3600  9.0000   0.500
  801  802   1.900          0.3600  9.0000   0.500
 END QUAL-INPUT

  IWT-PARM2
IMPLND ***      ELEV      AWTF      BWTF
  501  502      250.      34.0      0.3
  801  802       75.      34.0      0.3
  901  902      150.      34.0      0.3
  END IWT-PARM2

  MON-AWTF
IMPLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  501  902 32.9 36.0 39.1 45.1 50.3 57.4 60.4 59.6 55.9 49.5 42.4 37.4
  END MON-AWTF

  MON-BWTF
IMPLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  501  902 0.38 0.38 0.38 0.38 0.38 0.38 0.38 0.38 0.38 0.38 0.38 0.38
  END MON-BWTF

  IWT-INIT
*** <ILS > SOTMP       SODOX      SOCO2
*** x -  x(deg F)     (mg/l)     (mg C/l)
  501  902  55.
  END IWT-INIT
END IMPLND

RCHRES
  ACTIVITY
```

```
    RCHRES  Active Sections (1=Active; 0=Inactive)           ***
    # -  # HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG ***
    1    7    1    1    0    1    1    0    1    1    1    0
  END ACTIVITY

  PRINT-INFO
    RCHRES  Print-flags                                           ***
    # -  # HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB PIVL  PYR ***
    1    7    5    5         5    5         5    5    5             12
  END PRINT-INFO

  GEN-INFO
    RCHRES<-------Name------->Nexit   Unit Systems   Printer      ***
    # -  #                          User t-series  Engl Metr LKFG ***
                                           in  out                ***
    1     WEST BRANCH             1    1    1    1   90    0    0
    2     EAST BR-WEST BR         1    1    1    1   90    0    0
    3     MS-COOCHS GAGE          1    1    1    1   90    0    0
    4     LTL MILL-NEWPORT GA     1    1    1    1   90    0    0
    5     NEWPORT GA-CHRSTINA     1    1    1    1   90    0    0
    6     MUDDY RUN               1    1    1    1   90    0    0
    7     BELLTOWN RUN            1    1    1    1   90    0    0
  END GEN-INFO

**** HYDRAULICS

  HYDR-PARM1
    RCHRES  VC A1 A2 A3  ODFVFG for each *** ODGTFG for each     FUNCT  for each
    # -  #  FG FG FG FG  possible   exit *** possible   exit     possible   exit
    1    5   0  1  1  1    4  0  0  0  0       0  0  0  0  0       1  1  1  1  1
    6        0  1  1  1    4  0  0  0  0       0  0  0  0  0       1  1  1  1  1
    7        0  1  1  1    4  0  0  0  0       0  0  0  0  0       1  1  1  1  1
  END HYDR-PARM1

  HYDR-PARM2
    RCHRES    FTABNO       LEN     DELTH     STCOR        KS      DB50  ***
    # -  #             (miles)      (ft)      (ft)                (in)  ***
    1             1      4.79     201.0       0.0       0.5      0.01
    2             2      8.16     221.0       0.0       0.5      0.01
    3             3      3.24      51.0       0.0       0.5      0.01
    4             4      4.65     183.0       0.0       0.5      0.01
    5             5      2.30      63.0       0.0       0.5      0.01
    6             6      6.73      91.0       0.0       0.5      0.01
    7             7      2.08      46.0       0.0       0.5      0.01
  END HYDR-PARM2

  HYDR-INIT
    RCHRES       VOL ***   Initial value of COLIND      Initial value  of OUTDGT
    # -  #     ac-ft ***   for each exit                for each exit (ft3)
    1          0.75       4.0  0.0  0.0  0.0  0.0       0.0  0.0  0.0  0.0  0.0
    2          1.99       4.0  0.0  0.0  0.0  0.0       0.0  0.0  0.0  0.0  0.0
    3          2.17       4.0  0.0  0.0  0.0  0.0       0.0  0.0  0.0  0.0  0.0
    4          0.76       4.0  0.0  0.0  0.0  0.0       0.0  0.0  0.0  0.0  0.0
    5          0.75       4.0  0.0  0.0  0.0  0.0       0.0  0.0  0.0  0.0  0.0
    6          2.00       4.0  0.0  0.0  0.0  0.0       0.0  0.0  0.0  0.0  0.0
    7          0.44       4.0  0.0  0.0  0.0  0.0       0.0  0.0  0.0  0.0  0.0
  END HYDR-INIT

  HT-BED-FLAGS
RCHRES *** BDFG TGFG TSTP
    1    7    1    3
  END HT-BED-FLAGS

  HEAT-PARM
RCHRES ***      ELEV     ELDAT    CFSAEX    KATRAD     KCOND     KEVAP
    1          150.       75.       .50       9.4      10.0       2.2
    2          250.      175.       .50       9.4      10.0       2.2
    3           55.      -20.       .50       9.4      10.0       2.2
    4          130.       55.       .50       9.4      10.0       2.2
    5    7      50.      -25.       .50       9.4      10.0       2.2
  END HEAT-PARM

  HT-BED-PARM
RCHRES ***    MUDDEP     TGRND      KMUD     KGRND
    1    7      0.01       59.        50       0.0
  END HT-BED-PARM

  MON-HT-TGRND
RCHRES ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
    1    7 39.0 43.0 46.5 55.0 59.5 67.0 74.5 75.0 74.0 63.5 53.0 44.0
  END MON-HT-TGRND

  HEAT-INIT
RCHRES ***        TW    AIRTMP
    1    7       59.       50.
  END HEAT-INIT

  SANDFG
*** RCHRES

*** x -  x SNDFG
    1    7    3
```

```
  END SANDFG

  SED-GENPARM
RCHRES ***    BEDWID    BEDWRN       POR
    1    7       25.        6.       0.8
  END SED-GENPARM

  SAND-PM
RCHRES ***         D         W       RHO     KSAND    EXPSND
    1    7      .005       0.1       2.6      0.10      3.92
  END SAND-PM

  SILT-CLAY-PM
RCHRES ***         D         W       RHO     TAUCD     TAUCS         M
    1        0.00040    0.0003       2.2      0.18      0.65      0.90
    2        0.00040    0.0003       2.2      0.18      0.55      0.90
    3        0.00040    0.0003       2.2      0.18      0.50      0.90
    4        0.00040    0.0003       2.2      0.20      0.65      0.90
    5        0.00040    0.0003       2.2      0.18      0.58      0.90
    6        0.00040    0.0003       2.2      0.12      0.30      0.90
    7        0.00040    0.0003       2.2      0.18      0.53      0.90
  END SILT-CLAY-PM

  SILT-CLAY-PM
RCHRES ***         D         W       RHO     TAUCD     TAUCS         M
    1        0.00010   0.00001       2.0      0.15      0.68      0.90
    2        0.00010   0.00001       2.0      0.15      0.60      0.90
    3        0.00010   0.00001       2.0      0.15      0.55      0.90
    4        0.00010   0.00001       2.0      0.18      0.70      0.90
    5        0.00010   0.00001       2.0      0.15      0.62      0.90
    6        0.00010   0.00001       2.0      0.10      0.32      0.90
    7        0.00010   0.00001       2.0      0.15      0.58      0.90
  END SILT-CLAY-PM

  SSED-INIT
RCHRES ***     SSED1     SSED2     SSED3
    1    7        1.       25.       25.
  END SSED-INIT

  BED-INIT
RCHRES ***    BEDDEP    SANDFR    SILTFR    CLAYFR
    1    7        4.       .70       .20       .10
  END BED-INIT

  BENTH-FLAG
*** RCHRES  Benthic release flag
*** x -  x BENF
    1    7    1
  END BENTH-FLAG

  SCOUR-PARMS
RCHRES ***    SCRVEL    SCRMUL
    1    7        3.         2
  END SCOUR-PARMS

  OX-FLAGS
*** RCHRES Oxygen flags
*** x -  x REAM
    1    7    3
  END OX-FLAGS

  OX-GENPARM
RCHRES ***    KBOD20     TCBOD    KODSET    SUPSAT
    1    7      .020     1.050      .030      1.25
  END OX-GENPARM

  OX-BENPARM
RCHRES ***     BENOD     TCBEN     EXPOD    BRBOD1    BRBOD2    EXPREL
    1    7       10.       1.1       1.2       10.       15.       2.5
  END OX-BENPARM

  OX-REAPARM
RCHRES ***    TCGINV      REAK    EXPRED     EXPREV
    1    7     1.024      .726    -1.673       .969
  END OX-REAPARM

  OX-INIT
RCHRES ***       DOX       BOD     SATDO
    1    7      11.3      2.92      12.0
  END OX-INIT

**** NUTRIENTS ****
  NUT-FLAGS
    RCHRES  TAM  NO2  PO4  AMV  DEN ADNH ADPO PHFG ***
    # -  #                                         ***
    1    7    1    0    1    0    1    1    1    2
  END NUT-FLAGS

  NUT-NITDENIT
    RCHRES    KTAM20    KNO220     TCNIT    KNO320     TCDEN    DENOXT ***
    # -  #       /hr       /hr                 /hr                mg/l ***
    1    7       .05      .050     1.045      .005      1.04        1.
```

```
  END NUT-NITDENIT

  NUT-BEDCONC
    RCHRES       Bed concentrations of NH4 & PO4 (mg/kg)               ***
    # -  #  NH4-sand  NH4-silt  NH4-clay  PO4-sand  PO4-silt  PO4-clay ***
    1    7        1.       30.       50.       90.      700.      900.
  END NUT-BEDCONC

  NUT-ADSPARM
    RCHRES       Partition coefficients for NH4 AND PO4  (ml/g)        ***
    # -  #  NH4-sand  NH4-silt  NH4-clay  PO4-sand  PO4-silt  PO4-clay ***
    1    7       10.      500.      800.      600.    15000.    18000.
  END NUT-ADSPARM

  NUT-DINIT
    RCHRES       NO3       TAM       NO2       PO4        PH ***
    # -  #      mg/l      mg/l      mg/l      mg/l           ***
    1    7       2.0      .055                .033        7.
  END NUT-DINIT

  NUT-ADSINIT
    RCHRES        Initial suspended NH4 and PO4 concentrations (mg/kg) ***
    # -  #  NH4-sand  NH4-silt  NH4-clay  PO4-sand  PO4-silt  PO4-clay ***
    1    7       0.1       0.3       0.5       0.1       0.5       0.8
  END NUT-ADSINIT
**** PLANKTON ****

  PLNK-FLAGS
    RCHRES PHYF ZOOF BALF SDLT AMRF DECF NSFG ZFOO ***
    # -  #                                        ***
    1    7    1    0    1    0    0    1    1    2
  END PLNK-FLAGS

  PLNK-PARM1
    RCHRES    RATCLP    NONREF    LITSED     ALNPR      EXTB     MALGR ***
    # -  #                                              /ft       /hr ***
    1    7       .60        .5        0.       0.8       .20      .200
  END PLNK-PARM1

  PLNK-PARM2
    RCHRES *** CMMLT      CMMN     CMMNP      CMMP    TALGRH    TALGRL    TALGRM
    # -  # ***ly/min      mg/l      mg/l      mg/l     deg F     deg F     deg F
    1    7       .03      .045      .029      .015       95.       32.       55.
  END PLNK-PARM2

  PLNK-PARM3
    RCHRES     ALR20      ALDH      ALDL     OXALD     NALDH     PALDH ***
    # -  #       /hr       /hr       /hr       /hr      mg/l      mg/l ***
    1    7      .055      .010      .001       .03      .015      .001
  END PLNK-PARM3

  PHYTO-PARM
    RCHRES      SEED    MXSTAY      OREF    CLALDH    PHYSET    REFSET ***
    # -  #      mg/l      mg/l                ug/l                     ***
    1    7        .4        .8       20.       50.      .012      .010
  END PHYTO-PARM

  PLNK-INIT
    RCHRES     PHYTO       ZOO     BENAL       ORN       ORP       ORC ***
    # -  #      mg/l     org/l     mg/m2      mg/l      mg/l      mg/l ***
    1    7      .700       .03    1.0E-8        1.        .2        8.
  END PLNK-INIT

END RCHRES

FTABLES

  FTABLE      1
 ROWS COLS ***  West Br. to Main Stem
   15    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
      0.00       0.0       0.0       0.0        0.
      0.29      17.0       4.9       9.8      365.
      0.58      17.2       9.9      31.0      233.
      0.88      17.4      15.0      60.7      179.
      1.17      17.6      20.1      97.5      150.
      1.46      17.8      25.3     140.8      130.
      1.75      18.0      30.5     190.0      116.
      2.33      18.4      41.1     304.4       98.
      2.92      18.8      51.9     438.3       86.
      3.50      19.2      63.0     590.1       78.
      4.67      41.7      98.5     987.4       72.
      5.83      64.3     160.4     1496.       78.
      7.00      86.9     248.6     2133.       85.
      8.17     109.5     363.1     2913.       91.
      9.33     132.1     504.0     3848.       95.
  END FTABLE  1

  FTABLE      2
 ROWS COLS ***  East Br. to Main Stem to West Br.
   15    4
```

```
    DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
     0.00       0.0       0.0       0.0        0.
     0.38      35.0      13.1      14.5      655.
     0.75      35.4      26.3      45.7      418.
     1.13      35.9      39.6      89.3      322.
     1.50      36.3      53.2     143.5      269.
     1.88      36.7      66.8     207.1      234.
     2.25      37.1      80.7     279.3      210.
     3.00      37.9     108.8     447.2      177.
     3.75      38.7     137.5     643.5      155.
     4.50      39.6     166.9     865.9      140.
     6.00     138.5     300.4     1464.      149.
     7.50     237.4     582.3     2288.      185.
     9.00     336.3    1012.6     3399.      216.
    10.50     435.2    1591.2     4850.      238.
    12.00     534.1    2318.2     6687.      252.
 END FTABLE  2

 FTABLE      3
ROWS COLS ***  Main Stem at W.Br. to Cooch’s Gage
  15    4
    DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
     0.00       0.0       0.0       0.0        0.
     0.46      23.4      10.7      23.7      327.
     0.92      23.6      21.4      74.8      208.
     1.38      23.8      32.3     146.4      160.
     1.83      24.0      43.2     235.5      133.
     2.29      24.2      54.2     340.3      116.
     2.75      24.3      65.3     459.4      103.
     3.67      24.7      87.8     736.7       87.
     4.58      25.1     110.7     1061.       76.
     5.50      25.5     133.9     1429.       68.
     7.33      73.5     224.7     2390.       68.
     9.17     121.5     403.5     3677.       80.
    11.00     169.5     670.3     5368.       91.
    12.83     217.5    1025.1     7530.       99.
    14.67     265.5    1467.9    10222.      104.
 END FTABLE  3

 FTABLE      4
ROWS COLS ***  Little Mill to Newport Gage
  15    4
    DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
     0.00       0.0       0.0       0.0        0.
     0.42       8.9       3.6       8.1      324.
     0.83       9.4       7.4      25.7      210.
     1.25       9.9      11.4      50.5      165.
     1.67      10.3      15.7      81.7      139.
     2.08      10.8      20.1     118.8      123.
     2.50      11.3      24.7     161.5      111.
     3.33      12.2      34.4     263.5       95.
     4.17      13.2      45.0     387.1       84.
     5.00      14.1      56.4     532.3       77.
     6.67      45.4     105.9     986.4       78.
     8.33      76.7     207.7     1685.       89.
    10.00     108.0     361.7     2715.       97.
    11.67     139.3     567.8     4147.       99.
    13.33     170.7     826.1     6047.       99.
 END FTABLE  4

 FTABLE      5
ROWS COLS ***  Newport Gage to Christina R.
  15    4
    DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
     0.00       0.0       0.0       0.0        0.
     0.42       5.3       2.1       8.1      191.
     0.83       5.5       4.4      25.7      123.
     1.25       5.7       6.7      50.6       96.
     1.67       5.9       9.1      81.7       81.
     2.08       6.2      11.7     118.6       71.
     2.50       6.4      14.3     161.1       64.
     3.33       6.9      19.8     261.9       55.
     4.17       7.3      25.7     383.4       49.
     5.00       7.8      32.1     525.1       44.
     6.67      38.8      70.9     961.7       54.
     8.33      69.8     161.3     1638.       72.
    10.00     100.7     303.4     2640.       83.
    11.67     131.7     497.1     4040.       89.
    13.33     162.7     742.5     5905.       91.
 END FTABLE  5

 FTABLE      6
ROWS COLS ***  Muddy Run
  15    4
    DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
     0.00       0.0       0.0       0.0        0.
     0.42      12.8       5.2       5.2      727.
```

```
      0.83      13.5      10.7      16.5      471.
      1.25      14.1      16.4      32.3      369.
      1.67      14.7      22.4      52.2      312.
      2.08      15.3      28.7      75.7      275.
      2.50      15.9      35.2     102.7      249.
      3.33      17.1      48.9     166.9      213.
      4.17      18.4      63.7     244.1      190.
      5.00      19.6      79.5     334.3      173.
      6.67      87.6     168.8     611.5      200.
      8.33     155.5     371.4     1025.      263.
     10.00     223.5     687.3     1621.      308.
     11.67     291.5    1116.5     2435.      333.
     13.33     359.5    1658.9     3503.      344.
  END FTABLE  6

  FTABLE      7
 ROWS COLS ***  Belltown Run
   15    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
      0.00       0.0       0.0       0.0        0.
      0.33       2.7       0.9       3.1      205.
      0.67       2.9       1.8       9.7      134.
      1.00       3.0       2.8      19.1      105.
      1.33       3.2       3.8      31.0       89.
      1.67       3.4       4.9      45.2       79.
      2.00       3.5       6.1      61.5       71.
      2.67       3.9       8.5     100.8       61.
      3.33       4.2      11.2     148.9       55.
      4.00       4.5      14.1     205.7       50.
      5.33      21.3      31.4     385.9       59.
      6.67      38.2      71.0     660.4       78.
      8.00      55.0     133.1     1061.       91.
      9.33      71.8     217.6     1614.       98.
     10.67      88.6     324.5     2344.      101.
  END FTABLE  7

END FTABLES

COPY
  TIMESERIES
    # -  #  NPT  NMN ***
   10  500        20
  END TIMESERIES
END COPY

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   # <Name> # tem strg<-factor->strg <Name>   #   #        <Name> # #  ***
*** Meteorological data
WDM1    75 PREC   0 ENGL          0.94     PERLND 502 511 EXTNL  PREC   1 1
WDM1    75 PREC   0 ENGL          0.94     PERLND 802 811 EXTNL  PREC   1 1
WDM1    94 PREC   0 ENGL          0.95     PERLND 902 911 EXTNL  PREC   1 1
WDM1    75 PREC   0 ENGL       13421.3     COPY   200   0 INPUT  MEAN   4 1
WDM1    94 PREC   0 ENGL        3443.6     COPY   300   0 INPUT  MEAN   4 1
WDM1    50 ATMP   0 ENGL           1.0     PERLND 502 911 EXTNL  GATMP  1 1
WDM1    45 DWPT   0 ENGL           1.0     PERLND 502 911 EXTNL  DTMPG  1 1
WDM1    30 WIND   0 ENGL           1.0     PERLND 502 911 EXTNL  WINMOV 1 1
WDM1    20 PETX   0 ENGL           1.1     PERLND 502 911 EXTNL  PETINP 1 1
WDM1    10 SOLR   0 ENGL           1.0     PERLND 502 911 EXTNL  SOLRAD 1 1
WDM1    75 PREC   0 ENGL          0.94     IMPLND 501 502 EXTNL  PREC   1 1
WDM1    75 PREC   0 ENGL          0.94     IMPLND 801 802 EXTNL  PREC   1 1
WDM1    94 PREC   0 ENGL          0.95     IMPLND 901 902 EXTNL  PREC   1 1
WDM1    50 ATMP   0 ENGL           1.0     IMPLND 501 902 EXTNL  GATMP  1 1
WDM1    45 DWPT   0 ENGL           1.0     IMPLND 501 902 EXTNL  DTMPG  1 1
WDM1    30 WIND   0 ENGL           1.0     IMPLND 501 902 EXTNL  WINMOV 1 1
WDM1    20 PETX   0 ENGL           1.1     IMPLND 501 902 EXTNL  PETINP 1 1
WDM1    10 SOLR   0 ENGL           1.0     IMPLND 501 902 EXTNL  SOLRAD 1 1
WDM1    75 PREC   0 ENGL          0.94     RCHRES   1   3 EXTNL  PREC   1 1
WDM1    94 PREC   0 ENGL          0.95     RCHRES   4   5 EXTNL  PREC   1 1
WDM1    75 PREC   0 ENGL          0.94     RCHRES   6   7 EXTNL  PREC   1 1
WDM1    50 ATMP   0 ENGL           1.0     RCHRES   1   7 EXTNL  GATMP  1 1
WDM1    45 DWPT   0 ENGL           1.0     RCHRES   1   7 EXTNL  DEWTMP 1 1
WDM1    40 COVR   0 ENGL           1.0     RCHRES   1   7 EXTNL  CLOUD  1 1
WDM1    30 WIND   0 ENGL           1.0     RCHRES   1   7 EXTNL  WIND   1 1
WDM1    20 PETX   0 ENGL           1.1     RCHRES   1   7 EXTNL  POTEV  1 1
WDM1    10 SOLR   0 ENGL           1.0     RCHRES   1   7 EXTNL  SOLRAD 1 1
*** Point source Discharges ***
*** Meadowview
WDM1   300 PTSQ   0 ENGL           1.0     RCHRES   1     EXTNL  IVOL   1 1
WDM1   301 TSSX   0 ENGL           1.0     RCHRES   1     INFLOW ISED   3 1
WDM1   302 BODX   0 ENGL           1.0     RCHRES   1     INFLOW OXIF   2 1
WDM1   303 NH3X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  2 1
WDM1   304 NO3X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  1 1
WDM1   305 NO2X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  3 1
WDM1   306 PO4X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  4 1
WDM1   308 HEAT   0 ENGL           1.0     RCHRES   1     INFLOW IHEAT  1 1
*** Highlands
WDM1   310 PTSQ   0 ENGL           1.0     RCHRES   1     EXTNL  IVOL   1 1
WDM1   311 TSSX   0 ENGL           1.0     RCHRES   1     INFLOW ISED   3 1
WDM1   312 BODX   0 ENGL           1.0     RCHRES   1     INFLOW OXIF   2 1
WDM1   313 NH3X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  2 1
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```
WDM1   314 NO3X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  1 1
WDM1   315 NO2X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  3 1
WDM1   316 PO4X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  4 1
WDM1   318 HEAT   0 ENGL           1.0     RCHRES   1     INFLOW IHEAT  1 1
*** GM
WDM1   320 PTSQ   0 ENGL           1.0     RCHRES   5     EXTNL  IVOL   1 1
WDM1   321 TSSX   0 ENGL           1.0     RCHRES   5     INFLOW ISED   3 1
WDM1   322 BODX   0 ENGL           1.0     RCHRES   5     INFLOW OXIF   2 1
WDM1   323 NH3X   0 ENGL           0.1     RCHRES   5     INFLOW NUIF1  2 1
WDM1   324 NO3X   0 ENGL          0.15     RCHRES   5     INFLOW NUIF1  1 1
WDM1   325 NO2X   0 ENGL           0.1     RCHRES   5     INFLOW NUIF1  3 1
WDM1   326 PO4X   0 ENGL          0.05     RCHRES   5     INFLOW NUIF1  4 1
WDM1   328 HEAT   0 ENGL           1.0     RCHRES   5     INFLOW IHEAT  1 1
*** DuPont
WDM1   330 PTSQ   0 ENGL           1.0     RCHRES   4     EXTNL  IVOL   1 1
WDM1   331 TSSX   0 ENGL           1.0     RCHRES   4     INFLOW ISED   3 1
WDM1   332 BODX   0 ENGL           1.0     RCHRES   4     INFLOW OXIF   2 1
WDM1   333 NH3X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  2 1
WDM1   334 NO3X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  1 1
WDM1   335 NO2X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  3 1
WDM1   336 PO4X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  4 1
WDM1   338 HEAT   0 ENGL           1.0     RCHRES   4     INFLOW IHEAT  1 1
*** DuPont
WDM1   340 PTSQ   0 ENGL           1.0     RCHRES   4     EXTNL  IVOL   1 1
WDM1   341 TSSX   0 ENGL           1.0     RCHRES   4     INFLOW ISED   3 1
WDM1   342 BODX   0 ENGL           1.0     RCHRES   4     INFLOW OXIF   2 1
WDM1   343 NH3X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  2 1
WDM1   344 NO3X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  1 1
WDM1   345 NO2X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  3 1
WDM1   346 PO4X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  4 1
WDM1   348 HEAT   0 ENGL           1.0     RCHRES   4     INFLOW IHEAT  1 1
*** Withdrawals ***   NONE

END EXT SOURCES

EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Aggr Amd ***
<Name>   x        <Name> x x<-factor->strg <Name>   x <Name>qf  tem strg strg***
*** mult factor for rovol is 12/area
*** mult factor for others 1/area
***
***(Gage: Christina River at Coochs Bridge)
RCHRES   3 ROFLOW ROVOL     .000894099     WDM   1100 FLOW     ENGL      REPL
RCHRES   3 HYDR   RO                       WDM   1109 FLOW     ENGL      REPL
COPY   200 OUTPUT MEAN   1  .000074508     WDM   1101 SURO     ENGL      REPL
COPY   200 OUTPUT MEAN   2  .000074508     WDM   1102 IFWO     ENGL      REPL
COPY   200 OUTPUT MEAN   3  .000074508     WDM   1103 AGWO     ENGL      REPL
COPY   200 OUTPUT MEAN   4  .000074508     WDM   1104 PREC     ENGL      REPL
COPY   200 OUTPUT MEAN   5  .000074508     WDM   1105 PETX     ENGL      REPL
COPY   200 OUTPUT MEAN   6  .000074508     WDM   1106 TAET     ENGL      REPL
COPY   200 OUTPUT MEAN   7  .000074508     WDM   1107 UZSX     ENGL      REPL
COPY   200 OUTPUT MEAN   8  .000074508     WDM   1108 LZSX     ENGL      REPL
COPY   200 OUTPUT MEAN   9  .000074508     WDM   1200 UZI      ENGL      REPL
*** sediment, nutrient output from pervious areas, ground water, impervious areas
COPY   200 OUTPUT MEAN  10                 WDM   2100 SOSED    ENGL      REPL
COPY   200 OUTPUT MEAN  11                 WDM   2122 PONO3    ENGL      REPL
COPY   200 OUTPUT MEAN  18                 WDM   2123 SSNO3    ENGL      REPL
COPY   200 OUTPUT MEAN  12                 WDM   2124 PONH4    ENGL      REPL
COPY   200 OUTPUT MEAN  19                 WDM   2125 SSNH4    ENGL      REPL
COPY   200 OUTPUT MEAN  13                 WDM   2126 POPHOS   ENGL      REPL
COPY   200 OUTPUT MEAN  20                 WDM   2127 SSPHOS   ENGL      REPL
COPY   200 OUTPUT MEAN  14                 WDM   2130 SOSLD    ENGL      REPL
COPY   200 OUTPUT MEAN  15                 WDM   2135 IONO3    ENGL      REPL
COPY   200 OUTPUT MEAN  16                 WDM   2136 IONH4    ENGL      REPL
COPY   200 OUTPUT MEAN  17                 WDM   2137 IOPHOS   ENGL      REPL

***(Gage: Little Mill Creek near Newport)
RCHRES   4 ROFLOW ROVOL     .003484714     WDM   1110 FLOW     ENGL      REPL
RCHRES   4 HYDR   RO                       WDM   1119 FLOW     ENGL      REPL
COPY   300 OUTPUT MEAN   1  .000290393     WDM   1111 SURO     ENGL      REPL
COPY   300 OUTPUT MEAN   2  .000290393     WDM   1112 IFWO     ENGL      REPL
COPY   300 OUTPUT MEAN   3  .000290393     WDM   1113 AGWO     ENGL      REPL
COPY   300 OUTPUT MEAN   4  .000290393     WDM   1114 PREC     ENGL      REPL
COPY   300 OUTPUT MEAN   5  .000290393     WDM   1115 PETX     ENGL      REPL
COPY   300 OUTPUT MEAN   6  .000290393     WDM   1116 TAET     ENGL      REPL
COPY   300 OUTPUT MEAN   7  .000290393     WDM   1117 UZSX     ENGL      REPL
COPY   300 OUTPUT MEAN   8  .000290393     WDM   1118 LZSX     ENGL      REPL

***  Water temperature
RCHRES   3 HTRCH  TW                       WDM   1500 WTEM     METR      REPL
RCHRES   4 HTRCH  TW                       WDM   1510 WTEM     METR      REPL
RCHRES   3 SEDTRN SSED   4                 WDM   1550 SEDC     METR      REPL
RCHRES   4 SEDTRN SSED   4                 WDM   1580 SEDC     METR      REPL
*** Oxygen, BOD, nutrients
RCHRES   3 OXRX   DOX                      WDM   1551 DOXX     METR      REPL
RCHRES   3 OXRX   BOD                      WDM   1552 BODX     METR      REPL
RCHRES   3 NUTRX  DNUST  1                 WDM   1553 NO3X     METR      REPL
RCHRES   3 NUTRX  DNUST  2                 WDM   1554 NH4X     METR      REPL
RCHRES   3 NUTRX  DNUST  4                 WDM   1555 PO4X     METR      REPL
COPY    11 OUTPUT MEAN   1                 WDM   1556 NH4P     METR      REPL
COPY    11 OUTPUT MEAN   2                 WDM   1557 PO4P     METR      REPL
RCHRES   3 PLANK  PKST3  4                 WDM   1558 TORN     METR      REPL
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RCHRES   3 PLANK  PHYCLA 1                 WDM   1559 PHCA     METR      REPL
RCHRES   4 OXRX   DOX                      WDM   1581 DOXX     METR      REPL
RCHRES   4 OXRX   BOD                      WDM   1582 BODX     METR      REPL
RCHRES   4 NUTRX  DNUST  1                 WDM   1583 NO3X     METR      REPL
RCHRES   4 NUTRX  DNUST  2                 WDM   1584 NH4X     METR      REPL
RCHRES   4 NUTRX  DNUST  4                 WDM   1585 PO4X     METR      REPL
COPY    12 OUTPUT MEAN   1                 WDM   1586 NH4P     METR      REPL
COPY    12 OUTPUT MEAN   2                 WDM   1587 PO4P     METR      REPL
RCHRES   4 PLANK  PKST3  4                 WDM   1588 TORN     METR      REPL
RCHRES   4 PLANK  PHYCLA 1                 WDM   1589 PHCA     METR      REPL
RCHRES   2 OXRX   DOX                      WDM   1651 DOXX     METR      REPL
RCHRES   2 OXRX   BOD                      WDM   1652 BODX     METR      REPL
RCHRES   2 NUTRX  DNUST  1                 WDM   1653 NO3X     METR      REPL
RCHRES   2 NUTRX  DNUST  2                 WDM   1654 NH4X     METR      REPL
RCHRES   2 NUTRX  DNUST  4                 WDM   1655 PO4X     METR      REPL
RCHRES   1 NUTRX  DNUST  1                 WDM   1753 NO3X     METR      REPL
RCHRES   1 NUTRX  DNUST  2                 WDM   1754 NH4X     METR      REPL
RCHRES   1 NUTRX  DNUST  4                 WDM   1755 PO4X     METR      REPL
***Sediment calibration
RCHRES   1 HYDR   TAU                      WDM   9001 TAU      ENGL      REPL
RCHRES   2 HYDR   TAU                      WDM   9002 TAU      ENGL      REPL
RCHRES   3 HYDR   TAU                      WDM   9003 TAU      ENGL      REPL
RCHRES   4 HYDR   TAU                      WDM   9004 TAU      ENGL      REPL
RCHRES   5 HYDR   TAU                      WDM   9005 TAU      ENGL      REPL
RCHRES   6 HYDR   TAU                      WDM   9006 TAU      ENGL      REPL
RCHRES   7 HYDR   TAU                      WDM   9007 TAU      ENGL      REPL
***
PERLND 502 SEDMNT DETS ***                    WDM   9020 DETS     ENGL      REPL
PERLND 503 SEDMNT DETS ***                    WDM   9021 DETS     ENGL      REPL
PERLND 504 SEDMNT DETS                     WDM   9022 DETS     ENGL      REPL
PERLND 506 SEDMNT DETS                     WDM   9023 DETS     ENGL      REPL
PERLND 508 SEDMNT DETS                     WDM   9024 DETS     ENGL      REPL
PERLND 509 SEDMNT DETS                     WDM   9025 DETS     ENGL      REPL
PERLND 803 SEDMNT DETS                     WDM   9032 DETS     ENGL      REPL
PERLND 804 SEDMNT DETS                     WDM   9033 DETS     ENGL      REPL
PERLND 806 SEDMNT DETS                     WDM   9034 DETS     ENGL      REPL
PERLND 809 SEDMNT DETS                     WDM   9035 DETS     ENGL      REPL
PERLND 903 SEDMNT DETS                     WDM   9042 DETS     ENGL      REPL
PERLND 904 SEDMNT DETS                     WDM   9043 DETS     ENGL      REPL
PERLND 908 SEDMNT DETS                     WDM   9044 DETS     ENGL      REPL
PERLND 909 SEDMNT DETS                     WDM   9045 DETS     ENGL      REPL

END EXT TARGETS

SCHEMATIC
<-Source->                   <--Area-->    <-Target->   <ML>  ***
<Name>   #                   <-factor->    <Name>   #      #  ***
*** Note: All PLS-RCH and ILS-RCH multiplication factors are acres.
***       Conversion factors, where applicable, are in Mass-Link.
***
*** Segment 5 (Upper West, East Branch Christina)
*** Tributary to Reach 1 (Upper West Br. Christina)
PERLND 502                     109.248     RCHRES   1      1
PERLND 503                       0.000     RCHRES   1      1
PERLND 504                       4.868     RCHRES   1      1
PERLND 505                       0.000     RCHRES   1      1
PERLND 506                     696.412     RCHRES   1      1
PERLND 507                       0.000     RCHRES   1      1
PERLND 508                     355.717     RCHRES   1      1
PERLND 509                      12.677     RCHRES   1      1
PERLND 510                       0.000     RCHRES   1      1
PERLND 511                       1.861     RCHRES   1      1
IMPLND 501                      12.139     RCHRES   1      2
IMPLND 502                       4.868     RCHRES   1      2

*** Tributary to Reach 2 (Upper East Br. Christina)
PERLND 502                    1155.693     RCHRES   2      1
PERLND 503                     212.156     RCHRES   2      1
PERLND 504                      11.885     RCHRES   2      1
PERLND 505                       0.000     RCHRES   2      1
PERLND 506                    1861.976     RCHRES   2      1
PERLND 507                       0.000     RCHRES   2      1
PERLND 508                     981.170     RCHRES   2      1
PERLND 509                      27.181     RCHRES   2      1
PERLND 510                       3.114     RCHRES   2      1
PERLND 511                      46.181     RCHRES   2      1
IMPLND 501                     219.334     RCHRES   2      2
IMPLND 502                      11.885     RCHRES   2      2

*** Segment 8 (Coastal Plain, Mainstem Christina)
*** Tributary to Reach 1 (Upper West Br. Christina)
PERLND 802                     245.640     RCHRES   1      1
PERLND 803                     122.892     RCHRES   1      1
PERLND 804                     245.094     RCHRES   1      1
PERLND 805                       0.000     RCHRES   1      1
PERLND 806                     838.366     RCHRES   1      1
PERLND 807                       0.000     RCHRES   1      1
PERLND 808                     723.214     RCHRES   1      1
PERLND 809                     385.022     RCHRES   1      1
PERLND 810                       0.000     RCHRES   1      1
PERLND 811                     192.676     RCHRES   1      1
IMPLND 801                      79.962     RCHRES   1      2
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IMPLND 802                     258.123     RCHRES   1      2

*** Tributary to Reach 2 (Upper East Br. Christina)
PERLND 802                     130.977     RCHRES   2      1
PERLND 803                     438.686     RCHRES   2      1
PERLND 804                     163.001     RCHRES   2      1
PERLND 805                       0.000     RCHRES   2      1
PERLND 806                      77.130     RCHRES   2      1
PERLND 807                       0.000     RCHRES   2      1
PERLND 808                     181.729     RCHRES   2      1
PERLND 809                     233.640     RCHRES   2      1
PERLND 810                       0.000     RCHRES   2      1
PERLND 811                      95.433     RCHRES   2      1
IMPLND 801                     202.561     RCHRES   2      2
IMPLND 802                     173.604     RCHRES   2      2

*** Tributary to Reach 3 (confluence to Cooches)
PERLND 802                     137.008     RCHRES   3      1
PERLND 803                     501.478     RCHRES   3      1
PERLND 804                     365.605     RCHRES   3      1
PERLND 805                       0.000     RCHRES   3      1
PERLND 806                     263.490     RCHRES   3      1
PERLND 807                       0.000     RCHRES   3      1
PERLND 808                     524.686     RCHRES   3      1
PERLND 809                     227.950     RCHRES   3      1
PERLND 810                       6.005     RCHRES   3      1
PERLND 811                     257.298     RCHRES   3      1
IMPLND 801                     230.142     RCHRES   3      2
IMPLND 802                     389.565     RCHRES   3      2

*** Muddy Run (reach 6)
PERLND 802                     333.809     RCHRES   6      1
PERLND 803                     486.836     RCHRES   6      1
PERLND 804                     365.771     RCHRES   6      1
PERLND 805                       0.000     RCHRES   6      1
PERLND 806                     852.926     RCHRES   6      1
PERLND 807                       0.000     RCHRES   6      1
PERLND 808                    2125.246     RCHRES   6      1
PERLND 809                     588.951     RCHRES   6      1
PERLND 810                      62.495     RCHRES   6      1
PERLND 811                      96.513     RCHRES   6      1
IMPLND 801                     245.734     RCHRES   6      2
IMPLND 802                     374.186     RCHRES   6      2

*** Belltown Run (reach 7)
PERLND 802                      23.152     RCHRES   7      1
PERLND 803                     820.722     RCHRES   7      1
PERLND 804                     281.534     RCHRES   7      1
PERLND 805                       0.000     RCHRES   7      1
PERLND 806                     344.677     RCHRES   7      1
PERLND 807                       0.000     RCHRES   7      1
PERLND 808                    1398.689     RCHRES   7      1
PERLND 809                     328.540     RCHRES   7      1
PERLND 810                      34.250     RCHRES   7      1
PERLND 811                     189.419     RCHRES   7      1
IMPLND 801                     354.311     RCHRES   7      2
IMPLND 802                     302.295     RCHRES   7      2

    Reach Connections ***
RCHRES   1                                 RCHRES   3      3
RCHRES   2                                 RCHRES   3      3

***
*** Segment 9 (Little Mill Creek)
*** Tributary to Reach 4 (Little Mill Ck to gage)
PERLND 902                      50.688     RCHRES   4      1
PERLND 903                     965.315     RCHRES   4      1
PERLND 904                     448.435     RCHRES   4      1
PERLND 905                       0.000     RCHRES   4      1
PERLND 906                      48.634     RCHRES   4      1
PERLND 907                       0.000     RCHRES   4      1
PERLND 908                     627.608     RCHRES   4      1
PERLND 909                     316.954     RCHRES   4      1
PERLND 910                       8.451     RCHRES   4      1
PERLND 911                      89.883     RCHRES   4      1
IMPLND 901                     419.338     RCHRES   4      2
IMPLND 902                     468.305     RCHRES   4      2

*** Lower Little Mill - below gage to confl. (reach 5)
PERLND 902                       2.571     RCHRES   5      1
PERLND 903                     512.817     RCHRES   5      1
PERLND 904                     431.453     RCHRES   5      1
PERLND 905                       0.000     RCHRES   5      1
PERLND 906                       0.000     RCHRES   5      1
PERLND 907                       0.000     RCHRES   5      1
PERLND 908                     214.157     RCHRES   5      1
PERLND 909                     372.013     RCHRES   5      1
PERLND 910                      27.032     RCHRES   5      1
PERLND 911                     227.841     RCHRES   5      1
IMPLND 901                     220.064     RCHRES   5      2
IMPLND 902                     451.340     RCHRES   5      2
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```
    Reach Connections ***
RCHRES   4                                RCHRES   5      3

*** Copy Block outputs for tidal subbasins
***
*** Segment 8 (Coastal Plain)

*** Christina (Cooches to Smalleys Pond - reach 8)
PERLND 802                      29.162     COPY   400     91
PERLND 803                    1687.533     COPY   400     91
PERLND 804                     799.365     COPY   400     91
PERLND 805                       0.000     COPY   400     91
PERLND 806                     357.438     COPY   400     91
PERLND 807                       0.000     COPY   400     91
PERLND 808                    1843.667     COPY   400     91
PERLND 809                     476.203     COPY   400     91
PERLND 810                      36.714     COPY   400     91
PERLND 811                     698.509     COPY   400     91
IMPLND 801                     565.751     COPY   400     92
IMPLND 802                     642.866     COPY   400     92

*** Christina (Smalleys to Delaware confluence - reach 9)
PERLND 802                      69.386     COPY   500     91
PERLND 803                    1443.678     COPY   500     91
PERLND 804                    2489.162     COPY   500     91
PERLND 805                       0.000     COPY   500     91
PERLND 806                     251.481     COPY   500     91
PERLND 807                       0.000     COPY   500     91
PERLND 808                    1746.197     COPY   500     91
PERLND 809                    2801.890     COPY   500     91
PERLND 810                     600.317     COPY   500     91
PERLND 811                    1386.300     COPY   500     91
IMPLND 801                     626.429     COPY   500     92
IMPLND 802                    2588.088     COPY   500     92

*** HSPEXP ***
*** Christina at Cooches -output from Reach 3
PERLND 502                    1264.941     COPY   200     91
PERLND 503                     212.156     COPY   200     91
PERLND 504                      16.753     COPY   200     91
PERLND 505                       0.000     COPY   200     91
PERLND 506                    2558.388     COPY   200     91
PERLND 507                       0.000     COPY   200     91
PERLND 508                    1338.887     COPY   200     91
PERLND 509                      39.858     COPY   200     91
PERLND 510                       3.114     COPY   200     91
PERLND 511                      48.042     COPY   200     91
IMPLND 501                     231.473     COPY   200     92
IMPLND 502                      16.753     COPY   200     92
PERLND 802                     513.625     COPY   200     91
PERLND 803                    1063.056     COPY   200     91
PERLND 804                     773.700     COPY   200     91
PERLND 805                       0.000     COPY   200     91
PERLND 806                    1178.986     COPY   200     91
PERLND 807                           0     COPY   200     91
PERLND 808                    1429.626     COPY   200     91
PERLND 809                     846.612     COPY   200     91
PERLND 810                       6.005     COPY   200     91
PERLND 811                     545.407     COPY   200     91
IMPLND 801                     512.665     COPY   200     92
IMPLND 802                     821.292     COPY   200     92
*** Little Mill Ck to gage - output from reach 4
PERLND 902                      50.688     COPY   300     91
PERLND 903                     965.315     COPY   300     91
PERLND 904                     448.435     COPY   300     91
PERLND 905                       0.000     COPY   300     91
PERLND 906                      48.634     COPY   300     91
PERLND 907                       0.000     COPY   300     91
PERLND 908                     627.608     COPY   300     91
PERLND 909                     316.954     COPY   300     91
PERLND 910                       8.451     COPY   300     91
PERLND 911                      89.883     COPY   300     91
IMPLND 901                     419.338     COPY   300     92
IMPLND 902                     468.305     COPY   300     92
END SCHEMATIC

MASS-LINK
  MASS-LINK        1
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
PERLND     PWATER PERO       0.0833333     RCHRES         INFLOW IVOL
PERLND     SEDMNT SOSED           0.10     RCHRES         INFLOW ISED   1
PERLND     SEDMNT SOSED           0.40     RCHRES         INFLOW ISED   2
PERLND     SEDMNT SOSED           0.50     RCHRES         INFLOW ISED   3
PERLND     PWTGAS POHT                     RCHRES         INFLOW IHEAT
PERLND     PWTGAS PODOXM                   RCHRES         INFLOW OXIF   1
PERLND     PQUAL  POQUAL 1                 RCHRES         INFLOW NUIF1  1
PERLND     PQUAL  POQUAL 2                 RCHRES         INFLOW NUIF1  2
PERLND     PQUAL  POQUAL 3                 RCHRES         INFLOW NUIF1  4
PERLND     PQUAL  POQUAL 4                 RCHRES         INFLOW OXIF   2
PERLND     PQUAL  POQUAL 5                 RCHRES         INFLOW PKIF   3
  END MASS-LINK    1
```

```
  MASS-LINK        2
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
IMPLND     IWATER SURO       0.0833333     RCHRES         INFLOW IVOL
IMPLND     SOLIDS SOSLD           0.10     RCHRES         INFLOW ISED   1
IMPLND     SOLIDS SOSLD           0.40     RCHRES         INFLOW ISED   2
IMPLND     SOLIDS SOSLD           0.50     RCHRES         INFLOW ISED   3
IMPLND     IWTGAS SOHT                     RCHRES         INFLOW IHEAT
IMPLND     IWTGAS SODOXM                   RCHRES         INFLOW OXIF   1
IMPLND     IQUAL  SOQUAL 1                 RCHRES         INFLOW NUIF1  1
IMPLND     IQUAL  SOQUAL 2                 RCHRES         INFLOW NUIF1  2
IMPLND     IQUAL  SOQUAL 3                 RCHRES         INFLOW NUIF1  4
IMPLND     IQUAL  SOQUAL 4                 RCHRES         INFLOW OXIF   2
  END MASS-LINK    2

  MASS-LINK        3
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
RCHRES     ROFLOW                          RCHRES         INFLOW
  END MASS-LINK    3

  MASS-LINK       91
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->strg <Name>                <Name> x x  ***
PERLND     PWATER SURO                     COPY           INPUT  MEAN   1
PERLND     PWATER IFWO                     COPY           INPUT  MEAN   2
PERLND     PWATER AGWO                     COPY           INPUT  MEAN   3
PERLND     PWATER PET                      COPY           INPUT  MEAN   5
PERLND     PWATER TAET                     COPY           INPUT  MEAN   6
PERLND     PWATER UZS                      COPY           INPUT  MEAN   7
PERLND     PWATER LZS                      COPY           INPUT  MEAN   8
PERLND     PWATER UZI                      COPY           INPUT  MEAN   9
PERLND     SEDMNT SOSED                    COPY           INPUT  MEAN  10
PERLND     PQUAL  POQUAL 1                 COPY           INPUT  MEAN  11
PERLND     PQUAL  POQUAL 2                 COPY           INPUT  MEAN  12
PERLND     PQUAL  POQUAL 3                 COPY           INPUT  MEAN  13
PERLND     PQUAL  AOQUAL 1                 COPY           INPUT  MEAN  18
PERLND     PQUAL  AOQUAL 2                 COPY           INPUT  MEAN  19
PERLND     PQUAL  AOQUAL 3                 COPY           INPUT  MEAN  20

  END MASS-LINK   91

  MASS-LINK       92
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->strg <Name>                <Name> x x  ***
IMPLND     IWATER SURO                     COPY           INPUT  MEAN   1
IMPLND     IWATER PET                      COPY           INPUT  MEAN   5
IMPLND     IWATER IMPEV                    COPY           INPUT  MEAN   6
IMPLND     SOLIDS SOSLD                    COPY           INPUT  MEAN  14
IMPLND     IQUAL  SOQUAL 1                 COPY           INPUT  MEAN  15
IMPLND     IQUAL  SOQUAL 2                 COPY           INPUT  MEAN  16
IMPLND     IQUAL  SOQUAL 3                 COPY           INPUT  MEAN  17
  END MASS-LINK   92

  MASS-LINK       93
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->strg <Name>                <Name> x x  ***
COPY       OUTPUT MEAN   1                 COPY           INPUT  MEAN   1
COPY       OUTPUT MEAN   2                 COPY           INPUT  MEAN   2
COPY       OUTPUT MEAN   3                 COPY           INPUT  MEAN   3
COPY       OUTPUT MEAN   4                 COPY           INPUT  MEAN   4
COPY       OUTPUT MEAN   5                 COPY           INPUT  MEAN   5
COPY       OUTPUT MEAN   6                 COPY           INPUT  MEAN   6
COPY       OUTPUT MEAN   7                 COPY           INPUT  MEAN   7
COPY       OUTPUT MEAN   8                 COPY           INPUT  MEAN   8
COPY       OUTPUT MEAN   9                 COPY           INPUT  MEAN   9
COPY       OUTPUT MEAN  10                 COPY           INPUT  MEAN  10
COPY       OUTPUT MEAN  11                 COPY           INPUT  MEAN  11
COPY       OUTPUT MEAN  12                 COPY           INPUT  MEAN  12
COPY       OUTPUT MEAN  13                 COPY           INPUT  MEAN  13
COPY       OUTPUT MEAN  14                 COPY           INPUT  MEAN  14
COPY       OUTPUT MEAN  15                 COPY           INPUT  MEAN  15
COPY       OUTPUT MEAN  16                 COPY           INPUT  MEAN  16
COPY       OUTPUT MEAN  17                 COPY           INPUT  MEAN  17
  END MASS-LINK   93

END MASS-LINK

NETWORK
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   #        <Name> # #<-factor->strg <Name>   #   #        <Name> # #  ***
*** Results for calibration
     PARTICULATE N (ADSORBED NH3 + ORG N) ***
RCHRES   3 NUTRX  RSNH4  4                 GENER    1     INPUT  ONE
RCHRES   3 HYDR   VOL                      GENER    1     INPUT  TWO
GENER    1 OUTPUT TIMSER       0.368       COPY    11     INPUT  MEAN   1
RCHRES   4 NUTRX  RSNH4  4                 GENER    3     INPUT  ONE
RCHRES   4 HYDR   VOL                      GENER    3     INPUT  TWO
GENER    3 OUTPUT TIMSER       0.368       COPY    12     INPUT  MEAN   1
     PARTICULATE P (ADSORBED PO4 + ORG P) ***
RCHRES   3 NUTRX  RSPO4  4                 GENER    2     INPUT  ONE
```

```
RCHRES   3 HYDR   VOL                     GENER    2     INPUT  TWO
GENER    2 OUTPUT TIMSER       0.368      COPY    11     INPUT  MEAN   2
RCHRES   4 NUTRX  RSPO4  4                GENER    4     INPUT  ONE
RCHRES   4 HYDR   VOL                     GENER    4     INPUT  TWO
GENER    4 OUTPUT TIMSER       0.368      COPY    12     INPUT  MEAN   2
END NETWORK

GENER
  OPCODE
    #thru# code ***
    1    4   19
  END OPCODE
END GENER


END RUN
```