In cooperation with the Louisville and Jefferson County Metropolitan Sewer District

Hydrologic and Water-Quality Characterization and Modeling of the Chenoweth Run Basin, Jefferson County, Kentucky

Water-Resources Investigations Report 00–4239

U.S. Department of the Interior
U.S. Geological Survey

COVER ILLUSTRATION: Shaded-relief image of landforms in the Chenoweth Run Basin, Jefferson County, Kentucky.

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By **Gary R. Martin, Phillip J. Zarriello,** *and* **Allison A. Shipp**

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Louisville, Kentucky
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BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief, Kentucky District
U.S. Geological Survey
Water Resources Division
9818 Bluegrass Parkway
Louisville, KY 40299–1906

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
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CONVERSION FACTORS

Multiply	By	To obtain
acre	4,047	square meter
inch (in.)	25.4	millimeter
square inch (in^2)	6.452	square centimeter
inch per hour (in/h)	0.0254	meter per hour
foot (ft)	0.3048	meter
square foot (ft^2)	0.09290	square meter
mile (mi)	1.609	kilometer
foot per mile (ft/mi)	0.1894	meter per kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per day (gal/d)	0.003785	cubic meter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second
ounce, avoirdupois (oz)	28.35	gram
pound, avoirdupois (lb)	0.4536	kilogram
pound per acre (lb/acre)	1.121	kilograms per hectare
pound per acre per day (lb/acre)/d	1.121	kilogram per hectare per day
ton per day (ton/d)	0.9072	metric ton per day
ton per acre per year (ton/acre)/yr	2.243	metric ton per hectare per year

Temperature in degrees Fahrenheit (˚F) may be converted to degrees Celsius (˚C) as follows:

$$ ^\circ C = (^\circ F - 32) / 1.8 $$

VERTICAL DATUM

Sea level: In this report “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

ABBREVIATIONS

The following abbreviations are used in this report.

Abbreviation	Description
CV	Coefficient of variation
GIRAS	Geographic Information Retrieval and Analysis System
HRU	Hydrologic response unit
HSPF	Hydrological Simulation Program—Fortran
IMPLND	Impervious land segment
KDOW	Kentucky Division of Water (of the Department for Environmental Protection KNREPC)
KNREPC	Kentucky Natural Resources and Environmental Protection Cabinet
LOJIC	Louisville and Jefferson County Information Consortium
LOWESS	Locally weighted scatterplot smooth
MSD	Louisville and Jefferson County Metropolitan Sewer District
NPDES	National Pollutant Discharge Elimination System
PERLND	Pervious land segment
RCHRES	Reaches and reservoirs
UCI	User-control input
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WWTP	Wastewater-treatment plant
cm	Centimeter
CN^-	Cyanide
g	Gram
L	Liter
mg/L	Milligrams per liter
mL	Milliliter
mm	Millimeter
N	Nitrogen
NH_3	Ammonia
NH_4^+	Ammonium
NO_3	Nitrate
TN	Total nitrogen
P	Phosphorus
pH	Negative log (base-10) of the hydrogen ion activity, in moles per liter
PO_4	Orthophosphate
TP	Total phosphorus
TPO_4	Total orthophosphate
µS/cm	Microsiemens per centimeter at 25 degrees Celsius
$<$	Less than
$\leq$	Less than or equal

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Abstract

Rainfall, streamflow, and water-quality data collected in the Chenoweth Run Basin during February 1996–January 1998, in combination with the available historical sampling data, were used to characterize hydrologic conditions and to develop and calibrate a Hydrological Simulation Program—Fortran (HSPF) model for continuous simulation of rainfall, streamflow, suspended-sediment, and total-orthophosphate (TPO_4) transport relations. Study results provide an improved understanding of basin hydrology and a hydrologic-modeling framework with analytical tools for use in comprehensive water-resource planning and management.

Chenoweth Run Basin, encompassing 16.5 mi^2 in suburban eastern Jefferson County, Kentucky, contains expanding urban development, particularly in the upper third of the basin. Historical water-quality problems have interfered with designated aquatic-life and recreation uses in the stream main channel (approximately 9 mi in length) and have been attributed to organic enrichment, nutrients, metals, and pathogens in urban runoff and wastewater inflows.

Hydrologic conditions in Jefferson County are highly varied. In the Chenoweth Run Basin, as in much of the eastern third of the county, relief is moderately sloping to steep. Also, internal drainage in pervious areas is impeded by the shallow, fine-textured subsoils that contain abundant silts and clays. Thus, much of the precipitation here tends to move rapidly as overland flow and (or) shallow subsurface flow (interflow) to the stream channels.

Data were collected at two streamflow-gaging stations, one rain gage, and four water-quality-sampling sites in the basin. Precipitation, streamflow, and, consequently, constituent loads were above normal during the data-collection period of this study. Nonpoint sources contributed the largest portion of the sediment loads. However, the three wastewater-treatment plants (WWTP's) were the source of the majority of estimated total phosphorus (TP) and TPO_4 transport downstream from the WWTP's.

HSPF, a hydrologic model capable of simulating mixed-land-use basins, includes land surface, subsurface, and instream water-quantity- and water-quality-modeling components. The HSPF model was used to represent several important hydrologic features of the Chenoweth Run Basin including (1) numerous small lakes and ponds, through which approximately 25 percent of the basin drains; (2) potential seasonal ground-water-seepage losses in stream channels; (3) contributions from WWTP effluents and bypass flows; and (4) the transport and transformations of sediments and nutrients.

The HSPF model was calibrated and verified for flow simulation on the basis of measured total, annual, seasonal, monthly, daily, hourly, and 5-minute-interval storm discharge data. The occurrence of numerous storms during the study period permitted a split-sample procedure to be used for a model verification on the basis of storm volumes and

peaks. Total simulated and observed discharge during the model calibration period differed by approximately -5.4 percent at the upper gaging station and 3.1 percent at the lower station. The model results for the total and annual water balances were classified as very good on the basis of the calibration criteria reported in other modeling studies. The model had correlation coefficients ranging from 0.89 to 0.98 for hourly to monthly mean flows, respectively. The coefficients of model-fit efficiency for daily and monthly discharge simulations were near the excellent range (exceeding 0.97). However, the model was calibrated for a comparatively short 24-month period during which flows were above normal. Increased model error might be expected during an extended period of near-normal flows.

The model was calibrated for simulation of sediment and TPO_4 transport. The simulated mean-annual load (over 24 months) ranged from -33 to -28 percent of the estimated sediment load and within +/- 1 percent of the estimated TPO_4 load at the two streamflow-gaging stations. Sediment load was undersimulated, particularly during the year of major flooding (1997). Stream discharge and the sediment and TPO_4 loads tended to be oversimulated during the smallest storms sampled during summer and early fall low-flow periods. Annual and annual mean errors indicated a fair sediment simulation (25 to 35 percent error) and a good TPO_4 simulation (20 to 30 percent error). Percentage errors in simulation of individual storm sediment and TPO_4 loads were generally much larger than percentage errors in annual and total loads.

INTRODUCTION

Chenoweth Run Basin (16.5 mi^2) is a rapidly urbanizing tributary to Floyds Fork in suburban eastern Jefferson County in north-central Kentucky (fig. 1). Alterations in water use, land use, and land cover associated with urbanization can drastically alter and adversely affect the hydrologic character of a drainage basin. As land is developed, there is, in general, a decrease in the amount of pervious land area available for infiltration of precipitation. Increases in the magnitude and frequency of peak discharges during periods of flooding as a consequence of urbanization have been well documented (Leopold, 1968; Sauer and others, 1983). An increase in the types and amounts of contaminants entering waterways also generally occurs with urbanization, which often has resulted in degradation of water quality.

Water quality downstream from many urbanized locations in Jefferson County has historically been adversely affected by a variety of point and nonpoint sources of contaminants, including wastewater-treatment plants; land dedicated to a variety of industrial, commercial, residential, and agricultural uses; and leachates from septic tanks and landfills. Most of the contaminants are anthropogenic in origin and include organic debris, sediments, nutrients, petroleum products, and potentially toxic chemicals, such as heavy metals and pesticides. Water-quality conditions are such that the Jefferson County Board of Health has recommended avoiding contact recreation in all streams in Jefferson County for protection of public health (Louisville and Jefferson County Metropolitan Sewer District, 2000).

Water-quality problems in the Chenoweth Run Basin have been reported by several agencies, including the Kentucky Natural Resources and Environmental Protection Cabinet (KNREPC)—Division of Water (KDOW), the Louisville and Jefferson County Metropolitan Sewer District (MSD), and the U.S. Geological Survey (USGS) (Logan and others, 1986; Leist and others, 1991; Louisville and Jefferson County Metropolitan Sewer District 1990, 1991, 1994, and 1996; Evaldi and others, 1993; Evaldi and Moore, 1994a and 1994b). The KDOW has previously listed 9 mi of Chenoweth Run as not meeting criteria for either aquatic-life or swimming uses because of organic enrichment, nutrients, metals, and pathogens discharged in urban runoff and wastewaters (Kentucky Natural Resources and Environmental Protection Cabinet, 1994).

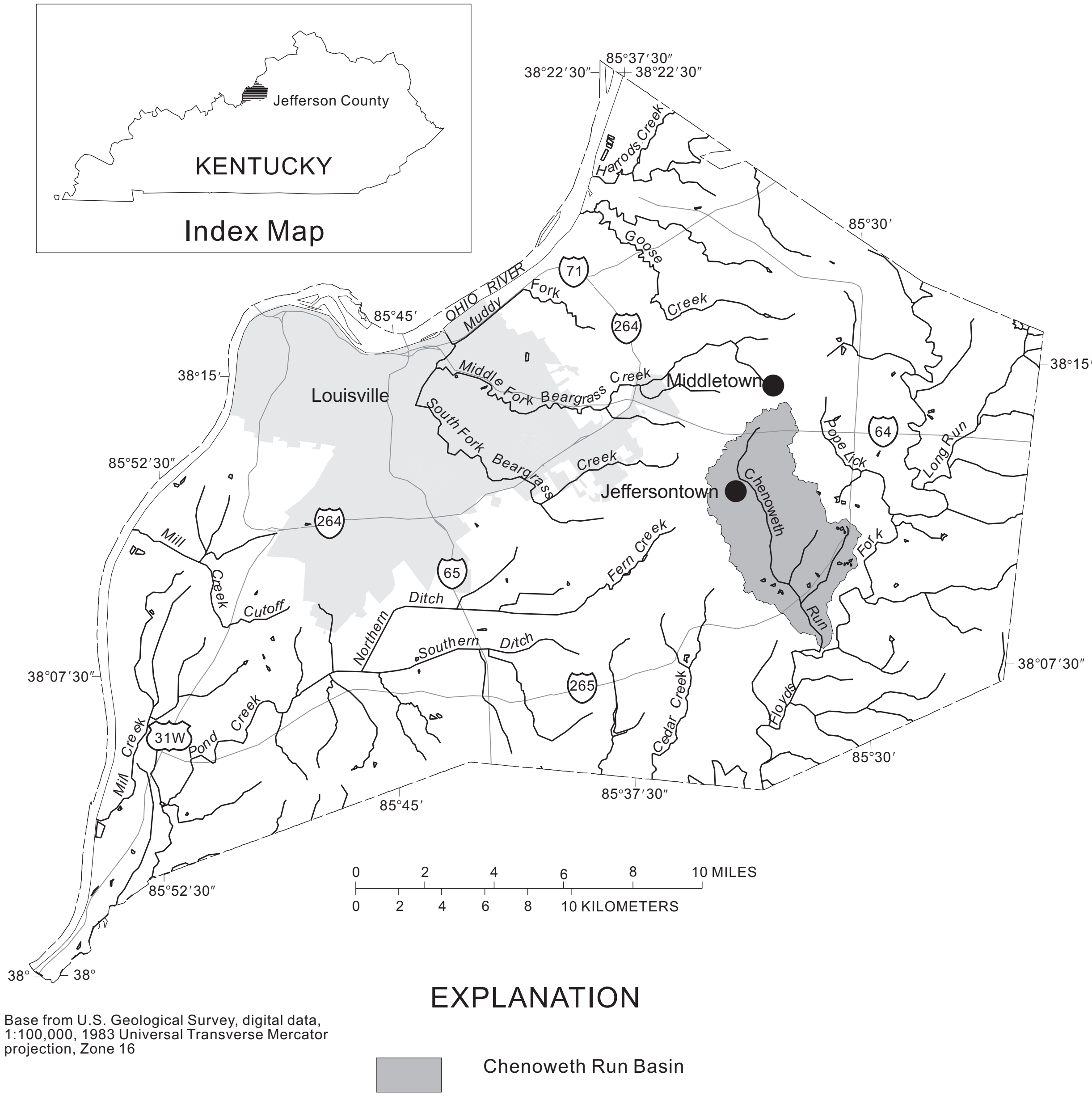


Figure 1. Location of the Chenoweth Run Basin, Jefferson County, Kentucky.

MSD is the lead water-resource-management agency in Jefferson County. MSD's responsibilities include wastewater collection, treatment, and disposal; storm-water management and flood control; and coordination of industrial-waste-pretreatment programs. MSD operates—under National Pollutant Discharge Elimination System (NPDES) permits issued by KDOW—wastewater- and storm-water-management facilities in Jefferson County. MSD operates the three wastewater-treatment plants (WWTP's) in the Chenoweth Run Basin. MSD assumed operation of the largest of these from the original owner/operator, the city of Jeffersontown, Ky., in September 1990.

MSD has prepared master plans and developed strategies for effective wastewater and storm-water management. Components of these plans include (1) construction of sanitary sewers in unsewered areas to replace failing septic systems and (2) procurement and elimination of numerous, small, inefficient WWTP's serving individual developments. Instead, MSD routes wastewaters to regional treatment facilities, which can be operated effectively and efficiently.

Since 1988, MSD has conducted, in cooperation with the USGS, a program for the study of urban hydrology in Jefferson County. This program has incorporated systematic data-collection activities, including water-quality sampling and concurrent discharge measurements at approximately 25 stream sites countywide (one in the Chenoweth Run Basin at Gelhaus Lane, downstream from the three WWTP's in the basin) and operation of several streamflow- and rainfall-gaging stations. Goals of the program have included characterization of hydrologic and water-quality conditions by collection and interpretation of base-line and long-term data that provide a technically sound, scientific basis for assessing changes in stream environmental quality over time and in response to selected water-resource-management strategies. The interpretive studies have assessed flood-frequency characteristics and water-quality-constituent concentrations, trends (if any), and loads. The studies have permitted identification of land areas and stream reaches that have, or contribute to, significant water-quality problems. Focused studies of selected problematic drainage basins using a "watershed framework" were undertaken following the countywide, water-quality assessments. Development of continuous hydrologic models for simulations of complex urban basins, such as Beargrass Creek Basin (Jarrett and others, 1998) and Chenoweth Run Basin, was initiated in this latest phase of the urban hydrology program. The Hydrological Simulation Program—Fortran (HSPF) model has been applied previously in agricultural basins (Moore and others, 1988; Chew and others, 1991) and in urban basins (Dinicola, 1990; Duncker and others, 1995).

This detailed study of hydrologic and water-quality conditions in the Chenoweth Run Basin began in 1996. The basic study goal was to improve understanding of the hydrology of the Chenoweth Run Basin by collection and interpretation of representative streamflow and water-quality data and by development of a comprehensive hydrologic simulation model that would provide resource managers a reliable tool for prediction of the probable hydrologic effects of land-use changes and alternative water-resource-management options. An HSPF model for continuous simulation of flow, sediment, and orthophosphate transport was developed and calibrated to base (existing) conditions during February 1996–January 1998. The model defines the conceptual hydrologic relations between land- and water-use activities and the corresponding stream-water-quality and water-quantity characteristics, and provides a basis for assessing the probable results of various possible scenarios for modifications in the basin.

This report describes the study approach, methods of data collection and analysis, and the hydrologic characteristics of the Chenoweth Run Basin. The report also describes the modeling approach and the features, capabilities, results of simulations, and limitations of the Chenoweth Run Basin HSPF model.

The authors thank Patti Grace-Jarrett, who facilitated transfer of stream-water- and wastewater-sampling results from the MSD laboratory; Kevin Ruhl, Brian Moore, and Paul Bruenderman, who coordinated USGS field data-collection work in Chenoweth Run; David Leist, who provided KDOW data collected in the Chenoweth Run Basin; Tom Jobes, of AquaTerra, Inc., who provided guidance on selected portions of the HSPF model coding; Jane Poole, who provided geographic data from the Louisville and Jefferson County Information Consortium (LOJIC);

Michael Callahan, who provided selected data sets from the National Weather Service; Bonnie Stich Fink, for preparation of report tables, editing, and final layout; and Hugh Nelson, who prepared the report maps.

PREVIOUS STUDIES

Water-quality problems in the Chenoweth Run Basin have been described in several reports released by local, state, and federal agencies. Potential sources of the problems cited in the reports have included wastewater-treatment plants, agriculture (including livestock), construction activities, loss of stream-bank vegetation and stream-bank erosion, lawn-care and golf-course-maintenance practices, and storm runoff from urban and industrial areas.

A KDOW study to determine appropriate stream-use designations in the Floyds Fork Basin (Logan and others, 1986) recommended classification of the main channel and tributaries under standards for warmwater aquatic habitat and primary and secondary contact recreation uses. The study report described adverse effects of constituent inflows from urban areas on aquatic biota in Chenoweth Run and on downstream from the confluence with Floyds Fork. Dense growths of algae and a sparse tree cover, which would provide shading to inhibit algal growth, were reported for Chenoweth Run. High values for dissolved-oxygen concentration (more than 20 mg/L) and pH (9.2), indicative of algal activity, were reportedly present during a low-flow period in 1986.

A series of three MSD reports described water-quality conditions and the physical, chemical, and biological data collected in 1989, 1990, 1991, and 1992 at a network of approximately 25 stream-sampling stations in Jefferson County, Ky., including one in Chenoweth Run Basin (Louisville and Jefferson County Metropolitan Sewer District, 1990, 1991, and 1994). These reports indicated that all streams then being sampled in Jefferson County were "severely stressed" and had experienced a general deterioration in water quality associated with land disturbance and urbanization. Suspended-solids, nitrogen, and phosphate levels were reported to be elevated and indicative of pollution problems. MSD (1990) reported that Chenoweth Run had the highest annual average of total phosphorus concentration of the 26 sites sampled in Jefferson County, Ky., in 1989. Probable sources of these countywide problems cited in the reports included a variety of point and nonpoint sources of contaminants, including numerous poorly performing WWTP's, failing septic-tank systems, and soil erosion and stormwater runoff from urban and agricultural areas. (Most of the WWTP's were small package plants serving individual residential developments, and most of these plants have since been acquired, deactivated, and flows diverted to regional wastewater-treatment facilities by MSD.)

Leist and others (1991) reported adverse effects on Chenoweth Run resulting from wastewater effluents and storm-water runoff. During certain periods of the year, wastewater discharges were reported to dominate streamflow in Chenoweth Run, resulting in nutrient enrichment. Soil erosion from construction sites leading to excess siltation in streams was reported, and excess fertilization and chemical application to lawns, golf courses, and other areas were reported as possible causes of nutrient enrichment and other problems. Dissolved-oxygen supersaturation, algal growth, and elevated pH observed in Chenoweth Run were reported to be indicators of nutrient enrichment. In 1991, KDOW proposed a moratorium on additional wastewater-treatment facilities in the Chenoweth Run Basin because of the existing water-quality problems. It was reported that in 1991, the Jefferson County government initiated new administrative procedures for review of development plans in the Floyds Fork Basin to provide additional protection of stream beds and banks from encroachment by the clearing of natural vegetation and earthwork.

Leist and others (1991) reported low-flow measurements in the lower reaches of Floyds Fork near the confluence with Chenoweth Run that indicated a gain in streamflow, probably caused by ground-water inflow. Data collection in the present study indicated probable losing stream reaches in Chenoweth Run, which may be supplying these observed inflows to Floyds Fork. Thus, contrary to the assumption that the ground-water inflows would help dilute nutrient-rich waters coming from wastewater facilities on the tributaries, such ground-water inflows may actually be supplied by wastewater effluents on Floyds Fork tributaries such as Chenoweth Run (see “Base-Flow Losses”).

(Note: Chenoweth Run is also referred to as Lower Chenoweth Run in some previous studies because another stream named Chenoweth Run enters Floyds Fork upstream at approximately stream mile 47, which is approximately 23 mi upstream from the confluence of (lower) Chenoweth Run and Floyds Fork.)

Statistical summaries of water-quality characteristics and estimates of constituent loads and yields at the network of water-quality-sampling sites in Jefferson County, Ky., were reported by Evaldi and Moore (1992), Evaldi and others (1993), and Evaldi and Moore (1994a and 1994b). Median concentrations of nutrients including total phosphorus, total orthophosphate, and nitrate nitrogen in Chenoweth Run were among the highest values reported for the network. Yields of total phosphorus, total orthophosphate, suspended solids, and biochemical oxygen demand in Chenoweth Run were also among the highest values reported for the network.

The *1994 Kentucky Report to Congress on Water Quality* (Kentucky Natural Resources and Environmental Protection Cabinet, 1994) listed 9 mi of Chenoweth Run as not meeting water-quality criteria for either aquatic life or swimming uses because of organic enrichment, nutrients, metals, and pathogens in urban runoff and wastewater effluents.

MSD (1996) described conditions in Chenoweth Run at Gelhaus Lane on the basis of data collected during 1991–94. Chenoweth Run was described as severely stressed: the KDOW stream-use designations for warmwater-aquatic habitat and the primary and secondary contact recreation designations were not being met. Forty-five percent of bacteriological sample counts exceeded contact standards. Quarterly water sampling for analysis of metals had indicated chronic-criteria violations for copper, mercury, nickel, selenium, and zinc and acute-criteria violations for chromium, copper, nickel, and zinc. Quarterly sampling for analysis of cyanide, pesticides, and herbicides indicated criteria violations for cyanide and lindane and the presence of 2,4-D. The data were reported as “clearly illustrating a significant level of influx of nutrients, erosional materials and very likely organic contamination from animal waste and (or) human sewage.” The report indicated “extremely abundant growths of filamentous algae develop during warmer periods.” Excessive growth of algae was reported to lead to increases in stream pH such that ammonia toxicity increased. The report indicated that stream “habitat quality is generally degraded throughout the county by rapid fluctuations in flow, removal of riparian communities (the botanical community adjacent to stream), and channelization.” Biological-sampling data indicated that approximately 90 percent of organisms sampled were species known to be tolerant of poor water quality, thus indicating a severe level of stress on aquatic life and elevated contaminant levels in Chenoweth Run.

Leist (1996), in reference to previous water-quality investigations in the Chenoweth Run Basin and other basins, reported “The most significant problems in Chenoweth Run and Floyds Fork downstream of Chenoweth Run were dense nuisance growths of algae, causing both aesthetic problems and water-quality criteria violations for dissolved oxygen, pH, and ammonia toxicity. Fueling this algal growth was an excess of nutrients, with phosphorus considered the nutrient of most concern.” The primary source of phosphorus during low and moderate flow was reported to be the 4-Mgal/d capacity Jeffersontown WWTP. The report indicated the primary source for phosphorus during high flows was nonpoint sources including fertilized lawns. On the basis of available information concerning eutrophication in the basin, KDOW had imposed a phosphorus-removal requirement on a proposed wastewater-treatment facility in the basin, had begun requiring phosphorus monitoring at the Jeffersontown WWTP, and had initiated an investigation of the major sources of nutrients in the Chenoweth Run Basin (Leist, 1996).

The report also described continuing land development in the basin, including construction of a large church complex with a 50-acre parking lot in the basin headwaters. Much of the urban development in the basin, including Jeffersontown, Ky. and the Bluegrass Industrial Park, was located in the upper portion of the basin, upstream from the Jeffersontown WWTP. The lower portion of the basin, downstream from the Jeffersontown WWTP, remained mostly rural in character with some residential subdivision development in place and planned for the future.

Despite the continuing development, the report noted that fish were observed throughout the stream, including large sport fish (bass and bluegill) in pools downstream from the WWTP. Ducks were noted to be routinely present in Chenoweth Run.

Leist (1996) initiated data collection at five additional sites in the basin for a broad range of water-quality characteristics during a wide range of flows from January 1995 through January 1996. The report described the effects of the eutrophication process in detail: algae and other rooted aquatic plants can proliferate where nutrient concentrations and light intensities are sufficient. As the algae later die, decomposition can release foul odors and deplete dissolved oxygen, causing fish kills. Algal respiration at night, or during extended periods of cloud cover, can also deplete dissolved oxygen. It was reported that streams with low slopes and little riparian tree cover have the greatest potential for algal blooms. The thick algal blooms and dissolved-oxygen violations reported for previous summers did not occur during this 1-year data-collection period, possibly because of scouring high flows in combination with high temperatures. Indications of algal activities were noted by reported sharp increases in dissolved-oxygen concentration occurring after sunrise and dissolved-oxygen supersaturation. Also reported were the typical algae-induced changes in pH. During daylight, as carbon dioxide (CO_2) is taken up during photosynthesis, pH increases; at night, as CO_2 is released in algal respiration, pH decreases. High pH in combination with elevated temperatures causes ammonia toxicity for aquatic life. The report indicated that even a stream with relatively low nitrogen content might still experience algae blooms if excess phosphorus is available and nitrogen-fixing forms of algae, which obtain nitrogen directly from the atmosphere, are present. During the January 1995–January 1996 data-collection period, iron and lead concentrations were in excess of chronic criteria, and iron concentration was in excess of acute criteria.

Leist (1996) described research (Water Environment & Technology, 1995) indicating how shading affects algal communities: when shading is removed, the type of algal species changes from those that are eaten by insect larvae and snails to algal species with no natural predators. The report noted that because of uncertainties related to complexities of the eutrophication process, no specific state or federal numerical standards had yet been developed for phosphorus (P) in streams. The U.S. Environmental Protection Agency (USEPA) was working to develop criteria for nutrients because of the need to control nutrient enrichment. USEPA had previously suggested a limit of 0.1 mg P/L in streams for control of eutrophication (United States Environmental Protection Agency, 1986).

Leist (1996) recommended (1) a limit of 1 mg P/L for the Jeffersontown WWTP effluent, which may be lowered in the future if eutrophication continues to cause water-quality-criteria violations, as the exact amount of phosphorus reduction needed at the plant to eliminate eutrophication problems could not be discerned from the existing data; (2) restoration of riparian vegetation for shading from solar radiation to limit the growth of algae species that have no natural predators; and (3) control of nonpoint sources of nutrients and other constituents in the basin.

An investigation of biological, chemical, and physical aspects of the eutrophication process in Chenoweth Run was conducted in conjunction with the study by Leist (1996). The purposes of this allied biological investigation were to define relations, if any, between nutrient concentrations (nitrate nitrogen, total orthophosphate, and total phosphorus) and algal biomass and also to assess the potential effectiveness of reductions of phosphorus concentrations for control of eutrophication in Chenoweth Run (Kentucky Natural Resources and Environmental Protection Cabinet, 1999). Samples of aquatic plants for measurement of biomass (chlorophyll *a*, dry weight, and ash-free dry weight) were collected periodically at five sites, all in unshaded reaches having limestone-bedrock channel bottoms. A control site was on the main channel, 0.8 mi upstream from the Jeffersontown WWTP, and three sampling sites were downstream from the plant on the main channel. One reference site unaffected by point sources was located on a relatively undisturbed tributary downstream from the Jeffersontown WWTP.

In April 1995, ideal environmental conditions (including abundant nutrient levels) led to heavy nuisance growth of filamentous green alga, *Cladophora glomerata,* in the Chenoweth Run main channel. Nuisance growth of algae was defined as a chlorophyll *a* level exceeding approximately 13.9 mg/ft^2 (150 mg/m^2). Storms in May 1995, however, scoured away the benthic-algae growth that had been established earlier in the spring. No algal biomass samples collected after the May storms exceeded the cited nuisance threshold level.

Analysis of the sampling data identified no statistically significant mathematical correlations of the biomass measurements with any of the nutrient concentrations sampled; however, all three biomass parameters were found to be positively correlated with dissolved-oxygen concentration and negatively correlated with water temperature. The primary abiotic factors that appeared to have affected biomass were streamflow and temperature. Increased water temperatures exceeding 20˚C that occurred after the scouring of the substrate in May 1995 may have inhibited algae regrowth later that year.

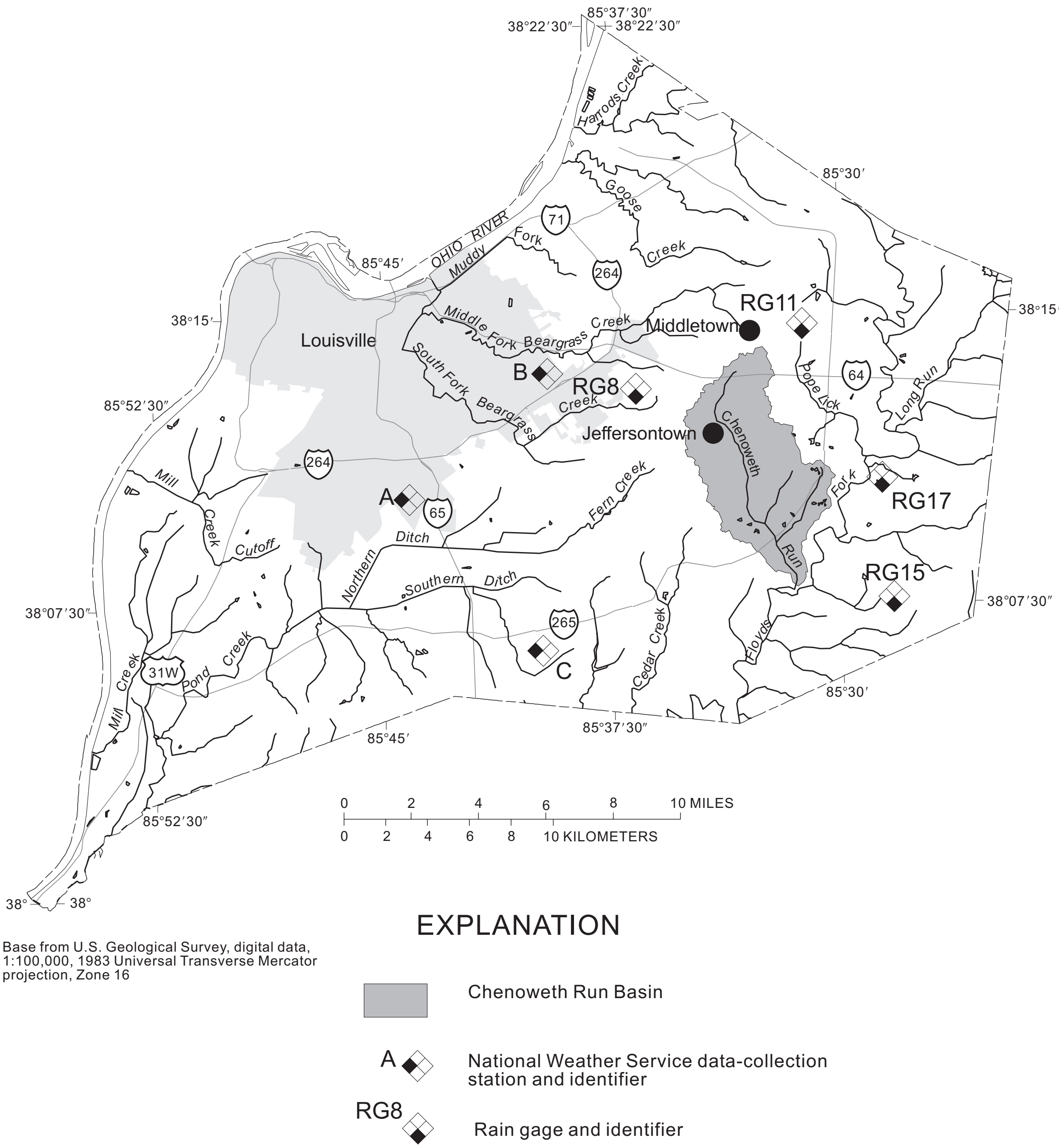
Although nutrient concentrations at the control site upstream from the Jeffersontown WWTP were much lower than nutrient concentrations observed downstream from the plant, the chlorophyll-*a* level at the control site remained above the reported nuisance level prior to the May 1995 storms. The reference site on the tributary had the lowest nutrient levels and the lowest biomass of any of the sampling sites—below any level of concern. Algal uptake of phosphorus was apparent on the main channel because total phosphorus concentrations declined progressively at the series of sampling sites downstream from the Jeffersontown WWTP. Total phosphorus concentrations downstream from the plant increased sharply following the May storms that scoured away the benthic algae, which was also indicative of algal consumption of phosphorus preceding the May storms. Consequently, additional nutrients were available for export from Chenoweth Run to Floyds Fork following the May storms.

The report from the biological investigation indicated that the observed nutrient concentrations, both before and after the May 1995 storms, were not limiting algal growth in Chenoweth Run, and excess nutrients were being exported downstream to Floyds Fork. The results of other studies were reported to indicate that nutrient concentrations were in excess (for aquatic-plant growth requirements) in Chenoweth Run. The report indicated that insufficient information was available (from the study) to determine whether control of phosphorus releases from the Jeffersontown WWTP would decrease the potential for nuisance growth of aquatic plants downstream from the plant. Controls of nonpoint sources of phosphorus were cited as a potential additional requirement to effectively limit excess algal growth during ideal environmental conditions for such growth. The report indicated that further studies were needed to determine accurately what instream nutrient limits would help maintain benthic-algal biomass at sub-nuisance levels in Chenoweth Run.

DESCRIPTION OF STUDY AREA

The Chenoweth Run Basin is in suburban eastern Jefferson County in north-central Kentucky (fig. 2). The basin is east of the city of Louisville, which lies along the banks of the Ohio River in northwestern Jefferson County. Louisville is the largest city and most densely populated area of the State. Parts of the city of Jeffersontown are located in the upper reaches of the Chenoweth Run Basin. The population of Jeffersontown was approximately 23,000 in 1990 and an estimated 28,000 in 2000 (Frank Greenwell, Jeffersontown City Hall, oral commun., 2000).

Chenoweth Run Basin has a drainage area of 16.5 mi^2. Chenoweth Run is a tributary to the Ohio River at a point downstream from Jefferson County, by way of Floyds Fork and the Salt River. Chenoweth Run flows about 9 mi to the confluence at stream-mile 24.2 of Floyds Fork.



Base from U.S. Geological Survey, digital data, 1:100,000, 1983 Universal Transverse Mercator projection, Zone 16

Figure 2. Location of the Chenoweth Run Basin and nearby data-collection stations, Jefferson County, Kentucky.

Climate

Jefferson County has a moist-continental climate with distinct seasonal variations and changeable weather patterns with generally short periods of extreme conditions. Winter temperatures are moderate, rarely below 0˚F. Typical summer temperatures are warm and rarely above 100˚F (fig. 3). The weather patterns are variably affected by the meeting of cold, arctic and continental air masses arriving from the northwest and warm, moist air masses moving up the Mississippi and Ohio Valleys from the southwest. Large amounts of precipitation have been associated with tropical cyclones or frontal systems originating from the primary source of regional precipitation, the subtropical Atlantic Ocean and Gulf of Mexico. Winter precipitation is associated with frontal activity; however, in summer, convective thunderstorms produce most of the precipitation. The thunderstorms can produce intense, short-duration rainfall over small areas; precipitation intensity is generally higher in the summer than in other seasons. The dry season occurs during the fall. The Bermuda High, which normally resides off the southeastern United States during summer, moves inland in the fall. In October, the normal position of the Bermuda High is over Kentucky and Tennessee. The High suppresses convective activity and inhibits the movement of fronts (Conner, 1982).

Mean daily minimum and maximum temperatures were approximately 35˚ and 43˚F, respectively, in winter, and 65˚ and 85˚F, respectively, in summer during 1961–90. The mean annual precipitation at Standiford Field at Louisville during 1961–90 was 44.39 in., ranging from 32.65 to 59.80 in. annually during this period (National Climatic Data Center, 2000). Annual precipitation extremes for the period of record include the maximum of 63.76 in. in 1996 and a minimum of 23.88 in. in 1930 (National Weather Service, 2000). Although precipitation in normal years is evenly distributed (fig. 3), the storm type and amount vary somewhat seasonally; mean seasonal precipitation is about 13.5 in. in spring (March through May), 11.5 in. in summer (June through August), 9.6 in. in fall (September through November), and 9.8 in. in winter (December through February). The wettest months are generally March, May, and July, respectively; October is generally the driest month. Mean annual snowfall during 1961–90 was 17.5 in. Snows generally remained on the ground for only a few days before melting. Annual precipitation for the period of USGS hydrological data collection in the Chenoweth Run Basin used in the study (1988–97) is shown in figure 4.

Geology

Geological characteristics of a basin affect local hydrology. The extent and type of surficial deposits determines the amount and rate of movement of water and constituents in subsurface storage. Movement of the infiltrated water and constituents into ground-water flow is controlled by bedrock characteristics.

The geological characteristics in Jefferson County and the region in general are highly varied; consequently, local hydrological characteristics vary considerably. The geology of Jefferson County is generally characterized by layered, sedimentary deposits including limestones, dolomites, and shales of the Devonian, Silurian, and Ordovician periods with overlying alluvial and lacustrine deposits of the Quaternary period in selected areas (fig. 5). Jefferson County lies on the west flank of the Cincinnati arch, a regional uplift feature extending south from Cincinnati, Ohio, into central Kentucky that was formed following Ordovician-aged deposits; this gives the bedrock formations a slight dip to the west in the county. Thus, the age of rocks, which tend to crop out in bands running north-northeast to south-southwest, tends to progressively increase from west to east in the county (Evaldi and others, 1993; McDowell and others, 1981; and McDowell, 1986).

Bedrock in the Chenoweth Run Basin consists primarily of Silurian- and Late-Ordovician-age interbedded shales and carbonates (limestones and dolomites). Residuum of Devonian-age Sellersburg and Jeffersonville Limestones also may be present locally, overlying the Silurian-age Louisville Limestone, but is unmapped. (If this formation is present, then the thin layers in the upper and lower parts of the Sellersburg Limestone

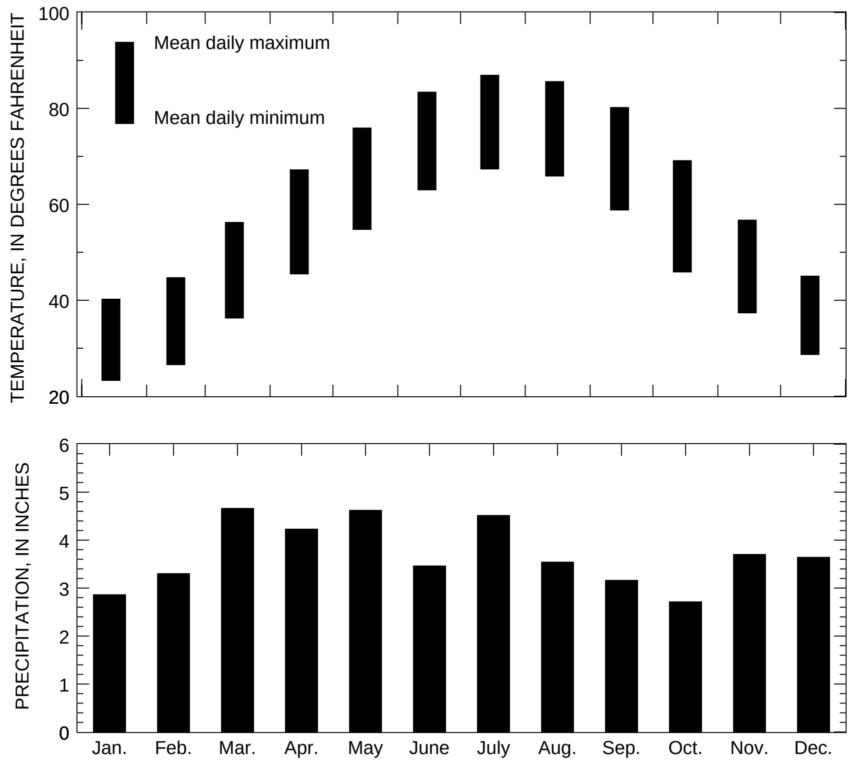


Figure 3. Monthly normal temperature and precipitation (1961–90) at Standiford Field, Louisville, Kentucky.

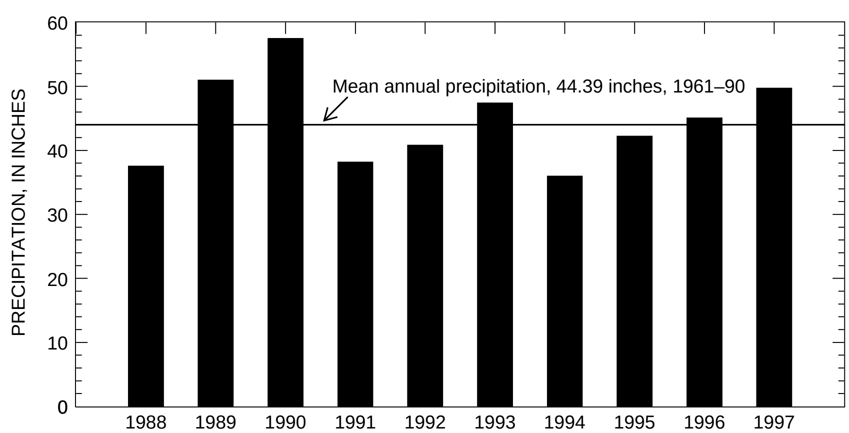


Figure 4. Annual precipitation at Standiford Field, Louisville, Kentucky, 1988–97.

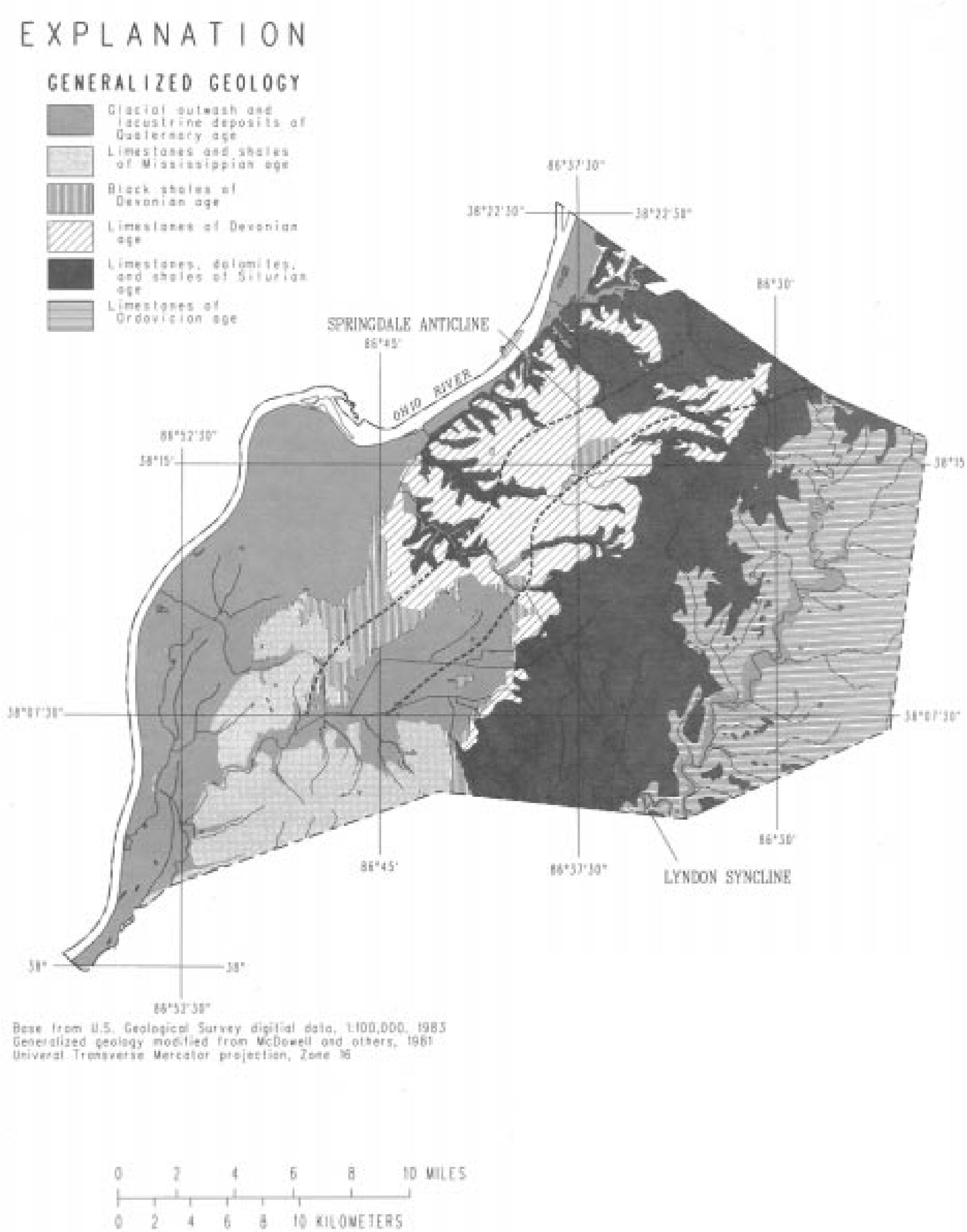


Figure 5. Generalized geology of Jefferson County, Kentucky.

containing phosphatic nodules would also likely be present in the basin.) Quaternary-aged alluvial deposits formed terraces along the Floyds Fork valley, and these alluvial deposits extend upstream to the middle reaches of Chenoweth Run, almost to Taylorsville Road (Moore and others, 1972).

There is a transition in hydrological characteristics in Jefferson County, which corresponds to the variation in the characteristics of the bedrock formations near the northern and western boundaries of the Chenoweth Run Basin. The Silurian- and Late-Ordovician-age interbedded limestones, dolomites, and shales in the Chenoweth Run Basin and on farther eastward into Shelby County, Ky., are more resistant than the Devonian-age limestones prominent in the surficial geology to the west and north in the Beargrass Creek Basin in Jefferson County (fig. 2). For example, soils tend to be less than 5 ft thick on Silurian-aged limestones, while soils up to 25 ft thick may develop on Devonian-age limestones (Moore and others, 1972).

Small, shallow springs are common on top of the Waldron Shale and Osgood Formations, which underlay the Louisville Limestone and Laurel Dolomite, respectively, in upland areas of the Chenoweth Run Basin. Some sinkholes supply underground drainage within the Louisville Limestone. The Waldron Shale and Osgood Formations, however, tend to impede the movement of infiltrated water farther down into ground-water flow in these upland areas (Moore and others, 1972). Outcrop areas of the Waldron Shale and Osgood Formations appear to approximately delineate the eastern limits (near the center of Jeffersontown and Middletown, Ky., fig. 2) of the shallow aquifer in the Louisville Limestone that was rated adequate for a domestic-well-water supply, which provided at least 100 gal/d. The bedrock formations eastward of this point in the basin and farther eastward into Shelby County, Ky., (unless situated in a stream valley) were generally inadequate for a domestic-well-water supply (Palmquist and Hall, 1960; Hall and Palmquist, 1960). Numerous farm ponds and small lakes (several of which have been commercialized for fishing) have been constructed on top of outcrops of resistant, impermeable formations in Chenoweth Run (Waldron Shale, Osgood Formation, and the Saludia Dolomite and Bardstown members of Drakes Formation) (Moore and others, 1972).

Losses to ground water are, however, not uncommon where thin, fractured sections of clastic rocks (shales) are intersected in stream channels. Also, bedrock-fracture zones may tend to be concentrated in and (or) near stream channels in this geologic setting.

A tendency for regional-regression relations to underestimate observed peak-discharge frequencies in the eastern end of Jefferson County and adjacent counties farther eastward was noted previously (Martin and others, 1997, p. 25). At stream sites in Chenoweth Run, Fern Creek, Cedar Creek, and also at rural stream sites farther eastward in Oldham, Shelby, and Spencer Counties, observed peak-discharge frequencies were larger than were predicted by the best-fit regional urban-peak-discharge regression equations for Jefferson County. This was indicative of the limited potential infiltration and storage of precipitation that consequently leads to generally excessive runoff of precipitation. An analysis and mapping of average annual hydrologic response (ratio of annual direct runoff to annual precipitation) in the Eastern United States (Woodruff and Hewlett, 1970) indicated a relation to regional geologic formations, and the largest values determined (exceeding 24 percent) were in basins located in north-central Kentucky (Outer Bluegrass area).

Physiography

The Chenoweth Run Basin lies in the Outer Bluegrass physiographic region of Kentucky, as does most of Jefferson County. Physiographic regions in Kentucky coincide closely with the geology. The Outer Bluegrass lies mostly on limestones, dolomites, and considerable amounts of interbedded shales of Late Ordovician and Silurian Age. The relief in the Outer Bluegrass is gently rolling, except near major streams, where the terrain is dissected and rugged. Soils are deepest over limestones and thinnest over shales. Some subsurface solution has occurred in the Outer Bluegrass, and small sinkholes are fairly common; however, most of the drainage is on the surface (McDowell, 1986; Palmquist and Hall, 1961).

Elevation in the Chenoweth Run Basin ranges from approximately 492 to 775 ft above mean sea level. Land slopes are steeper in the lower portion of the basin (in the areas approaching the confluence with Floyds Fork) than in the upper portion of the basin (see map on cover).

Soils

The Soil Survey of Jefferson County, Ky., (Zimmerman and others, 1966) describes soil development in the residuum and local alluvium derived from the sedimentary formations in the study area. In the level to moderately sloping upland areas and ridge tops, the soils developed in combination with a loess (windblown silt) mantle of variable thickness of up to 3 ft. Some soils that developed in the nearly level areas have a compact fragipan, generally from 1 to 3 ft deep, which impedes infiltration and root growth. Soils on the steep hillside areas tend to be rocky, readily erodible (if exposed), and thinner than the upland soils. Soils in the bottom lands along the small streams are subject to periodic flooding, but most are well drained.

The Soil Survey notes the large variability of soil parent materials (geologic formations) in the county. Thus, soil textural, chemical, mineralogical, and hydrological properties likewise vary significantly across the county. In the Chenoweth Run Basin, the Soil Survey estimates of the soil permeabilities ranges from 0.05 to 2 in/h.

Soils in the Chenoweth Run Basin are in the Crider-Corydon, Russellville-Crider-Dickson, and Beasley-Fairmount-Russellville soil associations (fig. 6). The Crider-Corydon and the Russellville-Crider-Dickson associations developed in residuum derived from high-grade limestones (Sellersburg, Jeffersonville, and Louisville limestones) of the Middle and Early Devonian and Middle Silurian periods. These soil associations are described as being well-drained to moderately well-drained at the surface; nearly level to moderately sloping in upland areas and ridgetops with typical depths to bedrock of 5 to 9 ft; and steep, shallow soils (1 to 3 ft deep) on hillsides. Russellville and Dickson, upland soil series, have a fragipan at a depth of 2 to 2.5 ft.

The Beasley-Fairmount-Russellville association, in contrast, developed in residuum derived from thinly bedded limestone and calcareous shale of the Middle and Early Silurian and Late Ordovician periods. This association is described as being moderately well to excessively well-drained at the surface; gently to moderately sloping on narrow ridges with typical depths to bedrock of 4 to 9 ft; and steep, shallow soils (1 to 3.5 ft) on hillsides. The Beasley series has slow to moderately slow permeability in the lower, fine-textured subsoil and a soft, interbedded, calcareous shale and limestone formation at a depth of about 2 to 4 ft that impedes root growth and infiltration.

The most extensive soils in the basin are the Beasley and Crider series in the rolling uplands—each covering approximately 25 percent of the basin. These series’ provide the most available-moisture-storage capacity among the soils in the basin because of the soil depths and the extensive area covered. Both soil series’ have fine-grained texture, with more than 90 percent by weight in the silt and clay soil-particle-size fraction (less than 0.00197 in., or 0.05 mm). However, these soils have different drainage properties because of the differences in the soil parent materials. The surface layer and the upper subsoil of the deep, well-drained Crider soil series developed primarily in loess, and the lower part of the subsoil developed primarily in residuum derived from the high-grade limestones (Sellersburg, Jeffersonville, and Louisville Limestones of the Middle and Early Devonian and Middle Silurian periods). The surface layer and the upper subsoil of the Beasley soil series developed primarily in loess and limestone residuum, and the lower part of the subsoil developed in residuum derived from calcareous shale (marl) and soft limestones of the Middle and Early Silurian and Late Ordovician periods. The Beasley series, thus, has lower moisture-storage capacity and permeability than the Crider series. Karst features (sinkholes) have developed in some areas of both the Beasley and Crider soils.

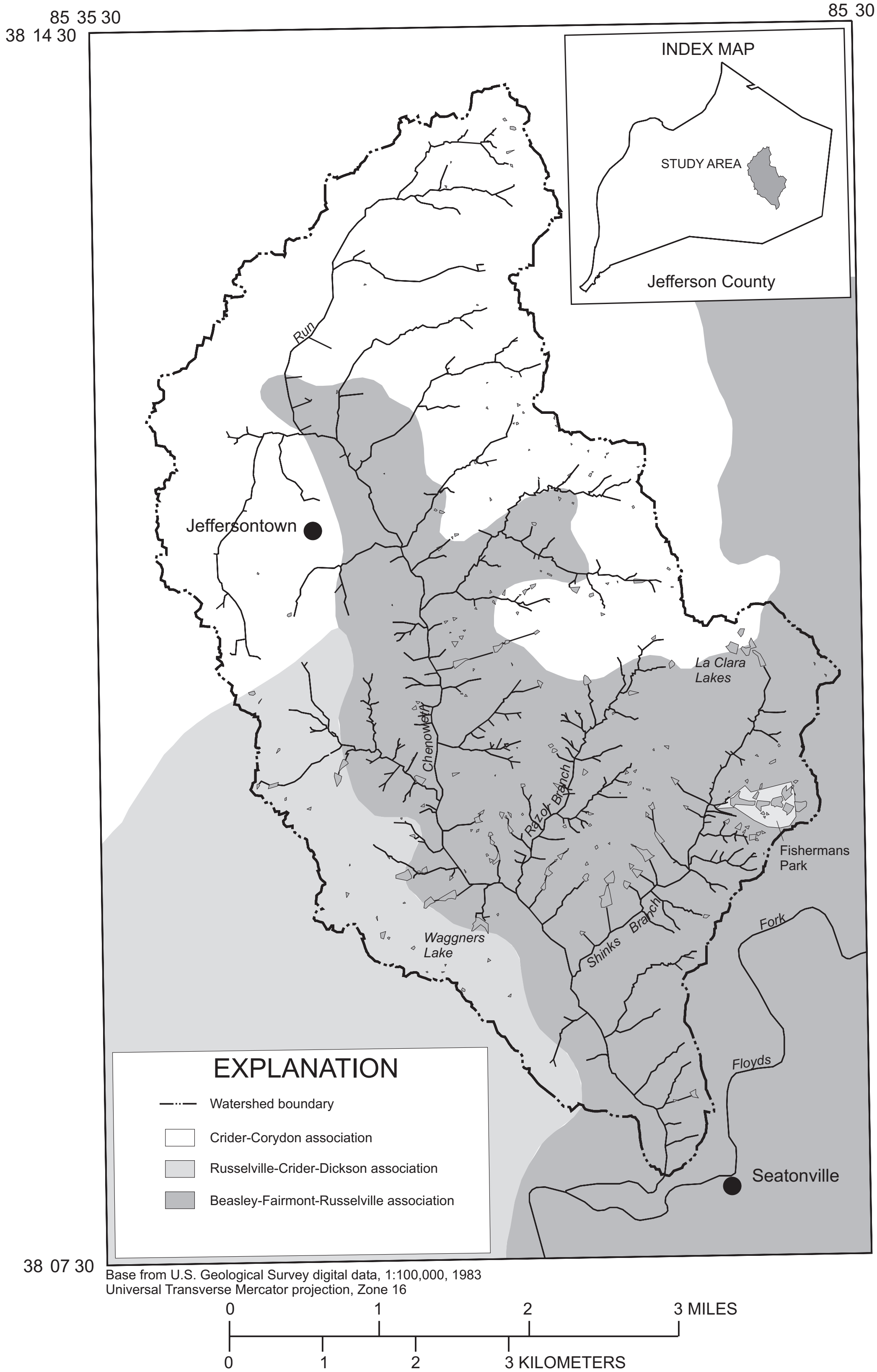


Figure 6. Generalized soils of the Chenoweth Run Basin, Jefferson County, Kentucky.

Land Use

Chenoweth Run Basin has undergone rapid urban development in recent years. The upper (north) third of the basin is the most developed portion of the basin at present (2000), and it includes areas of extensive residential, office, commercial, and light-industrial development in the city of Jeffersontown. This developed area within the upper basin includes portions of the Bluegrass Industrial Park, which extends south from Interstate 64 and contains businesses employing approximately 33,000 persons (John Cosby, Jeffersontown Development Council, oral commun., 2000). Also included is the large 9,100-seat church complex (Van Campen, 1998) constructed just north of Interstate 64 during the study data-collection period. Additional economic and land development spurred by the industrial park and church complex is anticipated in the future in and around the basin.

Land development in the lower two-thirds of the basin, downstream from the 4.0-Mgal/d-capacity Jeffersontown WWTP, has also been increasing in recent years. Residential subdivisions have been developed among the largely rural and agricultural land uses.

The transportation improvements within and surrounding the basin have facilitated recent land-development activity. Four freeway interchanges within or bordering the basin on the north, east, and west sides provide ready vehicular access.

Predominant land uses in the basin are listed in table 1. Land-cover characteristics in the basin are shown in table 2. See the section "Lane Use and Land Cover" for further description of land use in the basin.

Table 1. Land-use distribution at selected locations in the Chenoweth Run Basin, Jefferson County, Kentucky

[%, percent]

Site identifier (figure 7)	Location	Drainage area (acre)	Single-family residential %	Multi-family residential %	Commercial %	Industrial %	Public and semi-public %	Parks and open space %	Vacant or undeveloped %
401	Chenoweth Run at Ruckriegel Parkway at Jeffersontown	3,445	32.9	1.8	10.6	24.7	2.7	1.6	25.7
16	Chenoweth Run at Gelhaus Lane	7,327	42.5	1.3	5.3	12.3	1.7	10.8	26.1
403	Chenoweth Run at Seatonville Road	10,580	35.5	.9	3.7	8.5	1.3	9.2	40.9

Table 2. Land-cover characteristics at selected locations in the Chenoweth Run Basin, Jefferson County, Kentucky

[USGS, U.S. Geological Survey]

Site identifier (figure 7)	USGS station number	Location	Drainage area (acre)	Total impervious area (percent)	Pervious area	
					Open (percent)	Forest (percent)
401	03298135	Chenoweth Run at Ruckriegel Parkway at Jeffersontown	3,445	29.9	58.8	11.3
16	03298150	Chenoweth Run at Gelhaus Lane	7,327	18.4	71.5	10.1
403	03298160	Chenoweth Run at Seatonville Road	10,580	13.8	68.5	17.7

Hydrology

Streamflow and water-quality conditions reflect the integrated effects of numerous environmental processes and factors that affect the hydrology, including characteristics of the climate, physiography, geology, soil, and land use. The principal basin characteristics studied in Chenoweth Run that affect hydrologic response to precipitation and evapotranspiration included land use, land cover, land slope, and soils characteristics. External inflows and losses of water and constituents are also relevant to the hydrology of the Chenoweth Run Basin.

In the Chenoweth Run Basin, as in much of the eastern third of Jefferson County, relief is moderately sloping to steep. Also, internal drainage in the pervious areas is impeded by the fine-textured subsoils (silts and clays). Thus, much of the precipitation tends to move rapidly as overland flow and (or) interflow to the stream channels. Only a small amount of water infiltrates through the soil mantle to the underlying limestones (Bell, 1966); thus, stream base flows are generally low to zero.

Stormflow hydrographs, particularly in the developed upper third of the basin, have rapidly rising and receding limbs, and the time lag between rainfall and streamflow peaks is short. Urban development has reduced the pervious area available for the limited potential infiltration of precipitation. Drain pipes carry runoff from many impervious areas directly to the stream channels; frequent scouring stormflows result.

The stream channel in much of the upper third of the basin is confined by very steep, tree-lined banks with limited areas of riparian vegetation beyond the tops of the banks. In the lower two-thirds of the basin, downstream from the Jeffersontown WWTP, stream banks are less steep than in the upstream third, and riparian vegetation beyond the tops of banks is also more abundant than in the upstream third. A tree canopy to shade and cool the stream is absent in many stream reaches. The channel bottom is exposed bedrock, except in pooled segments where sediments are deposited during peak-flow-recession periods. Main-channel slopes are moderate, averaging 13 to 18 ft/mi. Some base-flow seepage losses are possible in the fractured sections of the channel bottoms.

Three WWTP's—the Jeffersontown WWTP and two minor plants farther downstream—release to the main channel the water, remaining chemical constituents, and thermal energy discharged from domestic, commercial, and industrial customers of the WWTP's. At times, wastewater effluent makes up the majority of base flows.

Additional and variable nonpoint-source areas exist in the basin for chemical constituents. The fine-textured soils are highly susceptible to erosion when exposed, as is often the case during construction activity. Large sediment concentrations and loads have often been transported during stormflows. The sediments also carry sorbed constituents including nutrients and metals. Streets, parking lots, treated turf grasses, pastures, and crop areas also are potentially significant constituent-source areas.

Increased stream-water temperatures resulting from the runoff from impervious surfaces, the loss of riparian tree canopy, and thermal energy added by the WWTP's reduces the oxygen-carrying capacity of streams and adversely affects habitat for aquatic organisms. Oxygen-demanding sediments and nutrients further impair stream biological integrity.

The numerous ponds and small lakes in the Chenoweth Run Basin also affect streamflow and water-quality conditions. Approximately 25 percent of the basin area is drained through these ponds. This adds detention storage in the basin and delays and (or) reduces the movement of water and constituents to some degree, including some sediments and nonpoint-source nutrients, through the basin. Detention storage located in the lower portion of a basin may, however, tend to locally increase peak discharges on the main channel because delayed peaks from the downstream tributary channel may at times coincide with peaks from the upper portion of the basin.

METHODS OF DATA COLLECTION AND ANALYSIS

A large variety of data were gathered to characterize and model the basin, including water-quantity, water-quality, meteorological, and geographical data. Field data collected during the study to supplement the historical field data included several chemical constituents and physical properties of water (table 3) determined at several locations (table 4 and fig. 7). Continuous time-series data (table 5) were either measured directly in the basin, estimated for the basin, or representative values were obtained for locations near the basin. Geographical data were used to develop selected model elements. In addition, several statistical, mathematical, and graphical methods were used to analyze the available data.

Historical Data

Historical sampling data compiled for this study included data gathered in two systematic water-quality-monitoring programs; data collected at Chenoweth Run at Gelhaus Lane during 1988–97 as part of a countywide MSD/USGS urban-hydrology program were compiled. Data for the KDOW Chenoweth Run study (Leist, 1996) were collected by the USGS during January 1995–January 1996 at sites CR5, CR4, 402, CR2, and 403 (table 4 and fig. 7) and compiled.

All samples, except selected quality-assurance samples and samples for state-lab trace-metals determinations, were analyzed by the MSD lab. The historical sampling data were collected by manual, cross-sectionally integrated, stream-water-sampling techniques.

Field Data

Field data collection was designed to supplement and expand the utility of available data. A sampling design was developed to meet study goals by collection of representative samples with appropriate spatial, temporal, and hydrologic distribution.

Sampling Design

A variety of field data were needed to adequately characterize and model the highly variable streamflow and water-quality conditions in this mixed-land-use urbanizing basin. Data were needed to describe spatial, flow-related, and seasonal variability of water quality. Much of the historical water-quality data represented single, discrete water samples that had been collected during prescheduled sampling trips of routine monitoring programs. Relatively few samples had been collected during above-average flows.

Thus, sampling during this data-collection period was targeted primarily toward storms, when a large portion of the constituent load is normally transported. Series of discrete water samples were to be collected over the duration of the storms in order to characterize constituent-transport processes and storm loads. The series of discrete storm samples were available for development of plots of constituent concentrations over time and plots of constituent loads over time.

Four sites were selected for water sampling during the data-collection period: sites 401, 402, 16, and 403 (table 4 and fig. 7). Criteria for selecting the sites included provision of adequate accessibility, mixing of flow in the sampling reach, and spatial resolution by including sites located upstream and downstream from the wastewater inflows and also a site near the basin outfall at the confluence with Floyds Fork. Also, it was desirable to continue use of sites where the historical sampling data had been collected. Two sites (401 and 16) were selected as locations for collection of continuous-record streamflow and four-parameter water-quality data.

The set of constituents analyzed (table 3) was the same set as was analyzed routinely (monthly) in the MSD stream-sampling program—pH, alkalinity, total dissolved solids, total suspended solids, total volatile suspended solids, biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, organic nitrogen, total orthophosphate (TPO_4), total phosphorus (TP), and fecal coliform and streptococcus. A filtered sample for total phosphorus analysis was also routinely submitted to the lab. As requested by MSD, samples for metals and chloride were also submitted to the lab when enough sample water was available.

The sampling goal was to collect a series of samples during 3 storms per year distributed seasonally at each of the 4 sampling sites, for a total of 12 storm-event samples per year. Also, low-flow samples were to be collected annually at each of these four sampling sites.

Table 3. Chemical constituents and physical properties analyzed for water samples collected in the Chenoweth Run Basin, Jefferson County, Kentucky, 1988–98

Alkalinity	Nickel, total
Arsenic, total	Nitrate, total
Barium, total	Nitrite, total
Beryllium, total	Nitrogen, ammonia, total
Biochemical oxygen demand, 5-day	Nitrogen, organic, total
Cadmium, total	Oxygen, dissolved
Calcium, total	pH
Chemical oxygen demand	Phosphorus, dissolved and total
Chloride, dissolved	Phosphorus, total orthophosphate
Chromium, total	Selenium, total
Copper, total	Silver, total
Cyanide, total	Specific conductance
Dissolved solids, total	Suspended solids, total
Fecal coliform	Suspended solids, total volatile
Fecal streptococci	Sulfate, dissolved
Iron, total	Temperature, air and water
Lead, total	Thallium, total
Magnesium, total	Zinc, total
Mercury, total	

Table 4. Water-quality-sampling sites in the Chenoweth Run Basin, Jefferson County, Kentucky, used in the study
[USGS, U.S. Geological Survey; WWTP, wastewater-treatment plant]

Site identifier (figure 7)	USGS station number	Location	Latitude*	Longitude*	Period of record used
CR5	03298129	Chenoweth Run at Old Watterson Trail at Jeffersontown	381205	853341	1995-97
401	03298135	Chenoweth Run at Ruckriegel Parkway at Jeffersontown	381141	853326	1996-97
CR4	03298138	Jeffersontown WWTP Effluent at Chenoweth Run	381133	853318	1995-98
402	03298140	Chenoweth Run at Taylorsville Road near Jeffersontown	381115	853311	1995-97
CR2	03298145	Chenoweth Run at Easum Road	381003	853305	1995-96
16	03298150	Chenoweth Run at Gelhaus Lane	380936	853232	1988-97
403	03298160	Chenoweth Run at Seatonville Road	380758	853131	1996-97

*Degree, minute, and second symbols omitted.

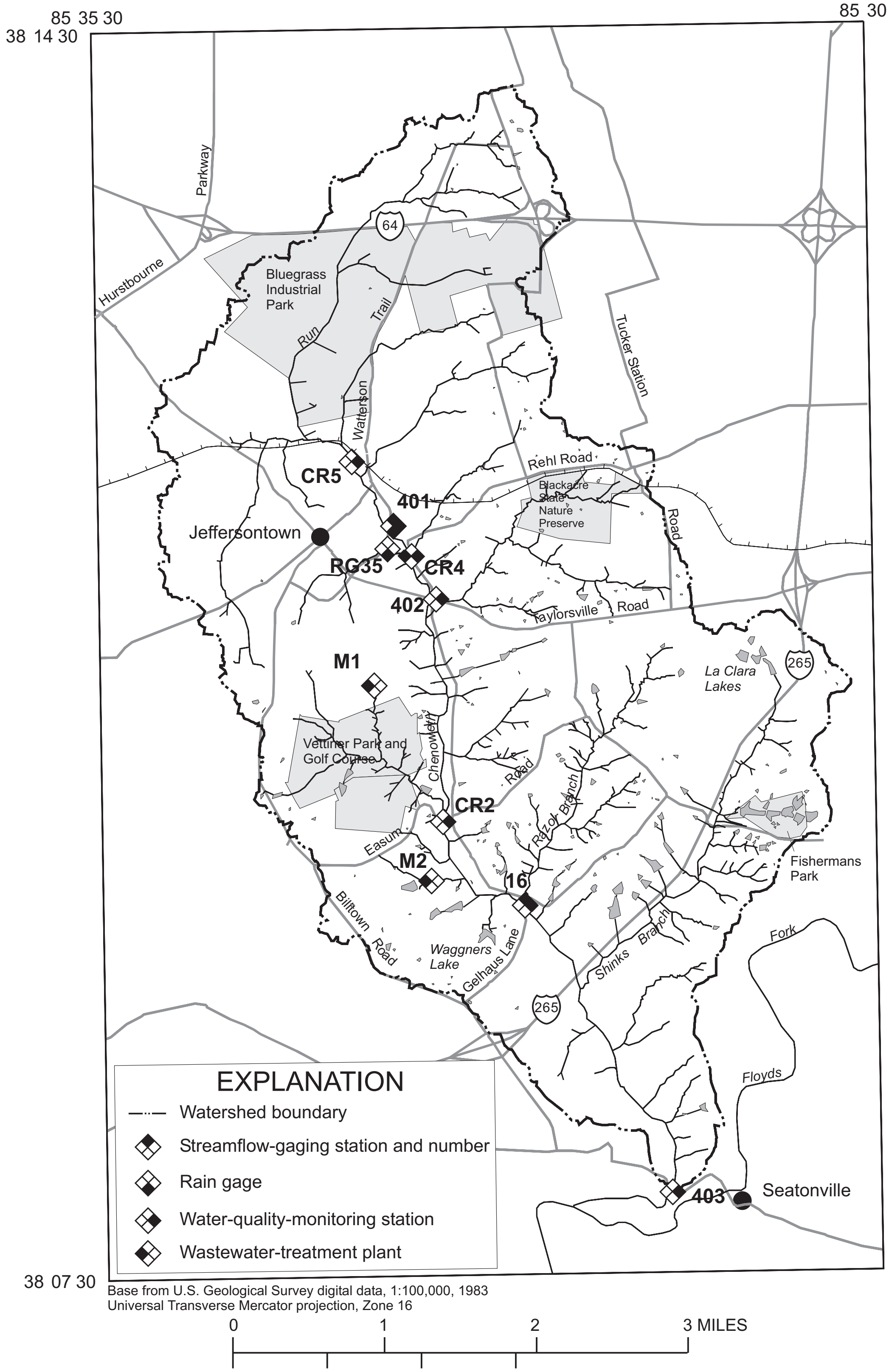


Figure 7. Locations of the streamflow-gaging, water-quality-monitoring, and rainfall-gaging stations, and wastewater-treatment plants in the Chenoweth Run Basin, Jefferson County, Kentucky.

Table 5. Time-series data compiled for hydrologic analysis and calibration of the model for Chenoweth Run Basin

[USGS, U.S. Geological Survey; ft^3/sec, cubic feet per second; ---, not applicable; *, indicates data used for model input; WWTP, wastewater treatment plant; in., inches; NWS, National Weather Service; ˚C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; ˚F, degrees Fahrenheit; locations shown in figures 2, 3, and 9]

Data type (units)	Location	Site identifier: Figure 2	Site identifier: Figure 3	USGS station number	Source	Time step	Period of record
Discharge (ft^3/sec)*	Chenoweth Run at Ruckriegel Parkway	---	401	03298135	USGS[a]	5 minute	01/25/96–02/25/98
Discharge (ft^3/sec)*	Chenoweth Run at Gelhaus Lane	---	16	03298150	USGS	5 minute	01/25/96–02/25/98
Discharge (ft^3/sec)*	Jeffersontown WWTP	---	CR4	03298138	MSD[b]	1 day	01/25/96–02/25/98
Discharge (ft^3/sec)*	Chenoweth Hills WWTP	---	M1	---	MSD	1 day	01/25/96–02/25/98
Discharge (ft^3/sec)*	Lake of the Woods WWTP	---	M2	---	MSD	1 day	01/25/96–02/25/98
Rainfall (in.)*	Chenoweth Run at Ruckriegel Parkway	RG28a	401	03298135	USGS	5 minute	12/01/95–02/25/98
Rainfall (in.)*	Jeffersontown WWTP	RG35	RG35	---	MSD	15 minute 5 minute	12/01/95–02/25/98
Rainfall (in.)	McMahon Fire Station at Taylorsville Road	RG8	---	381306085363601	USGS, MSD	5 minute	01/15/96–02/25/98
Rainfall (in.)	East County Government Center at Shelbyville Road	RG11	---	381457085315401	USGS, MSD	5 minute	01/15/96–02/25/98
Rainfall (in.)	Fire Station #3 at Routt Road	RG15	---	380739085281101	USGS, MSD	5 minute	01/15/96–02/25/98
Rainfall (in.)	Cedar Ridge Camp at Routt Road	RG17	---	381044085284201	USGS, MSD	5 minute	01/15/96–02/25/98
Rainfall (in.)	Standiford Field	A	---	---	NWS[c], MCC[d], NOAA[e]	1 day	01/01/48–05/13/98
Rainfall (in.)	NWS office at Theiler Lane	C	---	---	NWS	1 day	01/01/96–09/30/98
pH, water temperature (˚C)*, specific conductance (µS/cm), dissolved oxygen (mg/L)	Chenoweth Run at Ruckriegel Parkway	---	401	03218135	USGS	30 minute	01/17/96–09/30/97

Table 5. Time-series data compiled for hydrologic analysis and calibration of the model for Chenoweth Run Basin—*Continued*

[USGS, U.S. Geological Survey; ft^3/sec, cubic feet per second; ---, not applicable; *, indicates data used for model input; WWTP, wastewater treatment plant; in., inches; NWS, National Weather Service; ˚C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/

Data type (units)	Location	Site identifier Figure 2	Site identifier Figure 3	USGS station number	Source	Time step	Period of record
pH, water temperature (˚C)*, specific conductance (µS/cm), dissolved oxygen (mg/L)	Chenoweth Run at Gelhaus Lane	---	16	03298150	USGS	30 minute	01/24/96–09/18/97
Pan evaporation (in.)*	Dix Dam, Danville, Ky.[f]	---	---	---	MCC	1 day	04/01/96–10/31/97
Pan evaporation (in.)*	Nolin River Lake, Ky.[f]	---	---	---	MCC	1 day	04/01/96–10/31/97
Pan evaporation (in.)*	Lake Patoka, Dubois, Ind.[f]	---	---	---	MCC	1 day	05/01/96–10/31/97
Potential evapotranspiration (in.)	Standiford Field	A	---	---	MCC	1 day	01/01/96–02/25/98
Potential evapotranspiration (in.)	Bowman Field	B	---	---	MCC	1 day	01/01/96–12/16/98
Air temperature (˚F)*	Standiford Field	A	---	---	MCC	1 hour	01/01/96–02/25/98
Air temperature (˚F)	Bowman Field	B	---	---	MCC	1 day	01/01/96–12/16/98
Dew point temperature (˚F)	Standiford Field	A	---	---	MCC	1 hour	01/01/96–02/25/98
Dew point temperature (˚F)	Bowman Field	B	---	---	MCC	1 day	01/01/96–12/16/98
Wind speed (mile per hour)	Standiford Field	A	---	---	MCC	1 hour	01/01/96–02/25/98
Wind speed (mile per hour)	Bowman Field	B	---	---	MCC	1 day	01/01/96–12/16/98
Solar radiation (Langleys)	Standiford Field	A	---	---	MCC	1 day	01/01/96–02/25/98
Solar radiation (Langleys)	Bowman Field	B	---	---	MCC	1 day	01/01/96–12/16/98
Cloud cover (tenths of sky)	Standiford Field	A	---	---	NOAA	variable hourly	01/01/96–02/25/98

[a]U.S. Geological Survey (National Water Information System, electronic data)
[b]Louisville and Jefferson County Metropolitan Sewer District (Rainfall Database, electronic data)
[c]National Weather Service (local forecast office, Louisville, Ky., electronic data)
[d]Midwestern Climate Center (Illinois State Water Survey, Champaigne, Ill., electronic data)
[e]National Oceanic and Atmospheric Administration (National Climatic Data Center, Asheville, N.C., electronic data)
[f]Shown on figure 9

Instrumentation and Equipment

The two streamflow-gaging stations (sites 401 and 16, fig. 7) consisted of water-stage-recording devices that provided continuous stage (5-minute interval) records for use in computation of continuous discharge. Water-quality monitors at each streamflow-gaging station provided continuous (30-minute interval) records of water temperature, pH, specific conductance, and dissolved-oxygen concentration. Water-quality samples were collected by use of standard, manual, depth-integrating, isokinetic-nozzled samplers (Edwards and Glysson, 1988; Ward and Harr, 1990) and also by use of automatic, battery-powered-pump samplers equipped with 24 plastic 1-liter bottles. Water samples were composited and split into subsamples for laboratory analysis by use of a plastic churn splitter. The USGS-operated rainfall gages were the tipping-bucket type with a 50-in^2 opening, the cumulative depth of which was recorded at 5-minute intervals by a digital data logger.

Sampling Procedures

Most of the historical water-quality samples were collected by use of cross-sectionally integrated sampling procedures. These procedures, originally developed for obtaining representative suspended-sediment samples (Guy and Norman, 1970; Edwards and Glysson, 1988; Ward and Harr, 1990; Shelton, 1994), provided an isokinetic, discharge-weighted, composite sample. Specifically, the equal-width-increment, equal-transit-rate (EWI/ETR) sampling procedure was used. The sampler, oriented parallel to the flow direction, was lowered from the water surface to the streambed at a series of sampling positions (“verticals”) that were equally spaced across the sampling section. The sampler was lowered and raised at the same vertical transit rate in each sampling vertical. Because the volume of water collected at each vertical was proportional to the stream velocity at each vertical, and thus, to the flow within each width increment, a flow-proportioned, composite sample of the stream cross section was obtained by use of this procedure. The composite samples were subsampled for laboratory analyses by use of a plastic churn splitter.

Most of the storm samples collected during 1996–97 for this study, however, were collected by use of portable automatic samplers. Use of automatic samplers was necessitated by the logistical difficulties of collecting the series of samples in a small, urbanized basin where discharge during storms was rapidly changing. Sampling at multiple sites during a given storm was also planned. Many of the storms sampled began in late afternoon and continued throughout the night.

The automatic samplers were deployed in advance of forecasted storms. Samples were pumped from the stream through a 3/8-in.-internal-diameter vinyl tube secured to a 2-in.-diameter polyvinyl chloride (PVC) pipe mounted to a bridge abutment or pier at the sampling site. The sampling tube extended from just above the pre-storm water-surface elevation to the ice-filled automatic sampler that was generally placed at the roadway level along the bridge railing. The samplers were programmed to fill four sets of six 1-liter bottles—one set of six bottles for each discrete sample collected at a given time. The sample sets were pumped automatically at preprogrammed intervals following activation of the sampler by a rise of the stream. The total storm-runoff durations, and consequently the sampling-period durations (3, 6, 9, 12, or 15 hours), were projected on the basis of the latest weather forecasts at the time the samplers were deployed. The samplers were programmed to pump the samples more frequently in the early periods of a storm when concentrations of nonpoint-source constituents are often higher than in later periods of a storm. Ideally, there were four individual, discrete sample sets of 6 liters each collected during each sampled storm. The discrete sample sets (six 1-liter bottles) were composited and subsampled for laboratory analyses by use of a plastic churn splitter.

In 1996–97, there were 24 storm-sampling occasions at the 4 sites, and 79 discrete samples were collected, which was an average of 3.3 samples per storm. One cross-sectionally integrated, low-flow sample was collected annually in September at each of the four sites, for a total of eight low-flow samples.

Point samples, such as those pumped by automatic samplers, are often not fully representative of actual instream water quality, particularly for sediment-associated constituents

(Martin and others, 1992). A cross-sectionally integrated stream-sampling procedure provides a representative sample of sediment-associated constituents. To assess the representativeness of the point samples, several paired point and cross-sectionally integrated samples were collected for comparison. (See “Quality-Assurance Data.”)

Laboratory Data

Laboratory analysis of water constituents (table 3), except for selected quality-assurance samples, was provided by the MSD lab. These samples were analyzed by use of methods approved by the USEPA (table 6).

Quality-Assurance Data

Quality-assurance data collected with the field data during the study included equipment blanks (rinses), split samples, and concurrent (paired) sampling replicates. Additional quality-assurance data were collected in association with evaluations of the MSD lab performance.

Equipment blanks, which were made from de-ionized water and inorganic-free blank water, were collected to assess potential contamination introduced during sample collection and processing. It appears some possible minor low-level contamination was introduced for selected N and P species and calcium, barium, copper, iron, zinc, and magnesium (Appendix 1, coded as station 03123499).

Two split samples were drawn from one storm sample (March 19, 1996, at 1005 at site 401) for suspended-sediment analysis by USGS methods for comparison to the suspended-solids concentration from the MSD lab. Suspended-sediment concentrations of the split samples were 378 and 401 mg/L, compared to a suspended-solids concentration of 380 mg/L determined by the MSD lab. The USGS suspended-sediment concentrations differed from the MSD suspended-solids concentration by 0.5 and 5.5 percent, respectively. Both split samples were 99.6 percent by weight in the <62 micrometer particle-size fraction. Thus, the total suspended-solids data collected in this basin were considered essentially equivalent to suspended-sediment data as defined by USGS methods.

Split samples were drawn on two occasions (September 26, 1996, at 1205 at site 16 and September 16, 1997, at 1155 at site 16) for comparison of results for nitrogen and phosphorus species at the MSD lab and the USGS lab. Results for total ammonia nitrogen plus organic nitrogen were 0.66 and 0.68 mg/L, respectively, at the MSD lab. Results were 0.70 and 0.63 mg/L, respectively, at the USGS lab. Thus, the results for total ammonia nitrogen plus organic nitrogen differed by 5.7 and 7.9 percent, respectively, and the mean difference was 6.8 percent. Results for total phosphorus were 2.0 and 1.6 mg/L, respectively, on the two sampling dates at the MSD lab. Results for total phosphorus were 1.8 and 1.54 mg/L, respectively, at the USGS lab. Thus, the results for total phosphorus differed by 11.1 and 3.9 percent, respectively, and the mean difference was 7.5 percent.

The MSD lab was approved by the USEPA for routine wastewater analyses including BOD and COD. The MSD lab also has participated in the USGS Standard Reference Water Sample Program, which includes approximately 150 labs nationwide. Results for MSD laboratory analyses for selected constituents were approved for use in USGS interpretive studies (Ruhl and Jarrett, 1999). Review of historical MSD lab data indicated that determinations for phosphorus species prior to 1991 may not be accurate (Patti Grace-Jarrett, Louisville and Jefferson County Metropolitan Sewer District, oral commun., 1998). These early phosphorus data collected prior to 1991 were, therefore, not used in this study.

To assess the representativeness of the point samples collected by use of the automatic samplers, seven paired (concurrent replicate) point and cross-sectionally integrated samples were collected for comparison (Appendix 2). Comparisons indicated that the automatic samples underrepresented the total suspended-solids concentrations. The mean difference was 17 percent. Consistent differences were not observed for other sediment-associated constituents, such as total phosphorus. For load estimates, the total suspended-solids concentrations for samples collected by use of the automatic samplers were increased by 17 percent to compensate for this apparent bias.

Table 6. Methods used by the Louisville and Jefferson County Metropolitan Sewer District laboratory for analysis of water-quality samples collected in the Chenoweth Run Basin, Jefferson County, Kentucky, 1988–98

[USEPA, U.S. Environmental Protection Agency; mg/L, milligrams per liter; ---, not available; µg/L, micrograms per liter]

Constituent or property (units)	Method	USEPA method number	Reporting level
pH and alkalinity:			
pH	Electrometric, glass electrode	150.1	0.1
Alkalinity (mg/L as $CaCO_3$)	Electrometric titration to pH 4.5	310.1	1
Dissolved solids and related water-quality constituents and characteristics:			
Dissolved solids (mg/L)	Residue on evaporation at 105 degrees Celsius, dissolved, gravimetric	160.3	.5
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	Wheatstone bridge	120.1	10
Calcium, total (mg/L as Ca)	Atomic emission spectrometric, induction-coupled argon plasma	200.7	.01
Magnesium, total (mg/L as Mg)	Atomic emission spectrometric, induction-coupled argon plasma	200.7	.01
Hardness, total (mg/L as $CaCO_3$)	Calculation	200.7	---
Suspended solids:			
Suspended solids (mg/L)	Residue on evaporation at 105 degrees Celsius, suspended, gravimetric	160.2	1
Residue, volatile nonfilterable (mg/L)	Volatile-on-ignition, suspended, gravimetric	160.4	1
Major metals, trace elements, and miscellaneous inorganic compounds:			
Arsenic, total (µg/l as As)	Digestion, graphite furnace, atomic absorption	206.2	5
Barium, total (µg/L as Ba)	Atomic emission spectrometric, induction-coupled argon plasma	200.7	1
Beryllium, total, (µg/L as Be)	Atomic emission spectrometric, induction-coupled argon plasma	200.7	.5
Cadmium, total (µg/L as Cd)	Atomic emission spectrometric, induction-coupled argon plasma	200.7	2
Chromium, total (µg/L as Cr)	Atomic emission spectrometric, induction-coupled argon plasma	200.7	3
Copper, total (µg/L as Cu)	Atomic emission spectrometric, induction-coupled argon plasma	200.7	2
Iron, total (µg/L as Fe)	Atomic emission spectrometric, induction-coupled argon plasma	200.7	5

Table 6. Methods used by the Louisville and Jefferson County Metropolitan Sewer District laboratory for analysis of water-quality samples collected in the Chenoweth Run Basin, Jefferson County, Kentucky, 1988–98—*Continued*

[USEPA, U.S. Environmental Protection Agency; mg/L, milligrams per liter; ---, not available; µg/L, micrograms per liter]

Constituent or property (units)	Method	USEPA method number	Reporting level
Major metals, trace elements, and miscellaneous inorganic compounds—*continued*:			
Lead, total (µg/L as Pb)	Atomic emission spectrometric, induction-coupled argon plasma	200.7	20
Mercury, total recoverable (µg/L as Hg)	Atomic absorption spectrometric, flameless	245.1	.2
Nickel, total (µg/L as Ni)	Atomic emission spectrometric, induction-coupled argon plasma	200.7	5
Selenium, total (µg/L as Se)	Digestion, graphite furnace, atomic absorption	270.2	5
Silver, total (µg/L as Ag)	Atomic emission spectrometric, induction-coupled argon plasma	200.7	6
Zinc, total (µg/L as Zn)	Atomic emission spectrometric, induction-coupled argon plasma	200.7	5
Cyanide, total (µg/L as CN)	Colorimetric, barbituric acid	335.2	4
Nutrients:			
Nitrogen, ammonia, total (mg/L as N)	Electrometric, ion-selective electrode	350.3	.01
Nitrogen, nitrate, total (mg/L as N)	Cadmium reduction	353.2	.03
Nitrogen, nitrite, total (mg/L as N)	Colorimetric, diazotization, automated	354.1	.002
Nitrogen, organic plus ammonia (mg/L as N)	Titrimetric, digestion-distillation, electrode	351.3	.03
Phosphorus, total (mg/L as P)	Colorimetric, phosphomolybdate	365.2	.003
Phosphorus, orthophosphate, total (mg/L as P)	Colorimetric, phosphomolybdate	365.2	.003
Dissolved solids and oxygen demand:			
Dissolved oxygen (mg/L)	Winkler	360.2	---
Biochemical oxygen demand (mg/L)	Dissolved oxygen depletion, 5-day at 20 degrees Celsius	405.1	2
Chemical oxygen demand (mg/L)	Titrimetric, 0.25 N dichromate oxidation	410.1	2
Fecal-indicator bacteria:			
Coliform, fecal (colonies per 100 milliliters)	Membrane filtered, M-FC medium at 44.5 degrees Celsius	None	1
Streptococci, fecal (colonies per 100 milliliters)	Membrane filtered, KF agar at 35 degrees Celsius	None	1

Ancillary Hydrologic Data

Wastewater-treatment-plant effluent discharge and quality data were obtained from MSD. Some of these data were available only at large time steps (daily and monthly), and data were sometimes unavailable for selected portions of the study period. Unavailable values of time series' needed for basin characterization and modeling were estimated by interpolation or regression based on available data or by use of literature values reported for similar facilities.

Meteorological Data

Several meteorological time series' (table 5) were acquired. Rainfall data were collected by the USGS and MSD; these data were screened extensively to eliminate any periods of record when a gage may have been plugged or otherwise inoperable. Representative meteorological data for the basin were obtained from the National Weather Service, the National Climatic Data Center, and the Midwestern Climate Center. Missing values of selected time series' were estimated by interpolation or averaging procedures. The USGS METCMP program (Alan Lumb, U.S. Geological Survey, written commun., 1995) was used to estimate daily pan evaporation during winter periods by use of the Penman (1948) equation and also to disaggregate daily pan evaporation to hourly values.

Geographical Data

Detailed geographical data for the basin were obtained from the Louisville and Jefferson County Information Consortium (LOJIC) in 1996. The LOJIC data were originally digitized from 1:100-scale aerial imagery. The LOJIC data included coverages for streams, water bodies, land uses, roads, buildings, parking lots, tree canopy, 2-ft-interval elevation contours, digital elevation data, and soils. The LOJIC coverages were supplemented with USGS 1:250,000-scale Geographic Information Retrieval and Analysis System (GIRAS) (Mitchell and others, 1977) land-cover data that was used to identify crop, pasture, and forest land in the basin. Where significant changes in land use had made portions of the land-use covers obsolete (the Southeast Christian Church property and the Saratoga Woods residential development), recent imagery (spring 1997) showing the new developments was obtained from LOJIC for digitizing and updating the coverages or for later use in adjustment of the HSPF model elements.

The geographical data were prepared and analyzed by use of ARC/INFO and ARC/INFO-GRID (Environmental Systems Research Institute, 1991 and 1992). Vector data and arc polygons were converted into raster-based, "gridded" data (cell size of 13.1 ft by 13.1 ft or 4 m by 4 m) for the purpose of efficiently combining and intersecting hydrologically pertinent coverages.

A gridded digital elevation model (DEM) was developed by use of TOPOGRID (Hutchinson and Dowling, 1991). The DEM was subsequently used to develop a continuous land-slope grid coverage of the basin and also to delineate drainage-area boundaries for the numerous ponds and small lakes in the basin.

Extensive processing of some of the initial coverages, such as the stream and impervious-area features, was required before the coverages were in a form suitable for use in hydrological modeling. The stream cover was edited to make it continuous and "flowing" downstream. Several of the original LOJIC coverages having hydrological significance, such as the roads, buildings, parking lots, and tree canopy, were line coverages (vector data) from which areal information could not initially be determined. The LOJIC road coverage, for example, represented the road center lines. To estimate road areas, this coverage, in gridded form, was "expanded" in width on the basis of road class (residential, collector, arterial, etc.).

The LOJIC coverages for buildings, parking lots, and tree canopy were sets of unconnected vectors (arcs) defining the perimeters, or outer boundaries of these features. A detailed impervious-area polygon cover was formed by combining and editing the building, parking-lot, and road coverages. Closed polygons of these three impervious covers were formed by extending arcs containing disconnected, "dangle" nodes (end points) and (or) by eliminating short, disconnected, dangle arcs. Most of the expanded road boundaries were narrowed to intersect, and thus, eliminate many dangle nodes at parking-lot entrances. The impervious-area polygons retained attributes describing the impervious type (building, parking lot, and road). The tree-canopy-perimeter coverage was similarly processed to closed polygons.

Selected combinations of the 7 LOJIC land-use classes, 3 LOJIC impervious classes, and 2 GIRAS land-cover classes (table 7) were combined manually in a series of steps to create a gridded land-use/land-cover coverage of 13 basic classes (table 8). The GIRAS pasture/crop and forest areas were added to the LOJIC land-use cover where each area overlaid, or intersected, the LOJIC vacant/undeveloped and park/open-space land-use categories only. Also, a buffer area, approximately 50 ft (15 m) in width, was defined around buildings in the single-family-residential and commercial/industrial/multifamily-residential land-use categories only. This buffer was assumed to define the areal extent of disturbed soils within these land-use categories. The gridded land-use/land-cover coverage contained seven pervious classes and six impervious classes as listed in table 8.

A gridded soils coverage was also developed directly from the soils coverage provided by LOJIC, which had been digitized from the Jefferson County Soil Survey (Zimmerman and others, 1966). The gridded soils, land-use/land-cover, and land-slope coverages were further processed (classified) and combined by use of an Arc Macro Language (AML) program (*hru.aml* in Appendix 3) to define key HSPF-model elements, and the hydrologic response units (HRU). See “Model Development” for a description of this process.

Statistical, Mathematical, and Graphical Analysis

Several statistical, mathematical, and graphical methods were used to analyze data for this study. Graphical displays were used to analyze differences among data sets and to describe relations between variables. Graphical displays included hydrographs, scatterplots, and duration curves. The results for statistical analyses included estimates of associated errors. The HSPF model of the basin combines and integrates the available information to simulate hypothesized functional relations among the variables.

Descriptive Statistics

Water-quality data were described in terms of percentiles and extreme values during January 1991–December 1997. Discharge data during February 1996–January 1998 were presented as flow-duration curves, which display the daily mean discharge in terms of the percentage of time a given discharge was equaled or exceeded during the period.

Estimated Missing Values

Missing values of various meteorological data, water-quality constituent concentrations, and WWTP discharges were estimated by interpolation between available data or by use of ordinary least-squares regressions.

Box Plots

The distributions of selected water-quality constituents were displayed and compared by use of box plots (Tukey, 1977), which depict the median, interquartile range, and extreme values. A box plot is constructed by drawing a box from the 25th percentile to the 75th percentile; thus, the box length is the interquartile range. A line is drawn across the box at the median. Lines (whiskers) are drawn from the boxes to the ‘adjacent’ values. The upper adjacent value is the largest data value less than or equal to the upper quartile plus 1.5 times the interquartile range. The lower adjacent value is the smallest data value greater than or equal to the lower quartile minus 1.5 times the interquartile range. Values beyond the adjacent values are plotted individually. Values from 1.5 to 3 times the interquartile range (outside values) are plotted as an asterisk. Values more extreme than 3 times the interquartile range (far outside values) are plotted as a circle.

Table 7. Initially designated land-use and land-cover classes in the Chenoweth Run Basin

[LOJIC, Louisville and Jefferson County Information Consortium; GIRAS, Geographic Information Retrieval and Analysis System]

Class	Description
	LOJIC land uses
1	Single-family residential
2	Multi-family residential
3	Commercial
4	Industrial
5	Public/semi-public
6	Parks/open space
9	Vacant/undeveloped
	LOJIC impervious areas
1	Roads
2	Buildings
3	Parking lots
	GIRAS land covers
1	Pasture/crop
2	Forest

Table 8. Combined land-use/land-cover classes in the Chenoweth Run Basin

[USGS, U.S. Geological Survey]

Class[a]	Remapped USGS class[b]	Description
		Pervious areas
10	1	Pasture/crop
11	2	Forest
12	3	Disturbed soils; single-family residential
13	4	Disturbed soils; commercial, industrial, multi-family residential
14	5[c]	Open; single-family residential, public/semi-public, parks/open space
15	5	Open; commercial, industrial, multi-family residential
16	6	Open; vacant, undeveloped
		Impervious areas
21	7	Roads; commercial, industrial, multi-family residential
23	7	Buildings; commercial, industrial, multi-family residential
24	7	Parking lots; commercial, industrial, multi-family residential
25	7	Roads; single-family residential, public/semi-public, parks/open space, vacant undeveloped
26	7	Buildings; single-family residential, public/semi-public, parks/open space, vacant undeveloped
27	7	Parking lots; single-family residential, public/semi-public, parks/open space, vacant undeveloped

[a]Intermediate USGS classes of gridded coverages combined from separate land-use/land-cover classes shown in table 7 formed the input grid for the Arc Macro Language program (*hru.aml*, Appendix 3).

[b]Remapped classes define combined land-use/land cover classes for the hydrologic response units.

[c]For example, class 5, open (grass-covered) space outside the hypothetical zone of disturbed soils, were classified the same in single-family, multi-family, commercial, industrial, and residential areas (developed uses).

Loads and Yields

Loads (mass) and yields (mass per unit drainage area) of total suspended solids, total phosphorus, and total orthophosphate were estimated. Constituent loads discharged from WWTP's were estimated as daily mean constituent concentration multiplied by the daily mean discharge. Long-term instream loads were estimated by use of ESTIMATOR, a statistical, 'rating-curve' model that uses multiple regression to relate logarithms of constituent concentration to logarithms of daily mean discharge and, optionally, other explanatory variables that are available continuously (Cohn and others, 1992a; Cohn and others, 1992b). The regression relation was used to estimate constituent concentration at times when it was unknown. Daily constituent loads are estimated by multiplying estimated daily concentration times daily mean discharge; monthly and annual loads are summed from these daily loads. Instructions for the use of ESTIMATOR (G. Baier, T. Cohn, and E. Gilroy, U.S. Geological Survey, written commun., 1995) described details. Storm loads were estimated as the summation of the incremental storm runoff volumes times the representative constituent concentration during the incremental time period.

ANALYSIS AND SUMMARY OF HYDROLOGIC CONDITIONS

The available hydrologic data for the Chenoweth Run Basin were compiled, reviewed, and analyzed for improved understanding of basin hydrologic conditions and for development of modeling approaches and components. Precipitation, potential evapotranspiration, wastewater effluents, streamflow, and constituent concentrations, loads, and yields were characterized.

Precipitation

Most of the precipitation during the data-collection period was rainfall. Measurable snow totaling 26.3 in. fell in 22 days at the NWS office (fig. 2) during February 1996–January 1998. Thus, snowfall accounted for approximately 2 percent of total precipitation at this location during the data-collection period.

Errors in measurement of rainfall are often the major source of error in rainfall-runoff modeling. Rainfall measurement error can arise from mechanical deficiencies in the rain gage, poor rainfall capture by the gage, and spatial variability of rainfall over a basin.

Two rain gages were operated in the basin during the data-collection period: RG28a operated by the USGS at the streamflow-gaging station at Ruckriegel Parkway (site 403) and RG35 operated by MSD on a building at the Jeffersontown WWTP, about 500 ft from site 401 (fig. 7). Nearby rain gages surrounding the basin included RG8, RG11, RG15, and RG17 (figs. 2 and 8; table 5). On the basis of Thiessen polygons (fig. 8), rain gage RG28a provides from 80 to 93 percent coverage of the basin (table 9), depending upon the point of interest on the main channel. Continuous streamflow data were available at the Ruckriegel Parkway and Gelhaus Lane sites only. Thus, RG28a provided coverage of 85 and 93 percent, respectively, of the basin drainage area considering these two streamflow-gaging stations where model calibration data were available.

Monthly, quarterly, and annual rainfall totals and totals for the model calibration period (February 1996–January 1998) were computed (table 10). A short period of missing data at RG28a (part of a day) was estimated using data from RG35. Faulty or missing data at the rain gages surrounding the basin were substituted with data from RG28a. The standard deviation, mean, and coefficient of variation (CV, standard deviation divided by the mean) for the totals at RG8, RG11, RG15, RG17 and RG28a were also computed. The largest variability among the monthly totals at these rain gages occurred in the spring and summer periods (April-September). Quarterly, annual, and period-of-record totals were approximately equal at these rain gages in or near the basin.

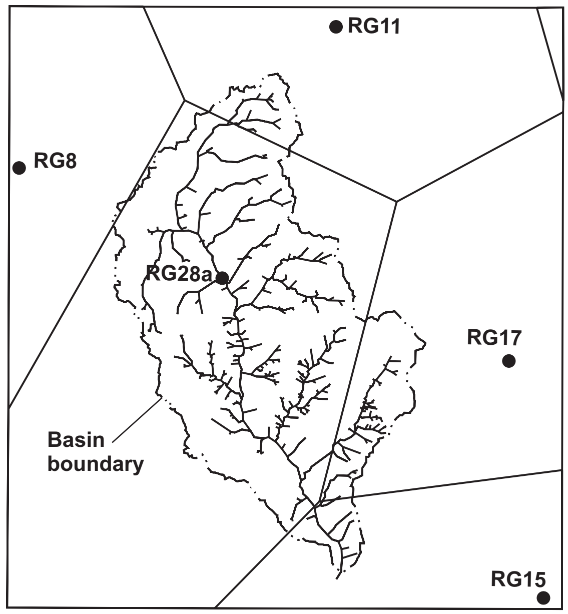


Figure 8. Rain-gage locations and the Thiessen polygons used to assess areal rainfall distribution in and near the Chenoweth Run Basin, Jefferson County, Kentucky.

Table 9. Percentage areal coverages of the basin by the rain gages based on Thiessen polygons at selected locations in the Chenoweth Run Basin, Jefferson County, Kentucky

[USGS, U.S. Geological Survey; RG, rain gage; %, percent; --, not applicable]

Site identifier (figure 7)	USGS station number	Location	Drainage area (acre)	Coverages by rain gages				
				RG 8 (%)	RG 11 (%)	RG 15 (%)	RG 17 (%)	RG 28a (%)
401	03298135	Chenoweth Run at Ruckriegel Parkway at Jeffersontown	3,445	0.3	14.3	--	--	85.4
16	03298150	Chenoweth Run at Gelhaus Lane	7,327	.1	6.7	--	--	93.2
403	03298160	Chenoweth Run at Seatonville Road	10,580	.1	4.6	3.9	11.4	80.0

Table 10. Statistical summary of the rainfall data collected at selected locations in and near the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[RG, rain gage; in., inch; NWS, National Weather Service; SD, standard deviation; CV, coefficient of variation (SD/mean)]

	Rain gage (see figure 8 and table 5)								Statistics (columns 2-6)		
Year/month	RG28a (in.)	RG8 (in.)	RG11 (in.)	RG15 (in.)	RG17 (in.)	RG35 (in.)	Standiford Field (in.)	NWS office (in.)	SD (in.)	Mean (in.)	CV
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1996/02	2.38	2.24	2.18	2.02	3.14	2.36	2.03	2.99	0.438	2.39	0.183
1996/03	5.58	5.5	4.98	5.75	5.66	5.36	4.99	6.54	.302	5.49	.055
Quarterly subtotals:	7.96	7.74	7.16	7.77	8.8	7.72	7.02	9.53	.592	7.88	.075
1996/04	6.22	6.32	6.29	5.04	5.45	6.41	5.65	6.37	.584	5.86	.100
1996/05	10.77	10.92	9.64	9.11	11.32	11.25	9.18	10.98	.933	10.35	.090
1996/06	4.35	3.82	4.53	5.76	4.91	4.25	3.84	5.21	.723	4.67	.155
Quarterly subtotals:	21.34	21.06	20.46	19.91	21.68	21.91	18.67	22.56	.707	20.89	.034
1996/07	5.07	4.88	6.16	5.71	6.69	5.51	2.86	5.11	.752	5.70	.132
1996/08	1.72	2.68	1.01	3.16	2.17	1.85	1.31	2.97	.835	2.15	.389
1996/09	5.64	6.46	6.43	5.64	6.00	6.00	5.66	6.55	.403	6.03	.067
Quarterly subtotals:	12.43	14.02	13.6	14.51	14.86	13.36	9.83	14.63	.943	13.88	.068
1996/10	2.42	2.15	2.17	2.37	2.54	2.6	2.59	2.42	.167	2.33	.072
1996/11	3.74	3.83	3.62	3.61	3.59	4.35	3.35	3.8	.103	3.68	.028
1996/12	5.04	5.24	4.94	5.11	5.51	4.89	4.56	5.47	.220	5.17	.043
Quarterly subtotals:	11.2	11.22	10.73	11.09	11.64	11.84	10.50	11.69	.326	11.18	.029
1997/01	3.88	3.54	3.71	3.95	4.36	4.16	3.35	3.57	.308	3.89	.079
1997/02	3.31	3.37	3.04	3.78	3.76	3.9	3.39	3.75	.316	3.45	.092
1997/03	13.15	12.9	12.99	14.17	16.83	13.33	12.58	17.52	1.658	14.01	.118
Quarterly subtotals:	20.34	19.81	19.74	21.9	24.95	21.39	19.32	24.84	2.194	21.35	.103
1997/04	2.00	1.90	2.00	1.93	2.23	2.13	2.01	2.23	.129	2.01	.064
1997/05	5.23	4.66	6.42	5.24	5.54	5.68	6.01	6.99	.644	5.42	.119
1997/06	9.82	9.70	7.65	10.31	8.14	10.57	8.11	8.15	1.158	9.12	.127
Quarterly subtotals:	17.05	16.26	16.07	17.48	15.91	18.38	16.13	17.37	.678	16.55	.041
1997/07	.68	1.05	1.93	.47	.14	.71	1.74	1.51	.686	.85	.804
1997/08	3.33	1.52	3.98	5.31	5.36	3.52	3.70	4.31	1.590	3.90	.408
1997/09	4.22	4.28	3.28	1.45	2.64	4.52	1.28	2.25	1.182	3.17	.372
Quarterly subtotals:	8.23	6.85	9.19	7.23	8.14	8.75	6.72	8.07	.919	7.93	.116
1997/10	1.35	1.57	1.61	1.6	1.45	1.46	1.41	1.43	.113	1.52	.074
1997/11	3.67	4.11	4.03	4.23	4.08	3.31	3.63	4.34	.211	4.02	.052
1997/12	2.75	2.75	2.88	2.81	2.59	3.19	2.50	3.32	.107	2.76	.039
Quarterly subtotals:	7.77	8.43	8.52	8.64	8.12	7.96	7.54	9.09	.351	8.30	.042
1998/01	3.82	3.79	4.04	3.94	4.13	4.3	2.88	4.68	.144	3.94	.037
Annual subtotal, 02/1996–01/1997:	56.81	57.58	55.66	57.23	61.34	58.99	49.37	61.98	2.147	57.72	.037
Annual subtotal, 02/1997–01/1998:	53.33	51.60	53.85	55.24	56.89	56.62	49.24	60.48	1.997	54.18	.037
Grand total, 02/1996–01/1998:	110.14	109.18	109.51	112.47	118.23	115.61	98.61	122.46	3.762	111.91	.034

Totals for the rain gage at the Standiford Field airport (about 10 mi west of the basin, fig. 2) tended to be lower than the totals at RG8, RG11, RG15, RG17, and RG28a. Totals for the NWS office in the southern part of the county (fig. 2) tended to be higher than totals measured near the basin. (The NWS office had a standard rain gage, whereas all others were tipping-bucket rain gages.) The normal annual precipitation (the mean for 1961–90) at Standiford Field was reported as 44.39 in. (National Climatic Data Center, 2000). The annual mean of the 24-month total rainfall at Standiford Field during the model calibration period exceeded the normal mean by 11 percent (table 10). Similarly, the wetter-than-normal conditions prevailed in the Chenoweth Run Basin during the model calibration period; mean-annual rainfall during the period was 55.07 in., approximately 11 in. above the long-term normal annual precipitation reported for Standiford Field. Calender year 1996 was reported as the wettest on record for Louisville, Ky., by the NWS (63.76 in. at the NWS office in southern Jefferson County, fig. 2).

Seventy-nine storms exceeding 0.4 in. at RG28a were identified (table 11). The standard deviation, mean, and CV (coefficient of variation) of the total storm rainfalls were computed; missing storm data are shown as dashes. CV had a median of 0.16 and mean of approximately 0.25. The spring and summer storms had the largest areal variability in rainfall. A CV value of less than or equal to 0.25 was used to classify the storms that had reasonably uniform areal distributions of rainfall. CV was less than or equal to 0.25 for 52 of these 79 storms. Review of temperature and snowfall records indicated that storm 5 occurred as rain, changing to snow, and storm 44 may have occurred on frozen ground, since the preceding overnight temperature was 15˚F. Thus, 50 rain storms were classified as uniform in areal distribution (excluding storms 5 and 44). The other 27 storms, which occurred mostly in spring and summer, were considered to have nonuniform areal distribution of rainfall.

The 50 storms classified as uniform were selected for use in model calibration and verification for the peak-flow periods. A split-sample approach was used to select the storms for model calibration: the 25 “odd” alternate storms (1, 3, 5...) taken in chronological order were selected as the model calibration storms and the other 25 “even” alternate storms (2, 4, 6...) were selected as the verification storms (table 11). The model calibration and verification storm sets were compared in terms of rainfall depth, average and maximum storm intensity, and antecedent 7-day rainfall. No statistically significant differences between the model calibration and verification storms were observed.

One of the model calibration storms (number 47) spanned the wettest day on record for the NWS in Louisville, Ky.—March 1, 1997—when 10.48 in. of rain fell at the NWS office in southern Jefferson County. Widespread flooding with loss of life occurred in Kentucky during this period; one drowning death occurred in Chenoweth Run Basin during the flood that resulted from this storm.

The continuous 5-minute and hourly rainfall time series at RG28a only were used for model simulations. The 5-minute simulation was used for comparison of observed and simulated storm volumes and peaks. The hourly simulation was used for comparison of hourly, daily, monthly, annual, and total flows and for calibration of suspended sediment and total orthophosphate transport.

Potential Evapotranspiration

Potential evapotranspiration (PET) for the model calibration period was estimated by use of available regional daily pan-evaporation data for the growing season (fig. 9 and table 5). Daily pan evaporation was estimated for the winter period by use of the Penman (1948) equation and daily meteorological data at Bowman Field (fig. 2 and table 5). The daily pan evaporation was disaggregated to hourly values by use of the USGS METCMP program. PET was estimated as 0.77 times the hourly disaggregated pan-evaporation values, based on data presented by Kohler and others (1959). Total estimated PET for the February 1996–January 1998 model calibration period was 70.30 in.—an annual mean of 35.15 in., which was below normal.

Table 11. Statistical summary of storm rainfall at selected locations in and near the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[RG, rain gage; in., inch; SD, standard deviation; CV, coefficient of variation (SD/mean); --, not available]

			Rain gage (see figure 8 and table 9)					Statistics		
Storm	Start date	End date	RG8 (in.)	RG11 (in.)	RG15 (in.)	RG17 (in.)	RG28a (in.)	SD (in.)	Mean (in.)	CV
[a]1	02/19/96	02/20/96	1.11	1.10	1.14	1.11	1.17	0.028	1.126	0.025
2	02/27/96	02/28/96	.50	.41	.45	1.40	.68	.411	.688	.598
[b]3	03/05/96	03/07/96	1.25	.95	1.67	1.43	1.35	.263	1.330	.198
[a]4	03/15/96	03/15/96	1.11	.93	.97	.83	.95	.101	.958	.105
[c]5	03/19/96	03/20/96	1.41	1.34	1.47	1.50	1.25	.101	1.394	.073
[b]6	03/31/96	04/02/96	1.11	1.07	1.11	.86	.86	.132	1.001	.132
[a]7	04/13/96	04/13/96	.64	.65	.55	.47	.50	.081	.562	.144
[b]8	04/20/96	04/20/96	1.15	1.04	1.26	1.11	.97	.110	1.106	.100
[a]9	04/22/96	04/24/96	1.09	1.42	1.19	1.15	1.70	.251	1.310	.192
10	04/28/96	04/30/96	1.97	1.79	.63	1.45	1.69	.524	1.506	.348
11	05/03/96	05/04/96	.93	.36	.30	--	1.23	.449	.704	.638
12	05/05/96	05/06/96	--	.54	.88	--	1.33	.396	.917	.432
[b]13	05/08/96	05/08/96	--	1.00	.74	--	.61	.199	.783	.255
14	05/10/96	05/11/96	--	2.66	1.12	--	1.33	.835	1.703	.490
[a]15	05/14/96	05/16/96	--	.90	.75	--	1.02	.134	.889	.150
16	05/26/96	05/26/96	--	1.18	2.40	--	1.53	.628	1.703	.369
17	05/27/96	05/27/96	--	1.31	.62	--	1.29	.393	1.073	.366
18	05/28/96	05/29/96	--	1.13	1.48	--	2.02	.448	1.543	.291
[b]19	06/02/96	06/02/96	--	.54	.56	--	.53	.014	.544	.027
20	06/06/96	06/07/96	.39	.61	1.28	1.16	.61	.387	.810	.479
21	06/08/96	06/09/96	1.01	1.30	2.39	1.86	1.22	.563	1.555	.362
22	06/10/96	06/11/96	1.23	1.03	.33	.76	.92	.339	.854	.397
23	07/02/96	07/03/96	.90	.62	.40	1.47	1.00	.406	.878	.463
24	07/07/96	07/08/96	.42	1.18	1.04	1.53	.69	.431	.972	.444
[a]25	07/14/96	07/15/96	--	1.94	1.63	1.77	1.61	.154	1.736	.089
26	07/21/96	07/21/96	--	.42	1.20	.68	.56	.340	.715	.476
27	07/29/96	07/29/96	--	1.07	.01	.30	.62	.454	.499	.909
28	08/08/96	08/08/96	.62	.14	1.32	1.42	.51	.549	.803	.684
29	08/21/96	08/21/96	.56	.00	.00	.23	.67	.310	.291	1.067
[b]30	09/09/96	09/09/96	.95	.50	.70	.90	.87	.184	.784	.235
[a]31	09/15/96	09/16/96	1.43	1.58	1.56	1.56	1.25	.140	1.476	.095
[b]32	09/21/96	09/21/96	.63	.64	.56	.65	.66	.039	.627	.062
[a]33	09/27/96	09/29/96	2.72	2.43	2.39	2.60	2.28	.175	2.484	.070
[b]34	10/17/96	10/18/96	1.09	1.02	1.11	1.29	1.23	.109	1.147	.095
[a]35	11/07/96	11/09/96	.61	.65	.78	.91	.76	.118	.742	.159
[b]36	11/25/96	11/26/96	1.31	1.12	1.02	.83	1.05	.174	1.065	.163
[a]37	11/29/96	12/01/96	1.35	1.32	1.25	1.29	1.33	.039	1.308	.030
[b]38	12/12/96	12/12/96	--	1.00	1.02	1.19	.96	.102	1.042	.097
[a]39	12/16/96	12/18/96	--	1.92	1.98	2.13	1.88	.110	1.978	.055
[b]40	12/23/96	12/24/96	--	1.14	1.46	1.35	1.26	.136	1.303	.104
[a]41	01/04/97	01/06/97	--	.61	.61	.60	.55	.028	.593	.048
42	01/22/97	01/23/97	.45	.40	.57	.69	.86	.185	.593	.311
[b]43	01/24/97	01/25/97	.64	.66	.89	.92	.66	.139	.753	.185

Table 11. Statistical summary of storm rainfall at selected locations in and near the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998—*Continued*

[RG, rain gage; in., inch; SD, standard deviation; CV, coefficient of variation (SD/mean); --, not available]

			Rain gage (see figure 8 and table 9)					Statistics		
Storm	Start date	End date	RG8 (in.)	RG11 (in.)	RG15 (in.)	RG17 (in.)	RG28a (in.)	SD (in.)	Mean (in.)	CV
[c]44	01/27/97	01/29/97	1.44	1.53	1.38	1.61	1.33	0.113	1.458	0.078
[a]45	02/03/97	02/05/97	1.14	1.16	1.71	1.36	1.24	.234	1.321	.177
[b]46	02/26/97	02/26/97	.43	.46	.41	.49	.48	.033	.453	.072
[a]47	02/28/97	03/02/97	8.48	8.40	8.85	11.47	8.78	1.286	9.196	.140
[b]48	03/03/97	03/04/97	.86	.82	.99	1.19	.85	.154	.941	.164
[a]49	03/09/97	03/11/97	.47	.41	.55	.53	.46	.057	.483	.118
[b]50	03/13/97	03/15/97	.51	.48	.49	.51	.42	.038	.482	.079
[a]51	03/18/97	03/19/97	1.95	1.75	2.22	2.31	1.93	.229	2.032	.113
[b]52	03/25/97	03/26/97	.52	.59	.69	.76	.53	.104	.618	.168
[a]53	03/28/97	03/29/97	.98	1.02	.83	.79	.81	.106	.886	.120
[b]54	04/27/97	04/28/97	.45	.47	.54	.57	.50	.049	.507	.097
[a]55	05/02/97	05/03/97	1.25	1.19	1.05	1.41	1.20	.130	1.219	.106
[b]56	05/08/97	05/09/97	.98	.87	.82	.90	.78	.077	.870	.089
57	05/19/97	05/20/97	.28	.45	.36	.61	.45	.123	.429	.286
58	05/24/97	05/26/97	.99	2.40	1.47	1.41	1.41	.520	1.535	.339
59	05/28/97	05/29/97	.07	.77	.42	.66	.82	.308	.547	.562
[a]60	05/30/97	06/02/97	1.24	.93	--	.91	.80	.189	.970	.195
[b]61	06/08/97	06/09/97	.92	1.02	1.32	1.14	1.30	.174	1.140	.152
[a]62	06/13/97	06/13/97	--	2.07	--	2.59	2.18	.275	2.279	.121
63	06/16/97	06/16/97	--	.85	--	1.64	1.96	.570	1.482	.385
[b]64	06/17/97	06/18/97	--	1.73	--	1.11	1.43	.310	1.422	.218
65	06/21/97	06/21/97	--	.31	--	.15	1.23	.580	.562	1.033
66	07/23/97	07/24/97	.00	.93	.30	.04	.42	.375	.338	1.110
67	08/09/97	08/09/97	.74	2.49	2.91	3.35	1.89	1.014	2.276	.445
68	08/19/97	08/20/97	.26	.51	.77	.67	.43	.201	.528	.380
69	09/09/97	09/10/97	--	2.61	.72	1.65	3.37	1.152	2.088	.552
[a]70	10/13/97	10/14/97	.75	.67	.74	.58	.57	.085	.662	.129
[b]71	10/24/97	10/24/97	.63	.71	.77	.74	.64	.062	.697	.089
[a]72	11/01/97	11/02/97	.79	.82	.55	.55	.66	.128	.673	.191
[b]73	11/13/97	11/14/97	.80	.88	.96	.91	.76	.081	.862	.094
[a]74	11/21/97	11/23/97	.55	.53	.69	.7	.52	.089	.599	.148
[b]75	11/29/97	12/01/97	1.70	1.55	1.71	1.61	1.52	.086	1.618	.053
[a]76	12/09/97	12/10/97	.78	.83	.85	.77	.83	.035	.811	.043
[b]77	12/21/97	12/22/97	.65	.70	.63	.67	.62	.033	.654	.050
[a]78	12/24/97	12/25/97	.88	.93	1.03	.76	.82	.104	.883	.118
[b]79	01/05/98	01/09/98	3.12	3.31	3.03	3.20	3.07	.111	3.146	.036
										Mean: .256
										Median: .159

[a]Calibration storm.
[b]Verification storm.
[c]Nonrepresentative storm affected by snow and (or) ice.

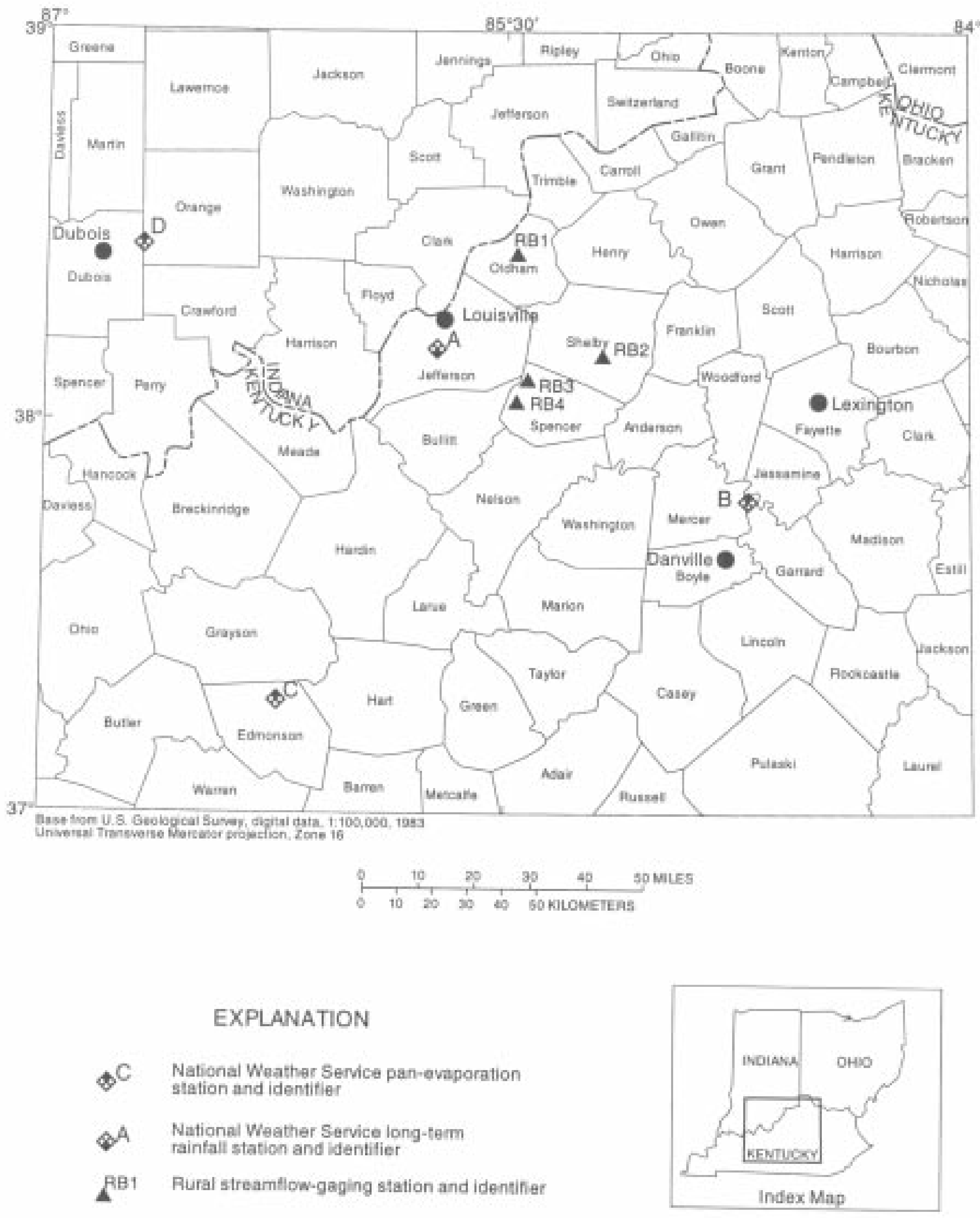


Figure 9. Approximate locations of the long-term precipitation, evaporation, and streamflow-gaging stations in Kentucky and Indiana, used or referenced in the study. [see table 5]

PET was estimated from the pan-evaporation data because NWS calculated values of PET at Standiford Field and Bowman Field appeared abnormally low in 1997: 28.46 in. at Standiford Field, which was almost 14 in. below the mean annual PET (42.2 in.) during the available period of record (1949–97) and 8.5 in. below the lowest of all previous annual PET values during the period of record. NWS calculated PET at Standiford Field totaled 67.56 in. for the full model calibration period, February 1996–January 1998, just 2.74 in. less than the PET estimated from the pan-evaporation data. These unusually low pan-evaporation and PET values, though seemingly contrary to the above-normal rainfall amounts, may have been a consequence of the unusual intensity and seasonal distribution of the rainfall in 1997. Annual moisture delivered in intense, flooding rainfalls that flowed quickly out of the basin during storms in certain periods of the year was not available for evapotranspiration at other times of the year. Indeed, rainfall in March 1997 accounted for 23 percent of the annual total for 1997, and rainfall in the months of March, May, and June accounted for 50 percent of the annual total for 1997 (table 11). A more uniform distribution of rainfall than this, which would be available for potential evapotranspiration evenly throughout the growing season, has been the typical pattern for the region (fig. 3).

Trends in the regional pan-evaporation data were not investigated. The paradoxical relation between increased precipitation and reported decreasing pan evaporation is discussed further by Brutsaert and Parlange (1998).

Wastewater-Treatment-Plant Effluents

Three permitted WWTP’s are in the Chenoweth Run Basin (fig. 7). Jeffersontown WWTP, the largest in the basin, had approximately 4,600 residential, 670 commercial, and 40 industrial sewer-service connections and had a treatment capacity of 4 Mgal/d. This plant provides wastewater treatment for the commercial and industrial customers in the Bluegrass Industrial Park located in the upper third of the basin. Two small plants, Chenoweth Hills WWTP and Lake of the Woods WWTP, serve residential communities farther downstream. These plants have treatment capacities of 0.2 and 0.04 Mgal/d, respectively. All three plants provide secondary-level (microbial) treatment of wastewater. MSD assumed responsibility for operation of these WWTP’s after acquisition from the original municipal or private owner-operators.

The Jeffersontown WWTP had been identified as a source of excess nutrients contributing to eutrophication of the stream and had been subject to periodic capacity exceedences that cause overflows of untreated or undertreated wastewater to the stream. Inflows to the plant during and following storms were estimated to be two to four times the design treatment capacity of 4 Mgal/d (Wade, 1999). The Jeffersontown WWTP was upgraded following the data-collection period for this study; a phosphorus-removal process and an ultraviolet-disinfectant unit were added. Also, work was done to reduce the rainwater inflows to the sanitary-sewer system. Typical nutrient concentrations associated with municipal wastewater influent and effluent, as reported by Thomann and Mueller (1987), are shown in table 12.

Table 12. Mean nutrient concentrations in municipal wastewaters

[mg/L, milligrams per liter; --, not available; from Thomann and Mueller, 1987, p. 391]

Nutrient form	Influent (mg/L)	Conventional secondary treatment effluent (mg/L)	After phosphorus removal processes (mg/L)
Phosphorus (as P)			
Total phosphorus with detergent	5–10	7	1–3
Total phosphorus without detergent	2–5	4	--
Total orthophosphate with detergent	2–5	5	1–2
Nitrogen (as N)			
Total nitrogen	50	18	14
Inorganic nitrogen	30	8	7

Discharge

Daily WWTP effluent discharge data were obtained from MSD by use of monthly discharge-monitoring reports to the KNREPC–KDOW. At the Jeffersontown WWTP, total effluent discharge included (1) the through-plant flow released by the principal effluent pipe and (2) bypass flow at an overflow point approximately 1,000 ft upstream from the principal effluent pipe. Bypass flows occurred during and following rain storms of about 0.5 in. or greater when infiltration and inflows to the sanitary-sewer system caused the WWTP inflow capacity to be exceeded. As a consequence, some untreated wastewater bypassed the WWTP and was discharged directly to the stream. Bypass flows, though not directly measured at the plant, were estimated to have occurred at a constant rate of 7.74 ft^3/s (5 Mgal/d) (Cliff Bristow, Louisville and Jefferson County Metropolitan Sewer District, oral commun., 1998) for the bypass periods (59 days) listed in the monthly discharge-monitoring reports.

Measured daily through-plant flows were not available at the Jeffersontown WWTP for the period July 2–October 7, 1997, during a repair of the effluent-flow meter. Therefore, daily through-plant flow during this period of missing data was estimated on the basis of regressions relating observed daily through-plant flow to daily mean flow at the streamflow-gaging station downstream from the WWTP's at Gelhaus Lane (figs. 10 and 11).

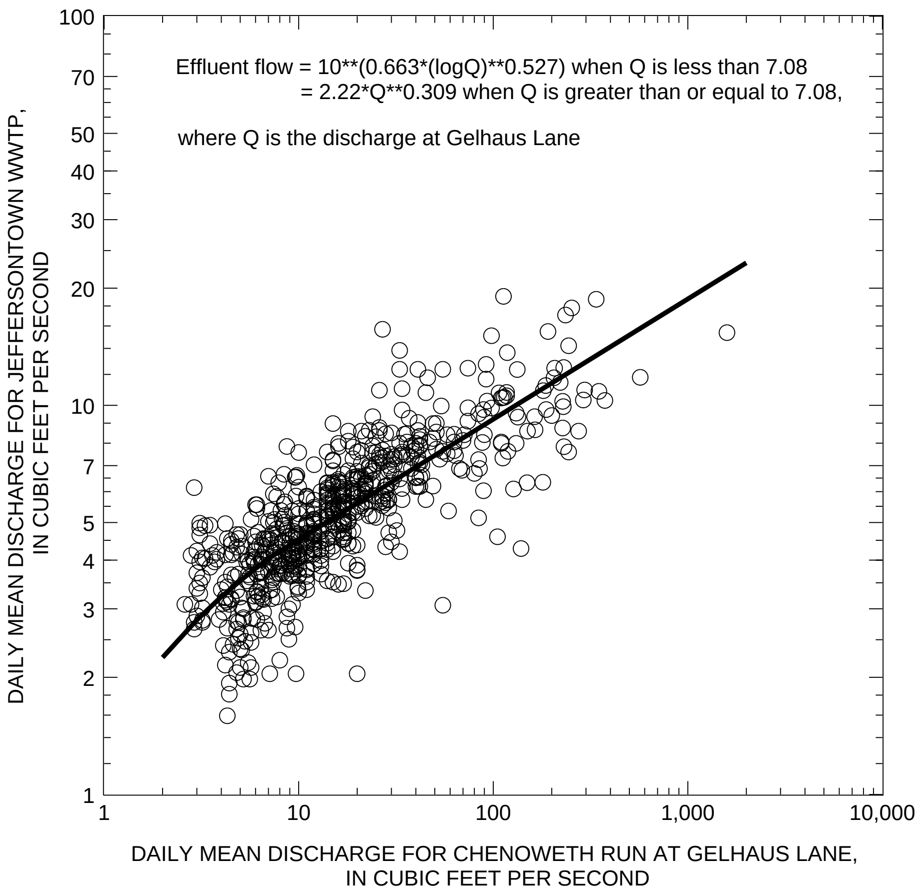


Figure 10. Scatterplot and regression for daily mean discharges at the Jeffersontown Wastewater-Treatment Plant (WWTP) and Chenoweth Run at Gelhaus Lane, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

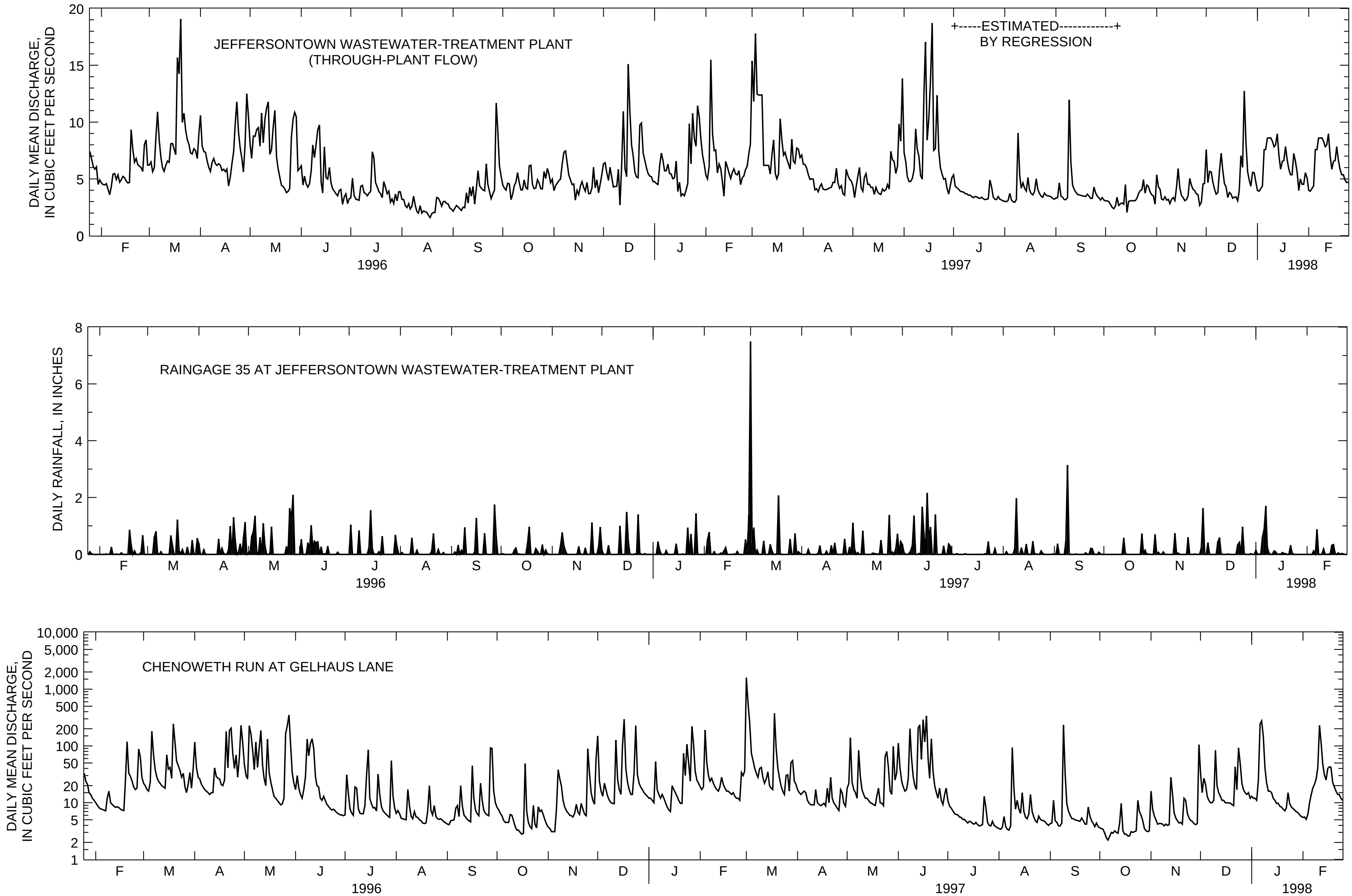


Figure 11. Daily mean discharge at the Jeffersontown Wastewater-Treatment Plant and at Chenoweth Run at Gelhaus Lane, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

Continuous through-plant effluent-discharge records at the Jeffersontown WWTP were incomplete and such continuous records were unavailable at one of the minor WWTP's. Representative hourly WWTP effluent flow rates were needed for developing the basin hydrologic model; therefore, hourly through-plant effluent flows were estimated by use of the daily through-plant flows and estimates of the typical hourly distribution of the daily through-plant flows. The typical hourly distribution of the total daily through-plant flows were estimated by averaging the observed hourly distributions of flow (figs. 12 and 13) during selected, representative, dry-weather flow periods at the Jeffersontown and Chenoweth Hills WWTP's (table 13). Continuous-flow-meter records were not available for the Lake of the Woods WWTP; therefore, the hourly distributions of daily flow observed at Chenoweth Hills were assumed adequately representative for the Lake of the Woods WWTP, as well.

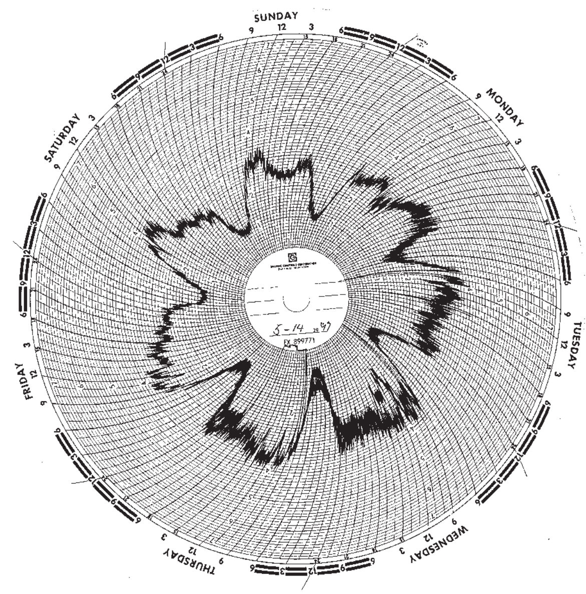


Figure 12. Circular-chart record of 7-day through-plant effluent discharge from Jeffersontown Wastewater-Treatment Plant, Jefferson County, Kentucky.

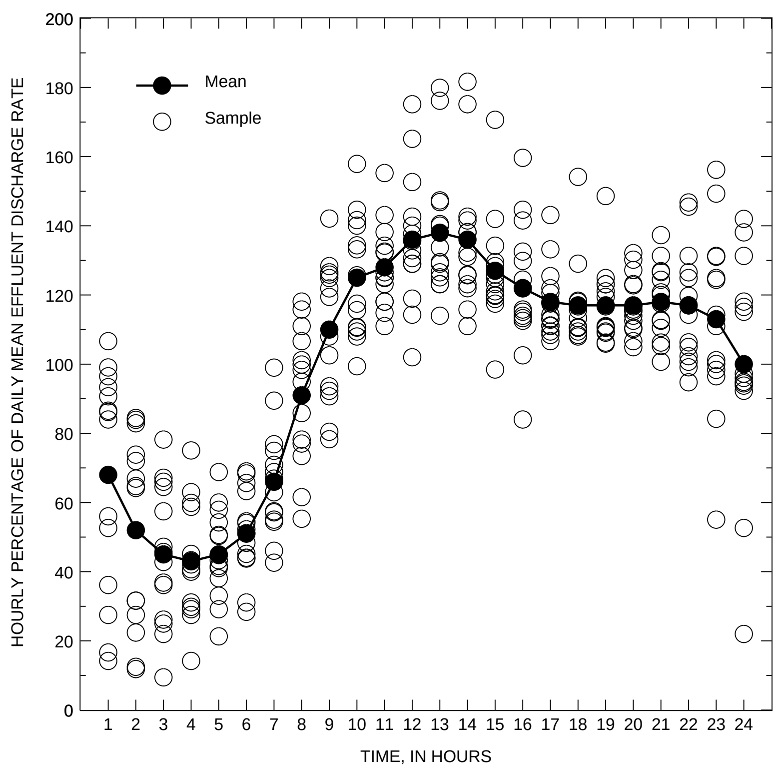


Figure 13. Sample and mean hourly percentages of daily mean effluent discharge at the Jeffersontown Wastewater-Treatment Plant, Jefferson County, Kentucky.

Table 13. Estimated typical hourly through-plant effluent-discharge rates at the Jeffersontown and Chenoweth Hills Wastewater-Treatment Plants in the Chenoweth Run Basin, Jefferson County, Kentucky

Time (hour)	Percentage of daily mean discharge rate	
	Jeffersontown	Chenoweth Hills
1	68	65
2	52	41
3	45	37
4	43	34
5	45	35
6	51	68
7	66	154
8	91	145
9	110	121
10	125	114
11	128	100
12 (noon)	136	104
13	138	100
14	136	89
15	127	97
16	122	104
17	118	101
18	117	118
19	117	128
20	117	123
21	118	143
22	117	153
23	113	133
24 (midnight)	100	93

In the case of the two minor WWTP's, the reported total daily flows were based on once-a-day observations of flow rate, which varies during each day. The reported total daily flows were adjusted systematically (generally decreased) to compensate for the variation in the time of day at which the single daily observation of flow was made.

Suspended Solids

Effluent loadings of total suspended solids (considered essentially equivalent to suspended sediment in this study) were estimated by use of relevant wastewater-discharge and water-quality-sampling data. At the Jeffersontown WWTP, periodic total suspended-solids analyses (299 samples) of the effluent were available throughout the model calibration period. Both influent and effluent suspended-solids concentrations indicated only a weak correlation with the daily effluent discharge rate; therefore, daily suspended-solids concentrations were estimated by linear interpolation of concentrations between the available sampling dates. Total suspended-solids effluent loads were estimated as the interpolated solids concentration times the daily flow. Estimated through-plant total suspended-solids loads ranged between 0.0006 to 1.28 ton/d and averaged 0.064 ton/d. Estimated bypass loads from the Jeffersontown WWTP ranged between 0.04 to 2.54 ton/d and averaged 0.96 ton/d during the 59 days that bypass flows were reported to have occurred.

At the two smaller WWTP's, monthly total suspended-solids sample concentrations and loading estimates were available from MSD discharge-monitoring reports. Daily total suspended-solids loadings were estimated as a uniform daily average of the reported monthly loads. For model application, hourly total suspended-solids loadings were estimated as a uniform hourly average of the estimated daily loads.

The combined annual and mean-annual model calibration period estimated loadings of total suspended solids in the WWTP effluents were determined (table 14).

Table 14. Estimated annual total suspended-solids loads in wastewater-treatment-plant effluents in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[WWTP, wastewater-treatment plant]

Period	Jeffersontown WWTP Through-plant (tons)	Jeffersontown WWTP Bypass (tons)	Chenoweth Hills WWTP (tons)	Lake of the Woods WWTP (tons)	Total (tons)
02/1996-01/1997	25.4	19.5	3.92	0.55	49.3
02/1997-01/1998	18.5	25.0	3.58	.62	47.7
Mean	21.9	22.3	3.75	.58	48.5

Total Phosphorus (TP)

The Jeffersontown WWTP daily through-plant and bypassed TP loads were estimated by use of the approximately bimonthly, 24-hour-composite-sample (approximately 200 mL drawn every 15 minutes) data reported by MSD (table 15). To obtain daily through-plant TP load estimates from the bimonthly samples, the 45 bimonthly sample concentrations were regressed with the daily WWTP effluent discharge. The effluent TP concentrations were inversely correlated ($r^2 = 0.43$) with the log of effluent discharge (Q). That is, when effluent discharge increased, the TP concentration decreased, probably because of dilution. Daily TP concentrations were calculated as $TP = 10.71 - 3.91 \, Log \, Q$ (fig. 14). Errors calculated as the difference between discharge-regression-estimated TP concentrations and observed TP concentrations indicate a mean error of 16 percent and a root mean square error of 53 percent. Estimated daily through-plant effluent TP loads ranged from 23 to 70 lb P/d and averaged 62 lb P/d.

TP concentration in the bypassed flow was estimated from three influent samples that were available when bypass flows were reported to have occurred. Daily TP load estimates during periods of bypassed flow (Q_B) were calculated by the relation $TP = 6.39 - 2.34 Log \, Q_B$ (fig. 14), which also indicates an inverse relation between TP concentration and discharge. Estimated daily bypass TP loads ranged from 7.5 to 45 lb P/d and averaged 34 lb P/d during the 59 days bypass flows that were reported to have occurred during March 1996–February 1998.

Phosphorus sampling data were unavailable for the minor WWTP's. Therefore, effluent TP loads were estimated by use of a typical TP effluent concentration (5.7 mg/L) for WWTP's of similar treatment level (Thomann and Mueller, 1987; Hammer, 1975; and Leist and others, 1990). Estimated daily minor WWTP effluent TP loads ranged from 0.98 to 28 lb P/d at Chenoweth Hills and 0.26 to 4.8 lb P/d at Lake of the Woods. TP loads averaged 6.7 lb P/d at Chenoweth Hills and 0.99 lb P/d at Lake of the Woods.

The combined annual and mean-annual model calibration period estimated loadings of total phosphorus in the WWTP effluents were determined (table 16).

Total Orthophosphate (TPO_4)

The Jeffersontown WWTP daily through-plant and bypassed TPO_4 loads were also estimated by use of the phosphorus-sampling data reported by MSD (table 15). In 1996, only TP concentrations were reported, but 22 samples of both TP and TPO_4 reported in 1997–98 indicated these constituents were highly correlated ($r^2 = 0.97$). Thus, TP concentrations were used to estimate by regression the TPO_4 concentrations for the samples collected in 1996 ($TPO_4 = TP * 0.99 - 0.19$) (fig. 15). A large portion (approximately 90 percent) of the total phosphorus content for the Jeffersontown WWTP

Table 15. Influent and effluent phosphorus concentrations reported for the Jeffersontown Wastewater-Treatment Plant, Jefferson County, Kentucky

[ft^3/s, cubic foot per second; mg/L, milligrams per liter; P, phosphorus; --, not available; *, outlier, not used in regressions]

Date	Effluent daily discharge (ft^3/s x hours)	Influent Total phosphorus (mg/L as P)	Influent Total orthophosphate (mg/L as P)	Effluent Total phosphorus (mg/L as P)	Effluent Total orthophosphate (mg/L as P)
02/07/1996	105.09	--	--	2.12	--
02/22/1996	163.02	--	--	1.19	--
03/07/1996	201.63	--	--	1.38	--
03/22/1996	258.82	1.54	--	1.31	--
04/05/1996	157.07	2.73	--	1.30	--
04/19/1996	123.65	2.35	--	1.69	--
05/08/1996	259.19	2.64	--	.96	--
05/21/1996	--	4.80	--	*.10	--
06/06/1996	110.29	5.90	--	2.51	--
06/20/1996	99.15	5.28	--	2.66	--
07/08/1996	106.20	4.91	--	3.69	--
07/19/1996	88.75	6.29	--	3.11	--
08/07/1996	62.01	5.05	--	2.21	--
08/21/1996	49.02	6.15	--	3.69	--
09/06/1996	53.10	7.24	--	4.21	--
09/19/1996	96.55	3.63	--	2.27	--
10/08/1996	105.46	5.00	--	3.61	--
10/21/1996	100.63	4.37	--	2.89	--
11/07/1996	176.38	4.65	--	3.85	--
11/21/1996	112.51	5.04	--	4.03	--
12/06/1996	124.03	3.50	--	2.63	--
12/19/1996	167.84	3.73	--	1.31	--
01/07/1997	137.02	3.59	2.97	2.19	2.14
01/22/1997	236.54	5.04	2.96	3.25	3.18
02/06/1997	179.73	*38.4	*11.4	3.26	3.26
02/21/1997	137.77	3.72	2.82	2.50	2.15
03/06/1997	297.07	2.41	1.65	1.53	1.11
03/21/1997	176.01	1.89	1.74	1.35	--
04/07/1997	119.57	3.63	2.24	1.76	1.52
04/21/1997	142.59	3.05	1.80	2.14	1.48
05/07/1997	93.95	5.91	4.44	3.01	3.01
05/22/1997	108.06	5.23	3.84	3.65	3.34
06/05/1997	114.74	3.50	2.28	2.54	2.32
06/19/1997	180.10	1.12	.613	.725	.680
07/08/1997	88.96	7.73	5.57	3.90	3.41
07/21/1997	77.21	7.41	5.24	3.56	3.51
08/07/1997	70.67	8.02	5.05	4.43	4.19
08/21/1997	97.04	4.41	2.16	2.71	2.55
09/05/1997	81.27	5.72	4.55	2.41	2.41
10/07/1997	62.70	6.14	4.78	4.65	4.46
10/21/1997	89.12	6.01	3.90	3.43	3.25
11/06/1997	82.06	7.21	4.76	3.83	2.10
11/20/1997	84.29	6.36	3.34	2.59	2.17
12/05/1997	113.63	3.59	2.04	1.06	1.05
01/08/1998	206.09	.99	.61	.59	.45
01/22/1998	128.85	4.63	2.57	1.92	1.51

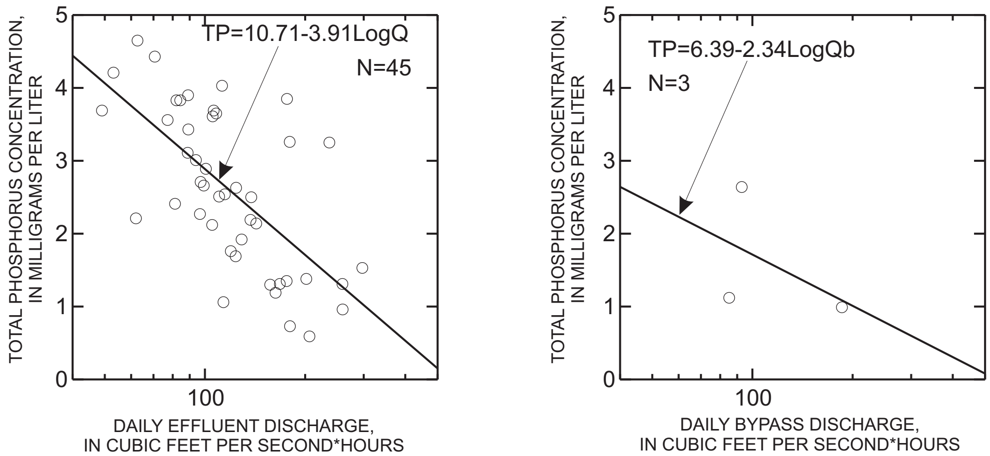


Figure 14. Comparison and regression relations of total phosphorus concentrations to daily effluent discharge, and total phosphorus concentrations to bypassed-wastewater discharge from the Jeffersontown Wastewater-Treatment Plant, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

Table 16. Estimated annual total phosphorus loads in wastewater-treatment-plant effluents in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[WWTP, wastewater-treatment plant; lb, pound; P, phosphorus]

Period	Jeffersontown WWTP Through-plant (lb as P)	Jeffersontown WWTP Bypass (lb as P)	Chenoweth Hills WWTP (lb as P)	Lake of the Woods WWTP (lb as P)	Total (lb as P)
02/1996-01/1997	25,200	796	2,320	399	28,700
02/1997-01/1998	24,100	853	2,670	331	28,000
Mean	24,600	824	2,500	365	28,300

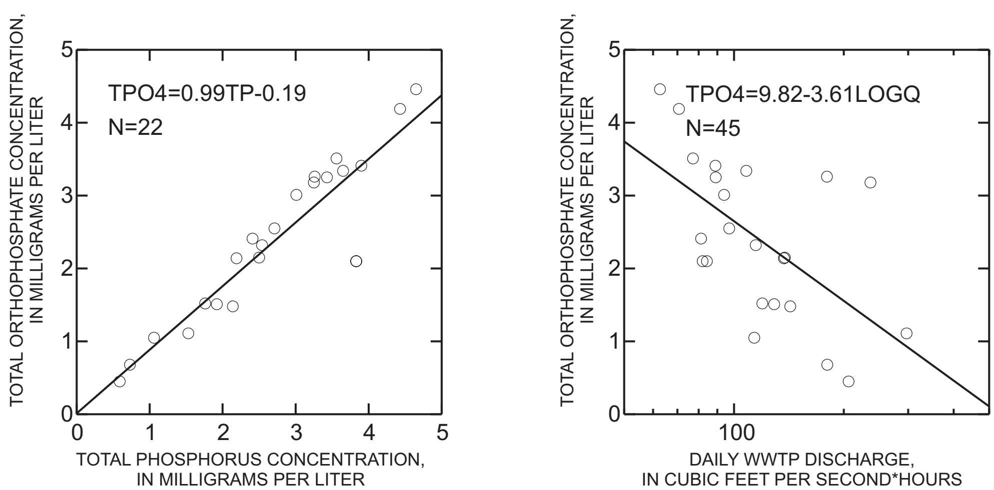


Figure 15. Comparison and regression relations of total phosphorus concentrations to total orthophosphate concentrations, and total orthophosphate concentrations to effluent discharged from the Jeffersontown Wastewater-Treatment Plant (WWTP), Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

effluent was the orthophosphate form (table 15). Also, effluent sampling data collected in 1995 indicated that dissolved phosphorus concentration was on average about 94 percent of the total phosphorus concentration. Thus, most of the phosphorus content of this wastewater was typically in the dissolved orthophosphate form.

To obtain daily through-plant TPO_4 load estimates from the bimonthly samples, the 45 bimonthly sample concentrations were regressed with the daily WWTP effluent discharge. The effluent TPO_4 concentrations were moderately inversely correlated ($r^2 = 0.39$) with the log of effluent discharge (Log Q). That is, when effluent discharge increased, the TPO_4 concentration decreased, probably because of dilution. Daily TPO_4 concentrations were calculated as $TPO_4 = 9.82 - 3.61 \text{ Log } Q$ (table 17 and fig. 15). Errors calculated as the difference between discharge-regression-estimated TPO_4 concentrations and observed TPO_4 concentrations (including the "observed" TPO_4 concentrations estimated by regression with TP) indicate a mean error of 19 percent and a root mean square error of 57 percent. Estimated daily effluent TPO_4 loads ranged from 22 to 68 lb P/d and averaged 60 lb P/d.

TPO_4 concentration in the bypassed flow was estimated from three influent samples that were available when bypass flows were reported to have occurred. One of the influent samples was obtained in 1996 when TPO_4 was not analyzed. The influent TPO_4 concentration for this sample was estimated from the relation of 23 influent samples of both TP and TPO_4 reported in 1997–98. Again, influent TPO_4 concentrations are highly correlated ($r^2 = 0.90$) with influent TP concentrations ($TPO_4 = TP * 0.68 - 0.05$) (fig. 16). Daily TPO_4 load estimates during periods of bypassed flow (Q_B) were calculated by the relation $TPO_4 = 3.93 - 1.43 \text{ Log } Q_B$ (fig. 16), which also indicates an inverse relation between TPO_4 concentration and discharge. Estimated daily bypass TPO_4 loads ranged from 6.8 to 30 lb P/d and averaged 25 lb P/d during the 59 days bypass flows that were reported to have occurred during March 1986–February 1998.

Phosphorus sampling data were unavailable for the minor WWTP's. Therefore, effluent TPO_4 loads were estimated by use of a typical TPO_4 effluent concentration (5.5 mg/L) for WWTP's of similar treatment level (Thomann and Mueller, 1987; Hammer, 1975; and Leist and others, 1990). Estimated daily minor WWTP effluent TPO_4 loads ranged from 0.95 to 27 lb P/d at Chenoweth Hills and 0.25 to 4.6 lb P/d at Lake of the Woods. TPO_4 loads averaged 6.5 lb P/d at Chenoweth Hills and 0.96 lb P/d at Lake of the Woods.

The combined annual and mean-annual model calibration period estimated loadings of total orthophosphate in the WWTP effluents were determined (table 18).

Streamflow

The water budget (table 19) at the Ruckriegel Parkway and Gelhaus Lane sites on Chenoweth Run reflects the wetter-than-normal conditions during much of the 24-month data-collection period.

Table 17. Statistical summary of observed and estimated daily mean effluent total orthophosphate (TPO_4) concentrations at the Jeffersontown Wastewater-Treatment Plant, Jefferson County, Kentucky

Statistic	Through-plant effluent (in milligrams per liter)		Bypass effluent (in milligrams per liter)	
	Observed[a]	Estimated	Observed	Estimated
Number	45	763	3	59
Mean	2.32	2.32	1.16	1.54
Minimum	.45	.22	.61	.66
Maximum	4.46	4.11	1.75	3.93

[a]TPO_4 concentrations for 22 samples were estimated by regression with total phosphorus concentrations.

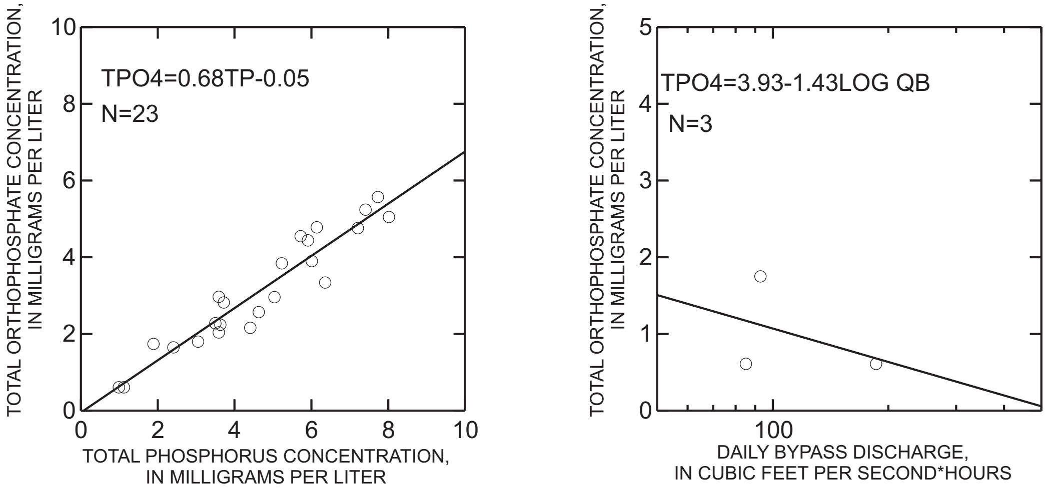


Figure 16. Comparison and regression relations of total phosphorus concentrations to total orthophosphate concentrations, and total orthophosphate concentrations to bypassed-wastewater discharge upstream from the Jeffersontown Wastewater-Treatment Plant, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

Table 18. Estimated annual total orthophosphate loads in wastewater-treatment-plant effluents in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[WWTP, wastewater-treatment plant; lb, pound; P, phosphorus]

Period	Jeffersontown WWTP		Chenoweth Hills WWTP (lb as P)	Lake of the Woods WWTP (lb as P)	Total (lb as P)
	Through-plant (lb as P)	Bypass (lb as P)			
02/1996-01/1997	22,000	595	2,240	386	25,200
02/1997-01/1998	21,500	658	2,580	319	25,100
Mean	21,800	626	2,410	352	25,200

Table 19. Annual water budget for the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[WWTP, wastewater-treatment plant; ---, not applicable; percentages reflect combined inflows to the basin as precipitation and wastewater effluents]

Period	Rainfall (inches)	WWTP effluent (inches)	Total streamflow		Estimated evapotranspiration and other losses	
			Inches	Percent	Inches	Percent
Chenoweth Run at Ruckriegel Parkway						
02/1996–01/1997	56.81	---	34.71	61	22.10	39
02/1997–01/1998	53.33	---	35.60	67	17.73	33
Mean	55.07	---	35.16	64	19.91	36
Chenoweth Run at Gelhaus Lane						
02/1996–01/1997	56.81	7.23	36.06	56	27.98	44
02/1997–01/1998	53.33	6.79	35.34	59	24.78	41
Mean	55.07	7.01	35.70	58	26.38	42

Mean-annual rainfall during the period was 55.07 in., approximately 11 in. above the long-term normal annual precipitation reported for Standiford Field. The WWTP inflows to the stream (an interbasin transfer of water supplies withdrawn from the Ohio River) contributed the equivalent of about 7 in. of water on the basin annually, or approximately 20 percent of all the water that entered the basin upstream from the Gelhaus Lane site. The WWTP's provided the majority of flow in the stream at times during low-flow periods. The relative proportions of water leaving the basin as streamflow and evapotranspiration (about 60 percent as streamflow and 40 percent as evapotranspiration and other losses) were almost reversed from the normal proportions for this region, which are about 40 percent as streamflow and 60 percent as evapotranspiration).

Though rainfall and discharge were above normal for much of the period, there were wide variations in the flow regime (figs. 17 and 18). The record flood discharges in March 1997 (which scoured much of the bedrock main-channel bottom clean) were followed by low base flows in late summer and early fall of 1997. Urban development and the associated impervious land cover, which was most dense in the upper portion of the basin upstream from the gage at Ruckriegel Parkway, will, in the absence of storm-water-control measures, typically tend to increase the volumes and rates of streamflow during storms (compared to predevelopment conditions), and streamflow recession and base flows may consequently be decreased.

Base-flow measurements available in the basin (table 20) indicated possible losing-stream conditions during low-flow periods. Some base-flow losses were hypothesized and represented in the calibrated basin model (see “Base-Flow Losses”).

Water Quality

Water quality can be described in several ways, and it is affected by many factors. Although this study focused primarily on aspects of sedimentation and eutrophication processes in the Chenoweth Run Basin, many other physical and chemical characteristics (table 3) were determined for water samples. Data compilation included approximately 8,500 physical- and chemical-parameter determinations for discrete water samples collected at seven sampling sites (fig. 7) during 1988–97. Data were also compiled for over 230,000 continuous-record determinations of stream temperature, specific conductance, pH, and dissolved-oxygen concentration measurements made at 30-minute intervals at the Ruckriegel Parkway and Gelhaus Lane sites during 1996–97.

A total of 103 discrete environmental water samples were collected in 1996–97 over a wide range of flows in each season of the year at the four sampling sites on the main channel (fig. 7). The distribution of samples collected in 1996–97 at the two gaging stations is shown in figures 17 and 18. During the full sampling period, which extends back to 1988 at Gelhaus Lane, water-quality samples have been collected for daily mean discharges of 117 ft^3/s at Ruckriegel Parkway and approximately 300 ft^3/s at Gelhaus Lane. These sampled discharges exceed flow durations of 2 percent and 1 percent, respectively, at these sites.

A statistical summary (Appendix 4) indicates large variability in some measurements, several orders of magnitude of variation in selected cases. Much of this variability in water quality derives from variations of the influx of the water, chemical constituents, and solar radiation into the stream. Daily variations of discharge, water temperature, specific conductance, pH, and dissolved-oxygen concentration at the Ruckriegel Parkway and Gelhaus Lane sites for February 1996–September 1997 are shown in figures 19 and 20.

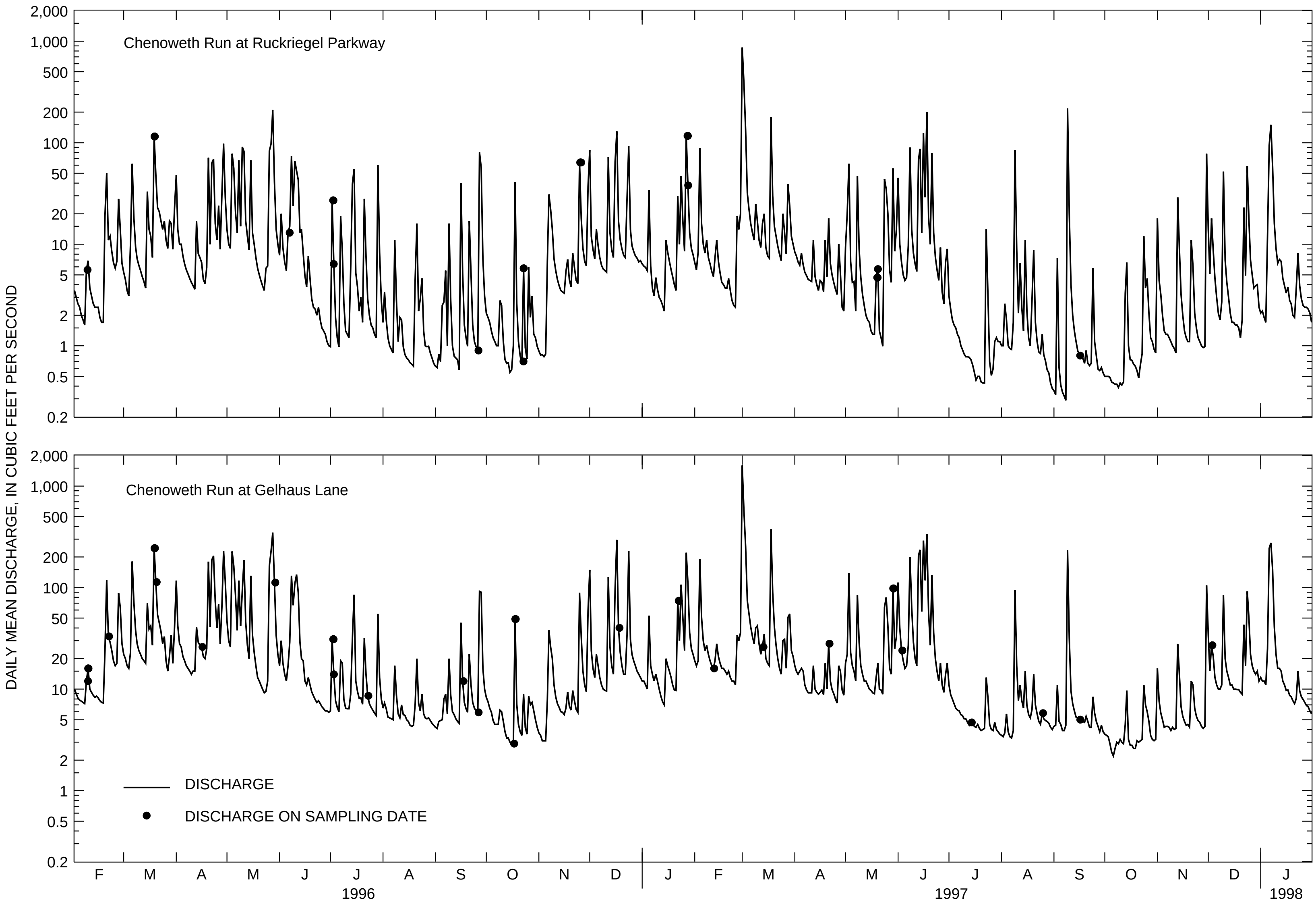


Figure 17. Daily mean discharge and discharge on sampling dates at Chenoweth Run at Ruckriegel Parkway and at Gelhaus Lane, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

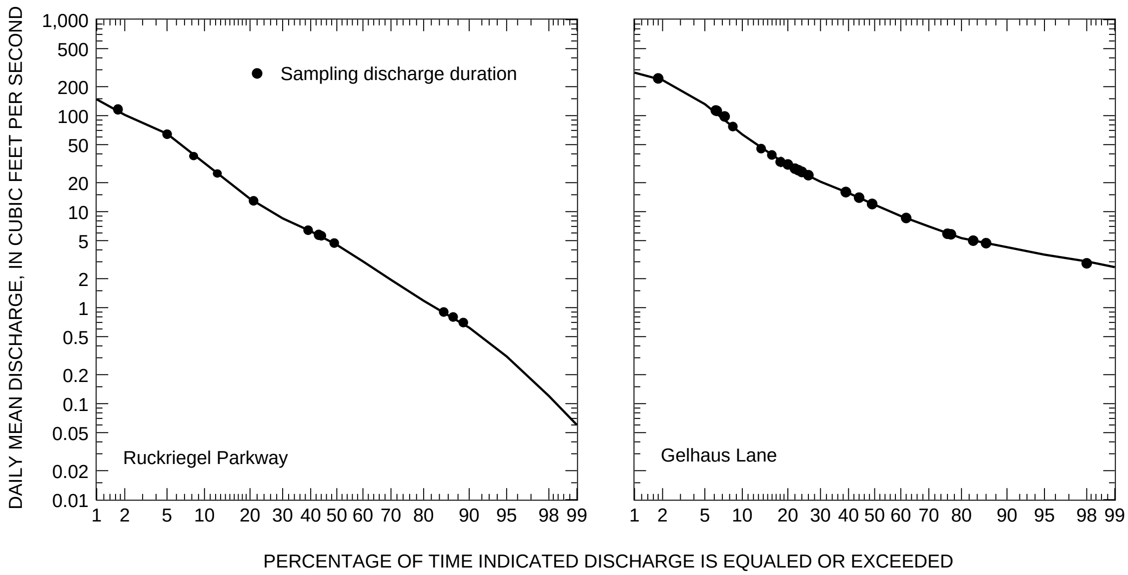


Figure 18. Flow duration and discharge on sampling dates at Chenoweth Run at Ruckriegel Parkway and at Gelhaus Lane, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

Table 20. Base-flow measurements in the Chenoweth Run Basin, Jefferson County, Kentucky, in 1995

[USGS, U.S. Geological Survey; HHMM, hours and minutes on 24-hour clock; ft^3/s, cubic foot per second; ---, not applicable]

Site identifier (figure 7)	USGS station number	Location	Stream mile	Drainage area (acres)	July 11, 1995		September 5, 1995	
					Time (HHMM)	Discharge (ft^3/sec)	Time (HHMM)	Discharge (ft^3/sec)
CR5	03298129	Chenoweth Run at Old Watterson Trail at Jeffersontown	6.012	2,862	0840	0.76	1040	0.13
CR4	03298138	Jeffersontown WWTP effluent at Chenoweth Run	5.219	---	0940	4.66	0930	3.98
402	03298140	Chenoweth Run at Taylorsville Road near Jeffersontown	4.870	4,150	1045	4.47	1150	4.02
CR2	03298145	Chenoweth Run at Easum Road	3.309	6,523	1135	4.65	1155	3.58
16	03298150	Chenoweth Run at Gelhaus Lane	2.456	7,327	1020	3.42	---	---
403	03298160	Chenoweth Run at Seatonville Road	.111	10,580	1225	3.09	1355	1.81

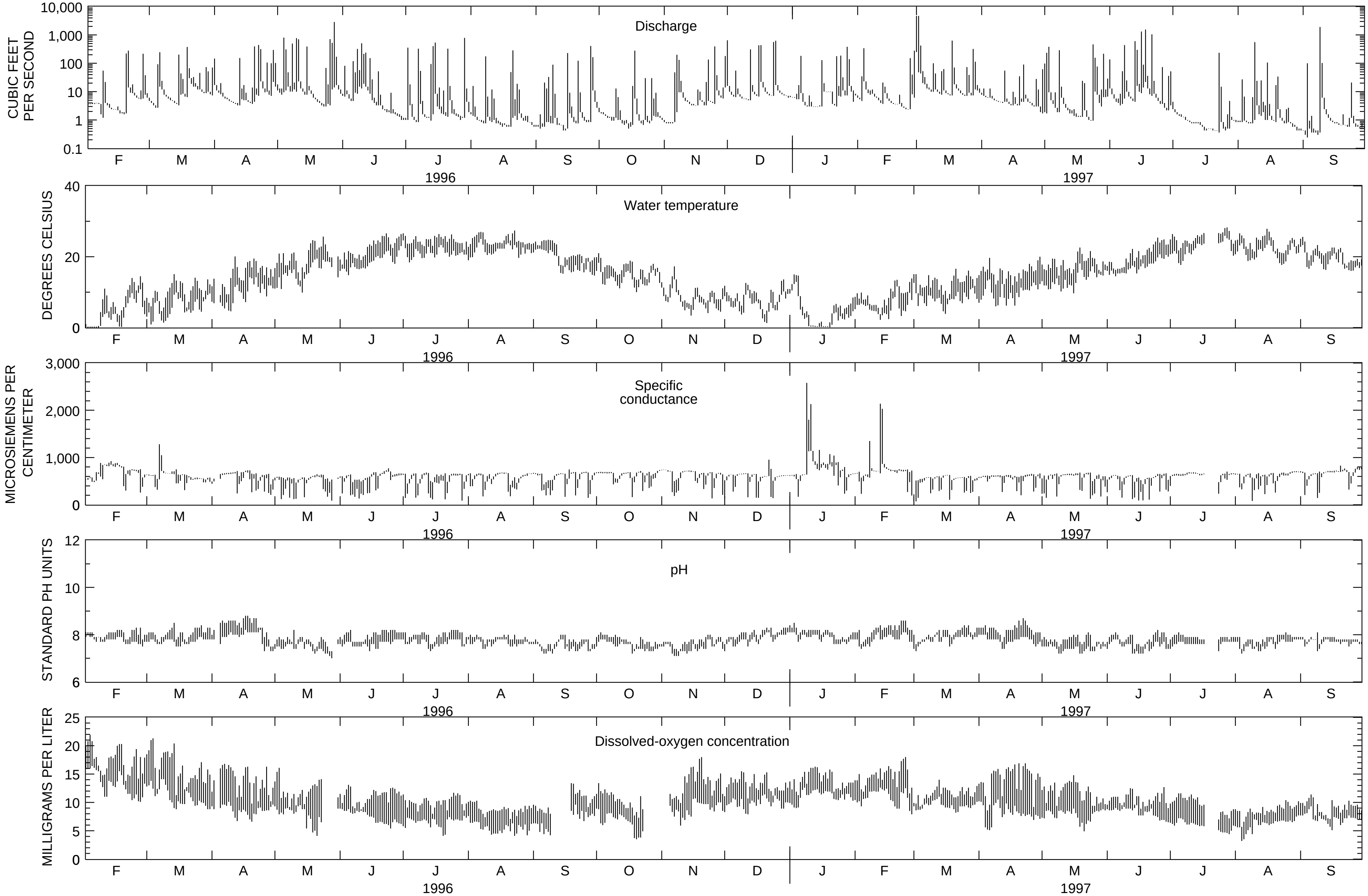


Figure 19. Daily range in discharge, water temperature, specific conductance, pH, and dissolved-oxygen concentration at Chenoweth Run at Ruckriegel Parkway, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

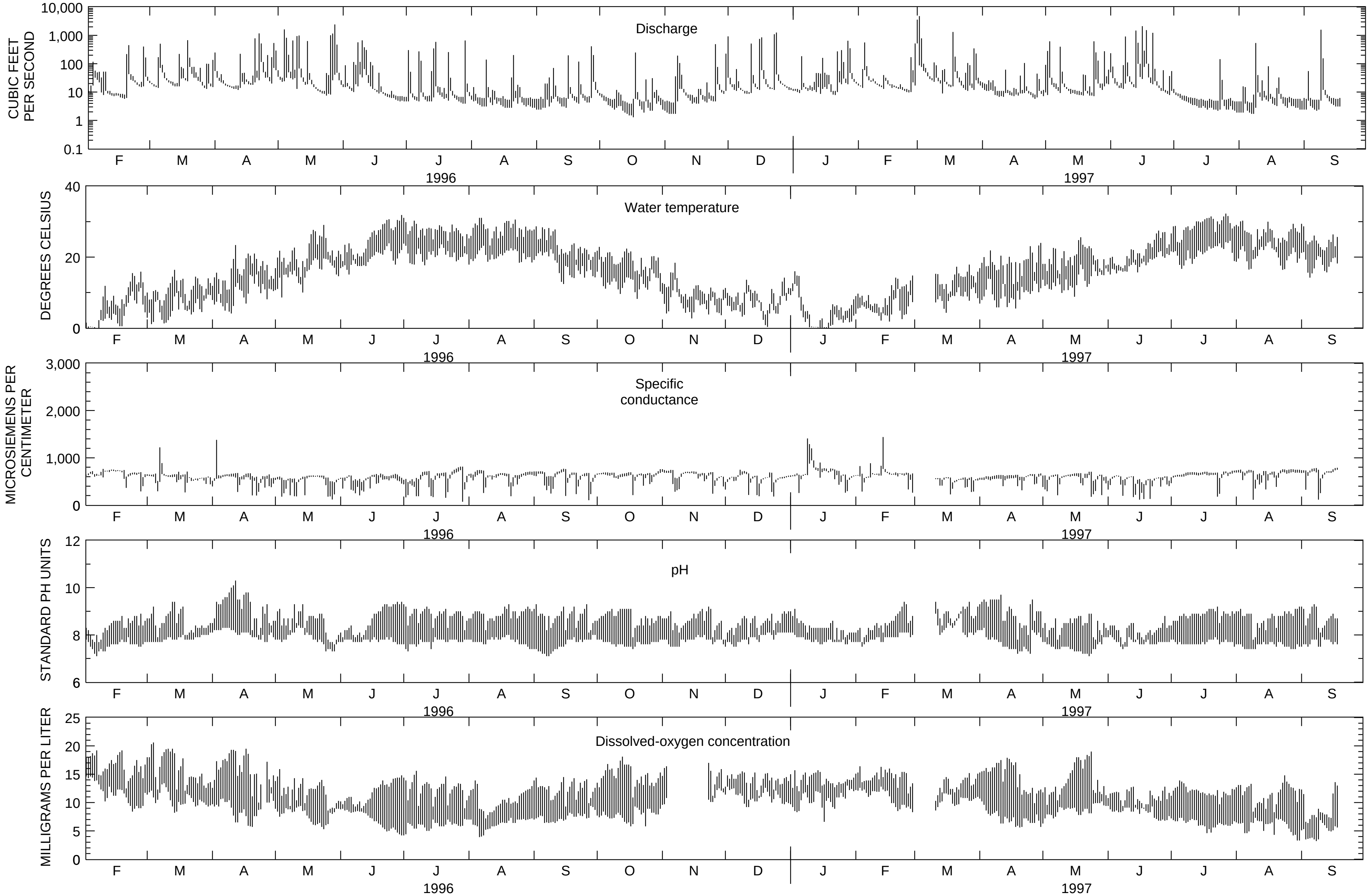


Figure 20. Daily range in discharge, water temperature, specific conductance, pH, and dissolved-oxygen concentration at Chenoweth Run at Gelhaus Lane, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

Stream water temperature was measured at the Ruckriegel Parkway and Gelhaus Lane sites at 30-minute intervals from January 24, 1996, to September 19, 1997, excluding periods of missing record (March 1-10, 1997, at Ruckriegel Parkway; July 16-23, 1997, at Gelhaus Lane; and after September 19, 1997, at both sites). Transformations of nutrients in streams are dependent upon water temperature; therefore, the periods of missing record were estimated by linear regression with air temperature for use in the water-quality modeling (see "Simulation of Water Quality"). Hourly average water temperature was determined for model input. Air temperature was a strong predictor of water temperature at both sites (r^2 of 0.85 and 0.88, respectively, at Ruckriegel Parkway and Gelhaus Lane). The regression equation was adjusted using the difference between predicted values and adjacent observed values for short periods of missing record. After September 19, 1997, the estimated stream temperature was smoothed by a 24-hour running average of temperature values. On average, measured water temperatures at the Gelhaus Lane site were 0.8˚F warmer than at the Ruckriegel Parkway site, probably because of thermal energy in wastewater inflows downstream from the Ruckriegel Parkway site. Air temperature and observed and estimated stream water temperature during the model calibration period are shown in figure 21.

Specific conductance, a measure of the ability of water to conduct an electrical current, is related to the types and concentrations of solids dissolved in water. Mean and median values of the continuous-record, daily mean specific conductance were 600 and 615 µS/cm, respectively, at the Ruckriegel Parkway site, and 598 and 608 µS/cm, respectively, at the Gelhaus Lane site. Specific conductance of natural waters typically reach maximal values during base-flow periods (owing to the background, geologic sources of the dissolved solids in ground water), and values are minimal (by dilution) during high-flow periods. In the urban setting of the Chenoweth Run Basin, maximal values of specific conductance were in winter storm periods (figs. 19 and 20), probably because of inflows of chloride in snow melt and (or) storm water following road-salt applications. Typical concentrations of chloride in rivers of North America are reported to range from 5.75 to 24 mg/L, in comparison to seawater chloride concentrations of 19,000 mg/L (Hem, 1989). None of the reported chloride-sample concentrations of the 83 samples collected in Chenoweth Run exceeded the KDOW warmwater-aquatic-habitat criteria for chloride concentration (600 mg/L). The maximum reported chloride concentration was 475 mg/L at the Ruckriegel Parkway site on March 19, 1996.

Diurnal patterns in dissolved-oxygen concentration and pH during low to moderate flows in spring 1996 show indications of the effects of aquatic-plant respirational and photosynthetic activity commonly associated with eutrophication of water bodies (fig. 22). At night, plant respiration (which proceeds continuously, night and day) consumes dissolved oxygen and releases carbon dioxide, which in turn lowers pH as carbonic acid is formed from water and the released carbon dioxide. The minimum dissolved-oxygen concentration is typically reached in the early morning hours before dawn. During daylight periods, aquatic-plant photosynthesis consumes carbon dioxide (which raises pH) and produces a sharp increase in dissolved-oxygen concentration. Maximum dissolved-oxygen concentrations are typically reached around mid-day. Pure oxygen is produced within the water column by the aquatic-plant photosynthesis. In comparison, the oxygen content of the atmosphere at the water surface where reaeration occurs is 21 percent. These oxygen-rich conditions during photosynthesis can lead to oxygen supersaturation with dissolved-oxygen concentrations of 150 to 200 percent of the saturation concentration not uncommon (Thomann and Mueller, 1987).

Suspended-solids and suspended-sediment concentrations were essentially equivalent for this study basin. Two suspended-sediment subsamples were drawn from the churn splitter when a paired suspended-solids subsample also was drawn. Concentrations for the two suspended-sediment subsamples were within 5.5 percent of the concentration of the suspended solids. Almost all of these two suspended-sediment samples (99.6 percent by weight) were in the clay/silt size fractions less than 0.00244 in. (0.062 mm) particle size.

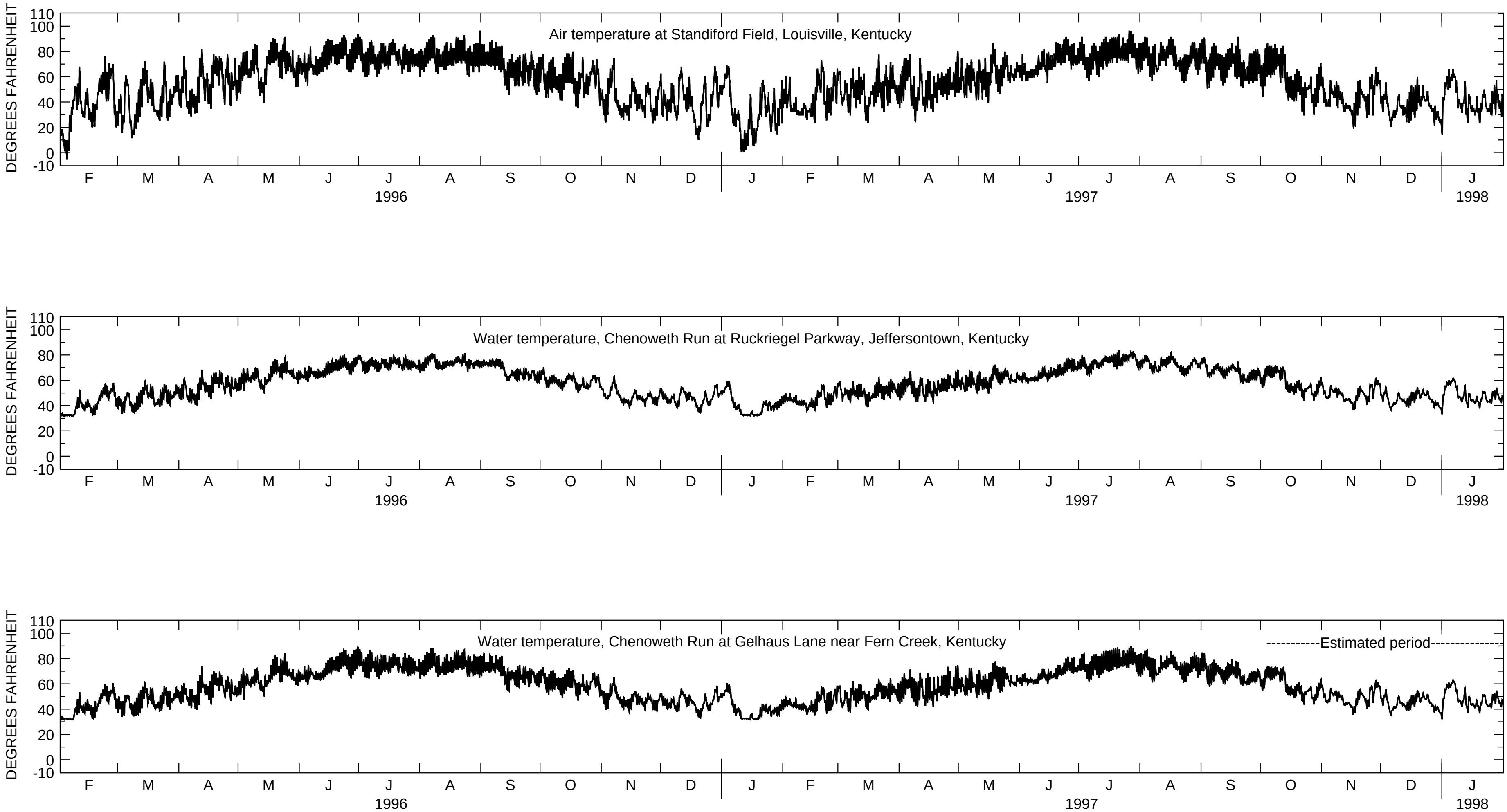


Figure 21. Hourly air temperature at Standiford Field, Louisville, Kentucky, and observed and estimated hourly water temperatures, Chenoweth Run Basin, Jefferson County, Kentucky.

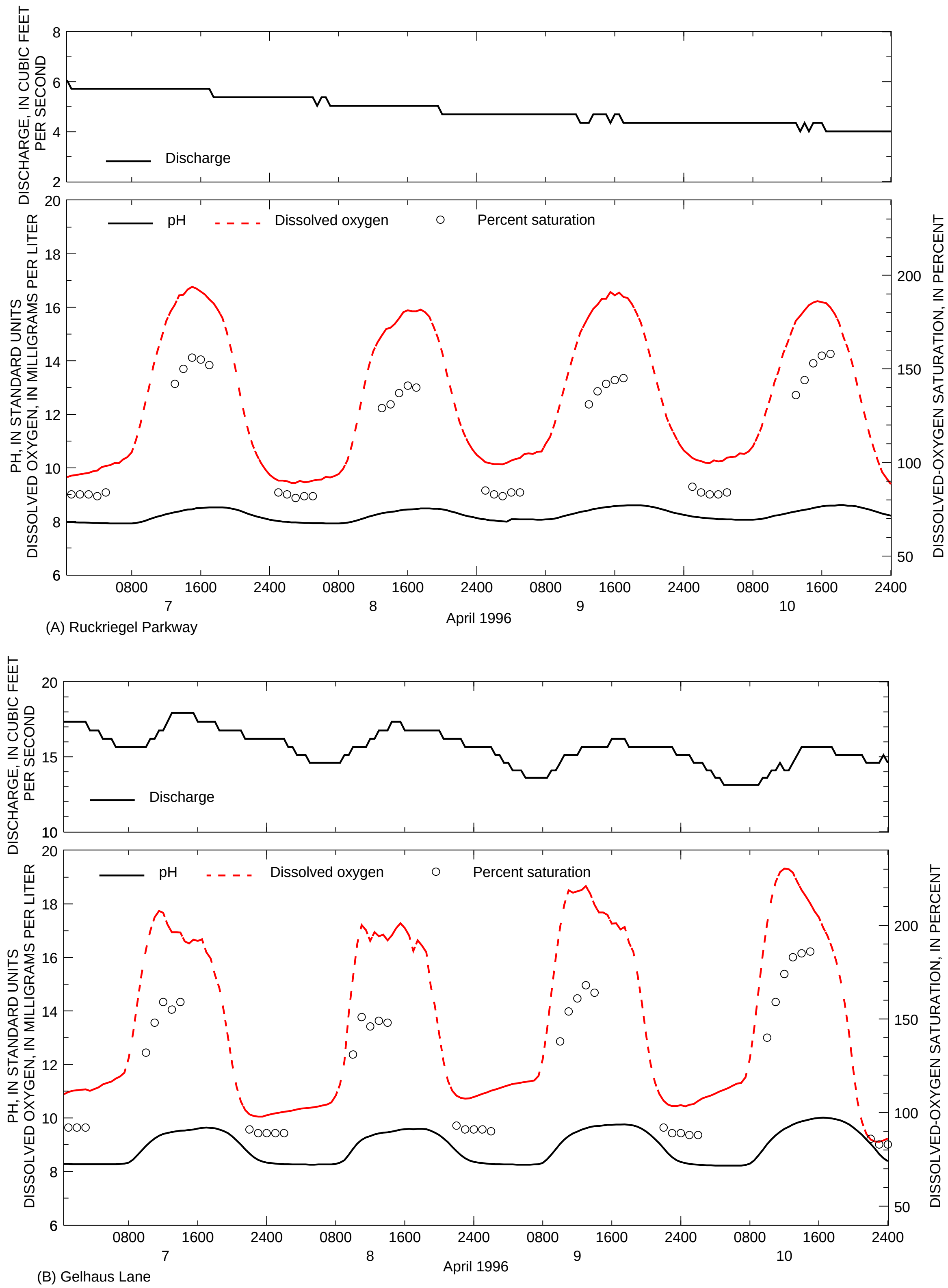


Figure 22. Diurnal dissolved-oxygen concentration, pH, and discharge patterns and oxygen saturation at selected times at selected sites, Chenoweth Run Basin, Jefferson County, Kentucky: (A) Ruckriegel Parkway and (B) Gelhaus Lane.

The flows coming from the abundant impervious surfaces in the upper portion of the basin may generally have low suspended-sediment (soils) loads initially, and thus have relatively large sediment-load-carrying and scouring capacity when entering the channels. Eroded sediments can (1) reduce channel capacity and reservoir capacity when deposited, (2) have deleterious effects on aquatic life, (3) introduce a dissolved-oxygen-demanding substance, and (4) provide a transport vehicle for nutrients and some metals, such as phosphorus and iron, respectively. Differences in the distribution of suspended solids shown in (fig. 23) most likely result from the different sampling periods for each site, rather than actual differences in sediment yield over the basin. Many of the suspended-solids samples at Ruckriegel Parkway, Taylorsville Road, and Seatonville Road were collected during high-flow conditions during 1996–97, whereas the majority of the samples at the other sites were collected during low and moderate flows.

Eutrophication is the excessive growth of aquatic plants caused by enrichment of a water body with nutrients such that water quality is adversely affected and water use is thus impaired. The major nutrients contributing to eutrophication are nitrogen and phosphorus. Potential sources of these nutrients include municipal and industrial wastewater, agricultural and urban runoff, atmospheric deposition, and geologic formations and the overlying soils. Some reported concentrations of total suspended solids, total nitrogen, and total phosphorus from point and nonpoint sources are shown in table 21.

Approximately one fourth of the earth's near-surface nitrogen content is contained in the crustal rocks and approximately three fourths is in the atmosphere (Hem, 1989). Most of the atmosphere is nitrogen. Nitrogen content of the hydrosphere and biosphere is much smaller than that of the crust and atmosphere.

The nitrogen cycle includes several complex chemical and biological processes that transfer nitrogen between the lithosphere, atmosphere, hydrosphere, and biosphere. Nitrogen fixation refers to the several energy-intensive processes by which N_2 gas is transformed in oxidation state to other nitrogen compounds. Biological fixation of nitrogen is done by blue-green algae and related organisms that draw energy from photosynthesis and also by certain species of bacteria. Production of synthetic fertilizers such as ammonia and other nitrogen compounds is a significant component of total world-wide nitrogen fixation (Hem, 1989). Nitrification refers to the process by which bacteria convert nitrogen in reduced forms (ammonium and organic nitrogen) into nitrite and nitrate. Denitrification refers to the processes by which certain bacteria reduce nitrate and nitrite to nitrous oxide or nitrogen gas.

Nitrogen oxides in the atmosphere, generated in part during combustion of fossil fuels, undergo chemical transformations leading to nitrogen as nitrate, which is available for deposition on earth. The atmospheric nitrate lowers the pH of precipitation. Ammonia nitrogen is generally in rainfall as well.

The major nitrogen-containing compounds in water include nitrate (NO_3^-), organic nitrogen, nitrite (NO_2^-), and ammonium (NH_4^+) (Hem, 1989, p. 124-126). Nitrite, an unstable transition compound in the conversion of organic nitrogen and ammonium to nitrate and in the conversion of nitrate to nitrogen gas, is generally present in low concentrations in natural waters. Other forms of nitrogen, such as cyanide (CN^-), may be present in industrial wastewaters.

There are substantial differences in chemical properties among the various nitrogen species. The cation ammonium is strongly absorbed on mineral surfaces. The anion nitrate is soluble, relatively stable under variable conditions, and thus is readily transported in water. Nitrite and organic species of nitrogen, which are unstable in aerated water, are often indicators (along with ammonium) of wastewater inflows (Hem, 1989, p. 124).

Extensive sampling data were not available on concentrations of nutrients from particular nonpoint-source types in the basin, such as atmospheric depositions and lawn treatments. However, four samples of ponded water remaining in drainageways in industrial and commercial areas of the basin collected on March 6, 1997, following a major storm had concentrations ranging from 0.12 to 1.88 mg/L nitrate as nitrogen and 0.05 to 0.28 mg/L ammonia nitrogen as nitrogen (B. Nichols, Louisville and Jefferson County Metropolitan Sewer District, written commun., 1996).

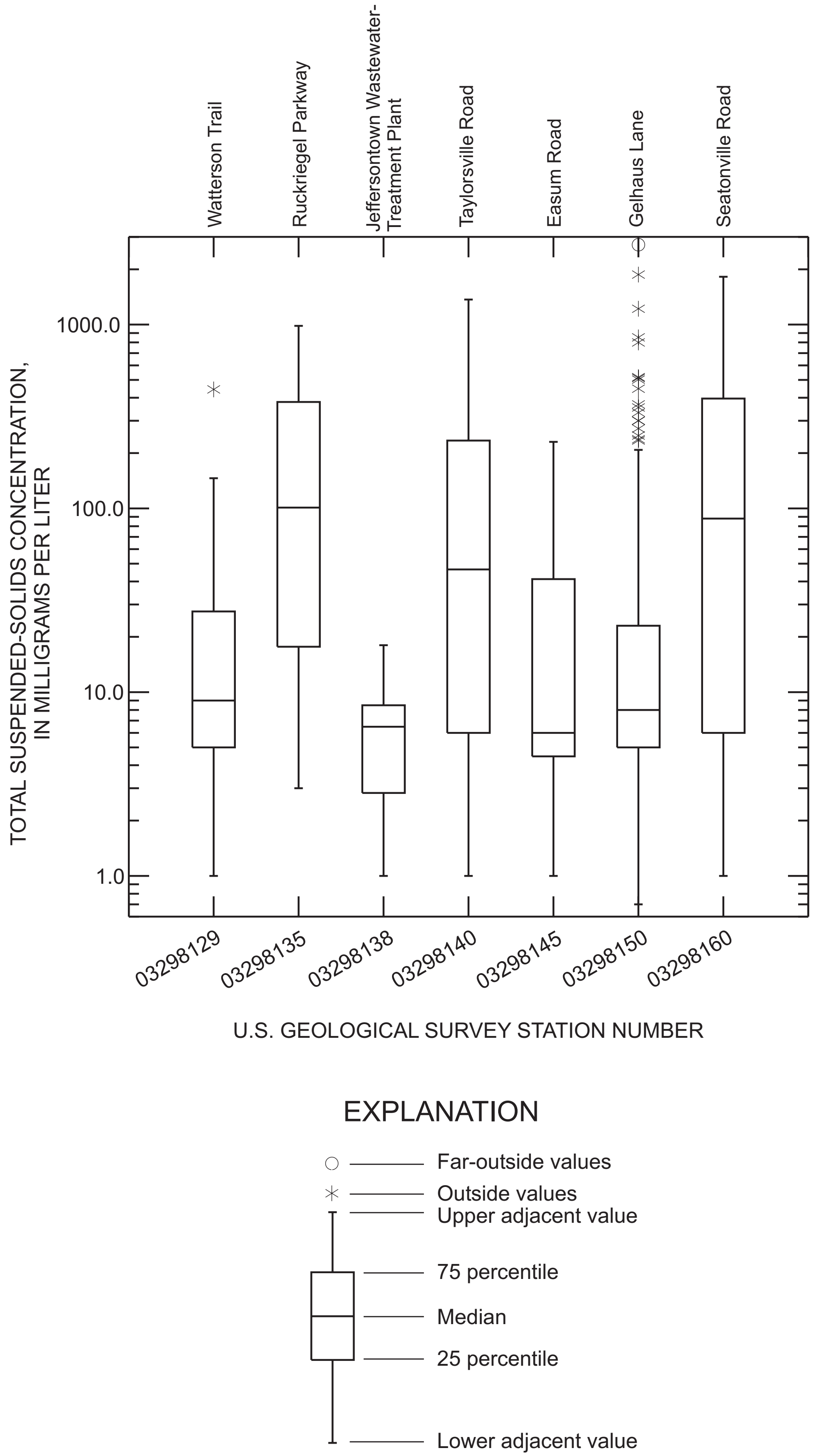


Figure 23. Distribution of total suspended-solids concentrations at sampling sites in the Chenoweth Run Basin, Jefferson County, Kentucky, during 1988–97.

Table 21. Reported total suspended-solids, total nitrogen, and total phosphorus concentrations in flows from point and nonpoint sources in the United States

[mg/L, milligrams per liter; from Thomann and Mueller, 1987, table 1.3, p. 22]

	Total suspended solids (mg/L)	Total nitrogen (mg/L)	Total phosphorus (mg/L)
Municipal wastewater influent	300	50	10
Combined-sewer overflow	410	9	3
Urban runoff	610	2.3	.5

Estimated national background concentrations of nitrogen including atmospheric depositions were reported to be 1.0 mg/L for total nitrogen, 0.6 mg/L of nitrate as nitrogen, and 0.1 mg/L ammonia as nitrogen (U.S. Geological Survey, 1999, p. 34). Waters with nitrogen concentrations exceeding these national background concentrations are considered to have been affected by human activities. Typical total nitrogen concentrations in wastewater influent and conventional-secondary-treatment effluent are reported as 50 and 18 mg/L, respectively (Thomann and Mueller, 1987, p. 391). Simple national regression models to estimate mean total nitrogen concentrations (Omernik, 1977) discharged from basins with combined percentage urban area plus percentage agricultural area ranging from 0 to 100 percent provide estimates of 0.57 to 3.69 mg/L mean total nitrogen concentrations.

The major phosphorus-containing compounds in water include orthophosphate (PO_4^{3-}) and other phosphate-containing compounds (H_3PO_4, $H_2PO_4^-$, HPO_4^{2-}) (Hem, 1989, p. 126). Hem suggests that other forms of dissolved phosphorus are unstable phosphates that will eventually revert to orthophosphate. The inorganic compounds of phosphorus have relatively low solubility in water, which favors precipitation and adsorption to soils and sediments. These chemical and physical characteristics and uptake by aquatic plants limit concentrations of phosphorus in solution in natural waters to generally no more than a few tenths of a milligram per liter (Hem, 1989, p. 126). Particulate forms of phosphorus constitute about 95 percent of the total transported in rivers (Meybeck, 1982). Hem also reported that the total extractable phosphorus concentrations in natural waters have little or no relation to the dissolved-phosphorus concentrations.

Though phosphorus is not very mobile in soils and sediments, use of phosphate fertilizers may potentially increase the content of phosphorus in drainage from fertilized fields and lawns. Runoff from both phosphate-fertilized and unfertilized lawns on soils that have elevated phosphorus fertility (greater than 20 lb/acre of available phosphorus) has been reported to contain elevated phosphorus concentrations (greater than 1 mg available P/L) (Barten, 1999). Further, eroded soils can add significant quantities of suspended phosphates to streams.

Where dissolved phosphorus exceeds a few tenths of a milligram per liter, human activities are likely the contributor. Given the low solubility of phosphorus and tendency to precipitate and adsorb to sediments and the role of phosphorus in eutrophication, dissolved phosphorus added through disposal of waste or leaching of fertilized lands may not remain available for long periods. The dissolved and total phosphorus content of streams will thus tend to decline naturally during transport downstream (barring additional phosphorus inflows along the stream).

Geologic formations were suggested as a potentially significant “background” source for nutrients in Kentucky by Thomas and Crutchfield (1974). These data indicated a strong relation between geology and the phosphorus content of streams and a partial relation between geology and the nitrogen (nitrate) content of streams. Plum Creek Basin, primarily in pasture land nearby in neighboring Shelby and Spencer Counties, Kentucky, was reported to lie in a “medium” phosphate Ordovician limestone, which is similar in character to the Ordovician limestone in the Chenoweth Run Basin. The mean “medium” phosphorus level among the streams sampled in the “medium” phosphate Ordovician limestone was approximately 0.1 mg P/L.

Estimated national background concentrations of total phosphorus including atmospheric depositions were reported to be 0.1 mg/L as phosphorus (U.S. Geological Survey, 1999, p. 34). Again, waters with nutrient concentrations exceeding these national background concentrations are considered to have been affected by human activities. For comparison, typical total phosphorus concentrations in wastewater influent and conventional-secondary-treatment-plant effluent are reported as 5 to 10 and 7 mg/L, respectively (Thomann and Mueller, 1987, p. 391). Simple national regression models to estimate mean total phosphorus concentrations (Omernik, 1977) discharged from basins with combined percentage urban area plus percentage agricultural area ranging from 0 to 100 percent provide estimates ranging from 0.020 to 0.133 mg/L total phosphorus concentrations. The four samples of ponded water remaining in drainageways in industrial and commercial areas of the basin collected on March 6, 1997, following a major storm had concentrations ranging from 0.03 to 0.33 mg/L total phosphorus (B. Nichols, Louisville and Jefferson County Metropolitan Sewer District, written commun., 1996).

The factors controlling eutrophication are extremely complex, and the nutrient that limits aquatic-plant growth depends on the characteristics of the nutrient source in relation to the characteristics of the receiving water body. Excess phosphorus is generally thought to cause eutrophication in freshwater, while excess nitrogen is generally thought to cause eutrophication in saltwater (U.S. Geological Survey, 1999). Relative amounts of nitrogen and phosphorus available for plant uptake (the nitrogen/phosphorus ratio), as well as the relative amounts of point and nonpoint nutrient inflows (which can change with flow regime), also control which nutrient actually most limits plant growth in a particular stream reach. Small upland streams that are dominated by point sources tend to be nitrogen-limited; however, such streams can become phosphorus-limited if phosphorus is removed at the point source (Thomann and Mueller, 1987, p 402).

A phosphorus-removal process was added to the Jeffersontown WWTP during 1998–99. This study focused on the transport of phosphorus and various aspects of the phosphorus cycle in Chenoweth Run.

The distribution of total phosphorus concentrations at sampling sites in the Chenoweth Run Basin during 1991–97 are shown in figure 24. Note a significant increase in concentrations beginning at the Jeffersontown WWTP effluent and continuing downstream.

Total phosphorus concentrations at the sampling sites during selected moderate and low-flow periods are shown in figure 25. The progressive decline in total phosphorus concentrations observed downstream from the Jeffersontown WWTP is consistent with biological uptake.

The total orthophosphate concentration was not determined by the laboratory for approximately one-half the samples collected during 1996–97. This necessitated estimation of TPO_4 concentrations for several stream water samples on the basis of TP concentrations for use in loads estimates, which were needed for calibration of the HSPF PO_4 simulation.

At the Ruckriegel Parkway sampling station (site 401) during 1996–97, 16 of 27 TPO_4 sample concentrations (59 percent) were unavailable; however, 2 of the 27 TPO_4 samples were paired automatic and cross-sectionally integrated samples. Therefore, 15 of 25 TPO_4 sample concentrations (60 percent) were estimated by ordinary least-squares regression against TP ($TPO_4 = 0.258*TP^{0.959}$; $r^2 = 0.66$, $n = 11$; see fig. 26). This relation indicated that, at this site where nonpoint sources were dominant, generally about one fourth to one third of TP is TPO_4. In contrast, the Jeffersontown WWTP data had indicated that a large portion (approximately 90 percent) of TP in the effluent was in the form of TPO_4 (table 15).

At the Gelhaus Lane sampling station (site 16) during 1996–97, 8 of 40 TPO_4 sample concentrations (20 percent) were unavailable; however, three of these values were for paired automatic samples. Therefore, 5 of 37 TPO_4 sample concentrations (14 percent) were estimated by ordinary least-squares regression against TP ($TPO_4 = 0.667*TP^{0.799}$; $r^2 = 0.77$, $n = 32$; see fig. 26).

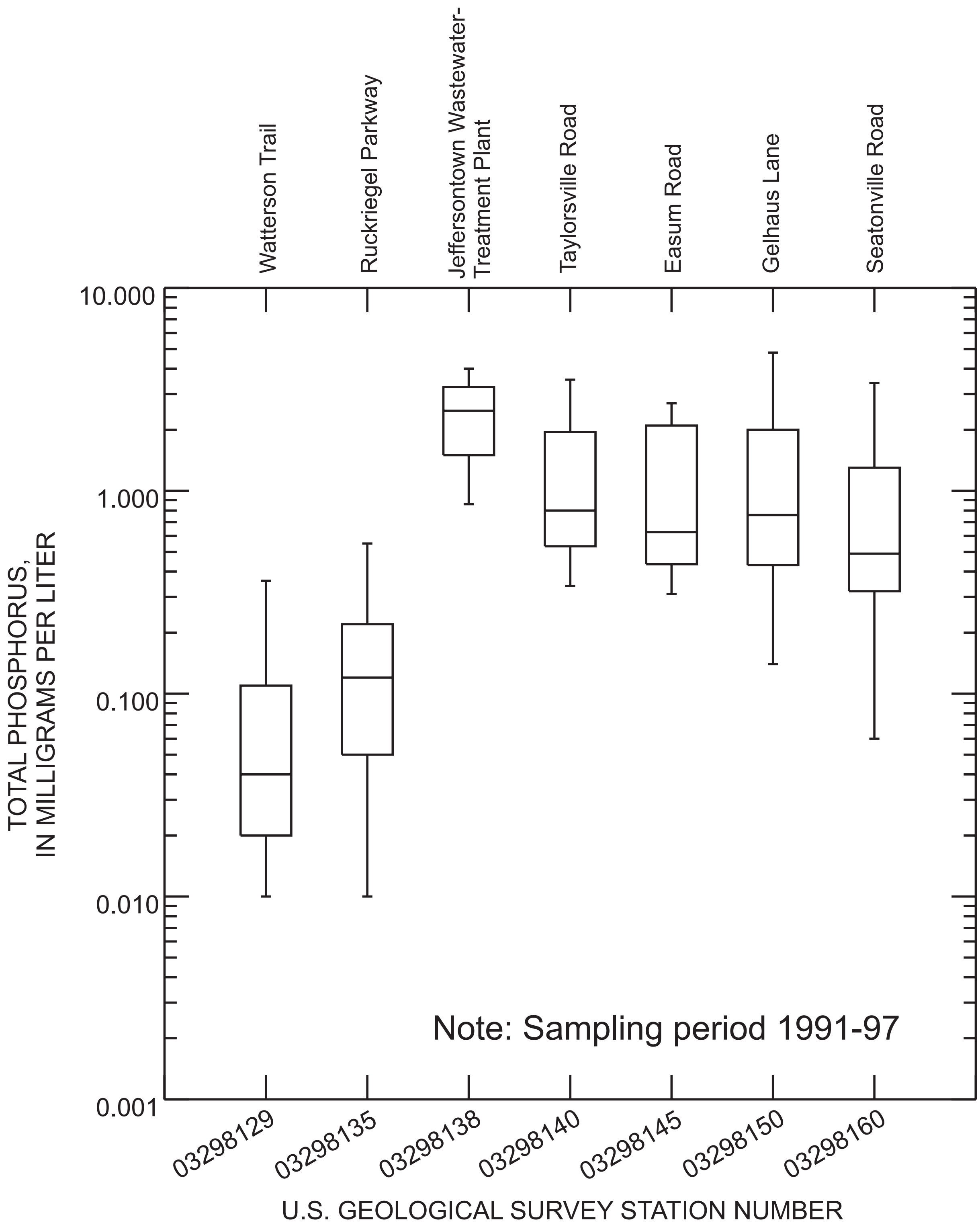


Figure 24. Distribution of total phosphorus concentrations at sampling sites in the Chenoweth Run Basin, Jefferson County, Kentucky, during 1991–97.

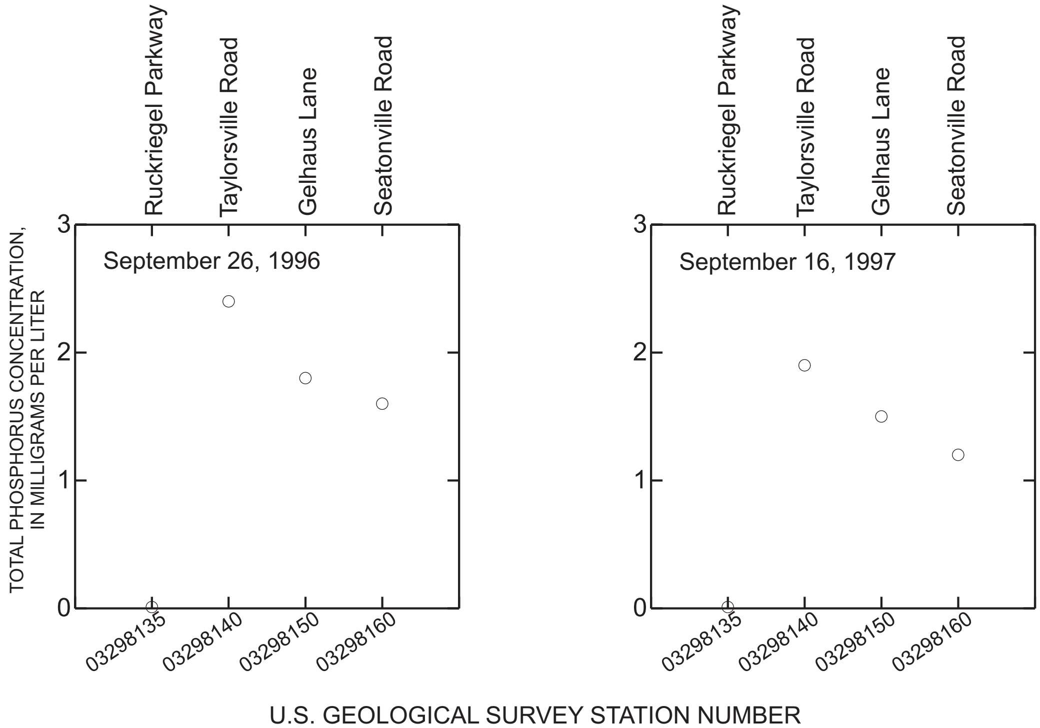


Figure 25. Total phosphorus concentrations at selected sites during selected moderate- and low-flow periods in the Chenoweth Run Basin, Jefferson County, Kentucky.

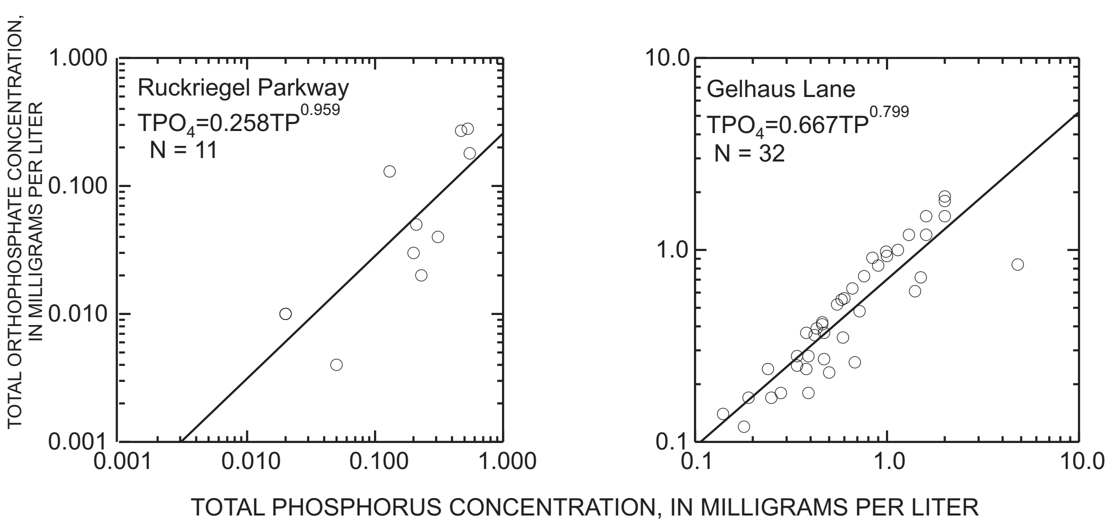


Figure 26. Comparison and regression relations of total phosphorus concentrations and total orthophosphate concentrations at selected sites in the Chenoweth Run Basin, Jefferson County, Kentucky, during 1996–97.

The relation of constituent concentration to discharge (fig. 27) is generally indicative of the type of constituent source: decreasing constituent concentration with increasing discharge (dilution) is typical for point sources and increasing constituent concentration with increasing discharge is typical for nonpoint sources. For total suspended solids, nonpoint sources dominated at the Ruckriegel Parkway and Gelhaus Lane sites. For total phosphorus and total orthophosphate, nonpoint sources were dominant at the Ruckriegel Parkway site, and point sources, though supplemented by nonpoint sources, were dominant at the Gelhaus Lane site. Notice also that at the Gelhaus Lane site, the upper end of the constituent concentration-discharge relation (where most constituent transport occurs) was almost entirely defined by storm water-quality-sampling data collected in 1996–97 for this study, despite the extensive but mostly routine, prescheduled sampling here during 1988–95. Water-quality samples have been collected for daily mean discharges of 117 ft^3/s at Ruckriegel Parkway and approximately 300 ft^3/s at Gelhaus Lane. These sampled discharges exceed flow durations of 2 percent and 1 percent, respectively, at these sites.

Instream-Constituent Load Estimates

Long-term instream constituent loads were estimated for suspended solids, total phosphorus, and total orthophosphate by use of ESTIMATOR—a statistical, regression-based, load-estimating program. ESTIMATOR generated daily constituent-load estimates (which were aggregated to monthly and annual loads) based on the daily mean discharges and a linear-regression relation between the sampling discharge and available water-quality-sampling data (fig. 27) at the two streamflow-gaging stations in the basin (Ruckriegel Parkway, site 401 and Gelhaus Lane, site 16, fig. 7). Note the large variability in sample concentrations in relation to discharge in figure 27 (a variation of one order of magnitude), which is not uncommon for small basins having variable constituent source areas and a relatively short period of sampling data. This large variability compounds the uncertainty in the loads estimates.

The varied, curvilinear relation of total suspended solids, total phosphorus, and total orthophosphate concentrations to discharge at the Gelhaus Lane site necessitated a piecewise-linear-regression approach for the loads-estimating relation. Separate linear regressions were done using 20 ft^3/s as a break point between a low-flow regression and a high-flow regression. The ESTIMATOR loads and yields for total suspended solids, total phosphorus, and total orthophosphate are shown in table 22.

The estimated annual suspended-solids yields during the model calibration period of over 4 (ton/acre)/yr were much larger than other reported suspended-solids yields that may be representative for average streamflow conditions. Agricultural and forested areas were reported by Thomann and Mueller (1987) to yield 0.71 and 0.11 (ton/acre)/yr of total suspended solids, respectively. Similar suspended-solids yields (approximately 0.05 to 0.7 (ton/acre)/yr) were estimated by Evaldi and Moore (1992 and 1994b) by use of a variety of statistical methods at selected sites in Jefferson County, Kentucky, including small drainage basins with relatively homogeneous residential, commercial, and industrial land uses (table 23). Other studies have reported larger yields than these for other basins in the region. Flint (1983) reported an average yield of 1.16 (ton/acre)/yr considering data from eight sediment-discharge stations in the Bluegrass Region of Kentucky. Measured yields of 4.59 and 2.34 (ton/acre)/yr were reported for long-term sediment-discharge stations in approximately 1 and 32 mi^2 basins, respectively, on rural Plum Creek in neighboring Shelby and Spencer Counties, Ky. (Anttila, 1970). Therefore, the ESTIMATOR suspended-solids loads and yields were deemed representative during this period, considering the above-normal precipitation, and the high level of construction activity and land disturbance in the basin. The WWTP's were a minor source of the total suspended solids (sediment) transported (tables 14 and 22).

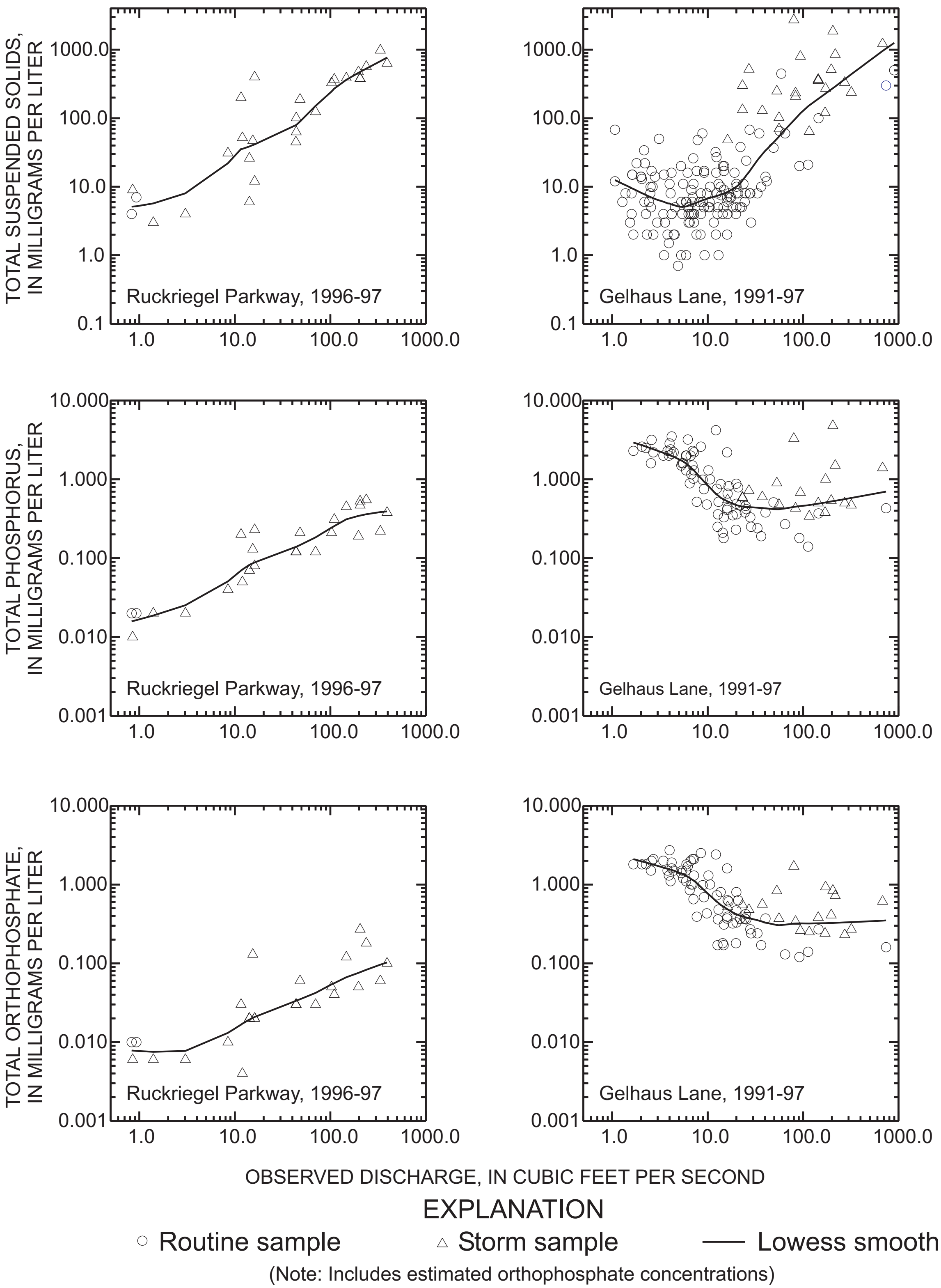


Figure 27. Comparison of total suspended-solids, total phosphorus, and total orthophosphate concentrations and discharge at streamflow-gaging stations in the Chenoweth Run Basin, Jefferson County, Kentucky.

Table 22. Estimated annual loads and yields of total suspended solids, total phosphorus, and total orthophosphate in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[lb, pound; P, phosphorus; --, not applicable]

	Total suspended solids			Total phosphorus			Total orthophosphate		
Period	Tons	Ton/acre	Percentage of load estimated beyond range of sampled discharge	lb as P	lb as P/acre	Percentage of load estimated beyond range of sampled discharge	lb as P	lb as P/acre	Percentage of load estimated beyond range of sampled discharge
Chenoweth Run at Ruckriegel Parkway									
02/1996-01/1997	6,150	1.78	--	6,210	1.80	--	1,820	0.529	--
02/1997-01/1998	23,300	6.77	--	11,600	3.37	--	3,360	.975	--
Mean	14,700	4.27	73.3	8,900	2.58	54.0	2,590	.752	53.7
Chenoweth Run at Gelhaus Lane									
02/1996-01/1997	17,700	2.42	--	43,900	6.00	--	28,400	3.88	--
02/1997-01/1998	42,400	5.79	--	43,300	5.91	--	27,100	3.70	--
Mean	30,100	4.10	54.1	43,600	5.96	11.4	27,800	3.79	7.7

Table 23. Annual suspended-solids yields estimated by several statistical methods at selected sites in Jefferson County, Kentucky

[--, not applicable; reported in Evaldi and Moore, 1992 and 1994b]

				Range of estimated annual yields	
Site	Drainage area (acres)	Estimated percent impervious	Predominate land use (percent of basin area)	Minimum (ton/acre)	Maximum (ton/acre)
South Fork Beargrass Creek tributary at Buechel	97	40	Residential (82 percent)	0.168	0.426
Hite Creek tributary at O'Bennon	108	21	Industrial (58 percent)	.100	.247
Middle Fork Beargrass Creek tributary at St. Matthews	134	35	Residential (80 percent)	.157	.384
Northern Ditch tributary at Okolona	44	46	Industrial (76 percent)	.168	.483
Big Run Tributary at Pleasure Ridge Park	84	69	Residential (51 percent) commercial (46 percent)	.168	.703
Middle Fork Beargrass Creek tributary at Hurstbourne Acres	180	64	Residential (50 percent) commercial (50 percent)	.168	.656
Long Run at State Highway 1531	15,168	14	Agricultural (75 percent)	.077	.248
Chenoweth Run at Gelhaus Lane	7,327	18	Mixed	.116	.344
All sites, all methods	--	--	--	.053	.703

Estimated total phosphorus yields from nonpoint sources located upstream from the Ruckriegel Parkway station (table 22) were consistent with other reported total phosphorus yields. As noted previously, Thomas and Crutchfield (1974) reported “medium” background phosphorus concentrations of approximately 0.1 mg P/L in the nearby Plum Creek Basin of the Outer Bluegrass Region of Kentucky. This concentration was approximately one third the concentration reported for “high” background levels in Cave Creek Basin in Fayette County in the Inner Bluegrass Region of Kentucky. Thomas and Crutchfield (1974) reported a yield for Cave Creek Basin of approximately 1 lb P/acre during the January–May periods in 1971–72. This would equate to an annual yield of approximately 1.5 lb P/acre/yr, assuming that two-thirds of annual runoff occurred in the January–May period. A background annual total-phosphorus yield of one third of that for Cave Creek would thus be approximately 0.5 lb P/acre/yr. Phosphorus yields reported for 13 central Kentucky streamflow-gaging stations in mostly rural basins averaged 0.63 lb P/acre/yr and ranged from 0.188 to 2.22 lb P/acre/yr (Garcia and Crain, 1998). Reported generalized mean total phosphorus yields (Thomann and Mueller, 1987) (table 24) ranged from 0.18 to 0.89 lb P/acre/yr, depending upon the nonpoint-source characteristics. The reported annual TP yields from urban areas ranged from 0.09 to 8.9 lb P/acre/yr. Total phosphorus yields estimated by Evaldi and Moore (1992 and 1994b) by use of a variety of statistical methods at the selected sites in Jefferson County including small drainage basins with relatively homogeneous residential, commercial, and industrial land uses ranged from approximately 0.5 to 8 lb/acre/yr (table 25). Evaldi and Moore (1994b) estimates of TPO_4 annual yields in Jefferson County ranged from 0.378 to 4.72 lb/acre.

The total phosphorus and total orthophosphate loads estimated at Ruckriegel Parkway, in combination with loads estimated for wastewater effluents, were consistent with the cumulative loads estimated at the Gelhaus Lane site.

Table 24. Reported total phosphorus yields from selected nonpoint sources in North America

[--, not available; from Thomann and Mueller, 1987, p. 394]

Type	Approximate mean (pound/acre per year)	Approximate range (pound/acre per year)
Forest, natural	0.36	0.009 – 0.80
Atmospheric rainfall	.18	.07 – .9
dry fallout	.71	--
Urban	.89	.09 – 8.9
Agricultural, general	.45	.09 – 4.5

The WWTP’s were the source of the majority of TP and TPO_4 transported in the basin. The load estimates indicated that roughly 65 percent (23,300 of 43,600 lb as P annually) of the TP and 90 percent (25,200 of 27,800 lb as P annually) of the TPO_4 load at the Gelhaus Lane site during the February 1996–January 1998 model calibration period may have been attributable to the WWTP effluents (see tables 14, 18, and 22).

Storm-load estimates were made by use of the series of discrete water-quality samples collected during selected storms at the two streamflow-gaging stations. The instantaneous streamflow and constituent concentration for the discrete water samples were used to estimate hourly and total storm loads. Estimated total storm loads for total suspended solids, total phosphorus, and total orthophosphate at the Ruckriegel Parkway and Gelhaus Lane sites are shown in table 26.

MODEL-SIMULATION APPROACH AND PROGRAMS

The HSPF model provides the capability to simulate several relevant processes affecting streamflow and water quality in the Chenoweth Run Basin. The model provides the capability to compute a suitable mass balance (water and constituents) for the basin. Features of HSPF and supporting software, HSPEXP and GENSCN, are described in the following sections.

Table 25. Annual total phosphorus yields estimated by several statistical methods at selected sites in Jefferson County, Kentucky

[lb, pound; --, not applicable; reported in Evaldi and Moore, 1992 and 1994b]

Site	Drainage area (acres)	Estimated percent impervious	Predominate land use (percent of basin area)	Estimated annual total phosphorus yields	
				Minimum (lb/acre)	Maximum (lb/acre)
South Fork Beargrass Creek tributary at Buechel	97	40	Residential (82 percent)	0.704	1.78
Hite Creek tributary at O'Bennon	108	21	Industrial (58 percent)	.667	1.04
Middle Fork Beargrass Creek tributary at St. Matthews	134	35	Residential (80 percent)	.701	1.61
Northern Ditch tributary at Okolona	44	46	Industrial (76 percent)	.690	2.02
Big Run Tributary at Pleasure Ridge Park	84	69	Residential (51 percent) commercial (46 percent)	.686	2.93
Middle Fork Beargrass Creek tributary at Hurstbourne Acres	180	64	Residential (50 percent) commercial (50 percent)	.700	2.73
Long Run at State Highway 1531	15,168	14	Agricultural (75 percent)	.506	3.25
Chenoweth Run at Gelhaus Lane[a]	7,327	18	Mixed	.710	4.50
All sites, all methods	--	--	--	.506	7.75

[a]Affected by point sources.

Table 26. Estimated loads of total suspended solids, total phosphorus, and total orthophosphate during sampled storm periods in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[lb, pound; P, phosphorus]

Period		Total suspended solids (tons)	Total phosphorus (lb as P)	Total orthophosphate (lb as P)
Begin (Julian date/time)	End (Julian date/time)			
Chenoweth Run at Ruckriegel Parkway				
19960208/1700	19960209/0100	0.82	3.92	3.90
19960319/0500	19960319/1100	91.5	175	74.9
19960606/2200	19960606/2300	4.25	4.65	1.12
19960702/1500	19960703/0100	21.1	29.5	3.77
19961022/2300	19961023/0500	.28	.95	.26
19961125/1000	19961125/2400	80.9	95.5	25.3
19970127/1800	19970128/0400	159	96.0	25.6
19970519/1600	19970520/0300	.15	2.29	.57
Chenoweth Run at Gelhaus Lane				
19960208/2300	19960209/0700	3.79	29.8	27.8
19960319/0500	19960319/1300	368	828	384
19960702/1600	19960703/0200	82.5	280	76.4
19961018/0100	19961018/0900	107	229	211
19970122/1300	19970122/1600	12.0	36	27.7
19970529/0200	19970529/1200	42.6	181	121

Hydrological Simulation Program—Fortran (HSPF)

HSPF, version 11, was selected for modeling the Chenoweth Run Basin. HSPF, which is an extension and refinement of the Stanford Watershed Model IV (Crawford and Linsley, 1966), was developed by the USEPA for use as a water-resources-planning and management tool (Bicknell and others, 1993). HSPF was first published in 1980 and the current revision became available in 1997.

HSPF is a versatile model capable of simulating hydrologic features and processes in mixed-land-use basins, both urban and rural. HSPF includes land surface, subsurface, and instream water-quantity- and water-quality-modeling components. The HSPF model was used to represent several important hydrologic features and processes of the Chenoweth Run Basin: (1) numerous small lakes and ponds, through which approximately 25 percent of the basin drains (2) potential seasonal ground-water-seepage loss in stream channels, (3) contributions from WWTP effluents and bypass flows, and (4) the transport and transformations of sediments and nutrients.

HSPF is a continuous, lumped-parameter, conceptual hydrologic model. It provides a continuous water and mass balance by tracking precipitation and water-quality constituents through the conceptual pathways of the hydrologic cycle based on the principles of conservation of mass. HSPF is composed of a series of computational routines that separately model key processes in the hydrologic cycle; it represents the hydrologic cycle as an interconnected series of storage (and processing) segments with fluxes of water and constituents between the various storages. Storages and fluxes are controlled by the system inputs and user-supplied parameter values. HSPF parameters have a physical meaning in terms of the conceptual-process models. Though some parameters are directly measurable, most are estimated during model calibration.

Requirements for meteorological time-series data input depend upon the modeling goal. The flow model is driven by input of precipitation and potential evapotranspiration time-series data; additional meteorological data are needed for detailed water-quality simulations. Generally, 3 to 6 years of data are desired for calibration of HSPF; however, satisfactory calibrations have been done with less data (Viessman and others, 1977). The output of HSPF is continuous streamflow and concentration (or load) of water-quality constituents at a user-specified time interval. Time intervals for simulation can range from 1 day to 1 minute. The model user must specify all input-output time-series linkages between HSPF program modules.

Continuous-simulation models permit modeling significant basin processes for a full range of the streamflow regime during the data-collection period. The relative importance of various processes and factors varies considerably with streamflow; processes that significantly affect water-quality conditions at low flows may have relatively insignificant effects on water-quality conditions during high flows. For assessment of peak-flow characteristics, continuous-simulation models can provide a more realistic evaluation of antecedent soil-moisture conditions than is generally possible with event-based models.

The hierarchical, block structure of HSPF has three primary application modules. The first primary module simulates movements and processing of water, sediment, and other water-quality constituents in pervious land segments (PERLND's). The second primary module simulates movement of water and constituents on impervious land segments (IMPLND's). The third primary module simulates hydrologic routing, sediment transport, and chemical-constituent transport and biochemical processes in stream or mixed-reservoir segments (RCHRES's). Each of these modules contains secondary modules; the secondary modules contain subroutines, which may in turn contain subordinate subroutines. Some of the subordinate subroutines may contain subsidiary subroutines (table 27). The definitions of the HSPF model parameters used in the Chenoweth Run Basin model are shown in table 28.

Table 27. Computer code structure of Hydrological Simulation Program—Fortran (HSPF) components used for modeling the Chenoweth Run Basin, Jefferson County, Kentucky

Primary module	Secondary module	Subroutine	Subordinate subroutine	Subsidiary subroutine
PERLND	PWATER	ICEPT		
		SURFAC	DISPOS	DIVISN
				UZINF
				PROUTE
		INTFLW		
		UZONE	UZONES	
		LZONE		
		GWATER		
		EVAPT	ETBASE	
			EVICEP	
			ETUZON	ETUZS
			ETAGW	
			ETLZON	
	SEDMNT	DETACH		
		SOSED1		
		ATTACH		
	PQUAL	QUALSD		
		QUALOF		
IMPLND	IWATER	RETN		
		IROUTE		
		EVRETN		
	SOLIDS	ACCUM		
		SOSLD2		
	IQUAL	WASHSD		
		WASHOF		
RCHRES	HYDR	ROUTE	DEMAND	
			SOLVE	
		NOROUTE	FNDROW	
		AUXIL		
		SHEAR		
	ADCALC			
	SEDTRN	COHESV	ADVECT	
			DBEXCH	
		SANDLD	TOFFAL	
	RQUAL	OXRX	ADVECT	
			SINK	
			OXBEN	
			OXREA	
			BODDEC	
		NUTRX	ADVECT	
			BENTH	
			ADDSNU	
			ADVNUT	
			DECBAL	

Table 28. Hydrological Simulation Program—Fortran (HSPF) parameters used to model the Chenoweth Run Basin, Jefferson County, Kentucky

[--, not applicable; BOD, biochemical oxygen demand]

Secondary module	Parameter	Units	Description
		Pervious Land (PERLND)	
		Water balance	
		Interception storage	
PWATER	CEPSC	inch	Interception storage capacity of plants
	CEPS	inch	Initial interception storage
		Surface and subsurface storages	
	UZSN	inch	Upper-zone nominal storage. An index to the amount of depression and surface-layer storage of a pervious area.
	LZSN	inch	Lower-zone nominal storage. An index to the soil-moisture-holding capacity.
	SURS	inch	Initial surface storage
	IFWS	inch	Initial interflow storage
	UZS	inch	Initial upper-zone storage
	LZS	inch	Initial lower-zone storage
	AGWS	inch	Initial active-ground-water storage
		Evapotranspiration	
	FOREST	--	Fraction winter forest transpiration
	LZETP	--	Lower-zone evapotranspiration. An index to the density of deep-rooted vegetation on a pervious area.
	AGWETP	--	Fraction of available potential evapotranspiration demand that can be met with stored ground water. Simulates evapotranspiration from phreatophytes, in general.
	BASETP	--	Fraction of available potential evapotranspiration demand that can be met with ground-water outflow. Simulates evapotranspiration from riparian vegetation.
		Recession rates	
	KVARY	1/inch	Ground-water outflow modifier. An index of how much effect recent recharge has on ground-water outflow.
	AGWRC	1/day	Ground-water recession parameter. An index of the rate at which ground water drains from the land.
	IRC	1/day	Interflow recession parameter. An index of the rate at which shallow subsurface flow drains from the land.
	GWVS	inch	Index to ground-water slope
		Infiltration	
	INFILT	inch/hour	Infiltration capacity. An index to the infiltration capacity at the soil surface, and an indirect index of the percolation rate from the bottom of soil zone.
	INFILD	--	Ratio of the maximum to mean infiltration rate of a pervious area. Accounts for the degree of variations in the infiltration capacity.

Table 28. Hydrological Simulation Program—Fortran (HSPF) parameters used to model the Chenoweth Run Basin, Jefferson County, Kentucky—*Continued*

[--, not applicable; BOD, biochemical oxygen demand]

Secondary module	Parameter	Units	Description
		Infiltration—*Continued*	
	INFEXP	--	Infiltration equation exponent. Controls the rate at which infiltration decreases with increasing soil moisture.
	INTFW	--	Interflow index. In combination with INFILT, an index to the amount of water that infiltrates and flows as shallow subsurface runoff.
	DEEPFR	--	Fraction of ground water that does not discharge to the surface within the boundaries of the modeled area
		Overland flow	
	LSUR	foot	Average length of the overland-flow plane
	SLSUR	--	Average slope of the overland-flow plane
	NSUR	--	Average roughness of the overland-flow plane
		Soil erosion	
SEDMNT	SMPF	--	Management factor to account for use of erosion control practices
	KRER	complex	Coefficient of the soil detachment equation
	JRER	complex	Exponent of the soil detachment equation
	AFFIX	1/day	Fraction by which detached sediment decreases daily through soil compaction
	COVER	--	Fraction of land surface shielded by vegetation or mulch from erosion by direct rainfall impact
	NVSI	pound/acre-day	Rate at which sediment enters detached-sediment storage from the atmosphere
	KSER	complex	Coefficient of the detached-sediment washoff equation
	JSER	complex	Exponent of the detached-sediment washoff equation
	KGER	complex	Coefficient of the soil-matrix scour equation
	JGER	complex	Exponent of the soil-matrix scour equation
		Orthophosphate flux	
PQUAL	SQO	pound/acre	Initial constituent storage on surface
	POTFW	pound/ton	Potency factor of sediment in washoff
	POTFS	pound/ton	Potency factor of scoured sediment
	ACQOP	pound/acre-day	Accumulation rate of constituent on surface
	SQOLIM	pound/acre	Maximum storage of constituent on surface
	WSQOP	inch/hour	Rate of surface runoff to remove 90 percent of stored constituent in one hour
		Impervious Land (IMPLND)	
		Water balance	
IWATER	LSUR	foot	Average length of the overland-flow plane
	SLSUR	--	Average slope of the overland-flow plane
	NSUR	--	Average roughness of the overland-flow plane
	RETSC	inch	Retention storage capacity of impervious areas

Table 28. Hydrological Simulation Program—Fortran (HSPF) parameters used to model the Chenoweth Run Basin, Jefferson County, Kentucky—*Continued*

[--, not applicable; BOD, biochemical oxygen demand]

Secondary module	Parameter	Units	Description
		Water balance—*Continued*	
	RETS	inch	Initial retention storage
	SURS	inch	Initial overland-flow storage
		Sediment washoff	
SOLIDS	KEIM	complex	Coefficient of the solids washoff equation
	JEIM	complex	Exponent of the solids washoff equation
	REMSDP	1/day	Fraction of solids removed on each day without runoff
	ACCSDM	ton/acre-day	Solids accumulation rate
	SLDS	ton/acre	Initial storage of solids
		Orthophosphate flux	
IQUAL	SQO	pound/acre	Initial constituent storage on surface
	POTFW	pound/ton	Potency factor of sediment in washoff
	ACQOP	pound/acre-day	Accumulation rate of constituent on surface
	SQOLIM	pound/acre	Maximum storage of constituent on surface
	WSQOP	inch/hour	Rate of surface runoff to remove 90 percent of stored constituent in one hour
		Reaches and Reservoirs (RCHRES)	
		Water balance	
HYDR	FTABNO	--	Number of the F-table that contains the RCHRES geometric and hydraulic properties
	LEN	mile	Length of the reach
	DELTH	foot	Drop in water elevation within the stream reach
	STCOR	foot	Correction in the reach depth to calculate stage
	KS	--	Weighting factor for flow routing
	DB50	millimeter	Median diameter of bed sediment
ADCALC	CRRAT	--	Ratio of maximum velocity to mean velocity in reach cross section under typical flow conditions
		Sediment transport	
SEDTRN	BEDWID	foot	Width of the streambed
	BEDWRN	foot	Depth of the streambed
	POR	--	Porosity of the streambed
	D	inch	Effective diameter of the sediment particle
	W	inch/second	Settling velocity of the sediment particle in still water
	RHO	gram/cubic centimeter	Density of the sediment particle
	KSAND	complex	Coefficient of the HSPF sand-load equation
	EXPSND	complex	Exponent of the HSPF sand-load equation
	TAUCD	pound/square foot	Critical bed shear stress for sediment deposition
	TAUCS	pound/square foot	Critical bed shear stress for sediment scour
	M	pound/square foot-day	Erodibility coefficient of the sediment
	BEDDEP	foot	Initial thickness of the bed material

Table 28. Hydrological Simulation Program—Fortran (HSPF) parameters used to model the Chenoweth Run Basin, Jefferson County, Kentucky—*Continued*

[--, not applicable; BOD, biochemical oxygen demand]

Secondary module	Parameter	Units	Description
		Sediment transport—*Continued*	
	SSAND	milligrams per liter	Initial concentration of sand in suspension
	SSILT	milligrams per liter	Initial concentration of silt in suspension
	SCLAY	milligrams per liter	Initial concentration of clay in suspension
	FRACSAND	--	Initial fraction by weight of sand in bed material
	FRACSILT	--	Initial fraction by weight of silt in bed material
	FRACCLAY	--	Initial fraction by weight of clay in bed material
		Oxygen balance	
RQUAL	SCRVEL	foot/second	Velocity above which the effects of scouring on benthal release rates will be considered
	SCRMUL	--	Multiplier to increase benthal releases during scour
	KBOD20	1/hour	Unit BOD decay rate at 20 degrees Celsius
	TCBOD	--	Temperature-correction coefficient for BOD decay
	KODSET	foot/hour	Rate of BOD settling
	SUPSAT	--	Allowable dissolved-oxygen supersaturation multiplier
	ELEV	foot	RCHRES elevation above sea level
	BENOD	milligram/square meter-hour	Benthal oxygen demand at 20 degrees Celsius
	TCBEN	--	Temperature-correction coefficient for benthal oxygen demand
	EXPOD	--	Exponential factor in the dissolved-oxygen term of the benthal-oxygen-demand equation
	BRBOD(1)	milligram/square meter-hour	Benthal release of BOD at high oxygen concentration
	BRBOD(2)	milligram/square meter-hour	Increment to benthal release of BOD under anaerobic conditions
	EXPREL	--	Exponential factor in the dissolved-oxygen term of the benthal-BOD-release equation
	TCGINV	--	Temperature-correction coefficient for surface-gas invasion
	DOX	milligrams per liter	Initial dissolved-oxygen concentration
	BOD	milligrams per liter	Initial BOD concentration
	SATDO	milligrams per liter	Initial dissolved-oxygen-saturation concentration
		Orthophosphate balance	
	BRPO4(1)	milligram/square meter-hour	Benthal release rate of orthophosphate, as phosphorus, under aerobic condition
	BRPO4(2)	milligram/square meter-hour	Benthal release rate of orthophosphate, as phosphorus, under anaerobic condition
	ANAER	milligrams per liter	Concentration of dissolved oxygen below which anaerobic conditions exist
	BPO4(1)	milligrams per kilogram	Constant bed concentration of orthophosphate, as phosphorus, adsorbed to sand

Table 28. Hydrological Simulation Program—Fortran (HSPF) parameters used to model the Chenoweth Run Basin, Jefferson County, Kentucky—*Continued*

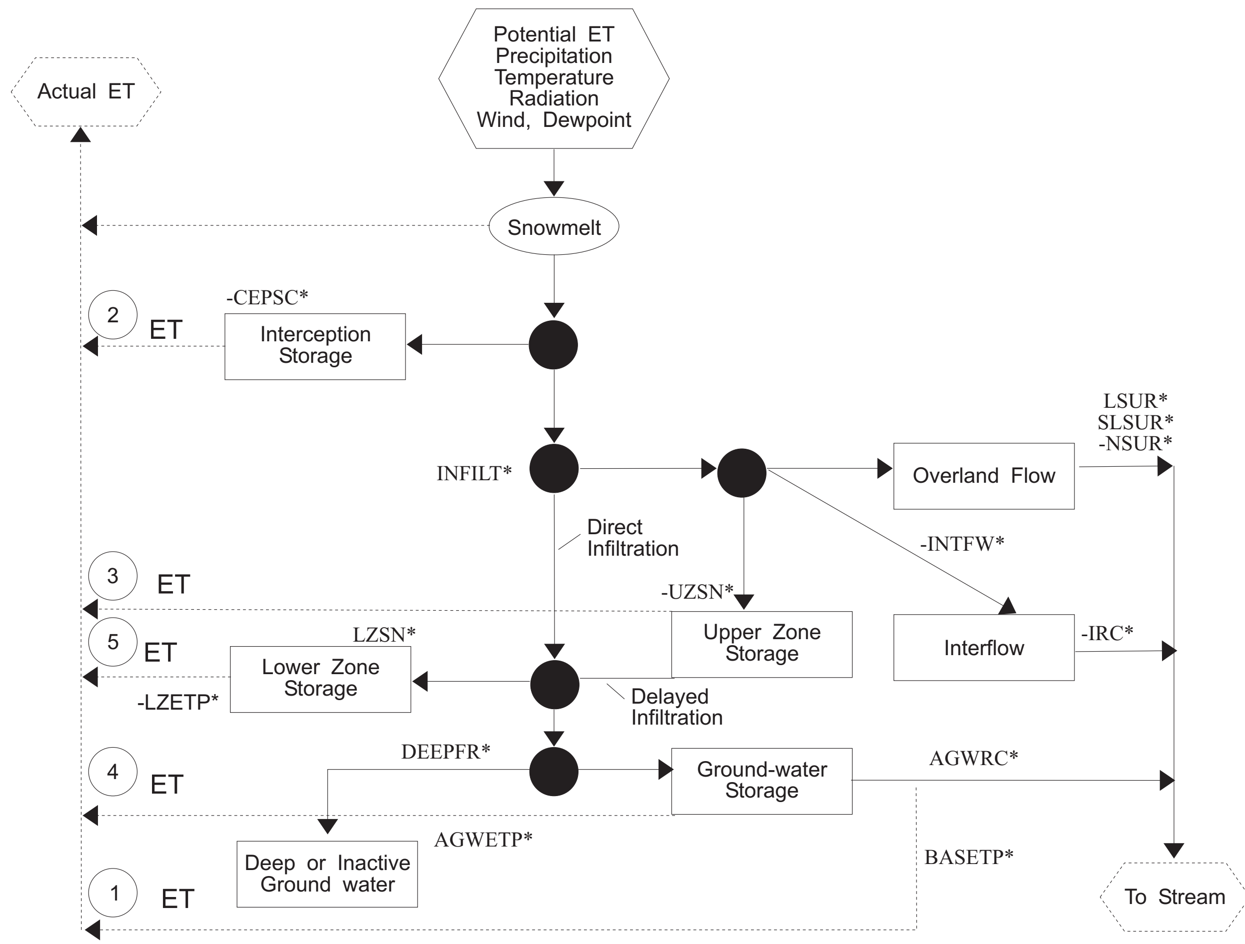
[--, not applicable; BOD, biochemical oxygen demand]

Secondary module	Parameter	Units	Description
		Orthophosphate balance—*Continued*	
	BPO4(2)	milligrams per kilogram	Constant bed concentration of orthophosphate, as phosphorus, adsorbed to silt
	BPO4(3)	milligrams per kilogram	Constant bed concentration of orthophosphate, as phosphorus, adsorbed to clay
	ADPOPM(1)	milliliter per gram	Partition coefficient of orthophosphate, as phosphorus, adsorbed to sand
	ADPOPM(2)	milliliter per gram	Partition coefficient of orthophosphate, as phosphorus, adsorbed to silt
	ADPOPM(3)	milliliter per gram	Partition coefficient of orthophosphate, as phosphorus, adsorbed to clay
	PO4	milligrams per liter	Initial concentration of dissolved orthophosphorus, as phosphorus
	PHVAL	pH units	Initial value of pH
	SPO4(1)	milligrams per kilogram	Initial concentration of orthophosphate, as phosphorus, adsorbed to sand
	SPO4(2)	milligrams per kilogram	Initial concentration of orthophosphate, as phosphorus, adsorbed to silt
	SPO4(3)	milligrams per kilogram	Initial concentration of orthophosphate, as phosphorus, adsorbed to clay

Pervious Land Segments (PERLND)

Flow over and through pervious land segments are modeled in the PERLND secondary module PWATER. The conceptualized movement of water overland and through the upper, lower, and ground-water zones of pervious land segments is illustrated in figure 28. Unsteady overland flow is routed using a modified kinematic-wave formulation. The Manning and continuity equations are used with average overland-flow-plane length, slope, and roughness estimates to continuously (at each time step) calculate surface detention storage, from which the overland-flow rate is calculated. The potential infiltration rate is computed as an empirical function of soil moisture. Actual infiltration depends upon rainfall excess remaining after subtracting interception losses from precipitation. Rainfall excess is available for surface detention, infiltration, or runoff. Infiltrated moisture can move to four subsurface storage reservoirs: upper-zone storage, lower-zone storage, active-ground-water storage, and inactive-ground-water storage. The upper-zone storage includes storage in surface depressions, surface vegetation, ground litter, and the shallow root zone in the upper few inches of soil. Moisture may leave the surface-detention/upper-zone storage by evapotranspiration, overland flow, interflow, or percolation to the lower zone. The lower zone extends a few feet to the depth of deep-rooted vegetation, which evapotranspires a portion of the moisture stored there. Active-ground-water storage feeds stream base flows during periods of no rainfall. Inactive or deep ground-water storage does not flow to the stream and is considered lost from the system.

Sediment erosion in pervious land segments is simulated in the PERLND secondary module SEDMNT. The processes modeled include sediment detachment from the soil matrix by rainfall, washoff of detached sediment, and scour of the soil matrix by overland flow and sediment reattachment.



EXPLANATION

2	Order taken to meet ET demand
	Process
	Input
	Output
	Storage
	Model decision point

*	Parameter
	Model flow direction
CEPSC	Interception storage
ET	Evapotranspiration
INFILT	Infiltration
LSUR	Length of overland flow path
NSUR	Roughness of overland flow path
INTFW	Interflow
UZSN	Upper zone nominal storage
IRC	Interflow recession constant
LZSN	Lower zone nominal storage
LZETP	Lower zone evapotranspiration
DEEPFR	Inactive ground water
BASETP	Baseflow evapotranspiration
AGWETP	Ground-water evapotranspiration
AGWRC	Ground-water recession constant
SLSUR	Slope of overland flow path

Figure 28. Schematic of the Hydrologic Simulation Program—Fortran (HSPF) model of flow in a pervious land segment.

Outflows of other water-quality constituents from pervious land segments can be simulated using simple relations to water and (or) sediment yield in the PERLND secondary module PQUAL. For this study, dissolved and sediment-associated orthophosphate yields from pervious land segments were simulated with PQUAL. Detailed simulation of nutrient, pesticide, and tracer constituents can also be done in available PERLND agri-chemical secondary modules; however, additional data including soil temperatures are needed for these detailed simulations.

Impervious Land Segments (IMPLND)

The processes of surface detention, evaporation, and overland flow on impervious surfaces are modeled in the IMPLND secondary module IWATER by functional relations similar to those used for pervious surfaces. Solids (sediment) accumulation and removal from impervious land segments was simulated by use of the SOLIDS secondary module, which uses equations based on those in the NPS Model (Donigian and Crawford, 1976). Outflows of water-quality constituents from impervious land segments were simulated using simple relations to water and (or) sediment yield in the IQUAL secondary module. Thus, IQUAL was used to simulate dissolved and sediment-associated orthophosphate yields from impervious land segments. Model parameters estimated for this simulation of impervious surfaces included potency factors for the constituent in solids (mass/mass) and the constituent accumulation and washoff rates.

Reaches and Reservoirs (RCHRES)

Channel and mixed-reservoir flow is routed in the RCHRES secondary module HYDR using a modified kinematic-wave model with Manning's equation. This is a "hydrologic" or "storage" routing method that does not account for momentum. No assumption is made regarding shape of the RCHRES (may be an open or closed channel, or a completely mixed lake), but a fixed relation between depth, surface area, and volume is needed for routing flow in HYDR.

Each RCHRES is composed of two nodes, or end points, and a single one-dimensional zone between the nodes. Mass-flux rates and depths are associated with nodes; mass-storage volumes are associated with zones. (HSPF land segments consist of zones only.) Each RCHRES has one inflow gate that receives inflows from upstream RCHRES and local sources. Each RCHRES has up to five outflow gates. Other fluxes, such as precipitation and evaporation, affect the RCHRES, but do not pass through the gates. All inflows to RCHRES are assumed to enter at the upstream end of RCHRES prior to routing downstream through the RCHRES. Nodes for the Chenoweth Run Basin were located, where possible, such that tributary inflows were at the upstream end of the RCHRES.

HSPF simulation of the transport, deposition, and scour of inorganic sediment in channels and mixed reservoirs is done in the RCHRES secondary module SEDTRN. Noncohesive sediment (sand) transport can be simulated in one of three alternate methods (Toffaleti, Colby, or an "input power function" method). Cohesive sediment (silts and clays) transport simulation includes two steps: (1) advective transport of entrained particles and (2) deposition and scour of particles based on bed shear stress. The sediment transport simulation requires input of data on sediment diameter, settling velocity, density, erodibility, and shear stress for deposition and scour. Sand, silt, and clay transport is modeled separately, thus armoring is not modeled. HSPF assumes sediment scour and deposition do not affect channel hydraulic characteristics, and bed-load transport is not modeled.

Detailed simulation of constituents involved in biochemical transformations in channels and mixed reservoirs is done in the RCHRES secondary module RQUAL. RQUAL allows users to selectively simulate various constituents and processes. Oxygen, biochemical oxygen demand (BOD), and total orthophosphate content were simulated for this study. Stream temperature data were input for the RQUAL simulation; the simulation was evaluated by comparison to estimated loadings of total orthophosphate at selected points in the basin. Obtaining a complete and satisfactory simulation of relevant constituents using RQUAL can be extremely complicated because of the complexity of the physical, chemical, and biological factors that affect the state of an individual water body.

Hydrologic Response Units (HRU)

Hydrologic response units (HRU's) are conceived as land segments with areally uniform properties that produce a similar hydrologic and water-quality response to a given precipitation and evapotranspiration input. (HRU's may also be distinguished on the basis of features that are expected to affect yields of various water-quality constituents.) The HRU's permit detailed accounting for, and model representation of, the spatial variability of hydrologic characteristics and yields of various water-quality constituents in a basin. Each particular HRU is defined by use of a unique set of HSPF land-segment parameters and meteorologic time series. Particular HRU's are not necessarily contiguous, but rather may be scattered throughout a drainage basin in a mosaic pattern composed of all the HRU types defined for the basin model.

PERLND's, IMPLND's, and RCHRES's are the basic elements of the HSPF model. In this study, each HRU represented unique land covers, as described in further detail in "Hydrological Response Units." HRU's are linked to RCHRES and RCHRES's are linked to other RCHRES's within the SCHEMATIC block of the HSPF user-control input (UCI) file (Appendix 5). The appropriate HRU's are linked to a corresponding RCHRES to represent subbasins, and RCHRES's are linked together to represent the entire basin hydrography.

Expert System HSPEXP for Model Calibration

The expert system for calibration of streamflow in HSPF (HSPEXP) (Lumb and others, 1994) was used to aid in model calibration. After each model is run, statistical measures of flow-simulation error are calculated by the expert system and provided to the user. The user is also provided advice concerning options for adjusting parameters and an explanation of the advice. The user may select a parameter-adjustment option and make the appropriate changes in the HSPF parameters in the model UCI file (working inside or outside the HSPEXP shell). The model is then run again; the iterations continue until the errors reach an acceptable level.

The HSPEXP software was developed to assist less-experienced modelers with calibration of a basin model and facilitate the interaction between the modeler and the modeling process not provided by mathematical optimization schemes (Lumb and others, 1994). The advice provided by the expert system is based on a set of rules that use statistical measures and subjective judgments provided by the user that recognize the relative sensitivity of the model parameters on the rainfall-runoff simulation. The calibration is a non-unique solution, meaning that essentially the same model results can be produced with another set of model parameter values. The calibration goal is to have reasonable approximation to the process modeled while retaining realistic and representative parameter values.

Program GENSCN for Simulation of Scenarios

An interactive computer program, GENeration and analysis of model simulation SCeNarios (GENSCN) (Kittle and others, 1998), is a tool for creation of model-simulation scenarios, analysis of results of the scenarios, and comparison of scenarios. GENSCN enables analysis and management of voluminous input and output to complex river-basin models that are used to simulate water quantity and quality for numerous scenarios of changes in land use, land-use management practices, and water-management operations. HSPF and other hydrologic-modeling tools have been ported to GENSCN.

A Chenoweth Run Basin HSPF model implementation in GENSCN was developed and used for water-quality calibrations (after the streamflow was calibrated in HSPEXP). The Chenoweth Run Basin GENSCN/HSPF model, at present, contains the base calibration for water quantity and quality for the period February 1996–January 1998. Development of actual alternative basin-management scenarios was beyond the scope of this study. The Chenoweth Run Basin

GENSCN/HSPF model does, however, provide a ready tool for development and analysis of alternative basin-management scenarios.

MODEL DEVELOPMENT

The HSPF model of Chenoweth Run Basin was developed by defining a set of unique model elements, which include the HRU's and RCHRES's. Basin-segmentation procedures were used to create model elements that have approximately homogeneous characteristics. Initial model parameter values were estimated for each element. The model elements were then specified and linked within the HSPF UCI file (Appendix 5). Associated time-series input-output files were prepared for the HSPF model execution.

Detailed geographic data were used to define the model elements and selected model parameters. ARC/INFO and ARC/INFO-GRID were used to prepare base gridded coverages of land use/land cover, soils, and land slope; TOPOGRID was used to prepare a digital elevation model (DEM) as described in "Methods of Data Collection and Analysis: Geographical Data." A description of the hydrological analysis of this geographic information follows.

Basin segmentation, or partitioning, establishes the areal boundaries of the model elements. Basin segmentation may be based on variations in many basin characteristics, such as meteorology, physiography, land use/land cover, soils, and stream channels. The initial basin segmentation required the definition of RCHRES boundaries and delineation of the subbasins that drain to each RCHRES. Basin segmentation continued further in the process of defining the HRU's.

The basin was segmented, by use of a 1:24,000-scale topographic map, into 23 subbasins draining to 14 channel reaches with significant storage volume (fig. 29). Considerations in defining RCHRES's included provision of (1) reach lengths with mean-flow travel times that approximate the minimum model-simulation time step used, which was 5 minutes; (2) approximately uniform, homogeneous channel properties, such as slope (fig. 30) and conveyance within the reaches; and (3) nodes at stream gages, water-quality-sampling sites, inflows from external sources, and outflows to external sinks.

Drainage areas were also delineated (segmented out) for the numerous ponds and small lakes in the basin (fig. 31). About 25 percent of the whole basin drains through these ponds and small lakes, which therefore may have significant hydrological effects. In the nine subbasins where combined pond-drainage area exceeded 10 percent of the total subbasin area, these multiple, dispersed ponds were represented as single, composite 'pond' RCHRES (nos. 15-23) through which the combined pond-drainage-area runoff was routed prior to routing through a channel RCHRES (nos. 1-14).

The basin was not further segmented on the basis of the rain-gage Thiessen-polygon boundaries (fig. 8), because RG28a alone provided coverage of approximately 90 percent of the drainage area to the two calibration points at Ruckriegel Parkway and Gelhaus Lane (table 9). Thus, RG28a rainfall was applied to the entire basin.

Model Elements and Selected Parameters

Model elements and the initial values of the associated model parameters were developed and estimated by use of observed, measurable basin characteristics, when possible. The procedures used to define the model elements and initial parameter values are described in this section.

Hydrologic Response Units (HRU)

Basin characteristics and classes were selected for defining HRU's that permit model representation of processes that affect both the quantity and quality of water in the basin. Nineteen different HRU's were developed.

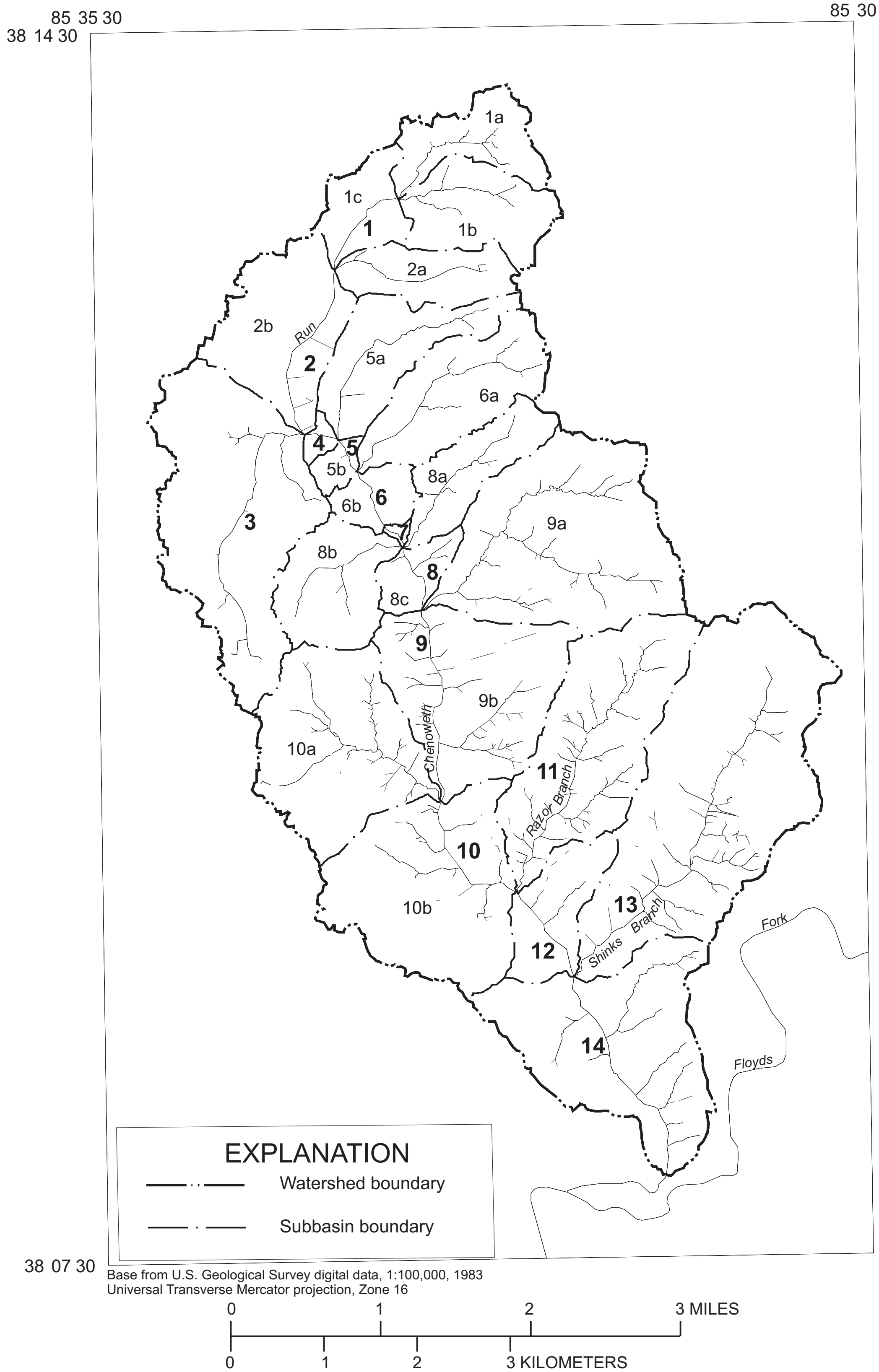


Figure 29. Model subbasin and stream-reach designations for the Chenoweth Run Basin, Jefferson County, Kentucky.

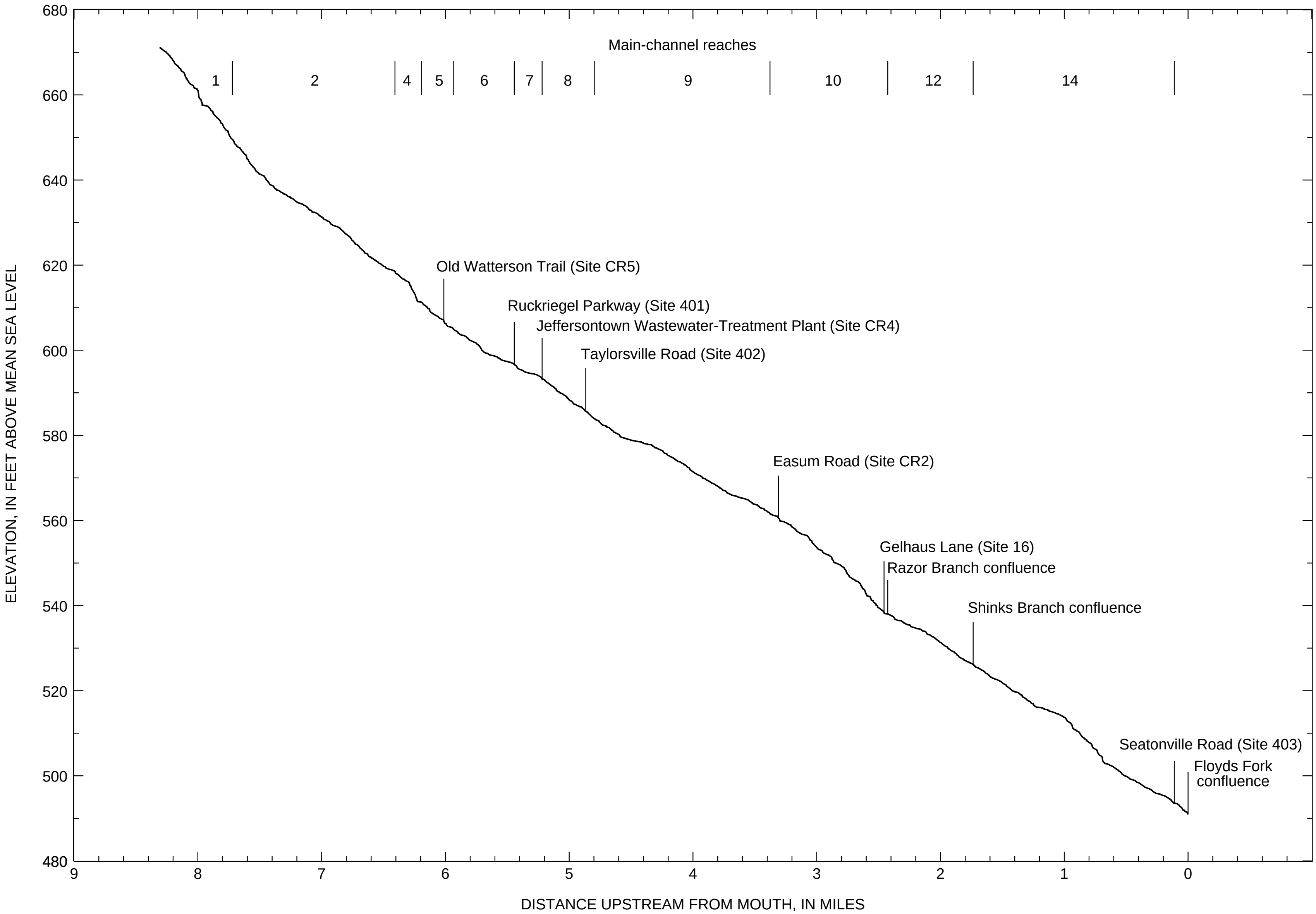


Figure 30. Approximate Chenoweth Run low-water profile based on 2-foot contour-interval data.

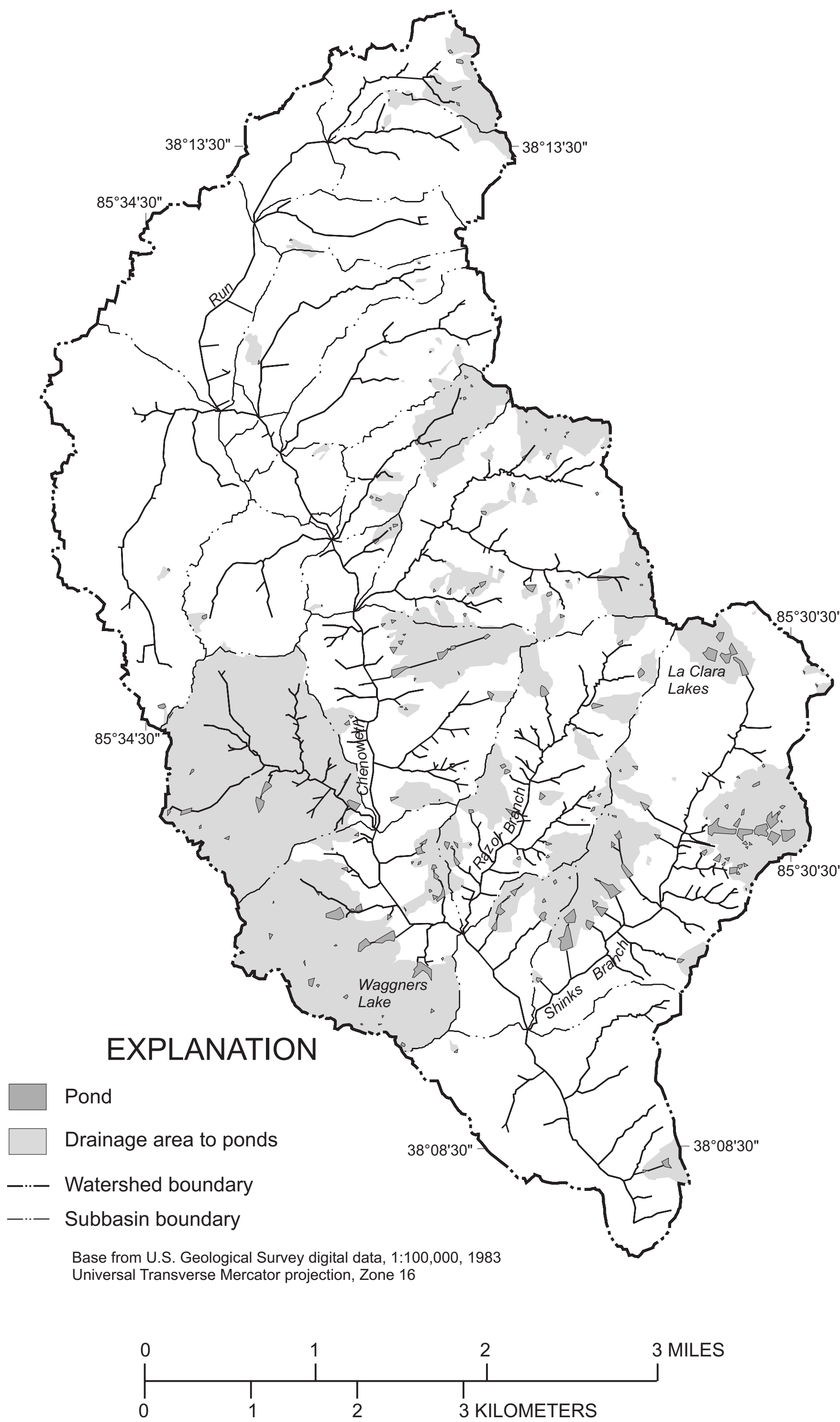


Figure 31. Areas draining to ponds and small lakes in the Chenoweth Run Basin, Jefferson County, Kentucky.

Analysis and Classification of Basin Characteristics

Available geographic data were compiled and analyzed in terms of three hydrologically relevant basin characteristics—land use/land cover, soils, and land slope. The HRU's were defined, as described in the following sections, on the basis of seven land-use/land-cover classes, three soil classes, and two land-slope classes.

Land Use and Land Cover

The types of land use and land cover in a basin significantly affect hydrologic response. Thirteen basic land-use/land-cover classes (table 8) were defined from the original geographical data sets. These included agricultural areas (pasture/crop and forest); nonagricultural, open, primarily grass-covered areas; and impervious areas.

The nonagricultural open areas were distinguished by the associated land uses and the degree of possible man-made alterations, including soil disturbances and lawn treatment. These classes permit representation of the effects of possible soil disturbance (compaction, regrading, etc.) and varied lawn-treatment practices. A zone of disturbed soils was assumed to exist within a buffer approximately 50 ft (15 m) in width around buildings in the single-family-residential and commercial/industrial/multifamily-residential land-use categories only. Different HRU's can be hypothesized and represented; land inside the 50-ft buffer can be assumed to have lower infiltration rates and water-storage capacity and also higher lawn-treatment rates than otherwise similar areas within the same land-use/land-cover class located outside this 50-ft buffer.

Impervious areas were distinguished by type (roads, buildings, and parking lots) and associated land uses. Impervious classes defined on the basis of land-use categories included (1) commercial/industrial/multi-family impervious, and (2) single-family-residential and other impervious areas in the public/semi-public, parks/open space, vacant/undeveloped land-use categories. Different constituent-accumulation rates may be hypothesized and modeled for these two different impervious classes.

The 13 basic land-use/land-cover classes were simplified and consolidated (remapped) into 7 land-use/land-cover classes by use of ARC/INFO-GRID prior to combining these with coverages of other basin characteristics of interest—the soils and land slopes. (See program *hru.aml* in Appendix 3). The seven land-use/land-cover classes included pasture/crop, forest, open vacant/undeveloped uses, open developed uses, open single-family residential-use areas having disturbed soils, open commercial/industrial/multifamily-residential use areas having disturbed soils, and impervious (fig. 32). The proportion of pervious area (open and forested) and total impervious area in the basin was shown in table 2.

Soils

For definition of the HRU's, soils were grouped on the basis of estimated drainage properties of each of the 18 soil series' in the basin. The HSPF soil parameter INFILT (table 28) was estimated as the (limiting) minimum permeability for each soil series as listed in the soil survey of Jefferson County. UZSN was estimated as the product of the average depth of the topsoil horizon and the available-water capacity in the topsoil. LZSN was estimated as the product of the average depth to the seasonally high water table (unsaturated zone) and the average available-water capacity in the subsoil. The K-means cluster-analysis technique (Hartigan, 1975; Wilkinson and others, 1996) was used to help distinguish the soil series' that have similar infiltration and storage characteristics. The cluster analysis was done for various numbers of groups with and without transformation (log base 10) and with and without standardizing the parameter values. Three soil-series clusters were identified using the transformed and standardized INFILT and LZSN parameters for the 7 soil series' that comprise at least 3 percent of the basin area (table 29 and fig. 33). These three groups of the seven primary soil series' were distinguished primarily on the basis of the INFILT value. UZSN was not a significant discriminator among the groups and was not used in the final clustering. The remaining minor soils were classified into the three groups with the most similar INFILT value, as shown in table 29 and figure 33.

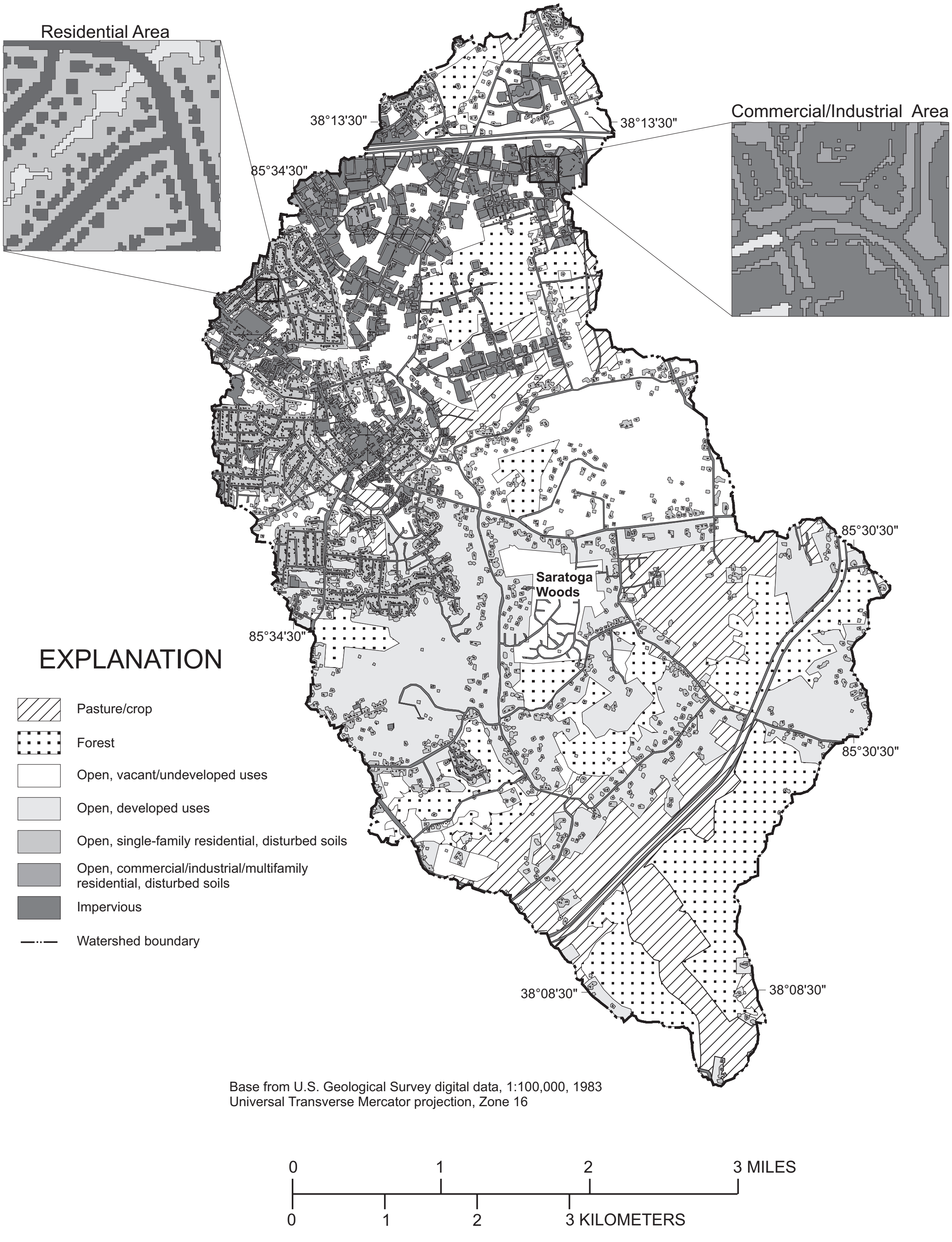


Figure 32. Distribution of land covers in the Chenoweth Run Basin, Jefferson County, Kentucky.

Table 29. Description of the soil-series groups defined for modeling the Chenoweth Run Basin, Jefferson County, Kentucky

[UZSN, upper-zone nominal storage; LZSN, lower-zone nominal storage; INFILT, infiltration capacity; *, indicates the primary soils used in the final clustering; --, not applicable]

Jefferson County soil series	Percentage of basin area	Estimated UZSN (inches)	Estimated LZSN (inches)	Estimated INFILT (inches per hour)
Soils-series group 1				
Beasley*	24.5	0.62	8.40	0.05
Dickson*	4.4	.88	3.42	.05
Ginat	1.1	.05	.72	.05
Guthrie	1.0	.88	1.32	.05
Lawrence	2.1	.88	1.32	.05
Otway	1.6	.08	2.52	.05
Russellville*	13.5	.88	5.70	.05
Taft	.3	.66	1.32	.05
Woolper	1.3	.57	5.25	.05
Subtotal:	**49.9**	**--**	**--**	**--**
Areally weighted mean:	**--**	**.70**	**6.30**	**.05**
Soils-series group 2				
Captina	.9	1.10	3.15	.20
Corydon*	6.6	.66	4.20	.20
Crider*	24.5	.88	10.5	.20
Lindside	2.4	.88	1.32	.20
Subtotal:	**34.3**	**--**	**--**	**--**
Areally weighted mean:	**--**	**.84**	**8.47**	**.20**
Soils-series group 3				
Ashton	.5	.88	13.2	.80
Elk	.7	.88	12.3	.80
Fairmount*	5.5	.40	2.16	2.00
Huntington*	3.1	.78	5.46	.80
Newark	2.1	1.10	1.32	.80
Subtotal:	**11.9**	**--**	**--**	**--**
Areally weighted mean:	**--**	**.67**	**3.97**	**1.35**

Note: Made land, rock land, and water bodies cover the remaining 3.9 percent of the basin.

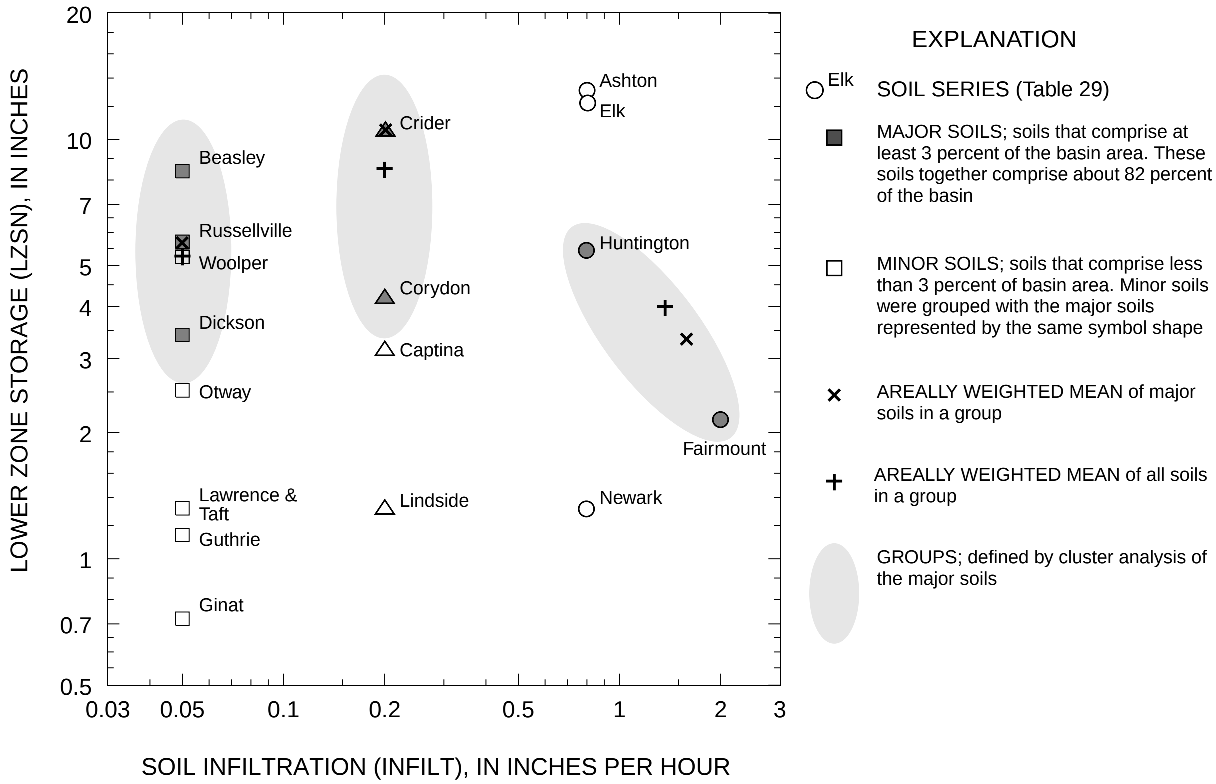


Figure 33. Estimated infiltration rates and lower-zone storages of the soil series and soil-series groups defined for modeling the Chenoweth Run Basin, Jefferson County, Kentucky.

Areally weighted average values of UZSN, LZSN, and INFILT were calculated for each soil-series group. These calculated values served as a guide for estimating initial HSPF soil-related parameter values for each HRU. The areal distribution of the soil-series groups is shown in figure 34.

Land Slope

Land slope was generally steeper in the lower half of the basin than in the upper half (see the shaded-relief map on cover). A 13.1 ft by 13.1 ft (4 m by 4m) continuous land-slope grid was computed from the LOJIC digital elevation data. Two slope classes were selected: less than or equal to 5 percent and greater than 5 percent. Approximately 40 to 45 percent of the basin has a land slope of less than or equal to 5 percent. The areal distribution of the two slope classes are shown in figure 35.

Definition and Adjustment

The model HRU's are selected geographic intersections (combinations) of the seven land-use/land-cover classes, three soil classes, and two slope classes. Processing the gridded land-use/land-cover, soils, and land-slope coverages by use of ARC/INFO-Grid (program *hru.aml*, Appendix 3) generated the combined grid consisting of the existent combinations of the seven land-use/land-cover classes, three soil classes, and two land slope classes (table 30). There were 36 different hypothetical basin-characteristic combinations for pervious HRU's (6 covers * 3 soils * 2 slopes). The impervious land use/land cover was restricted to only two classes (commercial/industrial/multifamily-residential land uses and single-family-residential and other land uses), and the impervious areas were not differentiated in terms of slope.

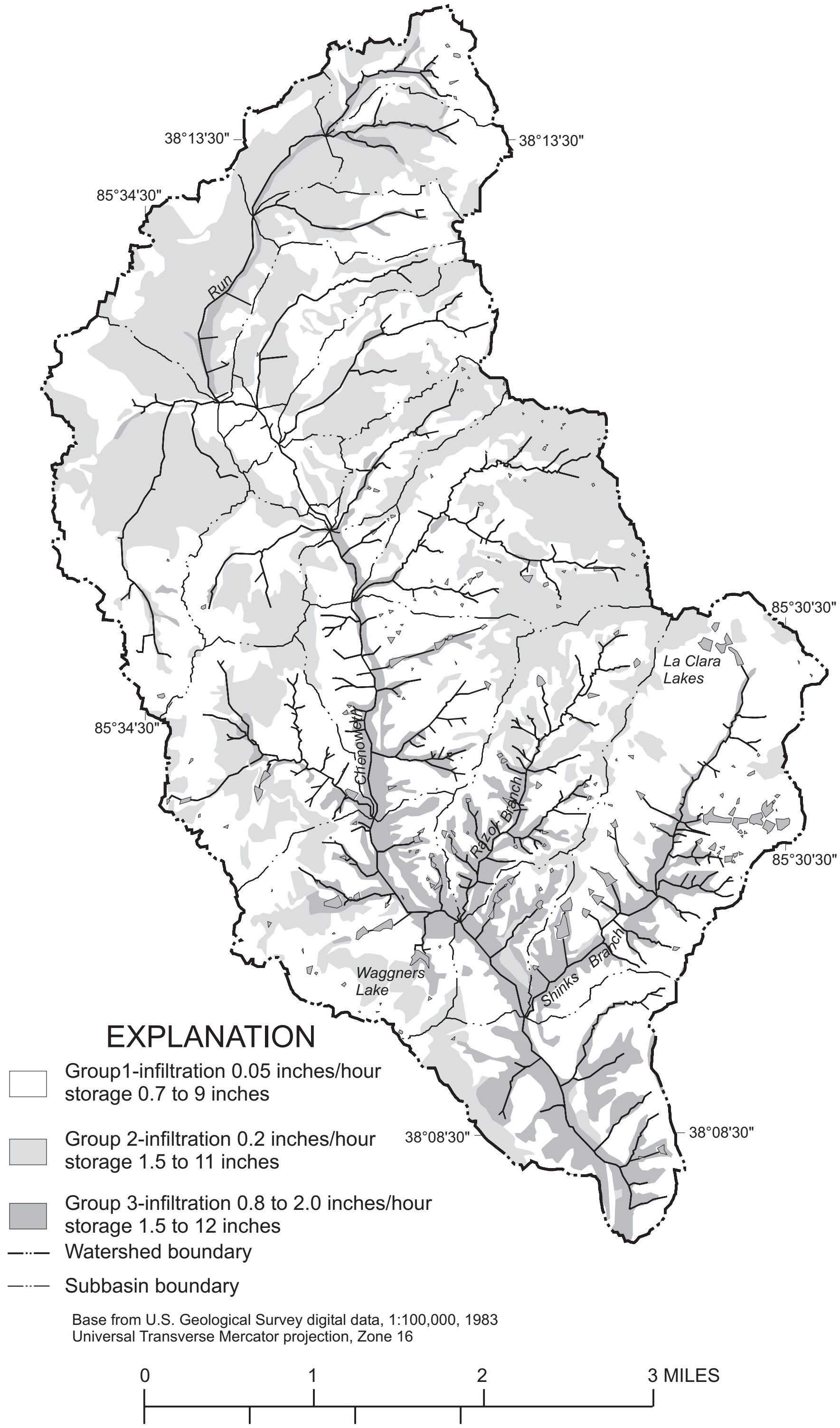


Figure 34. Distribution of soil-series groups defined for modeling the Chenoweth Run Basin, Jefferson County, Kentucky.

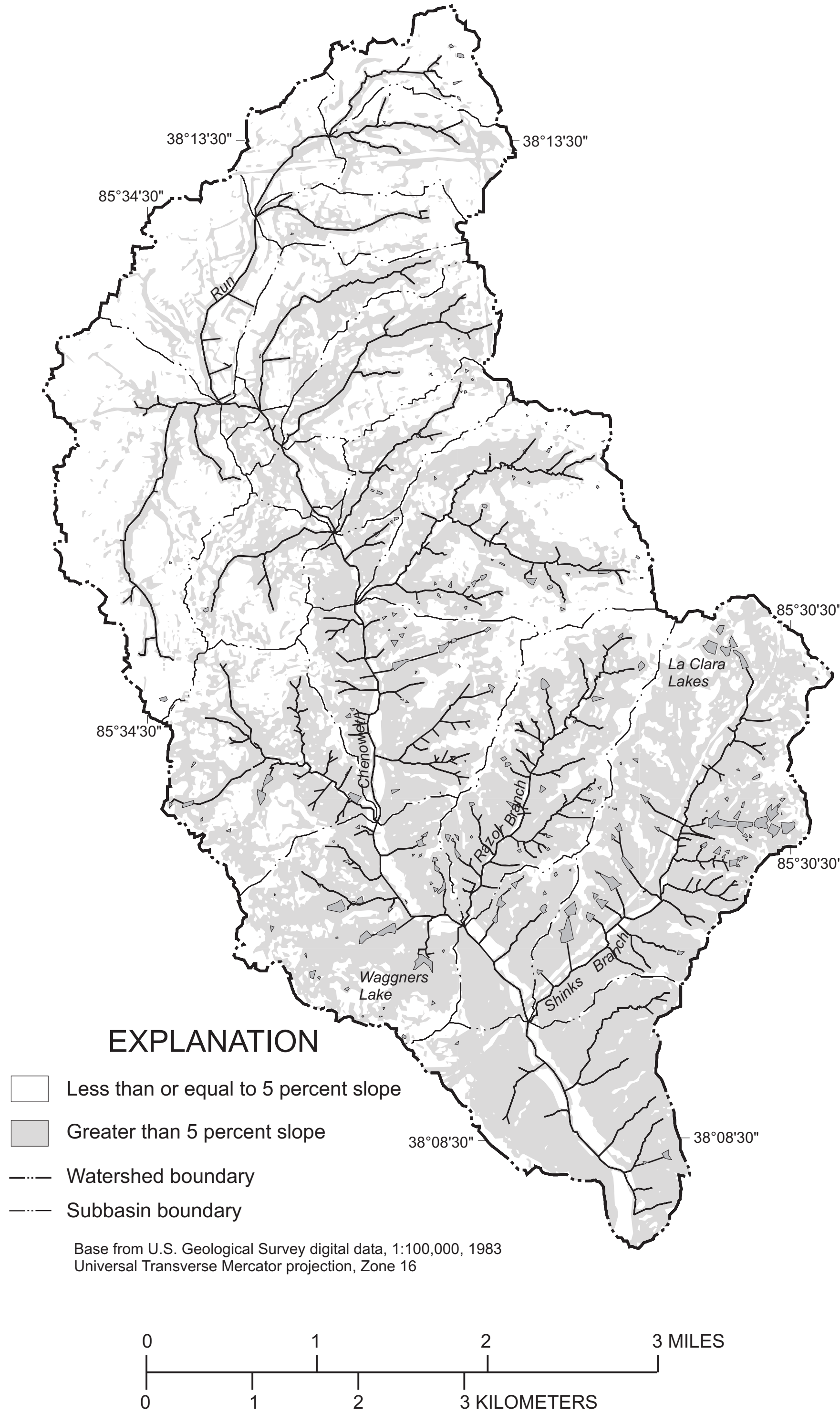


Figure 35. Distribution of land slopes in the Chenoweth Run Basin, Jefferson County, Kentucky.

Table 30. Hydrologic response units simulated in the Hydrological Simulation Program—Fortran (HSPF) model of the Chenoweth Run Basin, Jefferson County, Kentucky

[%, percentage of drainage area at point of interest; >, greater than; The open, developed uses hydrologic response unit includes open areas assumed undisturbed in the land uses designated as residential, commercial, industrial, public, semipublic, parks, and open space in the Louisville and Jefferson County Information Consortium (LOJIC) coverages]

Hydrologic response unit	Chenoweth Run at Ruckriegel Parkway		Chenoweth Run at Gelhaus Lane		Chenoweth Run at Seatonville Road		Description
	Acres	%	Acres	%	Acres	%	
Pervious hydrologic response units							
1	76	2.2	124	1.7	244	2.3	Pasture/crop, low-permeability soils, 0 to 5 percent slope
2	20	.6	121	1.6	548	5.2	Pasture/crop, low-permeability soils, > 5 percent slope
3	49	1.4	177	2.4	431	4.1	Pasture/crop, moderate-permeability soils, 0 to 5 percent slope
4	5	.2	41	.6	306	2.9	Pasture/crop, high-permeability soils, > 5 percent slope
5	79	2.3	128	1.7	242	2.3	Forested, low-permeability soils, 0 to 5 percent slope
6	126	3.7	290	4.0	930	8.8	Forested, low-permeability soils, > 5 percent slope
7	164	4.8	228	3.1	252	2.4	Forested, moderate-permeability soils, 0 to 5 percent slope
8	21	.6	93	1.3	445	4.2	Forested, high-permeability soils, > 5 percent slope
9	174	5.0	431	5.9	459	4.3	Open, vacant/undeveloped uses, low-permeability soils, 0 to 5 percent slopes
10	201	5.8	452	6.2	592	5.6	Open, developed uses, low-permeability soils, 0 to 5 percent slopes
11	124	3.6	834	11.4	1,238	11.7	Open, developed uses, low-permeability soils, > 5 percent slopes
12	217	6.3	726	9.9	823	7.8	Open, developed uses, moderate-permeability soils, 0 to 5 percent slopes
13	159	4.6	371	5.0	404	3.8	Open, developed uses, moderate-permeability soils, > 5 percent slopes
14	55	1.6	239	3.3	363	3.4	Open, developed uses, high-permeability soils, > 5 percent slopes
15	367	10.6	861	11.7	972	9.2	Open single-family residential, disturbed low-permeability soils, all slopes
16	423	12.3	726	9.9	777	7.3	Open single-family residential, disturbed moderate-permeability soils, 0 to 5 percent slopes
17	465	13.5	547	7.5	547	5.2	Open commercial/industrial/multi-family residential, disturbed moderate-permeability soils, 0 to 5 percent slopes
Subtotal:	**2,725**	**79.1**	**6,389**	**87.2**	**9,573**	**90.5**	
Impervious hydrologic response units							
1	237	6.9	425	5.8	495	4.7	Single-family residential/parks/public/vacant hydrologically effective impervious areas, all slopes
2	483	14.0	512	7.0	512	4.8	Commercial/industrial/multi-family residential hydrologically effective impervious areas, all slopes
Subtotal:	**720**	**20.9**	**937**	**12.8**	**1,007**	**9.5**	
Total:	**3,445**	**100**	**7,327**	**100**	**10,580**	**100**	

Thus, there were a total of 38 different hypothetical HRU's from which the final set of primary HRU's for modeling were selected and specified.

Adjustments of the hypothetical HRU categories and areas were made on the basis of the HRU prevalence in the basin, the hydrological effectiveness of the impervious areas, and other factors, such as land uses and land treatments that were not reflected in the original geographic data used to generate the initial set of hypothetical HRU's.

Drainage areas of each HRU to each of the two streamflow-gaging stations and the entire basin area are summarized in table 30. The areas listed in table 30 reflect the HRU adjustments described in the following sections.

For appropriate HSPF model routing of water and constituents through the basin, consistent with the basin-segmentation procedure, areas of each HRU were determined for the portion of each subbasin that drains (1) directly to the subbasin channel and (2) to the ponds (but only in cases where more than 10 percent of the subbasin area drains to ponds). These HRU areas, which were grouped by subbasin in the UCI file (Appendix 5), serve as areal "weightings" that specify the relative frequency of each HRU within each subbasin.

Prevalence of the Hydrologic Response Units

Some of the hypothetical HRU's were not present in the basin in hydrologically significant amounts. About one-half of the pervious hypothetical HRU's individually represented less than 2 percent of the basin area; therefore, these hypothetical HRU's were not included in the set of primary HRU's represented in the model. Areas of the pervious hypothetical HRU's covering less than 2 percent of the basin were shifted, or added, to other similar pervious HRU's that were selected, in order of priority, on the basis of similarity in (1) land-use/land-cover, (2) soils characteristics, and (3) slope. Seventeen primary pervious HRU's (table 30) remained after this consolidation procedure.

Prevalent HRU's in the upper third of the basin at Ruckriegel Parkway included the effective impervious areas, IMPLND's 1 and 2 (approximately 21 percent), open space in single-family-residential use with disturbed soils, PERLND's 15 and 16 (22.9 percent), and open space in commercial/industrial/multifamily-residential use with disturbed soils, PERLND 17 (13.5 percent). Further downstream, the proportion of basin area that is in the disturbed-soil and impervious HRU's declined. At the Seatonville Road site, for example, effective impervious area was approximately 10 percent of basin area; HRU's with disturbed soils, PERLND's 15, 16 and 17, were approximately 22 percent of basin area; open space with low-permeability soil and slopes exceeding 5 percent, PERLND 11, was approximately 12 percent of basin area; and forested area with low-permeability soil and slopes exceeding 5 percent, PERLND 6, was approximately 9 percent of basin area.

Hydrologically Effective and Ineffective Impervious Areas

Hydrologically effective impervious areas yield runoff directly to the basin drainage network. The proportion of the total impervious area that was hydrologically effective was estimated. The estimated percentage of the impervious types (roads, buildings, and parking lots) that were hydrologically effective were assumed to vary by land-use classification as shown in table 31. A similar approach has been used in other studies (Dinicola, 1990; Jarrett and others, 1998; Alley and Veenhuis, 1983).

Table 31. Estimates of the percentages of impervious land covers that are hydrologically effective in the Chenoweth Run Basin, Jefferson County, Kentucky

[LOJIC, Louisville and Jefferson County Information Consortium]

LOJIC land-use classification	Impervious type	Percentage hydrologically effective
Single family:		
	Roads	80
	Buildings	20
Multi-family:		
	Roads	90
	Buildings	80
	Parking	90
Commercial and industrial:		
	Roads	95
	Buildings	90
	Parking	95
Public, park and vacant:		
	Roads	70
	Buildings	40
	Parking	40

Conversely, hydrologically ineffective impervious areas convey runoff to nearby pervious areas. A significant proportion of roof tops in low- and moderate-density development is often hydrologically ineffective. The estimated hydrologically ineffective impervious areas were therefore subtracted from the total subbasin impervious area and shifted (added) to pervious HRU areas within the same subbasin.

The hydrologically ineffective impervious areas were added to selected pervious HRU's that have limited storage and infiltration capacity (PERLND's 15, 16, and 17). This indirectly simulated the effect of additional runoff from impervious areas flowing onto an adjacent pervious area, which would have diminished water storage and infiltration capacities because of the additional water added to the precipitation falling directly onto the pervious area. The hydrologically ineffective impervious area was shifted, or allocated, to PERLND's 15, 16, and 17 within a subbasin in proportion to the relative proportion of each of these HRU's within the subbasin. For example, if there was an equal area of PERLND's 15, 16, and 17 in a subbasin, then equal portions (one third) of the total hydrologically ineffective impervious area in the subbasin would be shifted to each of these three HRU's.

For improved fit during calibration of flow, hydrologically effective impervious areas in subbasins upstream from the Ruckriegel Parkway site were reduced an additional 10 percent and also shifted in like fashion to PERLND's 15, 16, and 17. Note that the total impervious area upstream from the Ruckriegel Parkway site was estimated to be approximately 30 percent of the drainage area (table 2), and the final effective impervious area at this site after model calibration was estimated to be approximately 21 percent of the drainage area (table 30).

Other Adjustment Factors

A change in land use that was not reflected in the original LOJIC geographic data set obtained in 1996 for use in the study occurred at the Saratoga Woods residential development (fig. 32) in subbasin 9b (fig. 29). Recent (spring 1997), aerial imagery of the area was obtained from LOJIC to supplement the original data. Approximately 400 new houses in the development were counted on the aerial imagery. Consequently, an adjustment of one quarter acre per house was made by shifting 100 acres from PERLND's 9 and 11 to PERLND 15 (table 30). The 100 acres was subtracted from these HRU's in proportion to the relative amounts of each of these HRU's that was measured in this subbasin. In addition, 2,500 ft^2 of impervious area (rooftops and driveways) per house were added by shifting 5 acres from PERLND 11 to IMPLND 1. (Roads within the development were already included in the impervious HRU areas.)

An adjustment of HRU's was also made for representation of more intensive land-disturbance and land-treatment activities likely at Vittner Golf Course in subbasin 10a (fig. 29) than was assumed typical for the open, developed-uses set of HRU's (PERLND's 10-14). One-hundred-fifty acres of these five PERLND's, which were subtracted from each of these HRU's in proportion to the relative amounts of each of these HRU's that were measured in this subbasin, were shifted to PERLND's 15-17. Seventy-five percent (112.5 acres) was shifted to PERLND's 15 and 16 in proportion to the relative amounts of each of these two HRU's that were measured in this subbasin. The remaining 25 percent (37.5 acres) was shifted to PERLND 17.

Reaches and Reservoirs (RCHRES)

Stream reach and reservoir (RCHRES) boundaries were defined as part of basin segmentation. The Chenoweth Run Basin was segmented into 23 subbasins with 14 actual RCHRES—11 in the main channel and 3 in the major tributary channels (fig. 29). In addition, nine composite, 'pond' RCHRES's were added to simulate the hydrologic effects of the numerous, dispersed small lakes and ponds in the basin. Each RCHRES had unique channel geometry and conveyance that was described in a function table (FTABLE) in the HSPF UCI file (Appendix 5). The FTABLES specified stage, surface area, storage, and discharge characteristics of a channel or reservoir.

The Channel Geometry Analysis Program (CGAP) by Regan and Schaffranek (1985) was used to define the average, stage-dependent storage-discharge characteristics for the 14 actual main- and tributary-channel RCHRES's. CGAP computations required channel cross-section and roughness information. A series of channel cross sections spaced at approximately 200 to 300 ft were developed for each RCHRES from the LOJIC 2-ft contour-interval maps. Estimates of channel roughness (Manning's "n" value) were made using procedures by Arcement and Schneider (1989) and "n" values estimated previously for indirect discharge measurements in Chenoweth Run.

Runoff in Chenoweth Run, particularly downstream from the Ruckriegel Parkway site, is influenced by numerous, but generally small, lakes and ponds (hereafter referred to as ponds). The LOJIC water-bodies coverage includes 248 ponds in the basin with an average surface area of 0.45 acres, ranging in size from less than 0.01 to 4.43 acres; drainage areas to these ponds were delineated (fig. 31). Total drainage area to ponds was 2,660 acres, about 25 percent of the whole basin drainage area.

The ponds were too numerous to represent individually in the model; therefore, they were represented in the model by composite pond RCHRES's that were intended to reflect the combined water and constituent storage and discharge characteristics of all the ponds within a subbasin. A pond RCHRES was included for each subbasin where drainage area to ponds was greater than 10 percent of the total subbasin area. The normal surface area of each pond RCHRES was estimated as the summation of the surface areas of all ponds within a subbasin. The normal volume of each pond RCHRES was estimated as 40 percent of the normal depth (12 ft assumed) times the surface area at normal depth. A typical, relative pond depth-area-volume relation (table 32) was assumed representative for each pond RCHRES. Mean 10-year and 100-year peak discharges were estimated separately for the drainage areas of the small pond RCHRES's (16, 17, 20, 21, 22, and 23) and the large pond RCHRES's (15, 18, and 19). Low flood-storage volume was assumed for the ponds. Thus, pond RCHRES hypothetical outflows specified in the FTABLES were set equal to approximately two-thirds of the estimated 10-year peak flow at a hydraulic head of 2 ft (stage of 14 ft) and at least equal to the estimated mean 100-year peak flow at a hydraulic head of 4 ft (stage of 16 ft). Pond drainage areas for subbasins 13, 12, 11, 10b, 10a, 9b, 9a, 8a, and 1a (fig. 29) drain to pond RCHRES 15, 16, 17, 18, 19, 20, 21, 22, and 23, respectively, as detailed in the UCI file, Appendix 5.

Table 32. Relative depth-area-volume relation used for the pond reaches and reservoirs (RCHRES) in the Chenoweth Run Basin model

Depth (in feet)	Depth divided by 12 feet	Area divided by area at 12 feet depth	Volume divided by volume at 12 feet depth
0	0	0	0
6	.5	.79	.33
7	.583	.84	.43
8	.667	.89	.55
9	.75	.92	.66
10	.833	.94	.76
11	.917	.97	.89
12	1	1	1
13	1.083	1.02	1.11
14	1.167	1.05	1.25
15	1.25	1.07	1.37
16	1.33	1.1	1.5

Base-Flow Losses

Available base-flow discharge measurements in Chenoweth Run (table 20) indicated a possibility for seasonal ground-water-seepage losses in the main channels. Discharge measurements during base flows in the Beargrass Creek Basin indicated base-flow losses occurred there also (Ruhl and Jarrett, 1999). Such losses were hypothesized and incorporated into the model by use of the multiple-outflow-gate feature of HSPF. Two outflow gates were included for RCHRES's 4 to 10, 12, and 14; the first outflow gate removed seepage water from the channel (and entirely out of the system), and the second outflow gate routed the remaining flow to downstream RCHRES's.

During low-flow calibration, the target total channel seepage losses were up to 0.5 ft^3/s upstream from Ruckriegel Parkway, 1.5 to 2.0 ft^3/s from Ruckriegel Parkway to Gelhaus Lane, and the same lineal loss rate continuing downstream from Gelhaus Lane as was assumed to exist between

Ruckriegel Parkway and Gelhaus Lane. A constant seepage-loss rate was assumed during June–November, except in October, when it increased 50 percent until October 30. Also, the base seepage loss rate was increased 50 percent during July–October 1998; at all other times the assumed seepage-loss rate was effectively zero. The seepage loss was implemented in HSPF as an outflow-demand time series (DSN 72) with a base value of 1 ft^3/s that was multiplied by weighting factors (see UCI file, Appendix 5) to provide a uniform lineal loss rate for each stream segment and the desired total loss in each segment. The combined base-flow loss after flow calibration was 0.37 ft^3/s in RCHRES's 4-6 upstream from Ruckriegel Parkway, 1.82 ft^3/s in RCHRES's 7-10 between Ruckriegel Parkway and Gelhaus Lane, and 1.37 ft^3/s in RCHRES's 10 and 12 downstream from Gelhaus Lane.

As noted in the 'Previous Studies' section, the gains in base flows observed in Floyds Fork near Chenoweth Run may be fed by base-flow losses in Chenoweth Run. Detailed base-flow seepage measurements are needed to confirm and refine the assumed seepage-loss rates.

Lower Zone Evapotranspiration Parameter (LZETP)

Evapotranspiration from lower-zone storage is limited by the amount of deep-rooted vegetation. This limit on evapotranspiration was represented in the model by a deep-rooted-vegetation density-index parameter, LZETP, which ranges in value from 0 to 1. Initial estimates of LZETP were calculated for each PERLND HRU by combining a gridded tree-canopy cover (developed from the LOJIC tree-canopy line coverage) with the HRU grid. The tree-canopy cover was also merged with the GIRAS cover of forest type to distinguish deciduous trees from evergreen trees, where possible. The deciduous and evergreen proportions were used to estimate variable monthly LZETP values.

Note that the spatial distribution of the forest HRU was not delineated by use of the LOJIC tree-canopy coverage. The forest-HRU distribution was determined directly from the GIRAS land-use/land-cover data. The forest areas delineated by use of the GIRAS data did have large values of LZETP estimated by use of the LOJIC tree-canopy cover.

Model Input and Output Files

Time-series data (table 5) that were used in the HSPF model were entered into ANNIE (Flynn and others, 1995), a watershed-data-management system designed to create files accessible directly from the HSPF model and other supporting applications, such as METCMP, HSPEXP and GENSCN; ANNIE also provides interactive access to manage, transform, plot, and analyze time-series data.

The UCI file (Appendix 5) controls execution of the HSPF model by specifying the program modules (table 27) and associated model parameters (table 28) to use. Appropriate linkages among the model elements (PERLND's, IMPLND's, and RCHRES's) and time-series data (source to target and input to output) must be explicitly specified in the UCI file.

SIMULATION OF STREAMFLOW

The HSPF model had to be calibrated for precipitation and runoff before it could be used to simulate sediment or chemical constituents. The streamflow-calibration process included steps to adjust appropriate model parameters to obtain representative discharges during a wide range of hydrologic conditions during the 24-month period February 1996–January 1998. Selected discharge data not used in the calibration process was used in model verification. Effluent discharges from the WWTP's in the basin were added to natural discharge: the Jeffersontown WWTP discharges into RCHRES 8, the Chenoweth Hills WWTP discharges into RCHRES 9, and the Lake of the Woods WWTP discharges into RCHRES 10 (fig. 29). (Note: The Chenoweth Hills WWTP is located in subbasin 10a; however, the effluent is pumped over to Reach 9 at a point approximately 3,000 ft downstream from Taylorsville Road.)

Calibration and Verification

Initial parameter values affecting discharge (table 28) were calculated from physical characteristics of the basin to the extent possible, as described in "Model Development." Initial values for parameters that were not physically measurable were estimated from literature values. A trial-and-error, iterative process was then used to modify the initial model parameter values. 'Guidelines for HSPF calibration' (Donigian and others, 1984) and the expert system for HSPF, HSPEXP (Lumb and others, 1994), were used to aid in model discharge calibration. In general, the model was calibrated to annual and seasonal water budgets for the calibration period, then adjusted to improve storm-runoff-volume and peak-discharge simulations while maintaining the annual and seasonal water balances. The quality of the model calibration trials was judged by use of a combination of graphical and statistical means.

Model testing (verification) can be considered an extension of the model calibration process. The purpose of verification is to assure the model adequately represents all conditions that can affect model results. One commonly used verification procedure is to split the available data into two independent data sets—one set is used in model calibration and the other set in model verification. Continuous streamflow data was unavailable prior to February 1996, which limited the available data to a 24-month period. A 3- to 5-year period of calibration data is optimal to provide a representative variety of hydrologic conditions for model calibration, although satisfactory calibrations have been achieved with less data (Viessman and others, 1977). The 24-month study data-collection period included a wide range of streamflows, from record floods to moderately low base flows. The available continuous 24-month data were not split into independent sets, because this would have unduly limited the period of calibration. A sufficient number of storms were available, however, to split storms into two groups for storm-runoff-volume and peak-discharge calibration and verification. Characteristics of these storms were described in "Analysis and Summary of Hydrologic Conditions: Precipitation."

Calibration Criteria

Various error measures were used to evaluate the quality of the model flow calibration. The expert system for calibration of flow in HSPF (HSPEXP) automatically computes errors in (1) total runoff volumes for the calibration period, (2) the mean of the low-flow-recession rates, (3) the mean of the lowest 50 percent of daily mean discharge, (4) the mean of the highest 10 percent of daily mean discharge, (5) flow volume for selected storms, (6) seasonal volume difference, and (7) runoff volume for selected summer storms.

The quality of the calibration for the total, annual, and monthly water balances was assessed on the basis of the percentage error. Donigian and others (1984) rate an annual or monthly water-balance error of less than 10 percent as very good, 10 to 15 percent as good, and 15 to 25 percent as fair.

The difference between simulated and observed discharge was reported by three statistics: (1) the correlation coefficient, (2) the coefficient of model-fit efficiency (Nash and Sutcliffe, 1970), and (3) the percentage of the calibration time periods for which the simulation error was less than 10 and 25 percent. In some instances, the difference between simulated and observed discharge was reported as the actual difference in discharge or a percent difference.

The correlation coefficient, C, is calculated as

$$C = \frac{\sum_{i=1}^{N}(Qo_i - Qo) \times (Qs_i - Qs)}{\left[\sum_{i=1}^{N}(Qo_i - Qo)^2 \times \sum_{i=1}^{N}(Qs_i - Qs)^2\right]^{1/2}}, \quad (1)$$

and the coefficient of model-fit efficiency, E, is calculated as

$$E = \frac{\sum_{i=1}^{N}(Qo_i - Qo)^2 - \sum_{i=1}^{N}(Qo_i - Qs_i)^2}{\sum_{i=1}^{N}(Qo_i - Qo)^2}, \quad (2)$$

where

Qo_i is the observed discharge volume for time period i,

Qs_i is the simulated discharge volume for time period i,

Qo is the average observed discharge volume,

Qs is the average simulated discharge volume, and

N is the number of time periods in the calibration period.

Additional error statistics computed to compare simulated and observed flows included

$$\text{Mean absolute error, average} = \Sigma[|(S-O)|/N], \quad (3)$$

$$\text{Mean absolute error, percent} = 100 \times \Sigma\left\{\left[\frac{|(S-O)|}{O}\right]/N\right\}, \quad (4)$$

$$\text{Root mean square error, average} = \sqrt{\Sigma[(S-O)^2/N]}, \quad (5)$$

$$\text{Root mean square error, percent} = 100 \times \sqrt{\Sigma\left[\left(\frac{S-O}{O}\right)^2/N\right]}, \quad (6)$$

$$\text{Bias, average} = \Sigma[(S-O)/N], \quad (7)$$

$$\text{Bias, percent} = 100 \times \Sigma\{[(S-O)/O]/N\}, \quad (8)$$

$$\text{Standard error of estimate, average} = [N/(N-1)] \times \sqrt{[(\text{Root mean square error, average})^2 - (\text{Bias, average})^2]}, \quad (9)$$

$$\text{Standard error of estimate, percent} = [N/(N-1)] \times \sqrt{[(\text{Root mean square error, percent})^2 - (\text{Bias, percent})^2]}, \quad (10)$$

where

S is the simulated discharge, in ft^3/s,

O is the observed discharge, in ft^3/s, and

N is the number of discharge values in the sample.

Hydrographs and scatterplots showing simulated and observed monthly, daily, and stormflows were prepared. Also, flow-duration curves of daily simulated and observed flows were plotted. These graphs were reviewed to identify biases during specific time periods and parts of the flow regime.

Modifications of Model Parameters and Elements

As described by Duncker and others (1995) and Donigian and others (1984), HSPF calibration is facilitated by the structure of the model wherein the annual balance is most affected by one set of parameters (LZETP, DEEPFR, LZSN, and INFILT), the seasonal balance is most affected by another set (UZSN, BASETP, KVARY, and CEPSC), and the stormflow is most affected by still another set (INFILT, INTFW, and IRC). Note the BASETP parameter, which controls evaporation losses from base flows, was set to zero. Nonzero BASETP values caused diurnal fluctuations in simulated flows that were inconsistent with the observed flows.

HSPF is a continuous simulation model, and thus, the calibration of the hydrologic processes occurring between storms is necessary to correctly simulate flows during storms. This is largely done by adjusting the parameter values for HRU's representing pervious areas (PERLND's). The PERLND properties have a relatively large effect on the annual and seasonal water balances (when compared to the IMPLND properties). Seventeen PERLND types, which varied by land use/land cover, soil, and slope (table 30), were simulated.

PERLND's stored water later released as base flow (slow-responding, consistent ground-water flow), as interflow (fast responding ground-water flow), or as surface runoff (in the same fashion as impervious runoff). Precipitation runoff from PERLND's is controlled by the soil-storage and infiltration properties. Initial values for UZSN, LZSN, and INFILT were estimated from soils data as described previously in "Model Development." Storage properties of disturbed soils (PERLND's 15 to 17) were decreased by about one-half or more of the values for similar soils in an undisturbed PERLND; the decreased storage capacity forces precipitation to exit sooner as surface runoff. Calibrated UZSN values ranged from a winter low of 0.10 in. in a disturbed commercial PERLND (no. 17) to an autumn high of 0.98 in. in forested PERLND's (nos. 5 to 8). Calibrated LZSN values ranged from 2.05 to 5.76 in. Calibrated INFILT values ranged from 0.028 to .356 in/h.

Water held in soil storage (including interception storage) is also available for evaporation, which is lost at a rate constrained by the potential evapotranspiration rate (PET). Evapotranspiration is limited by the amount of deep-rooted vegetation, which is indexed by the dimensionless LZETP value and was estimated from the tree-canopy data. The proportion of deciduous and evergreen trees was used to adjust LZETP monthly; calibrated LZETP values ranged from a summer high of 0.14 to 0.98 in. and a winter low of 0.12 to 0.89 in.

Many of the parameters affecting PERLND's were assigned monthly values to improve the agreement between the simulated and observed seasonal runoff. Calibrated PERLND parameter values are shown in the HSPF UCI file in Appendix 5.

Parameters describing impervious areas (IMPLND) that drain directly to channels (hydrologically effective impervious areas) have little effect on the annual hydrologic and seasonal water balance because there are no storage components except for interception storage (calibrated values ranged from 0.01 to 0.03 in.); however, IMPLND's have a large effect on the magnitude and timing of stormflow. The amount of hydrologically effective impervious area estimated for the urbanized area upstream from the gage at Ruckriegel Parkway was lowered an additional 10 percent (as described previously) to improve the model calibration.

Results of Model Streamflow Calibration and Verification

Statistical comparison of observed and simulated water balances for time periods ranging from hourly to the entire model calibration period were reported for the simulations at a 1-hour time step. The simulations at a 1-hour time step were also used during the water-quality simulations.

Results comparing stormflow volumes and peak discharges were reported for the simulations at a 5-minute time step, because these represented the actual instantaneous peaks in the observed 5-minute discharge data better than the hourly simulations. The following sections describe the simulated discharges in relation to observed discharges at the Ruckriegel Parkway and Gelhaus Lane gages (fig. 7).

Total, Annual, and Seasonal Water Budgets

Simulated interflow was on average approximately 20 and 27 percent of the simulated HRU outflow at Ruckriegel Parkway and Gelhaus Lane, respectively (table 33). The simulated ground-water-flow contribution to simulated HRU outflow was approximately equal to the simulated-interflow contributions at each station. Approximately 60 percent of the simulated HRU outflow at Ruckriegel Parkway was from surface runoff. In contrast, approximately 47 percent of the simulated HRU outflow at the Gelhaus Lane gage (which had a lower development density than at the upstream gage) was from surface runoff. The above-normal rainfall during the model calibration period probably caused the large proportion of simulated HRU outflows that were generated from surface runoff. The WWTP flows, representing imported water from the Ohio River, was approximately 7 in. of water on the basin at Gelhaus Lane, or 20 percent of the total observed discharge during the model calibration period. Estimated base-flow losses were 1.6 percent of total observed discharge at Ruckriegel Parkway and 4.4 percent of total observed discharge at Gelhaus Lane.

Total simulated and observed discharge during the model calibration period, February 1996–January 1998, differed by approximately -5.4 percent at Ruckriegel Parkway and 3.1 percent at Gelhaus Lane. Annually (in the year ending in January), the difference between the simulated and observed discharge for this period ranged from -5.2 to -5.6 percent at Ruckriegel Parkway and 1.1 to 5.0 percent at Gelhaus Lane (tables 33 and 34). The model results for the total and annual water balances were classified as very good on the basis of the criteria suggested by Donigian and others (1984).

Table 33. Simulated water budget and measured rainfall and streamflow in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[WWTP, wastewater-treatment plant; ---, not applicable; all values are in inches on the watershed]

		Simulated							Measured
Period	Measured rainfall	Evapotrans-piration	Surface runoff	Interflow	Ground-water flow	WWTP effluent	Channel loss	Total streamflow	Total streamflow
Chenoweth Run at Ruckriegel Parkway									
02/1996-01/1997	56.81	24.01	19.08	7.33	6.85	---	0.51	32.91	34.71
02/1997-01/1998	53.33	19.90	20.48	6.47	7.08	---	.62	33.61	35.60
Mean	55.07	21.96	19.78	6.90	6.96	---	.56	33.26	35.16
Chenoweth Run at Gelhaus Lane									
02/1996-01/1997	56.81	26.92	13.5	9.01	7.87	7.23	1.41	36.46	36.06
02/1997-01/1998	53.33	22.34	15.56	7.93	8.24	6.79	1.74	37.12	35.34
Mean	55.07	24.63	14.53	8.47	8.06	7.01	1.58	36.79	35.70

Table 34. Statistics for the criteria used in the calibration of streamflow using the Hydrological Simulation Program—Fortran (HSPF) model applied in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[--, not available]

	Observed	Simulated	Percent Error (simulated/ observed-1) (percent)	Suggested default criteria[1]
Chenoweth Run at Ruckriegel Parkway				
Total flow, in inches	70.33	66.52	-5.4	10.0
Total highest 10 percent flows, in inches	44.87	42.62	-5.0	15.0
Total lowest 50 percent flows, in inches	4.59	4.12	-10.3	10.0
Total storm volume, in inches	22.05	21.01	-4.7	20.0
Average storm peaks, in cubic feet per second	402	352	-12.5	--
Summer flow volume, in inches	13.07	13.75	5.2	30
Winter flow volume, in inches	16.12	14.3	-11.3	30
Summer storm volume, in inches	1.51	1.96	[2]34.5	50
Chenoweth Run at Gelhaus Lane				
Total flow, in inches	71.40	73.58	3.1	10.0
Total highest 10 percent flows, in inches	41.55	40.41	-2.7	15.0
Total lowest 50 percent flows, in inches	7.66	8.61	12.4	10.0
Total storm volume, in inches	19.63	20.23	3.1	20.0
Average storm peaks, in cubic feet per second	599	541	-9.7	--
Summer flow volume, in inches	13.60	14.63	7.6	30.0
Winter flow volume, in inches	17.62	17.32	-1.7	30.0
Summer storm volume, in inches	1.54	1.77	[2]11.8	50.0

[1]Lumb and others (1994), p. 56, 58.
[2]Summer storm volume error minus total storm volume error.

Simulated monthly discharge generally approximated the observed monthly discharge at both gages as indicated in figures 36 and 37 and by the error statistics reported in table 35. Monthly, the difference between the simulated and observed discharge for the model calibration period ranged from -26 to 75 percent at Ruckriegel Parkway and -28 to 86 percent at Gelhaus Lane. Errors in monthly simulated discharge were less than 10 percent at both gages during approximately one-half of the model calibration period. The largest relative differences between simulated and observed discharge generally occurred during the fall (September and October), possibly indicating seepage losses are larger than estimated for this time of year.

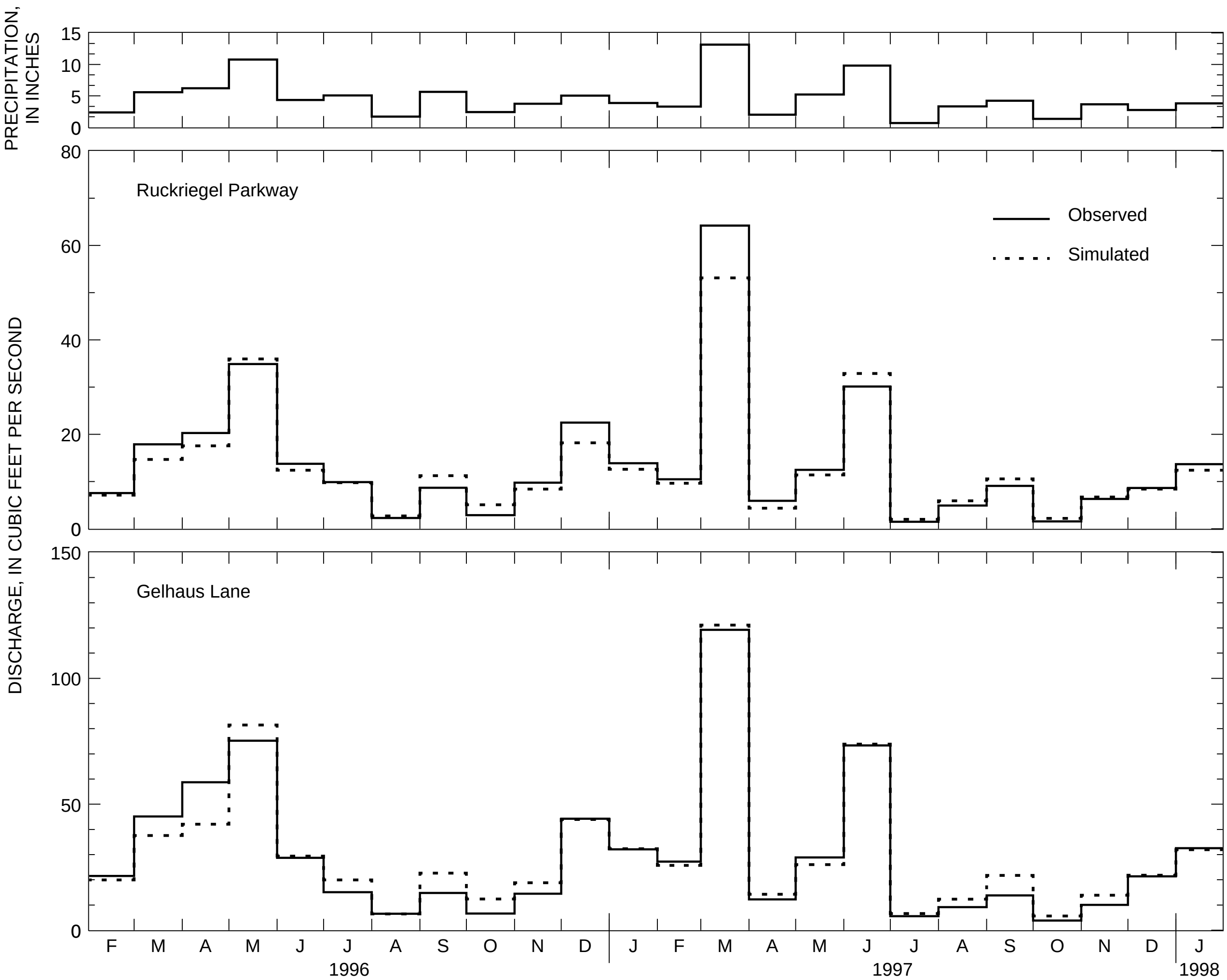


Figure 36. Observed and simulated monthly mean discharge hydrographs at Chenoweth Run at Ruckriegel Parkway and at Gelhaus Lane, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

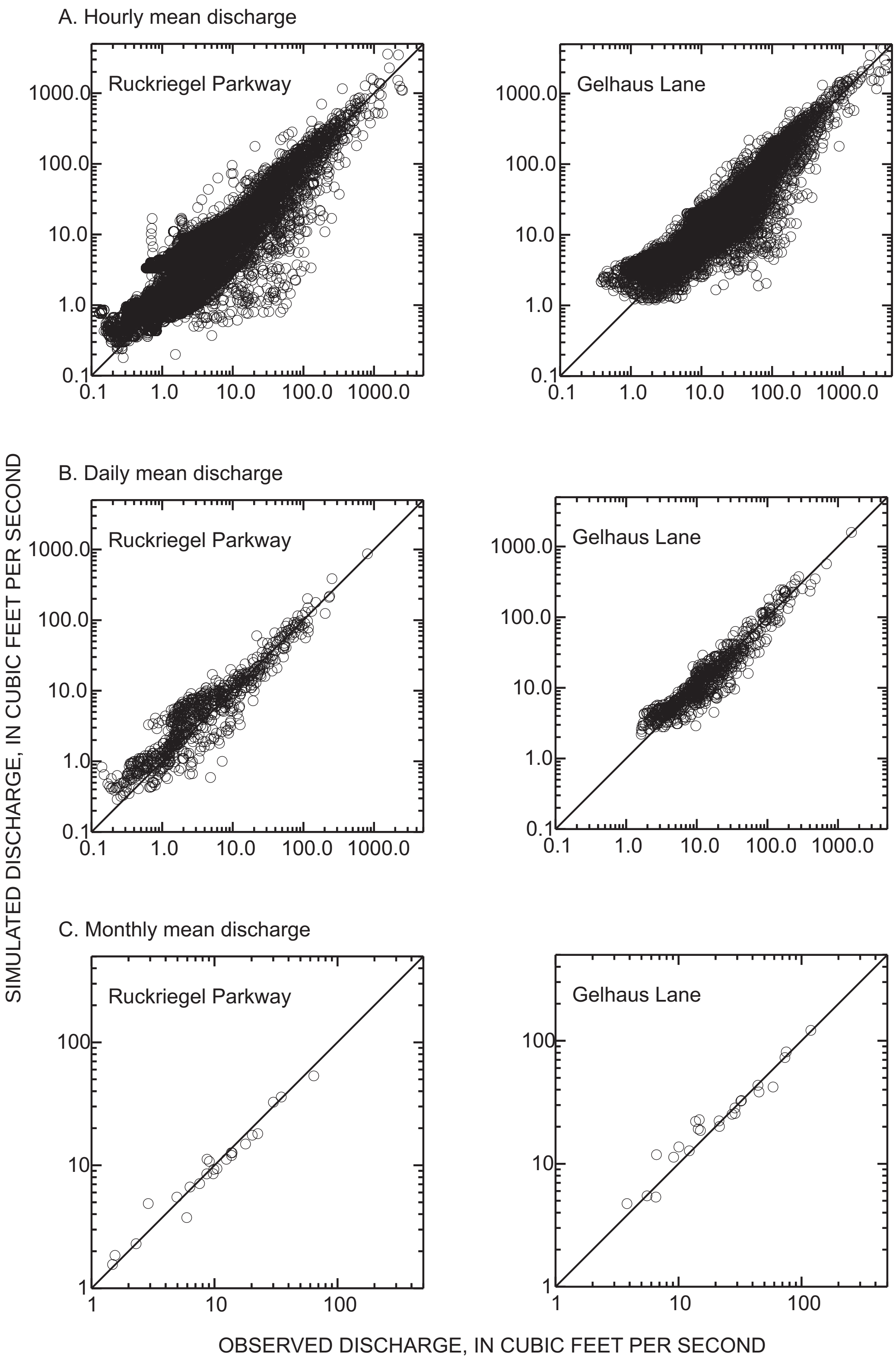


Figure 37. Comparison of observed and simulated hourly, daily, and monthly mean discharges in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

Table 35. Model-calibration statistics for hourly, daily, and monthly streamflows at the two streamflow-gaging stations in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

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

	Hourly streamflow		Daily streamflow		Monthly streamflow	
	Ruckriegel Parkway	Gelhaus Lane	Ruckriegel Parkway	Gelhaus Lane	Ruckriegel Parkway	Gelhaus Lane
Number of periods	17,544	17,544	731	731	24	24
Minimum (ft^3/s)						
Observed	.18	1.19	.29	2.20	1.48	3.80
Simulated	.31	.93	.32	2.21	1.99	5.61
Maximum (ft^3/s)						
Observed	3,580	4,350	868	1,590	64.2	119
Simulated	2,010	3,470	792	1,530	53.1	121
Mean (ft^3/s)						
Observed	13.9	30.1	13.9	30.1	13.9	30.0
Simulated	13.1	31.0	13.1	31.0	13.1	30.9
Standard deviation (ft^3/s)						
Observed	69.1	108	42.4	77.7	13.7	27.8
Simulated	61.8	111	38.7	76.4	11.9	26.9
Coefficient of model-fit efficiency	.79	.86	.95	.96	.95	.96
Correlation coefficient	.89	.93	.98	.98	.98	.98
Percentage of periods when the difference between simulated and observed average streamflow was less than 10 percent	17.5	24.9	19.0	28.2	45.8	50.0
Percentage of periods when the difference between simulated and observed average streamflow was less than 25 percent	40.4	55.9	46.4	59.2	79.2	62.5
Mean absolute error:						
Average (ft^3/s)	5.63	10.2	3.56	7.27	1.83	3.49
Percent	55.9	40.1	41.0	29.9	17.4	21.1
Root mean square error:						
Average (ft^3/s)	31.6	39.8	9.27	16.3	2.85	5.10
Percent	199	108	68.6	45.6	23.4	30.6
Bias:						
Average (ft^3/s)	-.75	.92	-.75	.90	-.74	.91
Percent	14.3	20.2	7.1	14.5	3.9	15.0
Standard error of estimate:						
Average (ft^3/s)	31.6	39.8	9.25	16.3	2.87	5.24
Percent	198	106	68.3	43.3	24.1	27.8

Daily Discharge

Observed and simulated daily mean discharge hydrographs at Ruckriegel Parkway and Gelhaus Lane are shown in figures 38 and 39, respectively. In general, the simulated daily discharge matches the observed daily discharge (figs. 37 and 40). The average difference (bias) between simulated and observed daily discharge was -0.75 and 0.90 ft^3/s at Ruckriegel Parkway and Gelhaus Lane, respectively (table 35). Errors in simulated daily discharge were less than 25 percent at both gages during approximately one-half of the model calibration period. The largest absolute difference between simulated and observed daily discharge occurred during high-flow periods and ranged from -99 to 69 ft^3/s at Ruckriegel Parkway and -99 to 147 ft^3/s at Gelhaus Lane. The model somewhat overestimates daily discharge at low flows (fig. 37), as was the case for monthly discharges. Percentage differences between the simulated and observed daily discharge ranged from -74 to 798 percent at Ruckriegel Parkway and -52 to 295 percent at Gelhaus Lane. The largest percentage differences between simulated and observed flows resulted during periods of lowest flow and during fall storms.

Duncker and others (1995) summarized model-application results in terms of the correlation coefficient and the coefficient of model-fit efficiency. Applications of HSPF and the Stanford Watershed Model were reported to have had correlation coefficients ranging from .8 to .98 and coefficients of model-fit efficiency ranging from .93 to .98 considering daily or monthly flows. The Chenoweth Run HSPF model had correlation coefficients ranging from 0.89 to 0.98 for hourly to monthly mean flows, respectively. The coefficients of model-fit efficiency for daily and monthly discharge simulations for the Chenoweth Run Basin HSPF model (table 35) approach the excellent range (exceeding 0.97) as defined by James and Burgess (1982). However, the model was calibrated for a comparatively short 24-month period during which flows were above normal. Increased model error might be expected during an extended period of near-normal flows.

Stormflow Volumes and Peak Discharges

Twenty-five storm events for model calibration and 25 storms for model verification were randomly selected from storms considered to have uniform precipitation over the basin (see “Analysis and Summary of Hydrologic Conditions: Precipitation.”) Comparisons of the model calibration and verification storms in terms of rainfall depth, average and maximum intensities, and antecedent 7-day rainfall indicated no statistically significant differences. The storm set that included the record February 28–March 2, 1997 storm was used for model calibration because of the low recurrence frequency of this storm. Simulated storm volumes and peak discharges for the model calibration and verification storms were also compared to observed discharges for 27 storms that were considered to have highly variable precipitation over the basin (nonuniform storms). In general, precipitation characteristics are similar among calibration, verification, and nonuniform storms with the exception that the storm intensities are generally twice as large for the nonuniform storms as for the calibration and verification storms. Nonuniform storms are mostly convective type summer storms; hence, summer storms are not well represented in the model calibration and verification storms because of the uneven rainfall distribution over the basin.

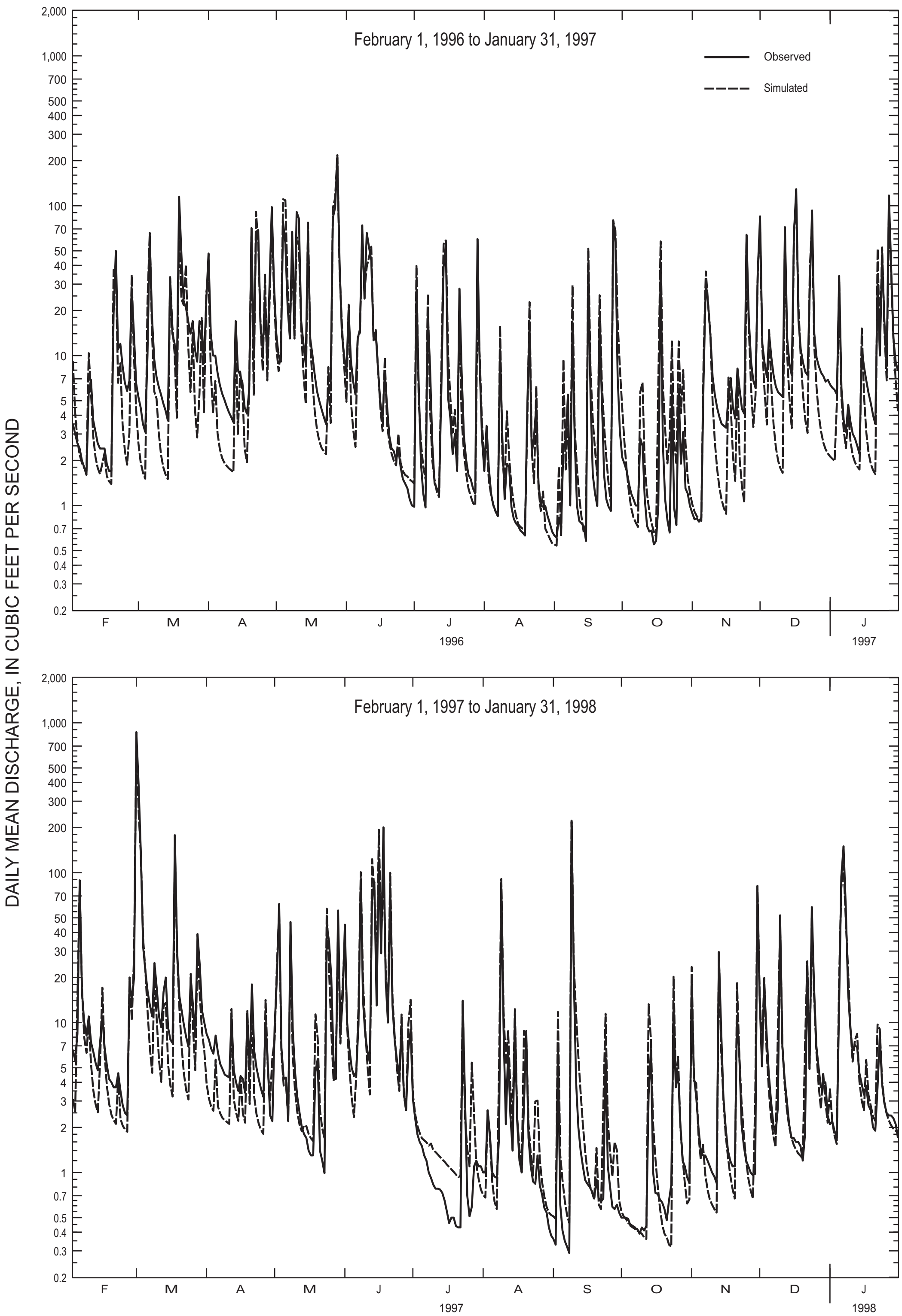


Figure 38. Observed and simulated daily mean discharge at Chenoweth Run at Ruckriegel Parkway, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

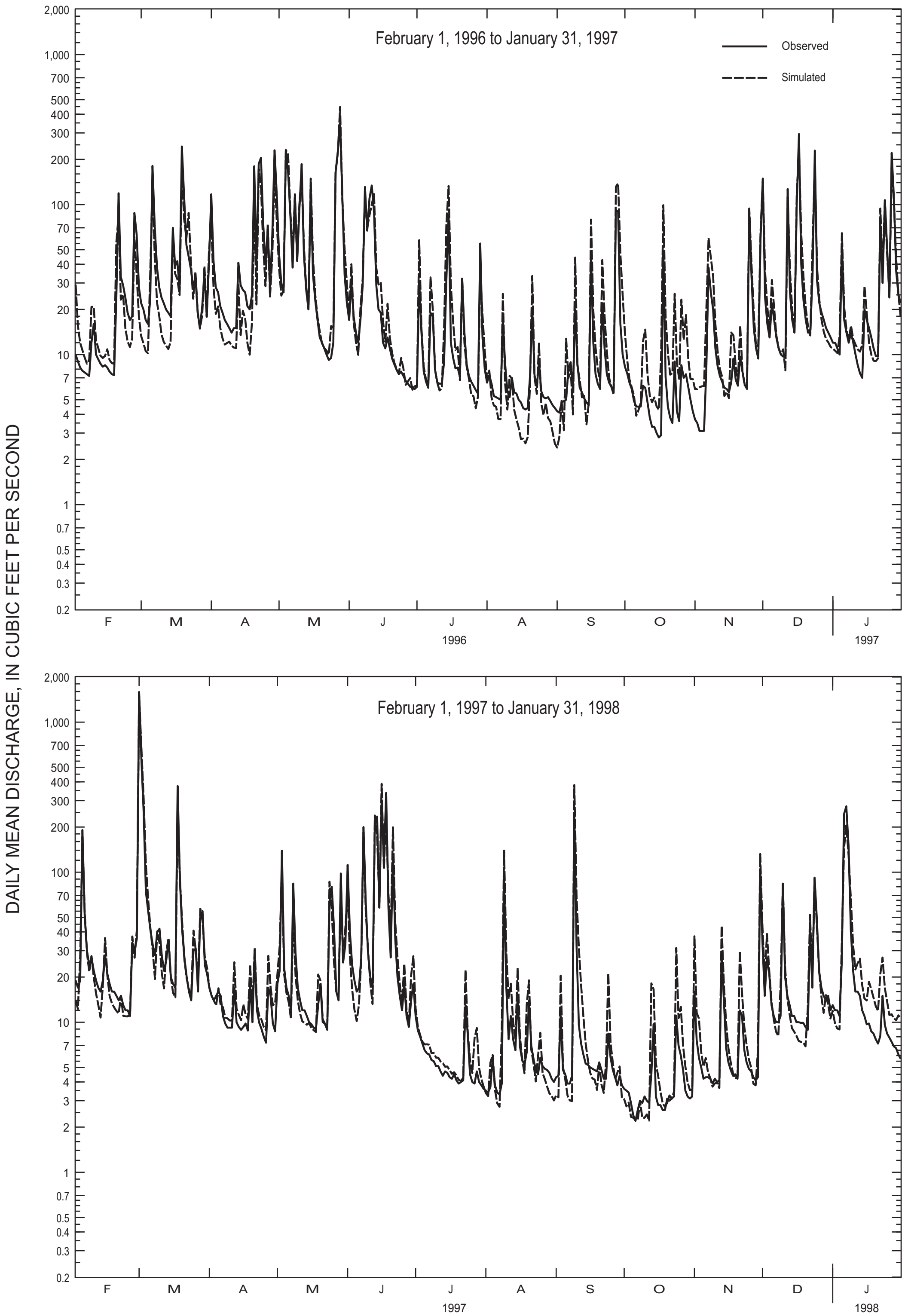


Figure 39. Observed and simulated daily mean discharge at Chenoweth Run at Gelhaus Lane, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

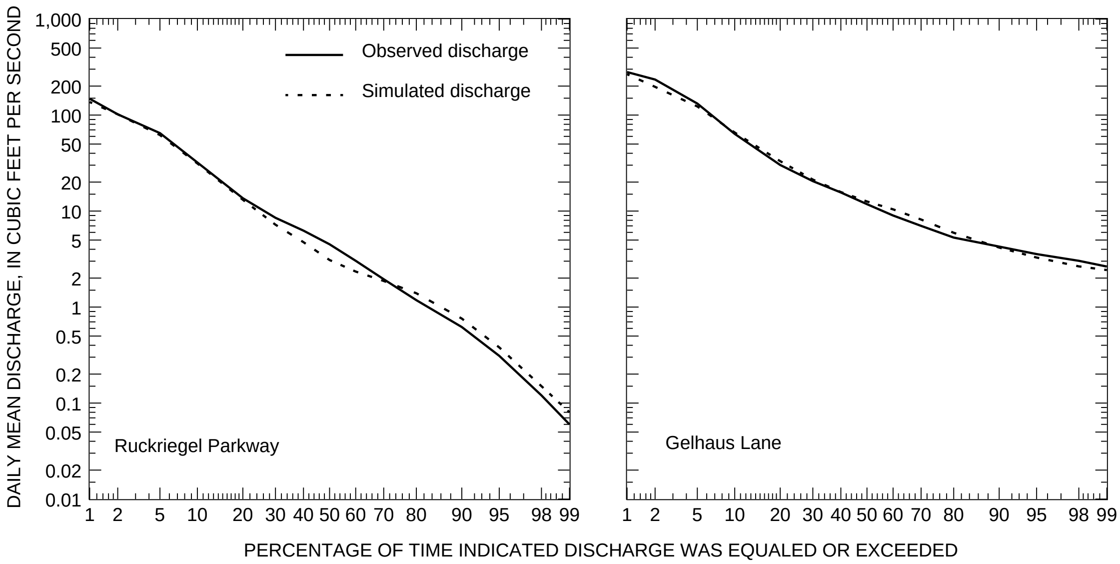


Figure 40. Flow-duration curves with observed and simulated daily mean discharge at Chenoweth Run at Ruckriegel Parkway and at Gelhaus Lane, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

Comparisons of observed and simulated stormflow volumes and peak discharges of selected model calibration and verification storms are shown in table 36. Hydrographs of observed and simulated flows for selected calibration storms are shown in figures 41 and 42.

Calibration Storms

Storm Volume—Simulated storm volumes were similar to observed storm volumes at both gages (fig. 43) with the exception of fall storms which tend to be overpredicted at both sites, particularly for low-magnitude fall storms. Errors in simulated storm volumes also tend to be larger at the Gelhaus Lane gage than at the Ruckriegel Parkway gage for fall storms of all magnitudes. The standard error of estimate of the simulated storm volume was 30.1 percent at Ruckriegel Parkway (table 37) and 41.5 percent at Gelhaus Lane (table 38). The error of the simulated storm volume ranged from -35 to 100 percent at Ruckriegel Parkway and from -31 to 100 percent at Gelhaus Lane.

Peak Discharge—Simulated storm peak discharges were also similar to observed peak discharges at both gages (fig. 44). Peak discharge is overpredicted at both sites for low-magnitude fall storms (particularly, October 14, 1997 and November 10, 1997). The standard error of estimate of the simulated storm peak discharge was 45.9 percent at Ruckriegel Parkway and 63.6 percent at Gelhaus Lane (tables 37 and 38). The errors of the simulated storm peak discharge ranged from -44 to 127 percent at Ruckriegel Parkway and from -46 to 260 percent at Gelhaus Lane. Note the coefficient of model-fit efficiency values are sensitive to the magnitude of the simulation error (equation 2). Thus, a large difference between observed and simulated discharge for a major storm can significantly affect this statistic.

Table 36. Precipitation and streamflow data for selected calibration storms at streamflow-gaging stations in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1988

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

				Flow volume				Peak flow			
Storm number	Beginning date	Ending date	Observed precipitation (inches)	Observed (inches)	Simulated (inches)	Difference (inches)	Difference (percent)	Observed (ft^3/s)	Simulated (ft^3/s)	Difference (ft^3/s)	Difference (percent)
Chenoweth Run at Ruckriegel Parkway											
7	04/13/1996	04/13/1996	0.50	0.12	0.10	-0.02	-16.7	154	114	-40	-26.0
9	04/22/1996	04/24/1996	1.70	1.03	1.15	.12	11.6	443	1,000	557	126.0
25	07/14/1996	07/15/1996	1.61	.65	.80	.15	23.1	536	582	46	8.5
39	12/16/1996	12/18/1996	1.89	1.46	1.35	-.11	-7.3	438	368	-70	-16.0
47	02/28/1997	03/02/1997	8.78	8.80	7.51	-1.29	-14.6	4,680	2,600	-2,080	-44.4
51	03/18/1997	03/19/1997	1.93	1.44	1.24	-.20	-13.9	631	585	-46	-7.3
55	05/02/1997	05/03/1997	1.20	.57	.54	-.03	-5.6	384	409	25	6.5
62	06/13/1997	06/13/1997	1.48	.47	.81	.34	72.3	608	1,160	552	47.6
76	12/09/1997	12/10/1997	.83	.38	.37	-.01	-2.6	228	222	-6	-2.6
Chenoweth Run at Gelhaus Lane											
7	04/13/1996	04/13/1996	.50	.13	.09	-.04	-30.8	225	122	-103	-45.8
9	04/22/1996	04/24/1996	1.70	1.51	1.18	-.33	-21.8	1,180	1,210	30	2.5
25	07/14/1996	07/15/1996	1.61	.37	.67	.30	81.1	594	808	214	36.0
39	12/16/1996	12/18/1996	1.89	1.41	1.37	-.04	-2.8	856	577	-279	-32.6
47	02/28/1997	03/02/1997	8.78	7.12	7.38	-.26	-3.6	4,810	4,620	-190	-4.0
51	03/18/1997	03/19/1997	1.93	1.51	1.21	-.30	-19.9	1,330	933	-397	-29.8
55	05/02/1997	05/03/1997	1.20	.52	.45	-.07	-13.5	617	496	-121	-19.6
62	06/13/1997	06/13/1997	1.48	.67	.72	.05	7.5	1,480	1,680	200	13.5
76	12/09/1997	12/10/1997	.83	.31	.33	.02	6.5	273	284	11	4.0

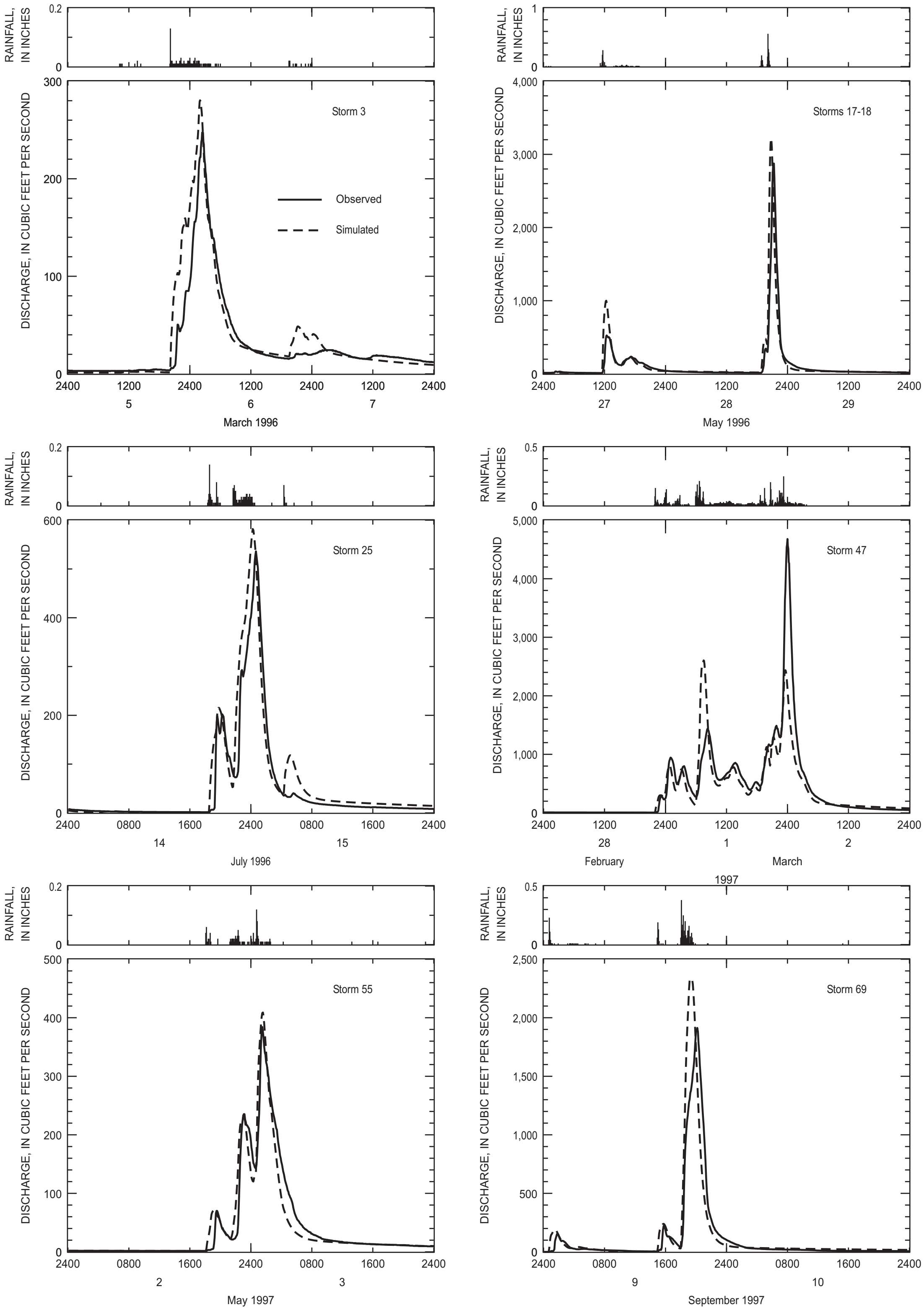


Figure 41. Discharge during selected storms at Chenoweth Run at Ruckriegel Parkway, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

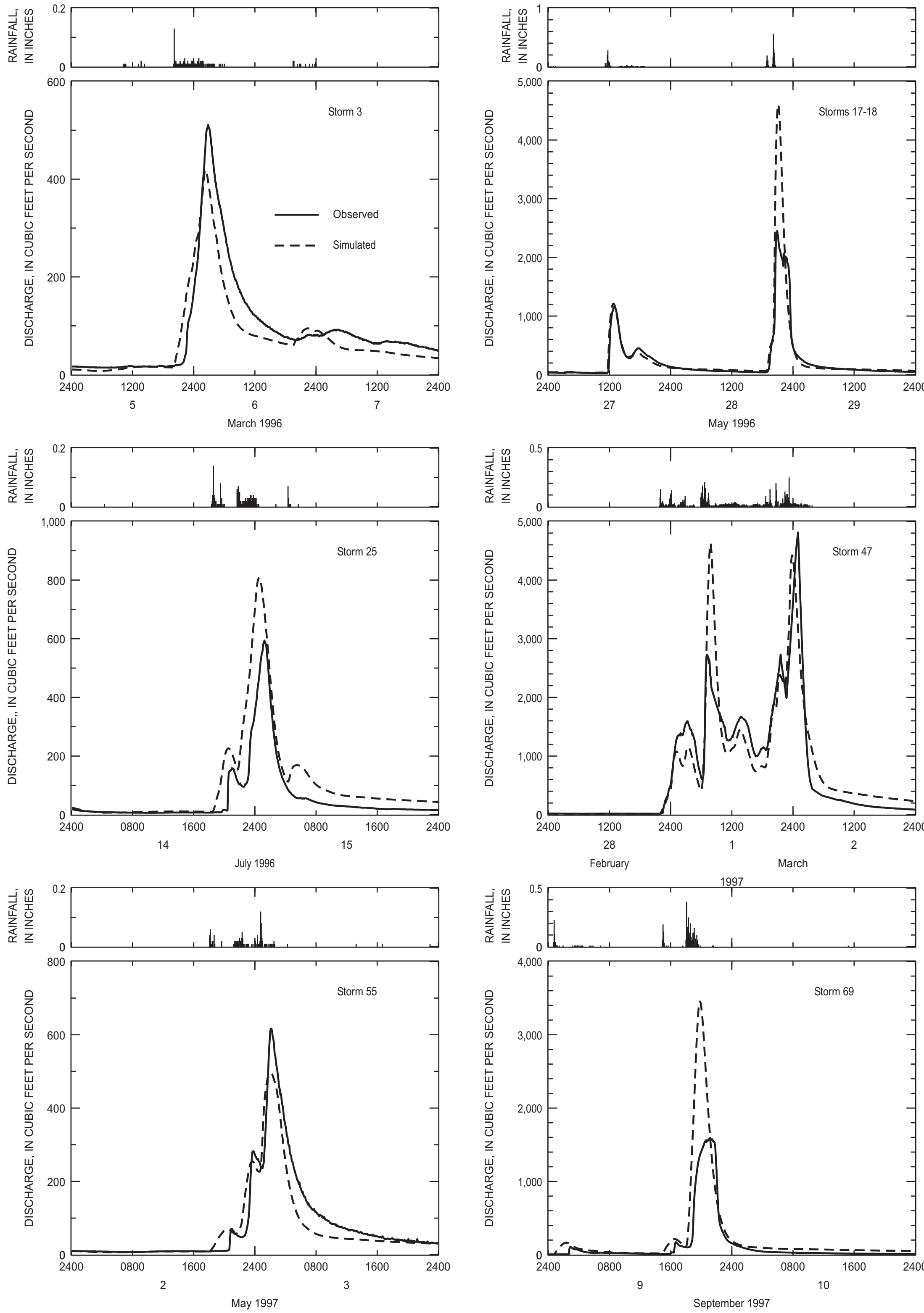


Figure 42. Discharge during selected storms at Chenoweth Run at Gelhaus Lane, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

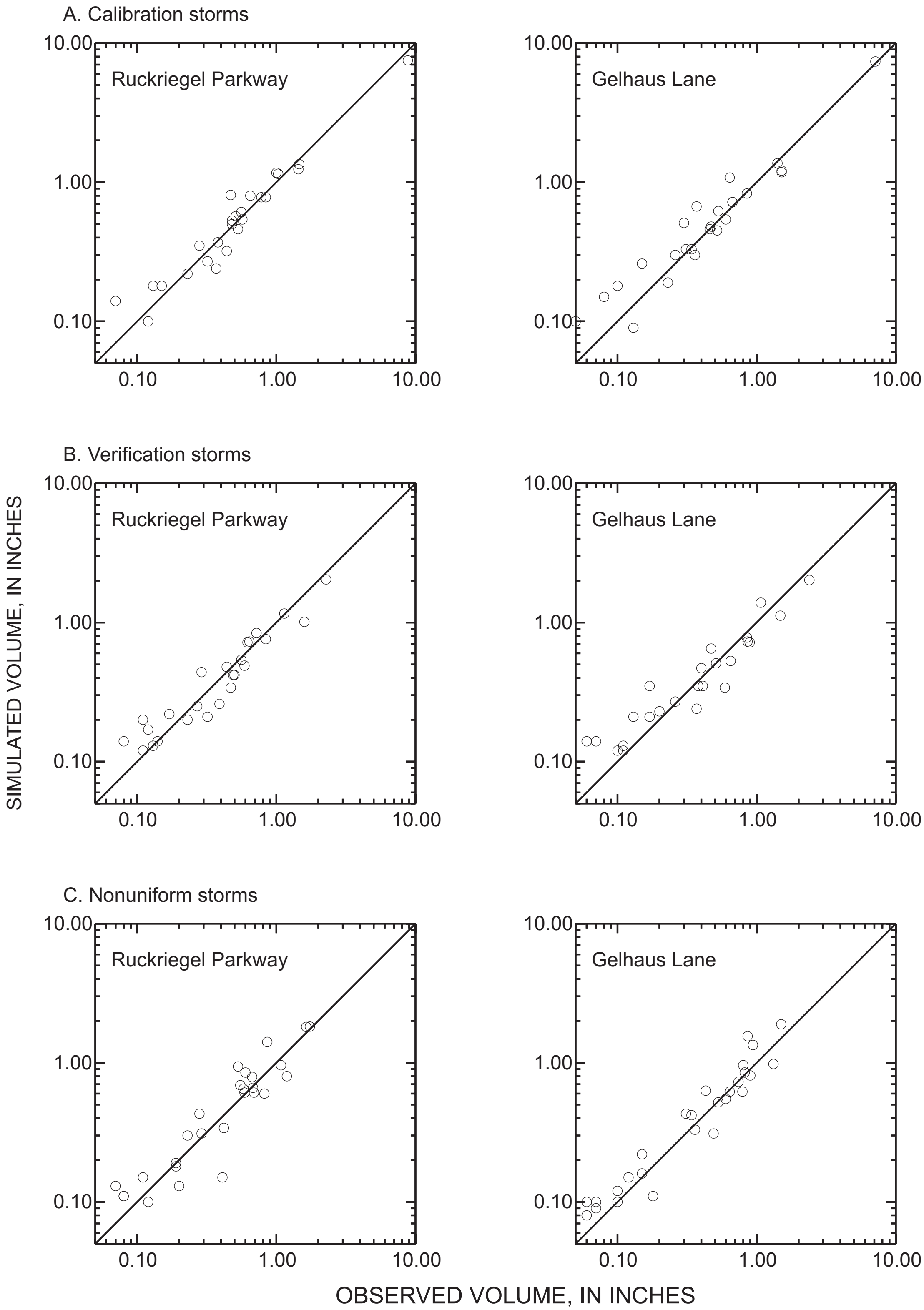


Figure 43. Comparison of the observed and simulated flow volumes in inches of water on the basin for the calibration, verification, and nonuniform storms in the Chenoweth Run Basin, Jefferson County, Kentucky.

Table 37. Model-calibration statistics for the volume and peak streamflow during storm periods at Chenoweth Run at Ruckriegel Parkway, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[in., inch; ft^3/s, cubic foot per second]

	Volume			Peak		
	Calibration storms	Verification storms	Nonuniform storms	Calibration storms	Verification storms	Nonuniform storms
Number of periods	25	25	27	25	25	27
Minimum (in. or ft^3/s)						
Observed	.07	.08	.07	28.3	28.3	24.4
Simulated	.10	.12	.10	48.2	49.1	49.0
Maximum (in. or ft^3/s)						
Observed	8.80	2.28	1.74	4,680	1,560	2,870
Simulated	7.51	2.04	1.82	2,600	832	3,220
Mean (in. or ft^3/s)						
Observed	.88	.53	.55	477	300	582
Simulated	.85	.50	.59	432	292	737
Standard deviation (in. or ft^3/s)						
Observed	1.69	.51	.45	893	312	620
Simulated	1.44	.43	.49	529	218	857
Coefficient of model-fit efficiency	.97	.91	.82	.74	.69	.54
Correlation coefficient	.94	.96	.92	.92	.85	.91
Percentage of periods when the difference between simulated and observed average streamflow was less than 10 percent	32.0	32.0	22.2	40.0	32.0	25.9
Percentage of periods when the difference between simulated and observed average streamflow was less than 25 percent	80.0	64.0	48.1	64.0	56.0	44.4
Mean absolute error:						
Average (in. or ft^3/s)	.13	.10	.13	164	86.8	234
Percent	20.2	22.8	28.5	29.9	29.2	47.2
Root mean square error:						
Average (in. or ft^3/s)	.28	.15	.19	446	170	413
Percent	29.8	31.0	36.7	45.7	37.1	73.7
Bias:						
Average (in. or ft^3/s)	-.04	-.03	.04	-44.4	-8.1	154
Percent	7.2	4.9	11.9	12.1	14.7	31.4
Standard error of estimate:						
Average (in. or ft^3/s)	.29	.15	.19	462	177	397
Percent	30.1	30.6	36.1	45.9	35.5	68.5

Table 38. Model-calibration statistics for the volume and peak streamflow during storm periods at Chenoweth Run at Gelhaus Lane, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[in., inch; ft^3/s, cubic foot per second]

	Volume (inches)			Peak (ft^3/s)		
	Calibration storms	Verification storms	Nonuniform storms	Calibration storms	Verification storms	Nonuniform storms
Number of periods	25	25	27	25	25	27
Minimum (in. or ft^3/s)						
Observed	.05	.04	.06	27.1	43.0	33.4
Simulated	.09	.10	.08	65.5	63.6	65.3
Maximum (in. or ft^3/s)						
Observed	7.12	2.39	1.50	4,810	1,540	2,450
Simulated	7.38	2.02	1.89	4,620	1,130	4,610
Mean (in. or ft^3/s)						
Observed	.79	.51	.50	652	432	708
Simulated	.82	.49	.55	614	389	938
Standard deviation (in. or ft^3/s)						
Observed	1.38	.54	.40	955	408	639
Simulated	1.41	.46	.48	920	308	1,240
Coefficient of model-fit efficiency	.99	.91	.74	.98	.87	-.24
Correlation coefficient	.99	.96	.91	.99	.96	.94
Percentage of periods when the difference between simulated and observed average streamflow was less than 10 percent	40.0	20.0	33.3	36.0	16.0	22.2
Percentage of periods when the difference between simulated and observed average streamflow was less than 25 percent	68.0	64.0	48.1	56.0	40.0	59.2
Mean absolute error:						
Average (in. or ft^3/s)	.11	.11	.12	104	105	334
Percent	30.3	37.1	26.2	35.1	36.5	36.4
Root mean square error:						
Average (in. or ft^3/s)	.16	.16	.20	139	144	699
Percent	44.3	54.7	32.9	62.3	51.6	51.5
Bias:						
Average (in. or ft^3/s)	.03	-.02	.05	-38.0	-42.7	230
Percent	19.3	21.0	14.6	12.2	16.0	19.3
Standard error of estimate:						
Average (in. or ft^3/s)	.16	.16	.20	134	143	686
Percent	41.5	52.6	30.6	63.6	51.1	49.6

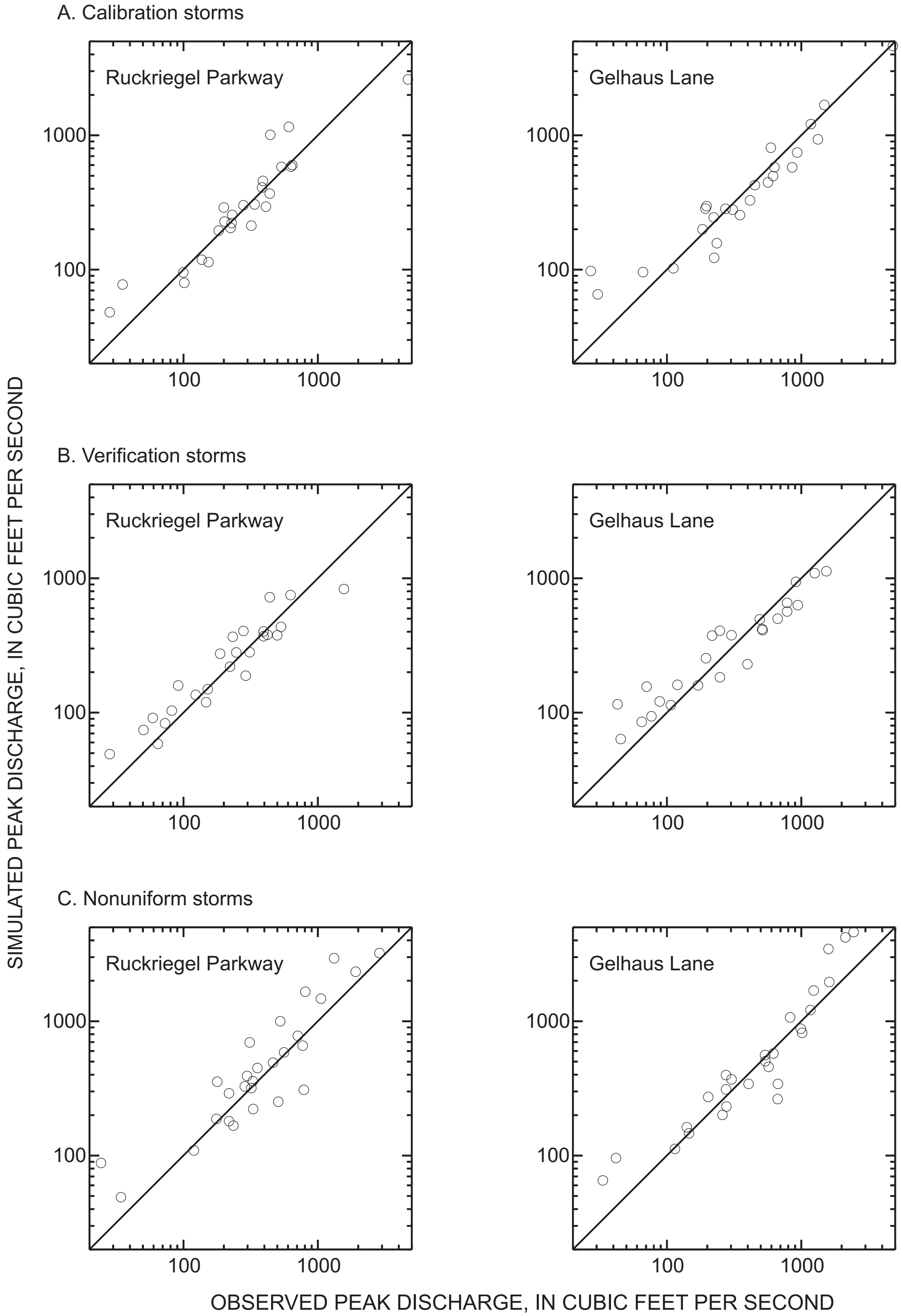


Figure 44. Comparison of the observed and simulated peak discharges for the calibration, verification, and nonuniform storms in the Chenoweth Run Basin, Jefferson County, Kentucky.

Verification Storms

Storm Volume—Simulated storm volumes for verification storms were also similar to observed volumes at both gages (fig. 43) with the exception of fall storms, which tended to be overpredicted at both sites, particularly for low-magnitude fall storms. Errors of the simulated storm volumes also tended to be larger at the Gelhaus Lane gage than at the Ruckriegel Parkway gage for fall storms of all magnitudes. The standard error of estimate of the simulated storm volume was 30.6 percent at Ruckriegel Parkway and 52.6 percent at Gelhaus Lane. The error of the simulated storm volume ranged from -36 to 82 percent at Ruckriegel Parkway and from -42 to 150 percent at Gelhaus Lane.

Peak Discharge—Simulated verification storm peak discharges were also similar to observed peak discharges at both gages (fig. 44). Peak discharge was overpredicted at both gages for low-magnitude fall storms (particularly, October 14, 1997 and November 10, 1997). The standard error of estimate of the simulated storm peak discharge was 35.5 percent at Ruckriegel Parkway and 51.1 percent at Gelhaus Lane. The error of the simulated storm peak discharge ranged from -47 to 74 percent at Ruckriegel Parkway and from -42 to 168 percent at Gelhaus Lane.

Nonuniform Storms

Storm Volume—Simulated storm volumes for nonuniform storms were also similar to observed volumes at both gages (fig. 43). The error in the simulated storm volume for nonuniform storms increased in comparison to calibration and verification storms at both gages. This probably reflects the increased error in measurement of rainfall over the basin associated with the nonuniform rainfall distribution. The standard error of estimate of the simulated storm volume was 36.1 percent at Ruckriegel Parkway and 30.6 percent at Gelhaus Lane. The error of the simulated storm volume ranged from -63 to 86 percent at Ruckriegel Parkway and from -39 to 80 percent at Gelhaus Lane.

Peak Discharge—Simulated nonuniform storm peak discharges were also similar to observed peak discharges at both gages (fig. 44). Peak discharge was overpredicted at both sites for low-magnitude storms. The standard error of estimate of the simulated storm peak discharge was 68.5 percent at Ruckriegel Parkway and 49.6 percent at Gelhaus Lane. The error of the simulated storm peak discharge ranged from -61 to 262 percent at Ruckriegel Parkway and from -60 to 129 percent at Gelhaus Lane. Note that errors in simulation of large peak discharges for some nonuniform storms resulted in a negative coefficient of model-fit efficiency (see table 38 and equation 2.)

Comparison of Simulated and Measured Discharge Near the Mouth of Chenoweth Run

During the model calibration period, four discharge measurements were made near the mouth of Chenoweth Run at Seatonville Road (fig. 7). These measurements provided an indication of the flow-model fit including the lower third of the basin downstream from the Gelhaus Lane gage. Simulated and measured discharges were fairly close (table 39). Discharge measurements made on September 16, 1996, were made during a storm recession. Simulated discharge during this storm was overpredicted, but matched the measured discharge within 1 hour.

Table 39. Comparison of simulated and measured discharge at Chenoweth Run at Seatonville Road, Jefferson County, Kentucky

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

Date	Time	Discharge (ft^3/s) Measured	Discharge (ft^3/s) Simulated
09/16/1996	1100	57.0	82.6
09/16/1996	1150	54.9	65.1
09/26/1996	1300	3.10	5.07
09/16/1997	1245	5.79	3.67

Sensitivity Analysis

A sensitivity analysis describes the effect of changes in the individual model input elements and parameter values on the resulting simulated hydrological processes. Evaluation of parameters to which the model is sensitive requires an understanding of the relative effect of each HRU on the various flow components. An iterative process, whereby the value of a given input parameter is varied while all others parameters are held constant, indicates the degree to which that parameter affects the model results.

Discharge Characteristics of the Hydrologic Response Units

The simulated amount of surface runoff, interflow, and base flow from each of the 2 IMPLND's and 17 PERLND's on average during the model calibration period (February 1996–January 1998), in a month of low flow and in a month of high flow are shown in figure 45.

IMPLND's have only a surface-flow component. Runoff from IMPLND's occurs when precipitation exceeds interception and surface storage; thus, the timing and magnitude of runoff from an IMPLND is in direct response to the timing and magnitude of precipitation. Losses through evaporation (averaging about 6 percent of total annual precipitation) were limited to water retained in these storage components. Consequently, during average and high-flow periods, a given IMPLND will generate more runoff than a given PERLND (fig. 45). Runoff values for the two types of IMPLND's were nearly identical whether on an average monthly basis, a wet month, or a dry month. This indicates that runoff from IMPLND's were insensitive to the differences defined for each IMPLND type.

Average simulated monthly surface runoff ranged from about 3 percent of total runoff for PERLND's with highly permeable soils (nos. 4, 8, and 14 in table 30) to about 24 percent for those with poorly permeable soils on slopes greater than 5 percent (nos. 2, 6, and 11). Surface runoff from PERLND's characterized as disturbed soils, which also received surface runoff from adjacent impervious surfaces (nos. 15, 16, and 17), had the largest surface-runoff component of any PERLND (averaged 62 percent of total discharge). Average monthly base flow was roughly inversely proportional to surface runoff; it was least in PERLND's with disturbed soils and largest in PERLND's with the deepest, most well-drained soils. Base flow ranged from 15 to 84 percent of total discharge. Average monthly interflow was also least in PERLND's with disturbed soils and largest in PERLND's with the deepest, most well-drained soils and ranged from 8 to 53 percent of total discharge.

During the July 1997 low-flow period (0.68 in. precipitation), simulated base flow accounted for 75 to 100 percent of the total discharge. Base flow was largest from the deepest, most well-drained soils (nos. 4, 8, and 14) and least on shallow, poorly drained soils (nos. 1, 2, 5, 6, 10, 11, 15, and 17). Surface runoff occurred only on disturbed PERLND's (nos. 15, 16, and 17) during July 1997 and only to an appreciable extent (18 percent of total discharge) on the disturbed, commercial PERLND (no. 17). Surface runoff from PERLND's 15 and 16 were about 1 percent of the total discharge in July 1997. Interflow accounted for less than 1 and up to 7 percent of total discharge. Losses through evapotranspiration during this period ranged from 114 to 616 percent of total precipitation for all PERLND's. Evaporation losses were mostly from lower-zone storage; losses were largest in deep, forested soils and smallest in shallow, disturbed soils. Therefore, under dry-weather conditions, discharge was most sensitive to model parameters that affect evapotranspiration and base flow.

During the March 1997 high-flow period (13.15 in. precipitation), simulated base flow accounted for 6 to 53 percent of the total discharge from PERLND's. The relative contribution to base flow was similar to that for dry-weather conditions. Surface runoff occurred on all PERLND's during March 1997 and accounted for 3 to 89 percent of the total discharge. Surface runoff was largest for PERLND's with disturbed soils (nos. 15, 16, and 17) and poorly drained soils (nos. 1, 2, 5, 6, 10, and 11), and least in PERLND's with the deepest, most well-drained soils (nos. 4, 8, and 14).

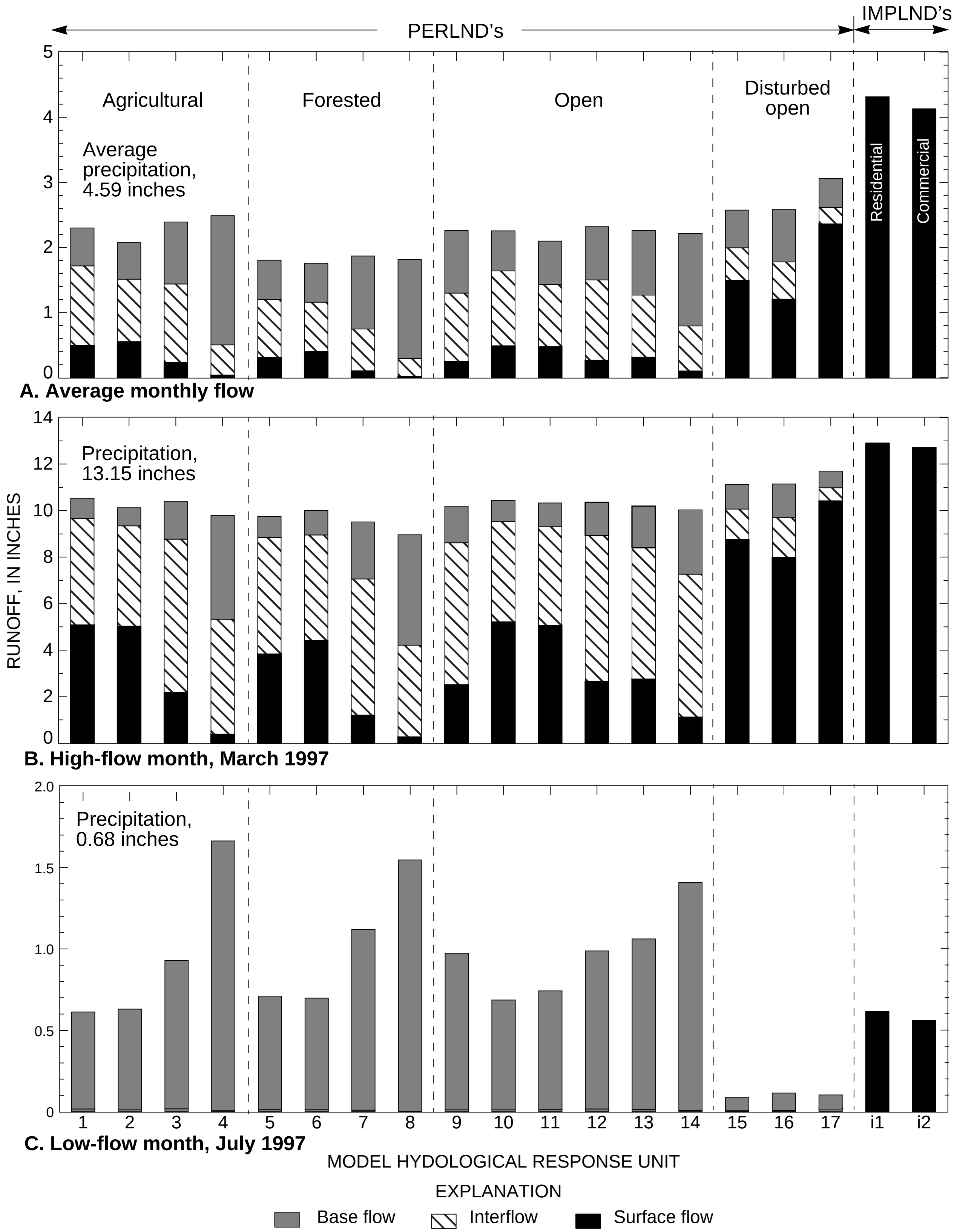


Figure 45. Simulated surface runoff, interflow, and base flow for 17 types of pervious land surfaces (PERLND) and 2 types of impervious land surfaces (IMPLND) in the Chenoweth Run Basin, Jefferson County, Kentucky: (A) Average monthly flow; (B) High-flow month, March 1997; and (C) Low-flow month, July 1997. [Note: Hydrologic response units are defined in table 30.]

Interflow was the largest component of total discharge, except from PERLND's with poorly drained and disturbed soils and accounted for 5 to 60 percent of the total discharge. Losses through evapotranspiration during this period ranged from 12 to 19 percent of total precipitation. Total discharge from any of the PERLND's during this high-flow period nearly equalled runoff from IMPLND's, because evapotranspiration losses were small, and subsurface storage was at or near capacity. Thus, under wet-weather conditions, discharge was most sensitive to parameters that affect surface flow and interflow.

Parameter Values

The response of the model to a specified change in a parameter value indicates the relative effect of that parameter on simulated discharge. The sensitivity analysis used only constant changes in parameter values, and the values were applied equally over seasons and among the HRU's. The following paragraphs summarize the sensitivity of the model discharge characteristics (listed in tables 40-43) to changes in selected PERLND parameters.

Model sensitivity to 10 PERLND parameters was examined by doubling, then halving the calibrated parameter value and measuring the effect on the various PERLND discharge components (tables 40 and 42) and on (1) the total flow volume, (2) high- and low-flow distribution, (3) total storm volume, (4) seasonal and summer flow, (5) summer storm volume, and (6) peak stormflow (tables 41 and 43). The active-ground-water recession rate (AGWRC) parameter was decreased by 50 percent but was not increased because the calibrated value was near the maximum allowed value. The effect of altering the base (calibrated) parameter values was expressed in tables 40 and 42 as percentage changes in the water fluxes and storages from the base values. The effect of altering the calibrated values was expressed in tables 41 and 43 as the revised percentage errors for comparison to the percentage errors as calibrated.

The following paragraphs summarize the sensitivity of the model discharge characteristics to selected model parameters.

Total flow volume was most sensitive to changes in the upper-zone storage (UZSN) and evapotranspiration from the lower-zone soil (LZETP), which in turn was affected by the available lower-zone storage (LZSN). Total flow volume was also moderately affected by interception storage (CEPSC) and the active-ground-water recession rate (AGWRC).

50-percent low flow and 10-percent high flow[1] were inversely proportional in that a change in value that decreased low flows increased high flows, and a change that increased low flows decreased high flows. These terms were most sensitive to the active-ground-water recession rate (AGWRC), and moderately sensitive to interflow-recession coefficient (IRC), lower-zone storage (LZSN), and infiltration rate (INFILT).

S*easonal and summer flow volumes* were most sensitive to soil infiltration rate (INFILT), which controlled the amount of water that drained to the subsurface, and by upper- and lower-zone soil storage (UZSN and LZSN), which determined the availability of water for evapotranspiration. Active-ground-water recession rate (AGWRC) then regulated the rate at which water that percolated down from upper- and lower-zone storages was released from active-ground-water storage.

Peak stormflow was affected most strongly by infiltration rate (INFILT), interflow (INTFLW), and upper-zone storage (UZSN) and, to a lesser extent, surface roughness (NSUR), length of the overland-flow surface (LSUR), lower-zone storage (LZSN), and evapotranspiration from the lower-zone soil (LZETP).

Interflow and surface runoff as a percentage of the total flow were most affected by interflow (INTFLW) and soil infiltration rate (INFILT) (tables 40 and 42).

The calibrated parameter values appear to yield the least overall model error. Changes in selected PERLND parameters, however, improved model fit for some runoff characteristics, but degraded model fit for other runoff characteristics (tables 41 and 43).

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[1]50-percent flow is the flow that is equaled or exceeded 50 percent of the time (low flow), and 10-percent flow is the flow that is equaled or exceeded 10 percent of the time (high flow).

Table 40. Sensitivity of simulated-flow characteristics to changes in selected model parameters expressed as a percentage change relative to the base calibration at Chenoweth Run at Ruckriegel Parkway, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

Parameter[a]	Streamflow: Total flow	Streamflow: Surface runoff	Streamflow: Interflow	Streamflow: Base flow	Pervious storage: Upper zone	Pervious storage: Lower zone	Pervious storage: Ground water	Pervious storage: Total	Evapotranspiration: Interception	Evapotranspiration: Upper zone	Evapotranspiration: Lower zone	Evapotranspiration: Ground water	Evapotranspiration: Total
Base calibration[b]	66.52	39.56	13.80	13.93	0.61	4.27	1.31	6.21	8.16	25.17	8.03	0.79	43.91
CEPSC (2x)	-1.1	-.4	-.9	-3.4	1.7	1.0	-2.6	.4	45.7	-9.1	-7.6	-10.1	1.7
CEPSC (0.5x)	.8	.3	.4	2.4	-1.0	-.5	1.4	-.2	-28.2	5.6	4.4	5.1	-1.1
INFILT (2x)	.7	-11.9	-4.3	41.4	-9.2	3.4	24.1	6.5	.0	-7.5	11.0	11.4	-2.1
INFILT (0.5x)	-.2	12.7	-5.7	-31.4	7.1	-3.8	-22.4	-6.7	.0	5.6	-8.6	-10.1	1.5
LZSN (2x)	-4.3	-6.1	-17.2	14.0	-6.3	73.9	6.9	51.6	.0	-5.6	5.9	8.9	-2.0
LZSN (0.5x)	1.8	8.9	15.7	-32.3	7.1	-28.5	-30.8	-25.3	.0	5.2	-5.9	-10.1	1.7
UZSN (2x)	-5.7	-5.8	-14.2	3.2	112.0	3.2	3.4	13.9	.0	15.5	-11.1	-16.5	6.6
UZSN (0.5x)	6.1	5.4	14.8	-1.0	-54.3	-3.7	-1.6	-8.2	.0	-18.8	13.3	20.3	-8.0
INTFW (2x)	.3	-12.5	40.7	-3.3	-1.0	-.7	-2.2	-1.0	.0	-.9	.7	1.3	-.3
INTFW (0.5x)	-.4	12.2	-41.8	4.7	1.5	1.1	3.6	1.5	.0	1.2	-1.0	-2.5	.4
IRC (2x)	.0	.0	-.1	.0	.0	.0	.0	3.4	.0	.0	.0	.0	.0
IRC (0.5x)	.0	.0	.0	.0	.0	.0	.0	-.1	.0	.0	.0	.0	.0
LZETP (2x)	-5.1	-5.1	-11.5	1.5	-9.0	-12.6	.3	-9.5	.0	-8.3	73.0	7.6	8.7
LZETP (0.5x)	3.0	4.5	9.9	-8.2	7.3	12.9	-4.0	8.7	.0	5.6	-47.4	-8.9	-5.6
NSUR (2x)	-.2	-3.1	6.2	1.7	.4	.3	.6	.4	.0	.5	-.2	-1.3	.2
NSUR (0.5x)	.2	2.9	-5.8	-1.6	-.4	-.3	-.7	-.4	.0	-.5	.4	.0	-.2
LSUR (2x)	-.2	-3.1	6.2	1.7	.4	.3	.6	.4	.0	.5	-.2	-1.3	.2
LSUR (0.5x)	.2	2.9	-5.7	-1.6	-.4	-.3	-.7	-.4	.0	-.5	.4	.0	-.2
KVARY (2x)	.5	.0	.0	2.1	.0	.0	-20.4	-4.3	.0	.0	.1	-2.5	.0
KVARY (0.5x)	-.3	.0	.0	-1.6	.0	.0	15.2	3.2	.0	.0	.0	.0	.0
AGWRC (0.5x)	3.3	-.1	-.6	13.0	-.7	-.7	-98.6	-21.4	.0	-.4	3.6	-62.0	-.7
N (0.8x)	.0	.0	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0
N (1.2x)	.0	.0	.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0

[a]INFILT, soil infiltration rate; LZSN, lower zone nominal storage; UZSN, upper zone nominal storage; INTFW, interflow parameter; IRC, interflow recession parameter; LZETP, lower zone evapotranspiration; CEPSC, interception storage; NSUR, Manning’s roughness coefficient for overland flow plane; LSUR, length of the overland flow plane; KVARY, ground-water recession-rate behavior; AGWRC, ground-water recession rate relative to previous day’s rate; n, Manning’s roughness coefficient for channels; (x), indicates the constant multiplied by the parameter value.

[b]Base calibration, base line for the calibrated model in inches of water on the watershed.

Table 41. Sensitivity of simulated-flow characteristics to changes in selected model parameters expressed as a percentage error relative to the observed flow characteristics at Chenoweth Run at Ruckriegel Parkway, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

Parameter[a]	Percent error: Total flow volume	50-percent lowest flow	10-percent highest flow	Seasonal volume[b]	Summer storm volume	Average storm peak
Base calibration[c]	-5.4	-10.3	-5.0	16.2	35.0	-12.5
CEPSC (2x)	-6.5	-15.1	-5.4	14.9	34.0	-12.8
CEPSC (0.5x)	-4.7	-7.2	-4.8	16.8	35.4	-12.5
INFILT (2x)	-4.8	20.2	-10.7	20.9	31.9	-21.5
INFILT (0.5x)	-5.6	-36.4	.8	12.4	39.4	-3.8
LZSN (2x)	-9.5	-2.4	-10.7	20.8	36.1	-17.6
LZSN (0.5x)	-3.7	-38.6	1.3	8.7	37.5	-5.6
UZSN (2x)	-10.8	-6.6	-11.9	14.0	27.8	-19.4
UZSN (0.5x)	.3	-11.3	.9	19.9	41.1	-7.3
INTFW (2x)	-5.1	-12.0	-6.8	16.3	31.2	-20.8
INTFW (0.5x)	-5.8	-7.6	-2.7	16.5	38.1	-5.2
IRC (2x)	-5.5	31.1	-12.2	16.7	34.5	-13.8
IRC (0.5x)	-5.4	-14.2	-1.7	16.2	36.5	-11.1
LZETP (2x)	-10.2	-15.9	-10.0	14.8	23.6	-17.0
LZETP (0.5x)	-2.6	-14.2	-1.2	13.7	38.3	-8.7
NSUR (2x)	-5.6	-9.2	-6.2	16.1	33.0	-17.6
NSUR (0.5x)	-5.3	-11.6	-4.0	16.3	37.0	-8.0
LSUR (2x)	-5.6	-9.2	-6.2	16.1	33.0	-17.6
LSUR (0.5x)	-5.3	-11.6	-4.0	16.3	37.0	-8.0
KVARY (2x)	-5.0	-14.8	-4.4	14.2	35.0	-12.5
KVARY (0.5x)	-5.7	-7.4	-5.4	17.5	35.5	-12.5
AGWRC (0.5x)	-2.3	-77.8	3.3	2.5	37.3	-11.1
N (0.8x)	-5.5	-10.5	-5.1	16.2	35.0	-8.0
N (1.2x)	-5.4	-10.0	-5.0	16.3	35.0	-16.2

[a]INFILT, soil infiltration rate; LZSN, lower zone nominal storage; UZSN, upper zone nominal storage; INTFW, interflow parameter; IRC, interflow recession parameter; LZETP, lower zone evapotranspiration; CEPSC, interception storage; NSUR, Manning's roughness coefficient for overland flow plane; LSUR, length of the overland flow plane; KVARY, ground-water recession-rate behavior; AGWRC, ground-water recession rate relative to previous day's rate; n, Manning's roughness coefficient for channels; (x), indicates the constant multiplied by the parameter value.

[b]Absolute value of difference between summer flow volume error and winter flow volume error.

[c]Base calibration, base line for the calibrated model as a percentage difference from the observed flow characteristics.

Table 42. Sensitivity of simulated-flow characteristics to changes in selected model parameters expressed as a percentage change relative to the base calibration at Chenoweth Run at Gelhaus Lane, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

	Streamflow				Pervious storage				Evapotranspiration				
Parameter[a]	Total flow	Surface runoff	Interflow	Base flow	Upper zone	Lower zone	Ground water	Total	Interception	Upper zone	Lower zone	Ground water	Total
Base calibration[b]	73.58	29.06	16.93	16.10	0.77	4.98	1.76	7.54	9.24	28.74	9.34	0.92	49.26
CEPSC (2x)	-1.1	-.3	-.8	-3.6	1.6	1.1	-2.6	.4	43.2	-9.2	-7.8	-8.7	1.6
CEPSC (0.5x)	.7	.2	.3	2.4	-.9	-.5	1.5	-.1	-26.7	5.3	4.4	5.4	-1.0
INFILT (2x)	.7	-16.5	-7.1	40.7	-9.2	3.2	24.4	6.9	.0	-7.8	11.1	13.0	-2.2
INFILT (0.5x)	-.1	18.9	-3.8	-30.8	7.1	-3.6	-22.5	-6.9	.0	5.9	-8.9	-8.7	1.6
LZSN (2x)	-4.5	-8.4	-18.3	14.0	-6.4	72.8	7.6	49.1	.0	-6.1	6.4	9.8	-2.2
LZSN (0.5x)	1.9	13.1	17.1	-33.0	7.1	-27.3	-30.2	-24.3	.0	5.5	-6.5	-8.7	1.8
UZSN (2x)	-5.4	-9.0	-14.4	3.4	110.9	3.2	3.3	14.2	.0	13.8	-10.9	-15.2	5.7
UZSN (0.5x)	5.8	6.4	14.9	-.9	-54.1	-3.8	-1.4	-8.3	.0	-17.5	13.4	21.7	-7.2
INTFW (2x)	.3	-17.2	33.9	-3.1	-1.0	-.7	-2.2	-1.0	.0	-.9	.9	2.2	-.4
INTFW (0.5x)	-.4	18.2	-37.7	4.7	1.5	1.1	3.5	1.6	.0	1.2	-1.2	-1.1	.4
IRC (2x)	.0	.0	-.1	.0	.0	.0	.0	3.2	.0	.0	.0	.0	.0
IRC (0.5x)	.0	.0	.0	.0	.0	.0	.0	-.1	.0	.0	.0	.0	.0
LZETP (2x)	-5.4	-6.7	-12.5	.9	-9.6	-13.4	-.1	-9.9	.0	-8.6	74.3	9.8	9.2
LZETP (0.5x)	3.2	6.3	10.8	-8.0	7.5	13.5	-4.5	8.6	.0	5.9	-48.7	-8.7	-6.0
NSUR (2x)	-.2	-4.6	5.8	1.4	.4	.3	.7	.4	.0	.5	-.3	.0	.2
NSUR (0.5x)	.2	4.4	-5.6	-1.3	-.4	-.3	-.7	-.4	.0	-.5	.3	1.1	-.2
LSUR (2x)	-.2	-4.6	5.8	1.4	.4	.3	.7	.4	.0	.5	-.3	.0	.2
LSUR (0.5x)	.2	4.4	-5.6	-1.3	-.4	-.3	-.7	-.4	.0	-.5	.3	1.1	-.2
KVARY (2x)	.5	.0	.0	2.5	.0	.0	-20.4	-4.8	.0	.0	.0	-1.1	.0
KVARY (0.5x)	-.4	.0	.0	-1.8	.0	.0	15.3	3.6	.0	.25	.0	1.1	.0
AGWRC (0.5x)	3.6	-.1	-.5	14.9	-.6	-.6	-98.8	-23.5	.0	-.4	3.3	-62.0	-.8
N (0.8x)	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
N (1.2x)	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

[a]INFILT, soil infiltration rate; LZSN, lower zone nominal storage; UZSN, upper zone nominal storage; INTFW, interflow parameter; IRC, interflow recession parameter; LZETP, lower zone evapotranspiration; CEPSC, interception storage; NSUR, Manning's roughness coefficient for overland flow plane; LSUR, length of the overland flow plane; KVARY, ground-water recession-rate behavior; AGWRC, ground-water recession rate relative to previous day's rate; n, Manning's roughness coefficient for channels; (x), indicates the constant multiplied by the parameter value.

[b]Base calibration, base line for the calibrated model in inches of water on the watershed.

Table 43. Sensitivity of simulated-flow characteristics to changes in selected model parameters expressed as a percentage error relative to the observed flow characteristics at Chenoweth Run at Gelhaus Lane, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

Parameter[a]	Percent error: Total flow volume	50-percent lowest flow	10-percent highest flow	Seasonal volume[b]	Summer storm volume	Average storm peak
Base calibration[c]	3.1	12.4	-2.7	9.3	11.8	-9.7
CEPSC (2x)	1.9	8.7	-3.1	7.8	10.4	-10.2
CEPSC (0.5x)	3.7	14.8	-2.5	9.9	12.4	-9.7
INFILT (2x)	3.8	36.2	-9.6	15.0	9.2	-23.1
INFILT (0.5x)	2.9	-7.6	4.1	4.6	16.1	2.6
LZSN (2x)	-1.6	19.5	-9.9	14.3	14.1	-17.1
LZSN (0.5x)	5.0	-8.7	5.2	.2	12.7	.1
UZSN (2x)	-2.5	14.8	-10.5	7.9	6.1	-17.6
UZSN (0.5x)	9.0	12.7	4.2	12.6	17.4	-3.8
INTFW (2x)	3.4	11.4	-3.9	9.3	7.6	-21.6
INTFW (0.5x)	2.6	14.2	-.9	9.4	15.6	.6
IRC (2x)	3.0	41.6	-13.2	10.3	13.4	-12.7
IRC (0.5x)	3.1	9.5	1.5	9.0	12.5	-7.3
LZETP (2x)	-2.5	7.2	-8.6	9.4	2.5	-16.2
LZETP (0.5x)	6.4	9.8	2.1	6.1	14.9	-4.3
NSUR (2x)	2.9	13.4	-3.8	9.1	8.9	-15.2
NSUR (0.5x)	3.2	11.5	-1.6	9.3	14.3	-4.8
LSUR (2x)	2.9	13.4	-3.8	9.1	8.9	-15.2
LSUR (0.5x)	3.2	11.5	-1.6	9.3	14.4	-4.8
KVARY (2x)	3.6	8.9	-2.0	6.6	11.8	-9.7
KVARY (0.5x)	2.6	14.9	-3.2	10.8	12.4	-9.7
AGWRC (0.5x)	6.7	-38.1	9.8	8.9	13.7	-7.3
N (0.8x)	3.0	12.3	-2.8	9.1	11.8	-5.3
N (1.2x)	3.1	12.7	-2.7	9.3	11.9	-14.7

[a]INFILT, soil infiltration rate; LZSN, lower zone nominal storage; UZSN, upper zone nominal storage; INTFW, interflow parameter; IRC, interflow recession parameter; LZETP, lower zone evapotranspiration; CEPSC, interception storage; NSUR, Manning's roughness coefficient for overland flow plane; LSUR, length of the overland flow plane; KVARY, ground-water recession-rate behavior; AGWRC, ground-water recession rate relative to previous day's rate; n, Manning's roughness coefficient for channels; (x), indicates the constant multiplied by the parameter value.

[b]Absolute value of difference between summer flow volume error and winter flow volume error.

[c]Base calibration, base line for the calibrated model as a percentage difference from the observed flow characteristics.

SIMULATION OF WATER QUALITY

Water-quality simulations included those for contribution of suspended sediment and TPO_4 from point and nonpoint sources and transport of these constituents through the basin. The model provides a rudimentary simulation of TPO_4 yield and transport, as only selected instream processes affecting TPO_4 were simulated. Simulation of TPO_4 in HSPF required data on temperature, sediment, dissolved oxygen and biochemical oxygen demand (BOD). Temperature data were input from observed and estimated data. Dissolved-oxygen and BOD simulation in HSPF were activated within the OXRX subroutine of the RCHRES secondary module RQUAL (table 27).

The water-quality-calibration process included steps to adjust appropriate model parameters to obtain representative total constituent loads and yields from the four major classes of pervious land use and the two classes of impervious land use (table 30). Calibration included land-surface and instream calibration phases. Instream processes affecting nutrients are extremely complex because of the numerous physical, chemical, and biological factors that affect nutrient concentrations. The calibrations were based on comparisons of simulated and estimated constituent loads during the whole 24-month calibration period, annually, monthly, and selected storm periods (see estimated loads in tables 22 and 26).

First-order transformations of nutrients in RCHRES are dependent upon water temperature. Water temperature measured at the Ruckriegel Parkway and Gelhaus Lane gaging sites was used in the model. Missing periods of stream-water temperature were estimated by regression against air temperature. (See “Analysis and Summary of Hydrologic Conditions: Water Quality.”) Alternatively, missing stream temperature data could be estimated using the RCHRES secondary module HTRCH, which requires data for solar radiation, cloud cover, dewpoint temperature, air temperature, and wind speed.

Sediment

Calibration of sediment concentrations and loads follows the calibration of flow and precedes the calibration of other water-quality constituents. Simulations of suspended-sediment transport were made by use of the HSPF secondary modules SEDMNT for PERLND’s, SOLIDS for IMPLND’s, and SEDTRN for RCHRES (table 27). Suspended-solids loading from the three WWTP’s, a minor source of suspended solids compared to nonpoint sources, were directed to the appropriate RCHRES. (The Jeffersontown WWTP flows into RCHRES 8, the Chenoweth Hills WWTP flows into RCHRES 9, and the Lake of the Woods WWTP flows into RCHRES 10.) The processes of detachment of sediment from the soil matrix and washoff of this sediment are simulated in SEDMNT on the basis of rainfall intensity, surface runoff, and the model parameters that control the accumulation, detachment, and transport of soils. SEDMNT also simulates production of sediment through gully or rill erosion by scour of the soil matrix. PERLND’s were assumed in the model to be an infinite source of sediment. An erosion-related vegetative-cover factor (FACTOR) was varied monthly and by HRU type (see the HSPF UCI file in Appendix 5).

SOLIDS determines the sediment available for washoff from IMPLND’s by use of a user-defined net-accumulation rate (which varied monthly) and the transport parameters. Solids removal that may occur independent of flow, such as by street sweeping, was set to zero.

One goal of sediment calibration was attaining an approximate balance between the accumulation and generation of sediment particles and the washoff or transport of sediment, such that sediment storage on the land surface will not be continually increasing or decreasing during the model calibration period. (Donigian and others, 1984). The sediment calibration was achieved by first adjusting the load from PERLND’s and IMPLND’s to match observed loads at the Ruckriegel Parkway and Gelhaus Lane sites. Once a reasonable match between simulated and observed loads was obtained, the soil detachment was approximately balanced with the soil washoff for each PERLND. Solids accumulation and washoff from IMPLND’s was adjusted to match simulated and observed loads at the Ruckriegel Parkway site, which had the largest percentage of impervious area of any of the sampling sites in the basin (total impervious area was about 30 percent).

The open, developed HRU’s have the highest suspended-sediment yield, whereas yields from forested HRU’s are about an order of magnitude lower than these (table 44). Suspended-sediment yields are about 50 percent higher for most HRU’s in 1997 compared to yields in 1996, because of the March 1997 flood.

The suspended-sediment load from PERLND’s and IMPLND’s is transported, deposited, and scoured in the RCHRES by SEDTRN. Transport, deposition, and scour processes in the RCHRES are functions of the sediment size, settling velocity, density, and erodibility, the bed depth, and the critical shear stress for scour and deposition. RCHRES sediment transport is computed separately for each sediment size fraction—sand, silt, and clay—whereas transport of sediments from the land surfaces is simulated as total suspended sediment. The particle-size distribution of the suspended-sediment yield from land surfaces was set to the average size distribution reported by Flint (1983) for similar, nearby basins in the Bluegrass Region—1.6 percent sand, 37.4 percent silt, and 61 percent clay.

During the adjustment of sediment loads from PERLND’s and IMPLND’s, the pond RCHRES’s (nos. 15-23) sediment parameters were set such that all sand, most silt, and some clay-size particles were deposited. During this adjustment process, the channel RCHRES’s (nos. 1-14) sediment parameters were set such that overland cohesive sediment loads (silt and clay) would “wash through” the RCHRES. RCHRES’s 1-14 sediment parameters were later adjusted to allow sediment deposition and scour after satisfactory overland sediment loads were obtained. This improved the match between simulated and observed loads during some storms. Sediment deposition generally occurs during minor storms and at the beginning and end of major storms. The deposited sediment was then available for scour during major storms, and thus, the total sediment load transported during the peak-flow period of the storm was increased to improve the simulation of the storm loads.

Sediment deposition and scour for silt and clays in channels is largely controlled by the bed shear stress (TAU), the values of the shear-stress threshold below which deposition occurs (TAUCD), and the shear-stress threshold above which scour occurs (TAUCS). Over time, the deposition and scour in channels should balance. Initial values of TAU were determined by examining the model-calculated TAU values for several reaches; values of TAUCD, and correspondingly TAUCS, were then adjusted to balance deposition with scour. This usually entailed an upward adjustment of these values because, in general, the cessation of surface runoff from PERLND’s stopped the inflow of sediment at the same time that the TAUCD threshold was reached. The deposition and scour of sand-size particles was determined by the Toffaleti method for the pond RCHRES’s (nos. 15-23) and by a power function for channel RCHRES’s (nos. 1-14).

Annual and mean-annual loads of simulated total suspended sediment and estimated total suspended solids are shown in table 45. The mean-annual simulated suspended-sediment loads ranged from -33 to -28 percent of the estimated mean-annual suspended-solids loads at the Ruckriegel Parkway and Gelhaus Lane sites. Sediment load was undersimulated during the year of major flooding (1997), in particular. Comparisons of simulated and estimated monthly loads (fig. 46) indicate a tendency to oversimulate during months of low sediment transport. Annual and mean-annual errors provided a fair sediment simulation (25 to 35 percent error), based on criteria suggested by Donigian and others, (1984).

Table 44. Simulated suspended-sediment yields by model hydrologic response unit in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[<, less than; >, greater than]

Hydrologic response unit	Description	Sediment yield (ton/acre/year) 12-month period ending 01/1997	12-month period ending 01/1998	Average
	Pervious hydrologic response units			
1	Pasture/crop, low-permeability soils, 0 to 5 percent slope	3.74	5.47	4.60
2	Pasture/crop, low-permeability soils, >5 percent slope	4.01	5.52	4.76
3	Pasture/crop, moderate-permeability soils, 0 to 5 percent slope	3.26	4.67	3.96
4	Pasture/crop, high-permeability soils, >5 percent slope	2.10	3.70	2.90
5	Forested, low-permeability soils, 0 to 5 percent slope	.170	.433	.302
6	Forested, low-permeability soils, >5 percent slope	.217	.426	.322
7	Forested, moderate-permeability soils, 0 to 5 percent slope	.106	.188	.147
8	Forested, high-permeability soils, >5 percent slope	.054	.105	.080
9	Open, vacant/undeveloped uses, low-permeability soils, 0 to 5 percent slopes	3.93	5.59	4.76
10	Open, developed uses, low-permeability soils, 0 to 5 percent slopes	8.67	10.6	9.64
11	Open, developed uses, low-permeability soils, >5 percent slopes	8.66	10.5	9.58
12	Open, developed uses, moderate-permeability soils, 0 to 5 percent slopes	8.50	10.0	9.25
13	Open, developed uses, moderate-permeability soils, >5 percent slopes	8.57	10.0	9.28
14	Open, developed uses, high-permeability soils, >5 percent slopes	8.32	9.61	8.96
15	Open single-family residential, disturbed low-permeability soils, all slopes	3.84	5.16	4.50
16	Open single-family residential, disturbed moderate-permeability soils, 0 to 5 percent slopes	1.32	1.93	1.62
17	Open commercial/industrial/multi-family residential, disturbed moderate-permeability soils, 0 to 5 percent slopes	1.55	2.26	1.90
	Impervious hydrologic response units			
1	Single-family residential/parks/public/vacant hydrologically effective impervious areas, all slopes	.789	.799	.794
2	Commercial/industrial/multi-family residential hydrologically effective impervious areas, all slopes	.823	.740	.782

Table 45. Annual ESTIMATOR suspended-solids loads and Hydrological Simulation Program—Fortran (HSPF)-simulated suspended-sediment loads in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

Period	Measured rainfall (inches)	Estimator suspended-solids load		Simulated suspended-sediment load		Difference
		Tons	Ton/acre	Tons	Ton/acre	Percent
Chenoweth Run at Ruckriegel Parkway						
02/1996-01/1997	56.81	6,150	1.78	7,790	2.26	27.0
02/1997-01/1998	53.33	23,300	6.77	11,900	3.46	-48.9
Mean	55.07	14,700	4.27	9,850	2.86	-33.0
Chenoweth Run at Gelhaus Lane						
02/1996-01/1997	56.81	17,700	2.42	16,400	2.23	-7.8
02/1997-01/1998	53.33	42,400	5.79	26,700	3.65	-37.0
Mean	55.07	30,100	4.10	21,500	2.94	-28.3

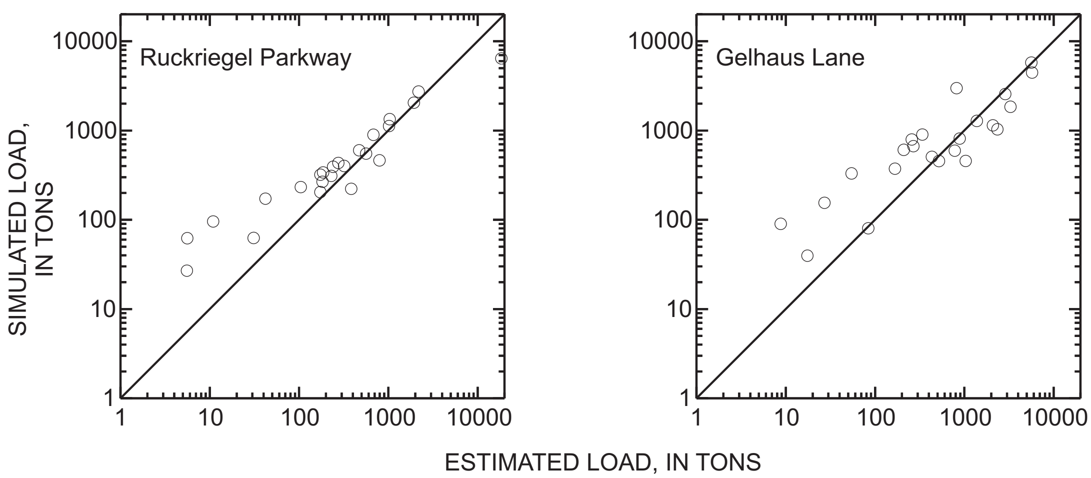

Figure 46. Comparison of the monthly ESTIMATOR suspended-solids loads and the monthly Hydrological Simulation Program—Fortran (HSPF)-simulated suspended-sediment loads in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

Observed total suspended-solids concentrations were reported for 9 storms at the Ruckriegel Parkway site and 6 storms at the Gelhaus Lane site; these storms represented a total of 23 and 27 samples, respectively, at the 2 sites. Comparisons of simulated and estimated storm loads are shown in table 46 and figures 47–49. Discharge and also the sediment loads tended to be oversimulated during the smallest storms sampled during summer and early fall low-flow periods. Percentage errors in simulation of individual storm sediment loads were, as would be expected, generally much larger than percentage errors in annual and mean-annual loads.

Table 46. Estimated suspended-solids loads and Hydrological Simulation Program—Fortran (HSPF)-simulated suspended-sediment loads for selected storms in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

Period				Load			
						Difference	
Begin (Julian date/time)	End (Julian date/time)	Observed flow (acre-feet)	Simulated flow (acre-feet)	Estimated suspended solids (tons)	Simulated suspended sediment (tons)	Tons	Percent
Chenoweth Run at Ruckriegel Parkway							
19960208/1700	19960209/0100	11.0	18.5	0.82	15.0	14.2	1,730
19960319/0500	19960319/1100	125	98.6	91.5	95.9	4.4	4.8
19960606/2200	19960606/2300	8.15	6.82	4.25	6.88	2.63	61.9
19960702/1500	19960703/0100	53.7	75.5	21.1	87.7	66.6	316
19961022/2300	19961023/0500	6.18	19.5	.28	19.8	19.5	6,960
19961125/1000	19961125/2400	123	111	80.9	134.0	53.1	65.6
19970127/1800	19970128/0400	160	104	159	90.0	-69	-43.4
19970519/1600	19970520/0300	11.8	27.9	.15	19.0	18.8	12,600
Chenoweth Run at Gelhaus Lane							
19960208/2300	19960209/0700	16.6	21.4	3.79	8.71	4.92	130
19960319/0500	19960319/1300	274	203	368	246	-122	-33.2
19960702/1600	19960703/0200	58.5	101	82.5	176	93.5	113
19961018/0100	19961018/0900	74.0	142	107	226	119	111
19970122/1300	19970122/1600	28.0	16.5	12.0	19.1	7.1	59.2
19970529/0200	19970529/1200	137	116	42.6	56.4	13.8	32.4

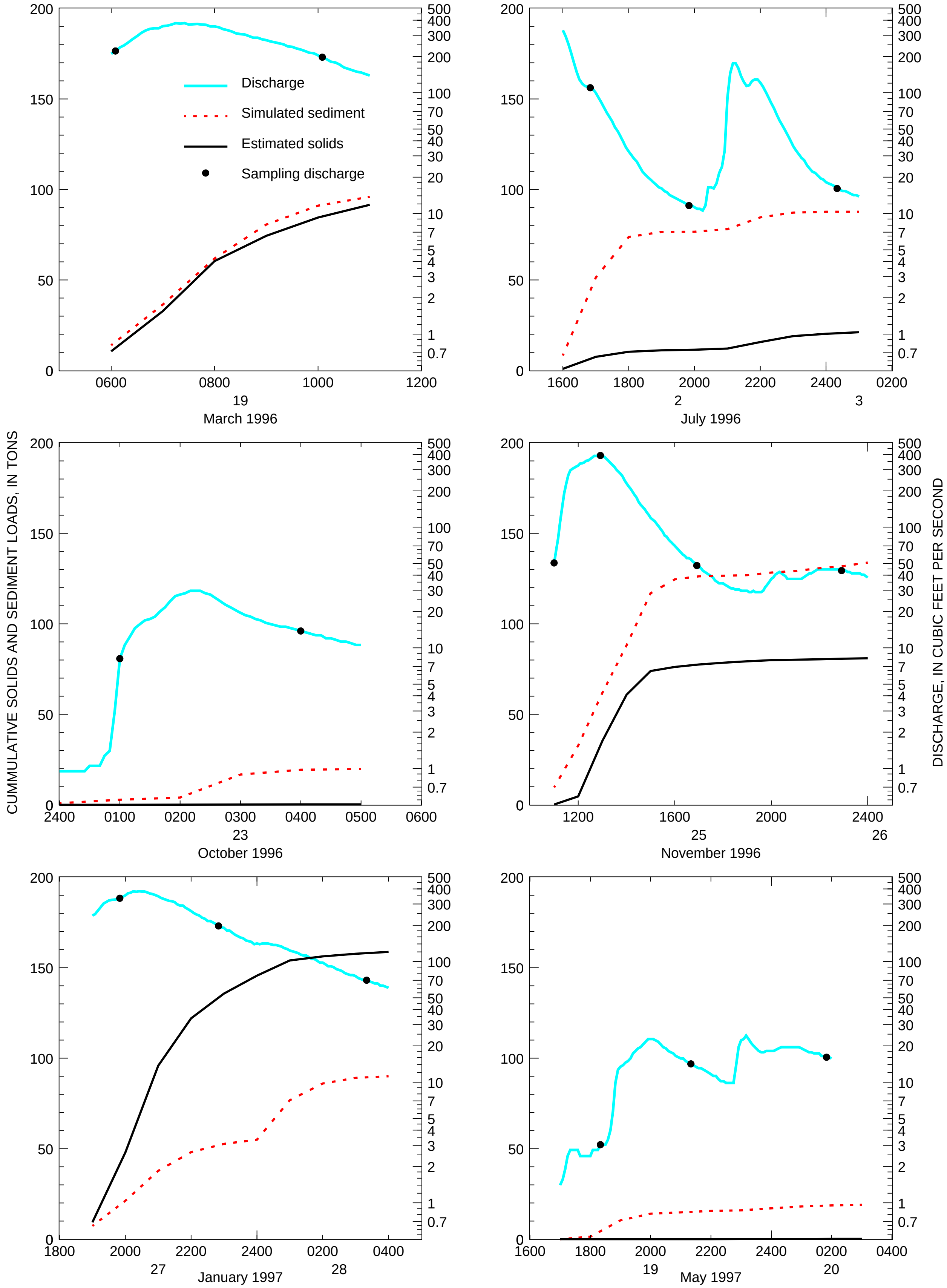

Figure 47. Hourly suspended-solids and suspended-sediment loads and 5-minute discharge and sampling discharge during selected storms, Chenoweth Run at Ruckriegel Parkway, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

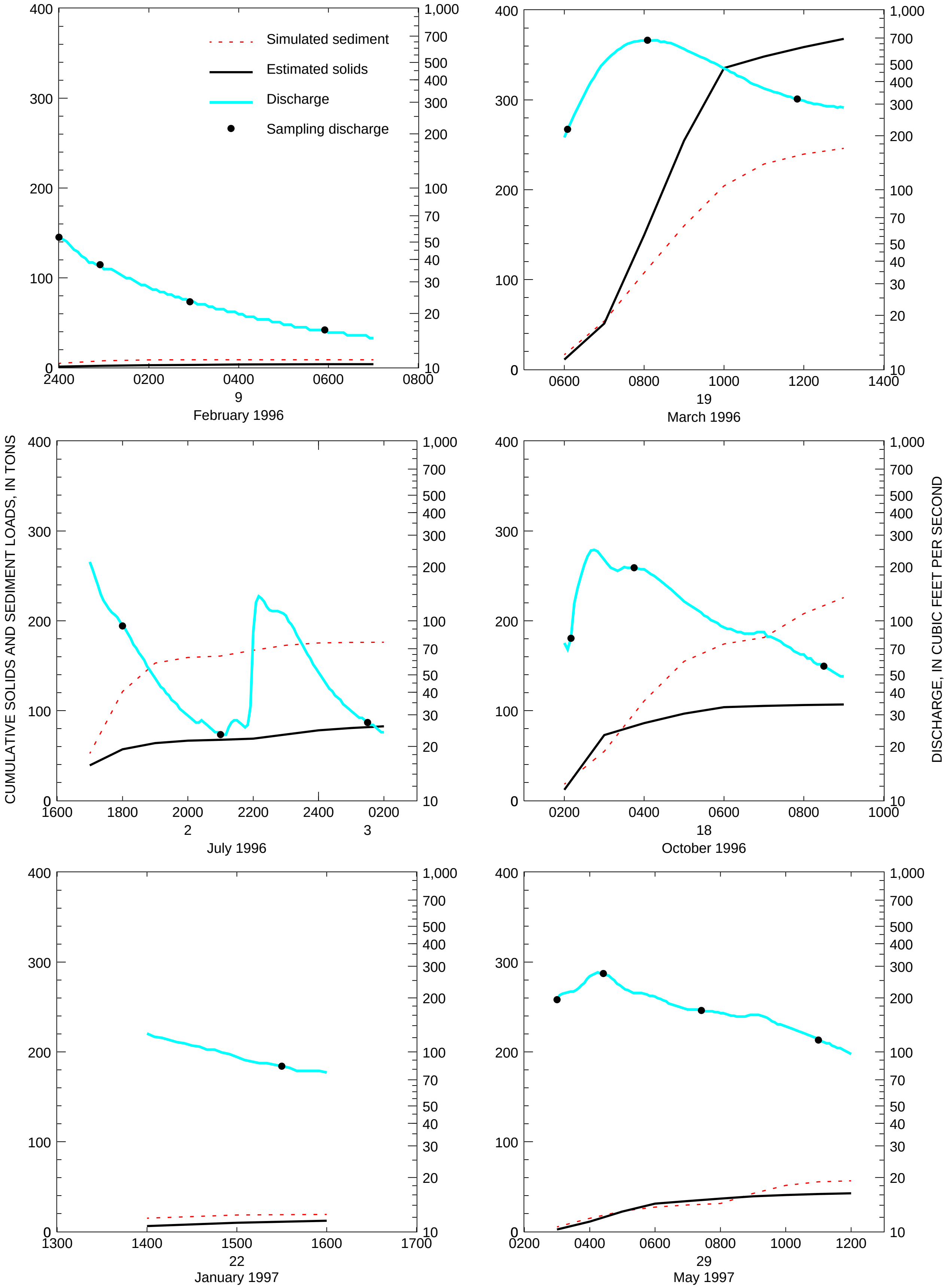

Figure 48. Hourly suspended-solids and suspended-sediment loads and 5-minute discharge and sampling discharge during selected storms, Chenoweth Run at Gelhaus Lane, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

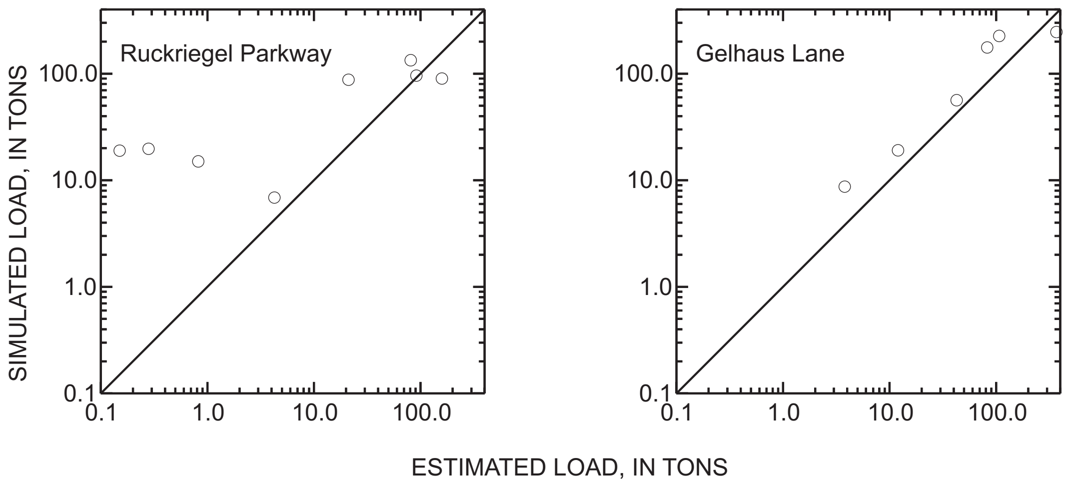

Figure 49. Comparison of total estimated suspended-solids loads and Hydrological Simulation Program—Fortran (HSPF)-simulated suspended-sediment loads for selected storms in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

Total Orthophosphate (TPO_4)

The simulation of TPO_4 included representation of point and nonpoint sources, as well as some instream processes, including settling of suspended TPO_4, adsorption and de-adsorption of PO_4 on suspended sediments, and release of PO_4 by benthic organisms and BOD decay. TPO_4 hourly point-source-load estimates were included as direct inflows to three main-channel RCHRES. The Jeffersontown WWTP flows into RCHRES 8, the Chenoweth Hills WWTP flows into RCHRES 9, and the Lake of the Woods WWTP flows into RCHRES 10. (See WWTP flow and sediment inputs.)

TPO_4 yields from pervious areas were simulated with the HSPF general water-quality secondary module, PQUAL, in the PERLND module. PQUAL accounts for a buildup and washoff of a constituent as a dissolved fraction on the surface and the entrainment of a constituent associated with sediment erosion as a suspended fraction. The quantity of a dissolved constituent available for washoff is controlled by the amount of surface flow and a user-defined accumulation rate (ACQOP), maximum storage limit (AQOLIM), and a washoff-susceptibility term (WSQOP). The quantity of a suspended constituent is directly proportional to the quantity of detached and scoured soils simulated by SEDMNT (as previously described) and a potency factor associated with each sediment source (POTFW for detached soil and POTFS for scoured soil). Phosphorus can also be input as atmospheric wet or dry deposition; however, this was not simulated explicitly because local information on atmospheric sources of TPO_4 was not available. The atmospheric source contribution was, however, represented in the general constituent accumulations.

The PERLND accumulation rates (ACQOP) ranged from 0.0001 to 0.0002 lb TPO_4 /acre/d, the upper storage limit (AQOLIM) ranged from 0.001 to 0.006 lb TPO_4 /acre and the stored-orthophosphate washoff-susceptibility factor (WSQOP) ranged from 1.9 to 5.4 in/h. Washoff potency factors for detached sediment (POTFW) ranged from 0.008 to 0.82 lb TPO_4 /ton sediment and the potency factor for scoured sediment (POTFS) ranged from 0.008 to 0.062 lb TPO_4 /ton sediment. Generally, the largest values for these terms were associated with disturbed PERLND's. Specific parameter values for each HRU are given in the PQUAL input block of the HSPF UCI file in Appendix 5. As calibrated, average annual TPO_4 yields for pervious areas (table 47) ranged from 0.001 to 1.36 lb/acre, for the forest and single-family-residential HRU's, respectively.

Table 47. Simulated total orthophosphate yields by model hydrologic response unit in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[<, less than; >, greater than]

Hydrologic response unit	Description	Total orthophosphate yield (pound/acre/year) 12-month period ending 01/1997	12-month period ending 01/1998	Average
	Pervious hydrologic response units			
1	Pasture/crop, low-permeability soils, 0 to 5 percent slope	0.183	0.243	0.213
2	Pasture/crop, low-permeability soils, >5 percent slope	.201	.247	.224
3	Pasture/crop, moderate-permeability soils, 0 to 5 percent slope	.152	.212	.182
4	Pasture/crop, high-permeability soils, >5 percent slope	.096	.168	.132
5	Forested, low-permeability soils, 0 to 5 percent slope	.004	.006	.005
6	Forested, low-permeability soils, >5 percent slope	.007	.006	.006
7	Forested, moderate-permeability soils, 0 to 5 percent slope	.002	.003	.002
8	Forested, high-permeability soils, >5 percent slope	.001	.001	.001
9	Open, vacant/undeveloped uses, low-permeability soils, 0 to 5 percent slopes	.278	.387	.332
10	Open, developed uses, low-permeability soils, 0 to 5 percent slopes	.611	.716	.664
11	Open, developed uses, low-permeability soils, >5 percent slopes	.610	.712	.661
12	Open, developed uses, moderate-permeability soils, 0 to 5 percent slopes	.596	.690	.643
13	Open, developed uses, moderate-permeability soils, >5 percent slopes	.603	.690	.646
14	Open, developed uses, high-permeability soils, >5 percent slopes	.582	.669	.626
15	Open single-family residential, disturbed low-permeability soils, all slopes	1.21	1.50	1.36
16	Open single-family residential, disturbed moderate-permeability soils, 0 to 5 percent slopes	.564	.683	.624
17	Open commercial/industrial/multi-family residential, disturbed moderate-permeability soils, 0 to 5 percent slopes	1.00	1.21	1.11
	Impervious hydrologic response units			
1	Single-family residential/parks/public/vacant hydrologically effective impervious areas, all slopes	.599	.599	.599
2	Commercial/industrial/multi-family residential hydrologically effective impervious areas, all slopes	.571	.510	.544

These represent hypothesized yields within the model framework, as no HRU-scale sampling was done as part of this study.

(HSPF provides an option for detailed simulation of TPO_4 flux in soil layers of pervious areas by use of the PHOS secondary module of PERLND; however, additional soils data (such as soil temperature) are needed for these detailed simulations.)

TPO_4 yields from impervious areas were simulated by use of the HSPF general water-quality secondary module, IQUAL, in the IMPLND module. Similar to PQUAL, this secondary module simulates accumulation and washoff of dissolved constituents and washoff of constituents associated with sediment, which was simulated in the SOLIDS secondary module of IMPLND. The accumulation rate (ACQOP) was 0.001 lb TPO_4/d. The stored orthophosphate washoff-susceptibility factor (WSQOP) was 5.4 in/h for both IMPLND types. The upper storage limit (SQOLIM) ranged from 0.045 lb TPO_4/acre on IMPLND1 to 0.035 lb TPO_4/acre on IMPLND2. All values for these terms are given in the IQUAL input block of the HSPF UCI file in Appendix 5. The simulated average annual TPO_4 yields for impervious areas (table 47) were approximately 0.5 lb TPO_4/acre for both IMPLND's.

All mass transfers in HSPF must be explicitly specified in the UCI input files. Yields of suspended and dissolved TPO_4 from PERLND's and IMPLND's were directed to appropriate RCHRES input members in the MASS-LINK block of the UCI file. Suspended PO_4 from PERLND's and IMPLND's was proportioned so that 10 percent was associated with sand-size particles, 20 percent with silt-size particles, and 70 percent with clay-size particles. A number of studies have indicated that fine-grain sediments provide the main bonding sites for adsorption of phosphorus (White, 1981; Raush and Schreiber, 1981; Carter and others, 1974; Brown and others, 1981). These studies indicate that phosphorus bonding with clay-size particles is about twice that for an equivalent mass of sand-size particles.

Although a number of transformations of PO_4 can occur in the stream reaches (RCHRES), only a partial set of these possible transformations was modeled for this study. The modeled transformations included settling of suspended TPO_4, adsorption and de-adsorption of PO_4 on suspended sediments, and release of PO_4 by benthic organisms and BOD decay. Other transformations of PO_4 that could be simulated, but were not, included uptake and release by phytoplankton and zooplankton, and benthic-algae uptake. These additional processes could be incorporated with additional data.

Changes of soluble phosphorus to an absorbed phase (adsorption) and from an adsorbed phase to a dissolved phase (de-adsorption) was simulated in HSPF with a linear-equilibrium isotherm defined by the user-supplied adsorption coefficient (Kd in NUT-ADSPARM block) for each of the three size fractions—sand, silt, and clay. In the calibrated model, PO_4 partition coefficients (Kd) ranged from 400 to 900 mL/g; values were higher for the silt/clay fractions than for the sand-size fractions.

Release of soluble PO_4 by benthic organisms is directly proportional to user-defined release rates under aerobic and anaerobic conditions (BRPO(1) and $BRPO_4$(2) respectively, in the NUT-BENPARM block) and benthal scour (SCRVEL and SCRUML in the RQUAL SCOUR-PARMS block). Aerobic and anaerobic conditions are determined by the current simulated value of dissolved oxygen in the OXRX module and the user-defined threshold value that determines which condition exists (ANAER in the NUT-BENPARM section of the HSPF UCI file).

BOD-decay release of soluble PO_4 was a function of the total BOD decay determined in the OXRX module and a stoichiometric conversion factor. A number of interconnected subordinate subroutines in the OXRX module (table 27) and their respective parameter values (table 28) affect the BOD decay. No other user-defined parameter values were required to adjust the BOD-decay release of soluble PO_4.

Suspended PO_4 was routed to the next downstream reach for each size fraction for all RCHRES including those with two outflow gates. (The first outflow gate was used to simulate ground-water-seepage losses and the second outflow gate was used to simulate the remaining main-channel flow downstream to the next RCHRES). Thus, there were assumed to be no losses of the suspended PO_4 in the ground-water-seepage. Dissolved PO_4 was routed to the next downstream reach only for that portion associated with the main-channel flow (that is, through the second outflow gate, for the RCHRES with two outflow gates), and the dissolved PO_4 associated with ground-water seepage was lost from the system.

TPO_4 loads were calibrated to the annual TPO_4 loads estimated at the Ruckriegel Parkway and Gelhaus Lane sites by use of ESTIMATOR. The simulated mean-annual TPO_4 load for the model calibration period differed from the ESTIMATOR load by -1.3 percent at the Ruckriegel Parkway site and 0.8 percent at the Gelhaus Lane site (table 48). Annual and mean-annual errors provided a good TPO_4 simulation (20 to 30 percent error), based on criteria suggested by Donigian and others (1984). Simulated monthly TPO_4 loads were generally in good agreement with the ESTIMATOR monthly loads (fig. 50), but loads were oversimulated for low-flow months, as was also the case for flows and sediment. (ESTIMATOR is not considered to provide very reliable estimates for time steps less than 1 year, particularly for small drainage areas and short periods of record.)

Agreement on HSPF-simulated and TPO_4 storm loads estimated directly from the discrete samples collected during individual storms was variable (see table 49 and figs. 51–53). There was a tendency to oversimulate loads at the Ruckriegel Parkway site, particularly for the smaller storms. Discharge and also the sediment and TPO_4 loads tended to be oversimulated during the smallest storms sampled during summer and early fall low-flow periods. Percentage errors in simulation of individual storm TPO_4 loads were, as expected, generally much larger than percentage errors in annual and total loads.

On average, the simulated suspended fraction of the TPO_4 load was 57 percent at the Ruckriegel Parkway site and 10 percent at the Gelhaus Lane site. The proportion of suspended PO_4 to dissolved PO_4 was greater in the reaches upstream from the Jeffersontown WWTP than the proportion just downstream from the Jeffersontown WWTP. Moving downstream from the Jeffersontown WWTP, the proportion of suspended PO_4 to dissolved PO_4 continued to rise. This might be expected because the available soluble PO_4 will adsorb to suspended sediments.

Table 48. Annual ESTIMATOR total orthophosphate loads and Hydrological Simulation Program—Fortran (HSPF)-simulated total orthophosphate loads in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[lb, pound; P, phosphorus]

Period	Measured rainfall (inches)	Estimator total orthophosphate load		Simulated total orthophosphate load		Difference
		lb as P	lb as P/acre	lb as P	lb as P/acre	Percent
Chenoweth Run at Ruckriegel Parkway						
02/1996-01/1997	56.81	1,820	0.529	2,360	0.685	29.5
02/1997-01/1998	53.33	3,360	.975	2,750	.799	-18.1
Mean	55.07	2,590	.752	2,560	.742	-1.3
Chenoweth Run at Gelhaus Lane						
02/1996-01/1997	56.81	28,400	3.88	28,200	3.84	-1.0
02/1997-01/1998	53.33	27,100	3.70	27,800	3.80	2.7
Mean	55.07	27,800	3.79	28,000	3.82	.8

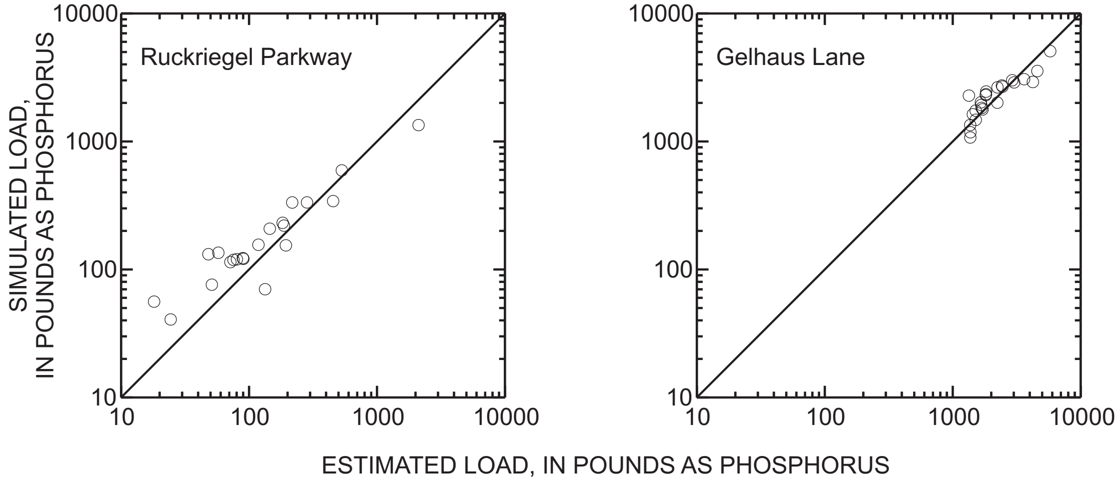

Figure 50. Comparison of the monthly ESTIMATOR total orthophosphate loads and the monthly Hydrological Simulation Program—Fortran (HSPF)-simulated total orthophosphate loads in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

Table 49. Estimated total orthophosphate loads and Hydrological Simulation Program—Fortran (HSPF)-simulated total orthophosphate loads for selected storms in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998

[lb, pound; P, phosphorus]

Period				Total orthophosphate load			
						Difference	
Begin (Julian date/time)	End (Julian date/time)	Observed flow (acre-feet)	Simulated flow (acre-feet)	Estimated (lb as P)	Simulated (lb as P)	lb as P	Percent
Chenoweth Run at Ruckriegel Parkway							
19960208/1700	19960209/0100	11.0	18.5	3.90	8.77	4.87	125
19960319/0500	19960319/1100	125	98.6	74.9	37.1	-37.8	-50.5
19960606/2200	19960606/2300	8.14	6.82	1.12	1.63	.51	45.5
19960702/1500	19960703/0100	53.7	75.5	3.77	28.4	24.6	652
19961022/2300	19961023/0500	6.18	19.5	.26	5.22	4.96	1,910
19961125/1000	19961125/2400	123	110	25.3	47.6	22.3	88.1
19970127/1800	19970128/0400	160	104	25.6	24.6	-1.0	-3.9
19970519/1600	19970520/0300	11.8	27.9	.57	9.29	8.72	1,530
Chenoweth Run at Gelhaus Lane							
19960208/2300	19960209/0700	16.6	21.4	27.8	28.2	-.6	-2.2
19960319/0500	19960319/1300	274	203	384	107.0	-277	-72.1
19960702/1600	19960703/0200	58.5	101	76.4	76.8	.4	.5
19961018/0100	19961018/0900	74	142	211	81.3	-130.0	-61.6
19970122/1300	19970122/1600	27.9	16.5	27.7	14.0	-13.7	-49.4
19970529/0200	19970529/1200	137	116	121	62.3	-58.7	-48.5

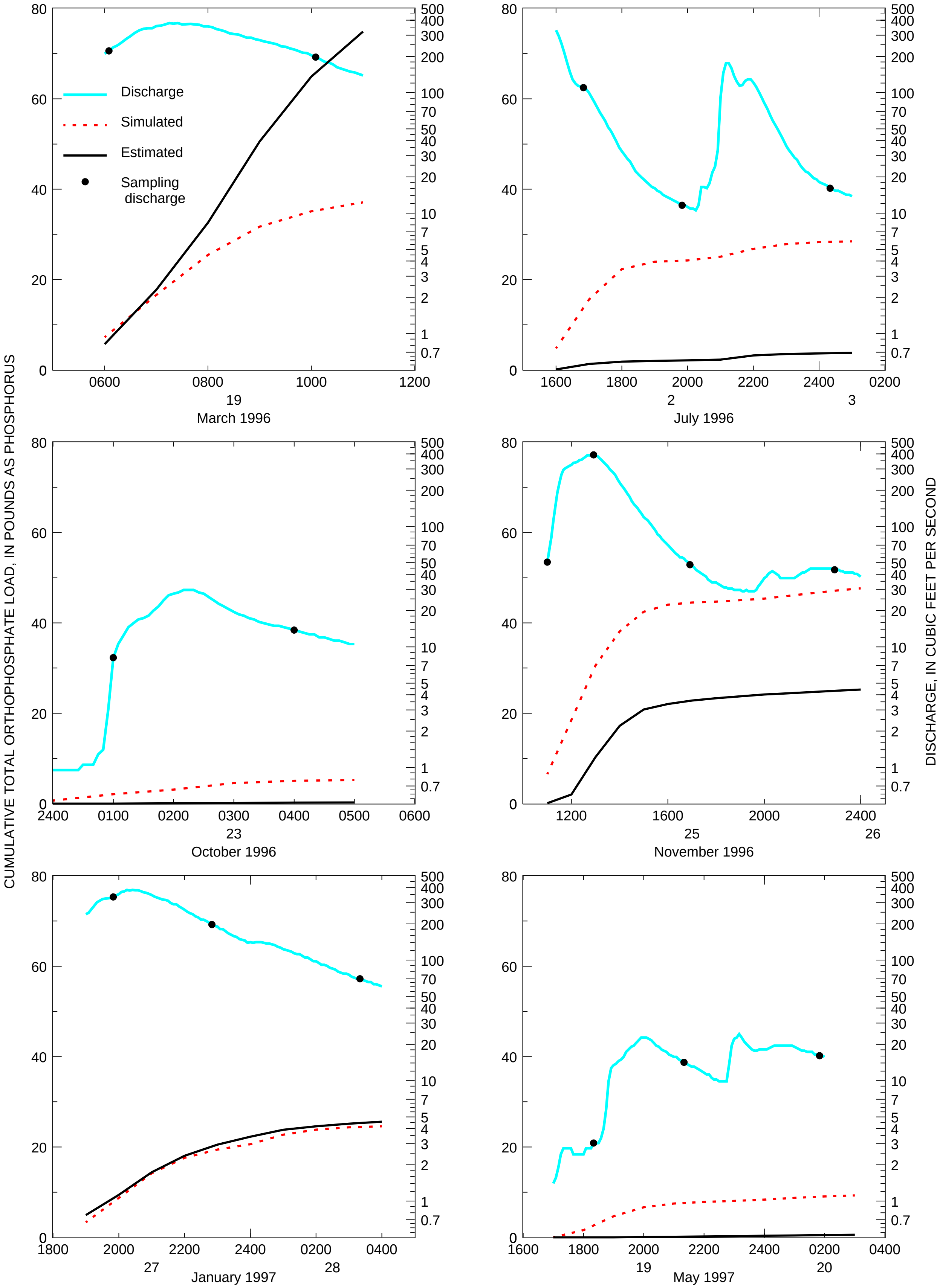

Figure 51. Hourly total orthophosphate loads and 5-minute discharge and sampling discharge during selected storms, Chenoweth Run at Ruckriegel Parkway, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

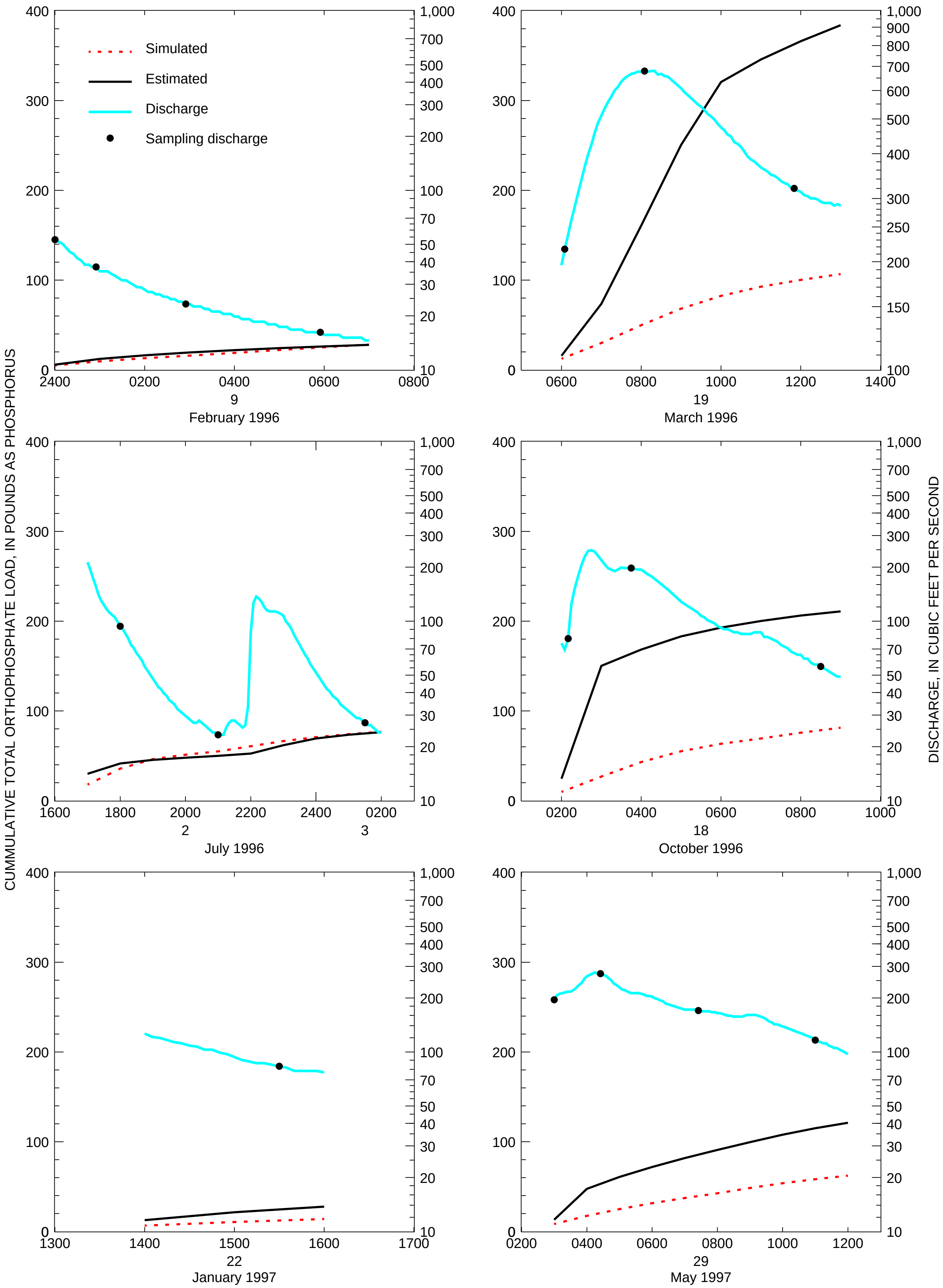

Figure 52. Hourly total orthophosphate loads and 5-minute discharge and sampling discharge during selected storms, Chenoweth Run at Gelhaus Lane, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

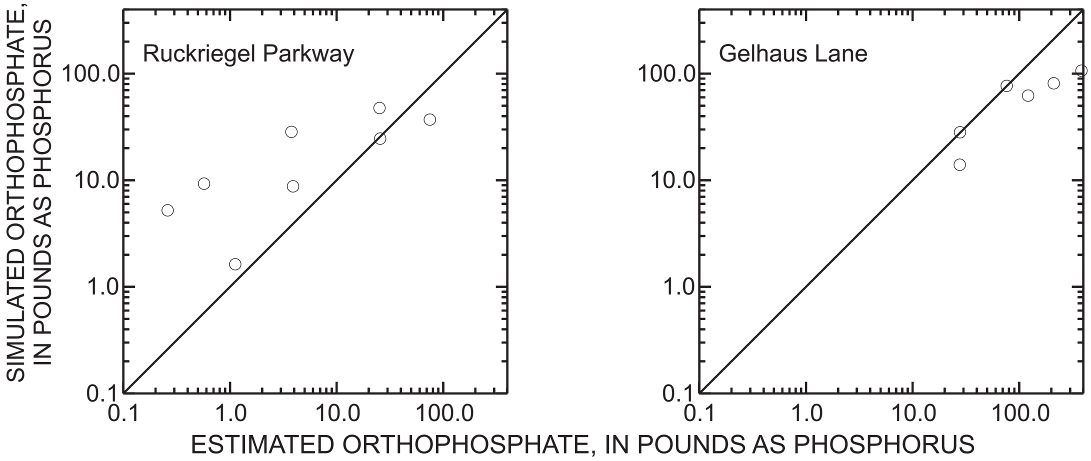

Figure 53. Comparison of total estimated total orthophosphate loads and Hydrological Simulation Program—Fortran (HSPF)-simulated total orthophosphate loads for selected storms in the Chenoweth Run Basin, Jefferson County, Kentucky, during the model calibration period, February 1996–January 1998.

There was no sampling data showing the actual suspended and dissolved fractions of TPO_4; however, data for total and dissolved phosphorus were available. Sampling data (19 samples) for this study indicated that, on average, the suspended fraction makes up approximately three-fourths of the TP concentration at the Ruckriegel Parkway site; however, only one fourth to one third of TP is TPO_4 at the Ruckriegel Parkway site. Twenty water samples collected for this study indicated approximately half of TP concentration was in the suspended fraction at the Gelhaus Lane site. Generally, approximately half of TP is TPO_4 at the Gelhaus Lane site. (See the regression relations developed between TP and TPO_4 in “Water Quality.”) The large majority of the Jeffersontown WWTP effluent was in the dissolved orthophosphate form.

MODEL APPLICATIONS AND LIMITATIONS

The model of the Chenoweth Run Basin described in this report can help managers, planners, and engineers examine the complexities of the basin hydrology and, thus, support comprehensive water-resource-management decisions in the basin. Such analyses are facilitated by the implementation of the HSPF model within GENSCN, which provides a tool for development and comparison of various alternative basin-development scenarios that can be defined by unique sets of water-resource-management operations and modeled basin characteristics.

The model can be used to assess the hydrological consequences of changes in the land-use/land-cover and (or) water-storage characteristics of the basin. Magnitudes of the effects of such changes on discharge and water quality may be assessed.

Flood frequency may be estimated through long-term simulation (record extension) by use of historical meteorological data with the calibrated model. Furthermore, estimates of peak-discharge frequency could be used to delineate floodways.

Perhaps with additional data on tributary flows, the model could also be used to examine the normal timing of inflows to the main channel from the many tributary subbasins within Chenoweth Run. Timing of subbasin inflows are important for determination of the effects of storm-water detention facilities on peak discharges.

The model calibration data were limited to a 2-year period when precipitation and streamflow were well above average. Although some periods of moderately low base flows were included, extended periods of low base flows were not. Also, base-flow-seepage losses in the main channel were hypothesized and included in the model, but such losses have not been confirmed and quantified by field measurements. Applications of the model for simulations of extended low base flows may therefore be less accurate than moderate- and high-flow simulations.

Calibration of the model for simulation of TPO_4 transport was rudimentary. Components of TPO_4 processing most critical to transport during moderate and high-flow portions of the model calibration period were considered. Biological uptake of TPO_4 was not modeled; therefore, not all linkages between instream TPO_4 concentrations and algal growth were represented in the model.

SUMMARY AND CONCLUSIONS

Rainfall, streamflow, and water-quality data collected in the Chenoweth Run Basin in Jefferson County, Ky., during February 1996–January 1998, and the available historical hydrological data collected in the basin beginning in February 1988, were used to characterize existing (base) hydrologic conditions and to calibrate a Hydrological Simulation Program—Fortran (HSPF) model for continuous simulation of rainfall, streamflow, suspended-sediment, and total-orthophosphate transport relations. Chenoweth Run Basin, encompassing 16.5 mi^2 in suburban eastern Jefferson County, includes areas of expanding urban development, particularly in the upper third of the basin, which contains a large industrial park and a new 9,100-seat church complex. Long-standing problems in meeting water-quality criteria for either of the state-designated aquatic-life or swimming uses in the approximately 9-mi-long main channel had been attributed to organic enrichment, and the presence of nutrients, metals, and pathogens in urban-runoff and wastewater inflows. Study results provided an improved understanding of the complexities of the basin hydrology and a basin-modeling framework with analytical tools for use in comprehensive water-resource planning and management.

The 2-year field data-collection (model calibration) period was designed to supplement and expand the utility of the available historical streamflow and water-quality data, most of which represented individual water samples collected and discharge measurements made during low-to-moderate flows in routine monitoring programs. For this study, stream-water sampling was targeted primarily toward stormflows to adequately characterize the highly variable hydrologic conditions of this mixed-land-use, urbanizing basin. Spatial, flow-related, and seasonal variability of water quality was represented by the collection of a series of discrete water samples during 3 storms each year, distributed seasonally at each of 4 sampling sites on the main channel, for a total of 12 storm-sampling events per year. In 1996–97, 24 storms were sampled at the 4 sites; 79 discrete water samples were collected, which provided an average of 3.3 samples per storm. Also, one low-flow sample was collected annually in September at each of the four sites. Constituents and properties analyzed included pH, alkalinity, total dissolved solids, total suspended solids, total volatile suspended solids, biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, organic nitrogen, total orthophosphate (TPO_4), total phosphorus (TP), and fecal coliform and streptococcus. A filtered sample for total phosphorus analysis was also routinely submitted for laboratory analysis. As requested by Louisville and Jefferson County Metropolitan Sewer District (MSD), samples for analysis of metals and chloride also were collected when enough sample water was available. Two streamflow-gaging stations (one upstream and one downstream) near the single major wastewater-treatment plant (WWTP) (4-Mgal/d capacity) and two minor WWTP's in the basin provided continuous, 5-minute-interval records of stream stage (water level) for use in computation of continuous discharge. Water-quality monitors at each streamflow-gaging station provided continuous, 30-minute-interval records of water temperature, pH, specific conductance, and dissolved-oxygen concentration. The two streamflow-gaging stations were also among the four water-quality-sampling sites, one of which was located upstream from the WWTP's.

Several types of other pertinent data, including meteorological, geographical, and WWTP-effluent data, were compiled and analyzed for the study. Rainfall was recorded at 5-minute intervals at one gage in the basin and at four other gages surrounding the basin. Mean annual precipitation in the basin (55.07 in.) averaged approximately 11 in. above the normal annual amount (44.39 in.) at a nearby long-term rain gage in 1996-97; record rainfalls (63.76 in. in 1996 and 10.48 in. on March 1, 1997) and flooding occurred.

Hydrological characteristics and the underlying surficial geological characteristics are highly varied in Jefferson County. In the Chenoweth Run Basin, as in much of the eastern third of Jefferson County and adjacent counties to the east within the Outer Bluegrass Physiographic Region of Kentucky, relief is moderately sloping to steep. Also, internal drainage in pervious areas here is impeded by the shallow (generally less than 5 ft deep), fine-textured subsoils that include abundant silts and clays. Thus, much of the precipitation here tends to move rapidly as overland flow and (or) interflow to the stream channels, and relatively little water infiltrates through the soil mantle to the underlying bedrock.

Seepage losses to ground water are not uncommon where thin, fractured sections of clastic rocks (shales) are intersected by stream channels. Bedrock-fracture zones tend to be concentrated in and (or) near stream channels in this geological setting. Some seepage losses in the main channel were hypothesized and modeled for base-flow periods.

Approximately 60 percent of the above-normal precipitation left the Chenoweth Run Basin as streamflow during the data-collection period, and approximately 40 percent of precipitation left the basin as evapotranspiration and other losses, such as to the ground water by channel losses. Typically, this distribution would be reversed; approximately 40 percent would leave as streamflow and the remaining 60 percent would leave as evapotranspiration and other losses.

The WWTP's provide secondary (biological) treatment of wastewaters from domestic, commercial, and industrial customers. At times, wastewater effluent makes up the majority of base flows in the main channel. Bypass flows occurred at the major WWTP during and following rain storms of approximately 0.5 in. or greater, when infiltration and inflows to the sanitary-sewer system caused the WWTP-inflow capacity to be exceeded. As a consequence, some untreated wastewater bypassed the WWTP and was discharged directly to the stream. Bypass flows, though not directly measured at the plant, were estimated to have occurred at a constant rate of 7.74 ft^3/s (5 Mgal/d) for the bypass periods (59 days) during the data-collection period. Overall, wastewater inflows constituted some 14 in. of water on the basin, or approximately 20 percent of flow measured, at the gaging station downstream from the WWTP's during the data-collection period.

Additional and variable nonpoint sources also exist for chemical constituents. The fine-textured soils are highly susceptible to erosion when exposed, as is often the case during construction activity. Large concentrations and loads of sediment have often been transported during stormflows. The sediments also carry sorbed constituents including nutrients and metals. Streets, parking lots, treated turf grasses, pastures, and crop areas also are potentially significant constituent-source areas.

Increased stream-water temperatures resulting from the runoff from impervious surfaces, the loss of riparian tree canopy, and thermal energy added by the WWTP's reduces the oxygen-carrying capacity of streams and thereby adversely affects habitat for aquatic organisms. Oxygen-demanding organic materials, sediments, and nutrients further impair aquatic habitat.

The numerous ponds and small lakes constructed on the resistant upland bedrock formations also affect streamflow and water-quality conditions. Approximately 25 percent of the basin area is drained through these ponds. This additional detention storage delays and (or) reduces the movement of water and constituents through the basin to some degree, including the sediments and nonpoint-source nutrients.

The water-quality-sampling and discharge data were used to estimate loads from point and nonpoint sources of suspended sediments, TP, and TPO_4. Above-average suspended-sediment loads and yields (exceeding 4 ton/acre) were estimated for the data-collection period; nonpoint sources contributed the largest portion of the sediment loads. The WWTP's were the source of most of the estimated TP and TPO_4 transported in the basin. The load estimates indicated that roughly 65 percent (23,300 of 43,600 lb as P annually) of the TP load and 90 percent (25,200 of 27,800 lb as P annually) of the TPO_4 load at the streamflow-gaging station downstream from the WWTP's during the February 1996–January 1998 data-collection period may be attributable to the WWTP effluents.

The 4-Mgal/d major WWTP was upgraded following the data-collection period for this study; a phosphorus-removal process and an ultraviolet-disinfectant unit were added. Also, work was done to reduce the rainwater inflows to the sanitary-sewer system that had previously caused overflows of untreated or undertreated wastewater to the stream.

The HSPF model was used to represent several important hydrologic features of the Chenoweth Run Basin: (1) numerous small lakes and ponds, (2) potential seasonal ground-water-seepage loss in stream channels, (3) contributions from WWTP effluents and bypass flows, and (4) the transport and transformations of sediments and nutrients. The model was calibrated and verified for flow simulation on the basis of measured total, annual, seasonal, monthly, daily, hourly, and 5-minute-interval storm discharge data. The numerous storms permitted a split-sample procedure to be used for a model verification on the basis of storm volumes and peaks. Total simulated and observed discharge during the model calibration period differed by approximately -5.4 percent at the upper streamflow-gaging station and 3.1 percent at the lower station. The model results for the total and annual water balances were classified as very good on the basis of the suggested calibration criteria. The model had correlation coefficients ranging from 0.89 to 0.98 for hourly to monthly mean flows, respectively. The coefficients of model-fit efficiency for daily and monthly discharge simulations approach the excellent range (exceeding 0.97). However, the model was calibrated for a comparatively short 24-month period during which flows were above normal. Increased model error might be expected during an extended period of near-normal flows.

The model was calibrated for simulation of sediment and TPO_4 transport on the basis of estimated constituent loads. The overall mass balance was within -33 percent for sediment and +/- 1 percent for TPO_4. Sediment was undersimulated during the major-flood year (1997). Close agreement between simulated and observed total loads of TPO_4 was obtained; however, the model tended to oversimulate discharge and also the sediment and TPO_4 loads during the smallest storms sampled during summer and early fall low-flow periods.

The model developed in the study described in this report can be applied to assessments or evaluation of several water-related issues or activities in the Chenoweth Run Basin, including:

- Estimates of flood frequency through long-term simulation (record extension) by use of historical meteorological data with the calibrated model.
- Predictions of the timing of inflows to the main channel from the many tributary subbasins within Chenoweth Run may be made with additional data collection on tributary inflows.
- Development and analysis of alternative basin- and water-resource-management scenarios.

The model calibration data were limited to a 2-year period when precipitation and streamflow were well above the long-term averages. Although some periods of moderately low base flows were included, extended periods of low base flows were not. Also, base-flow-seepage losses in the main channel were hypothesized and included in the model, but such losses have not been confirmed and quantified by field measurements. Applications of the model simulations of extended low base flows may therefore be less accurate than those for moderate and high flows.

Calibration of the model for simulation of TPO_4 transport was rudimentary. Components of TPO_4 processing most critical to transport during moderate- and high-flow parts of the model calibration period were considered. Biological uptake of TPO_4 was not modeled; therefore, not all linkages between instream TPO_4 concentrations and algal growth were represented in the model.

Additional refinement and extension of the HSPF-model application is suggested. Base-flow-seepage losses in the main channel could be confirmed and accurately quantified by investigation of surface- and ground-water relations in the basin area. Water-quality sampling of stormflows from small drainage areas (HRU-scale) are needed to establish definitive relations between specific land uses and nutrient yields in the basin. Capabilities of the water-quality model could be extended to assess questions concerning factors controlling algal growth and options for minimizing any future nuisance algal growth if additional water-quality and biological (algal) data were collected and the model were further calibrated for related constituents including dissolved oxygen, BOD, inorganic N, and plankton. Post-audit testing of the model would enable comparison of model predictions to actual water-quality conditions following implementation of any constituent-control strategies.

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APPENDIXES

Appendix 1. Results of analyses of field blanks for sampling in the Chenoweth Run Basin, Jefferson County, Kentucky, in 1996–97

WATER-QUALITY DATA

DATE	STATION	NUMBER	DATE	TIME	OXYGEN, DIS-SOLVED (MG/L) (00300)	PH WATER WHOLE FIELD (STAND-ARD UNITS) (00400)	PH WATER WHOLE LAB (STAND-ARD UNITS) (00403)	SPE-CIFIC CON-DUCT-ANCE (US/CM) (00095)	TEMPER-ATURE WATER (DEG C) (00010)	CALCIUM TOTAL RECOV-ERABLE (MG/L AS CA) (00916)
FEB 1996										
08...	03123499		960208	1600	--	--	--	--	--	2.1
MAR										
19...	03123499		960319	0915	--	--	--	--	--	1.5
19...	03123499		960319	1115	--	--	--	--	--	.13
JUL										
03...	03123499		960703	1215	--	--	5.8	5	--	.22
SEP										
26...	03123499		960926	0800	--	--	7.9	--	--	.10
JUN 1997										
09...	03123499		970609	1000	7.2	7.0	7.8	2	--	--
SEP										
16...	03123499		970916	0820	7.2	7.0	7.8	2	20.5	--

DATE	MAGNE-SIUM, TOTAL RECOV-ERABLE (MG/L AS MG) (00927)	ANC UNFLTRD TIT 4.5 LAB (MG/L AS CACO3) (90410)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL) (00940)	NITRO-GEN, AMMONIA TOTAL (MG/L AS N) (00610)	NITRO-GEN, NITRATE TOTAL (MG/L AS N) (00620)	NITRO-GEN, ORGANIC TOTAL (MG/L AS N) (00605)	NITRO-GEN, AMMONIA TOTAL (MG/L AS NH4) (71845)	NITRO-GEN, NITRITE TOTAL (MG/L AS N) (00615)	PHOS-PHORUS DIS-SOLVED (MG/L AS P) (00666)	PHOS-PHORUS TOTAL (MG/L AS P) (00665)
FEB 1996										
08...	.54	--	--	--	--	--	--	--	--	--
MAR										
19...	.42	--	--	--	--	--	--	--	--	--
19...	.04	--	--	--	--	--	--	--	--	--
JUL										
03...	.07	3.0	.50	.090	.090	.03	.12	--	.001	.001
SEP										
26...	.01	71	--	--	--	--	--	--	--	--
JUN 1997										
09...	--	240	.05	.010	<.100	.03	.01	.002	.010	.020
SEP										
16...	--	--	.05	.010	<.100	.03	.01	.002	.010	.020

DATE	OXYGEN DEMAND, BIO-CHEM-ICAL, 5 DAY (MG/L) (00310)	OXYGEN DEMAND, CHEM-ICAL (HIGH LEVEL) (MG/L) (00340)	RESIDUE FIXED NON FILTER-ABLE (MG/L) (00540)	RESIDUE AT 105 DEG. C, DIS-SOLVED (MG/L) (00515)	RESIDUE TOTAL AT 105 DEG. C, SUS-PENDED (MG/L) (00530)	FECAL COLI-FORM 24-HR MEM.FIL (COLS./ 100 ML) (31613)	STREP-TOCOCCI FECAL, KF AGAR (COLS. PER 100 ML) (31673)	ARSENIC TOTAL (UG/L AS AS) (01002)	BARIUM, TOTAL RECOV-ERABLE (UG/L AS BA) (01007)	BERYL-LIUM, TOTAL RECOV-ERABLE (UG/L AS BE) (01012)
FEB 1996										
08...	--	--	--	--	--	--	--	--	2	<1
MAR										
19...	--	--	--	--	--	--	--	<5	<1	<1
19...	--	--	--	--	--	--	--	<5	<1	<1
JUL										
03...	.3	2	4	192	5	K7.00	K10	<5	<1	<1
SEP										
26...	.2	--	.500	24	2	--	--	<5	1	<1
JUN 1997										
09...	.2	2	1	254	2	K2.00	K2	--	--	--
SEP										
16...	.2	2	--	254	--	K2.00	K2	--	--	--

Appendix 1. Results of analyses of field blanks for sampling in the Chenoweth Run Basin, Jefferson County, Kentucky, in 1996–97—*Continued*

DATE	CADMIUM WATER UNFLTRD TOTAL (UG/L AS CD) (01027)	CHRO-MIUM, TOTAL RECOV-ERABLE (UG/L AS CR) (01034)	COPPER, TOTAL RECOV-ERABLE (UG/L AS CU) (01042)	IRON, TOTAL RECOV-ERABLE (UG/L AS FE) (01045)	LEAD, TOTAL RECOV-ERABLE (UG/L AS PB) (01051)	MERCURY TOTAL RECOV-ERABLE (UG/L AS HG) (71900)	NICKEL, TOTAL RECOV-ERABLE (UG/L AS NI) (01067)	SELE-NIUM, TOTAL (UG/L AS SE) (01147)	SILVER, TOTAL RECOV-ERABLE (UG/L AS AG) (01077)	ZINC, TOTAL RECOV-ERABLE (UG/L AS ZN) (01092)
FEB 1996										
08...	<2	<3	6	240	<20	.2	<5	--	<6	29
MAR										
19...	<2	<3	4	33	<20	<.2	<5	<5	<6	18
19...	<2	<3	<2	39	<20	<.2	<5	<5	<6	13
JUL										
03...	<2	<3	<2	52	<20	<.2	<5	<5	<6	< 3
SEP										
26...	<2	<3	4	8	<20	<.2	<5	<5	<6	16
JUN 1997										
09...	--	--	--	--	--	--	--	--	--	--
SEP										
16...	--	--	--	--	--	--	--	--	--	--

Appendix 2. Results of analyses of paired water samples collected by use of automatic samplers and manual, cross-sectionally integrated sampling, Chenoweth Run Basin, Jefferson County, Kentucky

SAMPLE-COLLECTION METHOD	STATION NUMBER	DATE	TIME	DIS-CHARGE, INST. CUBIC FEET PER SECOND (00061)	SPE-CIFIC CON-DUCT-ANCE (US/CM) (00095)	PH WATER WHOLE FIELD (STAND-ARD UNITS) (00400)	PH WATER WHOLE LAB (STAND-ARD UNITS) (00403)	TEMPER-ATURE WATER (DEG C) (00010)	OXYGEN, DIS-SOLVED (MG/L) (00300)	OXYGEN DEMAND, BIO-CHEM-ICAL, 5 DAY (MG/L) (00310)	OXYGEN DEMAND, CHEM-ICAL (HIGH LEVEL) (MG/L) (00340)	CALCIUM TOTAL RECOV-ERABLE (MG/L AS CA) (00916)
INTEGRATED	03298135	03-19-96	1005	205.	339.	7.5	7.8	5.4	12.2	4.	28.	28.3
AUTOMATIC	03298135	03-19-96	0955	205.	339.	7.5	7.6	5.4	12.2	3.	27.	26.7
INTEGRATED	03298135	11-25-96	1055	43.8	475.	7.8	7.8	8.97	9.27	3.	20.	59.5
AUTOMATIC	03298135	11-25-96	1100	43.8	475.	7.8	8.	8.97	9.27	2.	16.	59.
INTEGRATED	03298140	01-22-97	1500	--	765.	--	7.8	--	--	7.	20.	46.3
AUTOMATIC	03298140	01-22-97	1505	--	766.	--	7.9	--	--	6.	21.	45.1
INTEGRATED	03298150	03-19-96	1145	362.	292.	7.7	--	6.	11.1	--	--	38.2
AUTOMATIC	03298150	03-19-96	1150	362.	292.	7.7	8.	6.	11.1	8.	40.	38.9
INTEGRATED	03298150	10-18-96	0830	55.	317.	7.46	8.	16.	9.	5.	20.	32.3
AUTOMATIC	03298150	10-18-96	0835	55.	264.	7.46	8.	16.	9.	5.	21.	32.5
INTEGRATED	03298150	01-22-97	1335	151.	583.	7.72	7.9	4.4	12.47	7.	23.	41.3
AUTOMATIC	03298150	01-22-97	1340	151.	589.	7.72	7.9	4.4	12.47	7.	22.	42.9
INTEGRATED	03298150	01-22-97	1530	82.4	616.	7.75	8.	4.9	12.01	6.	21.	44.5
AUTOMATIC	03298150	01-22-97	1535	82.4	621.	7.75	8.	4.9	12.01	6.	18.	44.9

STATION NUMBER	DATE	TIME	MAGNE-SIUM, TOTAL RECOV-ERABLE (MG/L AS MG) (00927)	ANC WATER UNFLTRD CARBON-ATE (MG/L CACO3) (00430)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL) (00940)	RESIDUE AT 105 DEG. C, DIS-SOLVED (MG/L) (00515)	RESIDUE TOTAL AT 105 DEG. C, SUS-PENDED (MG/L) (00530)	RESIDUE FIXED NON FILTER-ABLE (MG/L) (00540)	RESIDUE VOLA-TILE, SUS-PENDED (MG/L) (00535)	NITRO-GEN, NITRATE TOTAL (MG/L AS N) (00620)	NITRO-GEN, NITRITE TOTAL (MG/L AS N) (00615)	NITRO-GEN, NO2+NO3 TOTAL (MG/L AS N) (00630)
03298135	03-19-96	1005	9.94	73.	20.6	196.	380.	352.	28.	2.4	.18	2.58
03298135	03-19-96	0955	9.38	66.	20.4	168.	378.	348.	30.	2.4	.23	2.63
03298135	11-25-96	1055	24.5	--	31.	--	101.	--	--	--	--	1.2
03298135	11-25-96	1100	24.1	--	30.	--	63.	--	--	--	--	1.2
03298140	01-22-97	1500	16.2	--	146.	--	210.	--	--	--	--	3.5
03298140	01-22-97	1505	16.1	--	148.	--	178.	--	--	--	--	3.2
03298150	03-19-96	1145	13.6	--	--	--	--	--	--	--	--	--
03298150	03-19-96	1150	13.3	131.	19.8	196.	238.	214.	24.	2.3	.14	2.44
03298150	10-18-96	0830	11.	--	18.	--	102.	--	--	--	--	2.3
03298150	10-18-96	0835	10.9	--	19.	--	70.	--	--	--	--	2.
03298150	01-22-97	1335	15.6	--	92.	--	368.	--	--	--	--	2.7
03298150	01-22-97	1340	16.	--	96.	--	354.	--	--	--	--	2.7
03298150	01-22-97	1530	17.3	--	93.	--	234.	--	--	--	--	2.5
03298150	01-22-97	1535	17.	--	94.	--	208.	--	--	--	--	2.8

STATION NUMBER	DATE	TIME	NITRO-GEN, AMMONIA TOTAL (MG/L AS N) (00610)	NITRO-GEN, AMMONIA TOTAL (MG/L AS NH4) (71845)	NITRO-GEN, ORGANIC TOTAL (MG/L AS N) (00605)	PHOS-PHORUS TOTAL (MG/L AS P) (00665)	PHOS-PHATE, TOTAL (MG/L AS PO4) (00650)	PHOS-PHORUS DIS-SOLVED (MG/L AS P) (00666)	ARSENIC TOTAL (UG/L AS AS) (01002)	BARIUM, TOTAL RECOV-ERABLE (UG/L AS BA) (01007)	BERYL-LIUM, TOTAL RECOV-ERABLE (UG/L AS BE) (01012)	CADMIUM WATER UNFLTRD TOTAL (UG/L AS CD) (01027)
03298135	03-19-96	1005	.3	0.386	1.43	.47	.27	.06	<5.	98.	<.5	<2.
03298135	03-19-96	0955	.26	0.335	1.3	.53	.28	.05	7.	103.	<.5	<2.
03298135	11-25-96	1055	.12	0.155	--	.12	--	.02	<5.	68.	<.5	<2.
03298135	11-25-96	1100	.25	0.322	--	.13	--	.03	<5.	63.	<.5	<2.
03298140	01-22-97	1500	.89	1.146	--	.65	--	.46	<5.	80.	1.	<2.
03298140	01-22-97	1505	.88	1.133	--	.59	--	.45	<5.	79.	<.5	<2.
03298150	03-19-96	1145	--	--	--	--	--	--	<5.	72.	<.5	<2.
03298150	03-19-96	1150	.31	.399	1.56	.47	.27	.12	<5.	72.	<.5	<2.
03298150	10-18-96	0830	.09	0.116	--	.48	--	.37	5.	47.	<.5	<2.
03298150	10-18-96	0835	.08	0.103	--	.48	--	.37	<5.	46.	<.5	<2.
03298150	01-22-97	1335	.55	0.708	--	.5	--	.2	<5.	101.	1.	<2.
03298150	01-22-97	1340	.51	0.657	--	.36	--	.23	<5.	103.	1.	<2.
03298150	01-22-97	1530	.54	0.695	--	.43	--	.27	<5.	83.	<.5	<2.
03298150	01-22-97	1535	.54	0.695	--	.5	--	.26	<5.	85.	<.5	<2.

Appendix 2. Results of analyses of paired water samples collected by use of automatic samplers and manual, cross-sectionally integrated sampling, Chenoweth Run Basin, Jefferson County, Kentucky—*Continued*

STATION NUMBER	DATE	TIME	CHRO-MIUM, TOTAL RECOV-ERABLE (UG/L AS CR) (01034)	COPPER, TOTAL RECOV-ERABLE (UG/L AS CU) (01042)	IRON, TOTAL RECOV-ERABLE (UG/L AS FE) (01045)	LEAD, TOTAL RECOV-ERABLE (UG/L AS PB) (01051)	MERCURY TOTAL RECOV-ERABLE (UG/L AS HG) (71900)	NICKEL, TOTAL RECOV-ERABLE (UG/L AS NI) (01067)	SELE-NIUM, TOTAL (UG/L AS SE) (01147)	SILVER, TOTAL RECOV-ERABLE (UG/L AS AG) (01077)	ZINC, TOTAL RECOV-ERABLE (UG/L AS ZN) (01092)
03298135	03-19-96	1005	<3.	11.	11100.	<20.	.3	8.	<5.	<6.	75.
03298135	03-19-96	0955	10.	11.	10500.	20.	<.2	8.	<5.	<6.	67.
03298135	11-25-96	1055	<3.	3.	2080.	<20.	.1	<5.	<5.	<6.	37.
03298135	11-25-96	1100	<3.	4.	1800.	<20.	.1	<5.	<5.	<6.	29.
03298140	01-22-97	1500	<3.	8.	7020.	<20.	.1	8.	<5.	<6.	43.
03298140	01-22-97	1505	<3.	13.	6130.	24.	.1	<5.	<5.	<6.	41.
03298150	03-19-96	1145	<3.	8.	7100.	<20.	.7	<5.	<5.	<6.	43.
03298150	03-19-96	1150	7.	10.	6890.	20.	<.2	9.	<5.	<6.	41.
03298150	10-18-96	0830	15.	6.	3500.	<20.	.2	9.	<5.	<6.	25.
03298150	10-18-96	0835	<3.	4.	3300.	<20.	<.2	5.	<5.	<6.	24.
03298150	01-22-97	1335	<3.	13.	11200.	21.	.1	8.	<5.	<6.	50.
03298150	01-22-97	1340	<3.	16.	11800.	<20.	.2	9.	<5.	<6.	53.
03298150	01-22-97	1530	<3.	9.	7510.	<20.	.1	6.	<5.	<6.	44.
03298150	01-22-97	1535	<3.	11.	8100.	20.	.1	8.	<5.	<6.	37.

STATION NUMBER	DATE	TIME	SEDI-MENT. SUS-PENDED (MG/L) (80154)	SED. SUSP. SIEVE DIAM. %FINER THAN .062MM (70331)
03298135	03-19-96	1005	390	99.6
03298135	03-19-96	0955	--	--
03298135	11-25-96	1055	--	--
03298135	11-25-96	1100	--	--
03298140	01-22-97	1500	--	--
03298140	01-22-97	1505	--	--
03298150	03-19-96	1145	--	--
03298150	03-19-96	1150	--	--
03298150	10-18-96	0830	--	--
03298150	10-18-96	0835	--	--
03298150	01-22-97	1335	--	--
03298150	01-22-97	1340	--	--
03298150	01-22-97	1530	--	--
03298150	01-22-97	1535	--	--

Appendix 3. Arc Macro Language (AML) program for definition of hydrologic response units (HRU's), **hru.aml**

```
/*  PURPOSE: Develop model HRU's

/*  Continuous grids of slope, soils, and land-use are simplified as
/*  defined by remap tables (xxxx.rmp). The reclassed grids are then
/*  combined with the subbasin grid. This combined grid is used to extract
/*  the unique combination of slope, soils and land-use type by subbasin that
/*  is written to an ascii, comma-delimited file

/*  WRITTEN: P. Zarriello 7/1998


/* INPUT GRIDS Required (xxx_ig)
&sv slp_ig = slope7fm_grd           /* smoothed slope grid 7x7 cell focalmedian
&sv soil_ig = soils_grd             /* soils grid
&sv lulc_ig = lulc_grd              /* lulc grid
&sv sub_ig = subbas_grd             /* subbasin grid
&sv lk_ig = lkda_grd                /* drainage area to ponds

/*  OUTPUT GRIDS created (xxx_og)
&sv slp_og = rc_slopeg              /* reclassed slope grid
&sv soil_og = rc_soilg              /* reclassed soils grid
&sv lulc_og = rc_lulcg              /* reclassed land use grid
&sv HRU_og = HRU_grd                /* combined reclassed slope, soils, & lulc
&sv outf = HRU.dat                  /* ASCII output file of HRU's by subbasin
&sv outf2 = HRU_sum.dat             /* ASCII output file summarizing HRU's

/* &echo &on

&s .grd_char = %slp_ig%     /* set cell characteristics to an existing grid

/* Check that required input grids exist
  &if [exist %slp_ig% -grid] = .FALSE. &then &do
    &type %slp_ig% does not exist
    &stop
  &end
  &if [exist %soil_ig% -grid] = .FALSE. &then &do
    &type %soil_ig% does not exist
    &stop
  &end
  &if [exist %lulc_ig% -grid] = .FALSE. &then &do
    &type %lulc_ig% does not exist
    &stop
  &end
  &if [exist %sub_ig% -grid] = .FALSE. &then &do
    &type %sub_ig% does not exist
    &stop
  &end
  &if [exist %lk_ig% -grid] = .FALSE. &then &do
    &type %lk_ig% does not exist
    &stop
  &end

  &type 'Required input grids exist..... processing'

/* Check for and delete output grids
  &if [exist %slp_og% -grid] = .TRUE. &then &do
    kill %slp_og% all
  &end
  &if [exist %soil_og% -grid] = .TRUE. &then &do
    kill %soil_og% all
  &end
  &if [exist %lulc_og% -grid] = .TRUE. &then &do
    kill %lulc_og% all
```

```
  &end
  &if [exist %HRU_og% -grid] = .TRUE. &then &do
    kill %HRU_og% all
  &end


display 9999 position 40 40 size 600 820

/* ---------------------------------------------------------------------------
/* Grid processing
/* -----------------

GRID
  mape %.grd_char%
  setcell %.grd_char%
  setwindow %.grd_char% %.grd_char%

/* get cell size from .grd_char
  &describe %.grd_char%
  &sv cellX = %GRD$dx%
  &sv cellY = %GRD$dy%

  &sv a_mult = %cellX% * %cellY% * 0.0002471    /*  ac/m^2


/* reclass grids into user defined groups by ASCII remap tables (xxxxx.rmp)
/*  NOTE: A item in the GRID can be used, other than value, by specifying the item
/*        after the grid (e.g. reclass{in_grid.item, rmp_file)
  &type 'Reclassing SLOPE grid'
  %slp_og% = reclass(%slp_ig%, slope2.rmp)
  &type 'Reclassing SOILS grid'
  %soil_og% = reclass(%soil_ig%.code, soil3.rmp)
  &type 'Reclassing LULC grid'
  %lulc_og% = reclass(%lulc_ig%.lulc_code, lulc.rmp)

/* combine reclassed grids with subbasins and pond drainage areas
  &type 'Combining reclassed SLOPE, SOIL, & LULC GRIDS with SUBBASIN & LKDA GRID'
  %HRU_og% = combine(%sub_ig%, %lk_ig%, %slp_og%, %soil_og%, %lulc_og%)

quit


/* ----------------------------------------------------------------------------
/* Arc processing
/* ----------------
/* additem to combined grid to get area in acres

additem %HRU_og%.vat %HRU_og%.vat acres 7 7 n 2
&type 'Added item ACRES to %HRU_og%.vat'


/* calculate area in acres and cleanup old output info files
TABLES
  sel %HRU_og%.vat
  calc acres = count * %a_mult%
  &if [exist HRU.TAB -info] = .TRUE. &then kill HRU.TAB
  &if [exist HRU.SUM -info] = .TRUE. &then kill HRU.SUM
quit
&type 'Calculated area in acres'

/* delete the case item if it exist
  &if [iteminfo %HRU_og% -vat table# -exist] = .TRUE. &then &do
    dropitem  %HRU_og%.vat  %HRU_og%.vat table#
  &end
```

```
/* summarize unique combination of slope, soils, & lulc by subbasin
  &DATA arc frequency %HRU_og%.vat hru.tab table#
    %sub_ig%
    %lk_ig%
    %slp_og%
    %soil_og%
    %lulc_og%
    END
    ACRES
    END
  &END
  &type 'Frequencies by subbasin computed'

/* -----------------------------------------------------------------------------
/* produce output report to an ASCII file
/* -------------------------------------------

/*  &if [exist %outf% -file] = .TRUE. &then &do
/*    &sys mv  %outf% %outf%_old
/*  &end


  &DATA arc TABLES
    sel hru.tab
    unload %outf% %sub_ig% %lk_ig% %slp_og% %soil_og% %lulc_og% acres delimited init
    statistics %sub_ig% hru.sum
    sum acres
    end
    sel hru.sum
    unload %outf2%  %sub_ig% sum-acres delimited init
    kill hru.sum
    Quit
  &END
&type '----------------------------------------
&type 'Output HRU data written to:  ' %outf%
&type 'Summary of HRU's written to:' %outf2%
&type '----------------------------------------

&type DONE

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REMAP TABLES
++++++++++++++++++++++++++++++++++++++++++

# remap table for slope
0.00 5.00 : 1      #0 to 5 %
5.00 1000. : 2     #> 5%

+++++++++++++++++++++++++++++++++++++++++++

# remap table for soils
 1 : 2    #CaA
 2 : 3    #AsB
 3 : 2    #CnD
 4 : 2    #CnE
 5 : 2    #CrE3
 6 : 2    #CmC3
 7 : 1    #RuA
 8 : 3    #EkA
 9 : 1    #Ta
10 : 2    #CsC
11 : 1    #WmC2
12 : 2    #CsD2
13 : 3    #EkB
14 : 3    #AsA
```

```
15 : 1    #BeB3
16 : 2    #Ma
17 : 2    #CdB2
18 : 1    #WmB
19 : 2    #CaB
20 : 1    #DcA
21 : 2    #Rd
22 : 3    #FaF
23 : 1    #OcD3
24 : 3    #FaE
25 : 2    #CsC3
26 : 1    #Gn
27 : 3    #FaD
28 : 1    #WA
29 : 3    #Ne
30 : 1    #Gu
31 : 1    #RuC2
32 : 1    #BaB
33 : 2    #CsA
34 : 1    #Ld
35 : 3    #FaE3
36 : 2    #CrD3
37 : 1    #BaD2
38 : 2    #CrC3
39 : 1    #BaB2
40 : 1    #Lb
41 : 1    #RuB2
42 : 3    #Hs
43 : 2    #CsB2
44 : 1    #DcB
45 : 2    #CsC2
46 : 3    #FaD3
47 : 1    #BeD3
48 : 1    #BaC2
49 : 1    #RuB
50 : 1    #BeC3
51 : 2    #CsB

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# remap table for lulc
10 : 1     #Pasture/Crop
11 : 2     #Forest
12 : 3     #Dist residential
13 : 4     #Dist Comm/indust/Mfam
14 : 5     #Open residential
15 : 5     #Open comm/indust/Mfam
16 : 6     #Open other
21 : 7     #Roads-comm/indust/Mfam
23 : 7     #Buildings-comm/indust/Mfam
24 : 7     #Parking-comm/indsut/Mfam
25 : 7     #Roads-residential
26 : 7     #Buildings-residential
27 : 7     #Parking-residential

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
OUTPUT FILES - Note the head line has to be added manually

SUMMARY FILE - hru_sum.dat
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14,756.220000
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40,318.090000
41,241.840000

++++++++++++++++++++++++++++++++++++++++++++++++++++
 COMPLETE LISTING - hru.dat  (header added manually)
+++++++++++++++++++++++++++++++++++++++++++++++++++++
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11,2,2,3,7,7.870000

Truncated to listing of the first subbasin.
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Appendix 4. Statistical summary of constituent concentrations and water-quality characteristics measured at selected locations in the Chenoweth Run Basin, Jefferson County, Kentucky, 1991–97

Station number	Station name	Period analyzed	N	Mean	Minimum	Value at indicated percentile 5	25	50	75	95	Maximum
					Discharge, in cubic feet per second [00061]						
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	17	29.901	0.130	0.130	0.815	1.690	15.000	330.000	330.000
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	35	66.293	0.830	0.846	11.600	18.600	98.000	345.800	393.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	13	4.278	0.890	0.890	3.540	3.920	4.760	7.550	7.550
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	16	30.194	4.020	4.020	4.892	9.215	28.550	211.000	211.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	15	40.625	3.580	3.580	6.110	11.100	40.900	252.000	252.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	100	54.729	1.670	2.595	6.800	16.050	39.650	270.200	739.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	17	48.400	1.810	1.810	5.610	9.910	53.500	331.000	331.000
					Specific conductance, in microsiemens per centimeter at 25 degrees Celsius [00095]						
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	17	667.941	168.000	168.000	534.000	660.000	780.000	1211.000	1211.000
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	35	438.143	142.000	158.000	299.000	389.000	600.000	870.000	942.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	15	875.533	572.000	572.000	718.000	752.000	1140.000	1220.000	1220.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	27	690.704	187.000	188.600	500.000	699.000	811.000	1132.800	1138.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	14	719.000	310.000	310.000	525.750	717.000	914.000	1100.000	1100.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	99	544.856	162.000	255.000	441.000	573.000	662.000	758.300	850.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	33	552.151	129.000	178.700	368.000	472.000	730.000	1089.500	1135.000
					pH, in standard units [00400]						
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	19	7.316	6.200	6.200	6.600	7.600	7.900	8.200	8.200
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	35	7.634	7.180	7.204	7.500	7.690	7.760	7.920	8.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	16	7.387	6.500	6.500	6.800	7.350	7.675	8.800	8.800
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	21	7.476	6.600	6.620	7.000	7.400	7.800	9.100	9.200
03298145	Chenoweth Run at Easum Road	01/95-01/96	15	7.940	6.500	6.500	7.400	7.900	8.600	8.800	8.800
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	99	7.939	6.300	6.900	7.580	8.000	8.400	8.800	9.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	2	--	8.700	--	--	--	--	--	8.900
					pH, laboratory, in standard units [00403]						
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	15	7.987	7.600	7.600	7.900	8.000	8.100	8.300	8.300
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	25	7.692	7.000	7.030	7.450	7.700	8.000	8.240	8.300
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	15	7.580	7.200	7.200	7.400	7.500	7.800	8.100	8.100
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	32	7.806	6.300	7.015	7.725	7.850	8.000	8.270	8.400
03298145	Chenoweth Run at Easum Road	01/95-01/96	15	8.487	7.700	7.700	8.200	8.500	8.800	9.000	9.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	94	8.036	6.500	6.900	7.800	8.100	8.400	8.800	9.400
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	37	8.049	6.600	7.050	7.750	7.900	8.600	9.250	10.600

Appendix 4. Statistical summary of constituent concentrations and water-quality characteristics measured at selected locations in the Chenoweth Run Basin, Jefferson County, Kentucky, 1991–97—*Continued*

Station number	Station name	Period analyzed	N	Mean	Minimum	Value at indicated percentile 5	25	50	75	95	Maximum
Water temperature, in degrees Celsius [00010]											
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	19	13.479	1.000	1.000	5.000	14.600	21.000	22.000	22.000
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	35	13.059	3.500	3.988	6.010	11.310	19.620	24.542	25.230
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	15	16.413	5.000	5.000	11.500	17.200	22.500	25.500	25.500
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	20	16.540	5.000	5.050	9.000	16.900	22.875	25.495	25.500
03298145	Chenoweth Run at Easum Road	01/95-01/96	15	13.647	3.000	3.000	4.000	16.000	23.000	25.500	25.500
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	99	13.859	2.400	3.200	6.800	15.000	19.800	25.000	29.300
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	21	16.162	0.500	0.700	5.250	19.000	23.700	25.950	26.000
Dissolved oxygen, in mg/L [00300]											
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	19	10.042	6.000	6.000	7.700	9.100	12.300	14.200	14.200
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	35	9.705	6.770	6.794	8.020	9.410	11.440	12.672	13.800
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	15	7.653	4.000	4.000	7.100	8.000	8.500	9.900	9.900
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	20	10.235	7.400	7.410	8.225	9.000	12.225	14.195	14.200
03298145	Chenoweth Run at Easum Road	01/95-01/96	14	12.457	7.700	7.700	9.600	12.450	14.500	20.000	20.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	96	11.494	6.270	7.371	10.125	11.200	12.923	16.215	17.500
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	18	13.044	8.200	8.200	10.075	12.350	14.925	23.900	23.900
Dissolved oxygen, in percent of saturation [00301]											
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	68	116.441	84.000	90.000	100.000	113.500	124.000	163.750	189.000
Biochemical oxygen demand, 5-day at 20 degrees Celsius, in mg/L [00310]											
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	17	1.985*	--	*0.392	*0.989	*1.500	*3.500	*5.000	5.000
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	25	4.346*	--	*1.132	*2.500	*4.000	*6.000	*9.700	10.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	16	4.575*	--	*1.000	*1.925	*3.000	*8.000	*10.000	10.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	35	5.037	1.000	1.080	2.000	4.000	6.000	13.800	17.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	15	2.488*	--	*1.000	*1.213	*2.000	*4.000	*6.000	6.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	94	3.388*	--	*0.897	*2.000	*2.000	*4.000	*10.000	13.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	39	4.722*	--	*0.852	*2.000	*4.000	*7.000	*12.000	12.000
Chemical oxygen demand, 0.25N dicromate, in mg/L [00340]											
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	25	27.280	7.000	7.300	15.000	20.000	30.500	98.000	110.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	18	25.667	1.000	1.000	18.750	23.500	32.250	63.000	63.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	93	20.106*	--	*7.708	*14.000	*18.000	*23.500	*43.200	55.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	22	35.455	14.000	14.150	18.000	31.000	41.750	95.850	99.000

Appendix 4. Statistical summary of constituent concentrations and water-quality characteristics measured at selected locations in the Chenoweth Run Basin, Jefferson County, Kentucky, 1991–97—*Continued*

Station number	Station name	Period analyzed	N	Mean	Minimum	Value at indicated percentile 5	25	50	75	95	Maximum
					Fecal coliform, membrane filter, M-FC agar, in colonies/100 [31613]						
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	15	1681.004*	--	*2.057	*53.000	*410.000	*1560.000	*7500.000	7500.000
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	14	3931.572	2.000	2.000	432.500	650.000	7075.000	18500.000	18500.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	14	771.860*	--	*1.015	*8.255	*189.500	*1395.000	*3300.000	3300.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	27	2988.667	1.000	3.800	260.000	700.000	4600.000	14400.001	15000.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	14	919.568*	--	*4.949	*73.250	*300.000	*590.000	*7500.000	7500.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	82	2286.902	3.000	23.300	109.500	345.000	2425.000	14119.989	38400.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	22	2623.191*	--	*1.232	*70.000	*645.000	*4650.000	*14014.502	15000.000
					Fecal streptococci, membrane filter, KF agar, in colonies/100 [31673]						
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	14	12592.786	12.000	12.000	78.750	960.000	19125.000	100000.000	100000.000
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	13	17139.309	371.000	371.000	1780.000	9800.000	26000.000	65500.000	65500.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	13	1459.462	10.000	10.000	51.000	200.000	1150.000	12700.000	12700.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	25	15844.880	12.000	19.200	172.500	7800.000	23050.000	66400.008	70000.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	13	9262.308	23.000	23.000	38.000	600.000	17050.000	60000.000	60000.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	80	5218.800	8.000	20.100	67.000	500.000	3650.000	41329.996	60000.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	20	8214.150	10.000	10.000	103.000	417.000	12200.000	49000.016	50000.000
					Hardness, total, in mg/L as CaC03 [00900]						
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	4	--	191.000	--	--	--	--	--	292.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	1	--	--	--	--	--	--	--	173.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	4	--	188.000	--	--	--	--	--	209.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	24	196.901	125.600	126.287	149.233	197.235	241.410	284.365	292.320
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	4	--	174.000	--	--	--	--	--	230.000
					Calcium, total, in mg/L as Ca [00916]						
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	1	--	--	--	--	--	--	--	74.500
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	45.318	20.900	20.900	27.750	38.400	64.750	74.000	74.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	1	--	--	--	--	--	--	--	49.700
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	18	44.322	21.800	21.800	31.425	39.800	58.700	89.000	89.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	1	--	--	--	--	--	--	--	55.500
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	44	55.698	29.200	29.625	40.525	53.200	61.975	105.000	179.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	23	48.832	25.800	26.140	40.100	46.100	58.200	70.660	71.400

Appendix 4. Statistical summary of constituent concentrations and water-quality characteristics measured at selected locations in the Chenoweth Run Basin, Jefferson County, Kentucky, 1991–97—*Continued*

Station number	Station name	Period analyzed	N	Mean	Minimum	Value at indicated percentile 5	25	50	75	95	Maximum
				Magnesium, total, in mg/L as Mg [00927]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	1	--	--	--	--	--	--	--	31.400
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	22.170	6.830	6.830	9.615	13.900	28.650	93.000	93.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	1	--	--	--	--	--	--	--	17.500
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	18	15.234	8.050	8.050	10.363	13.750	19.650	30.700	30.700
03298145	Chenoweth Run at Easum Road	01/95-01/96	1	--	--	--	--	--	--	--	21.700
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	44	18.677	9.350	9.680	13.950	18.000	23.375	26.300	36.500
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	23	15.918	7.620	7.818	13.670	16.800	18.000	23.240	23.600
				Alkalinity, carbonate, in mg/L as CaC03 [00430]							
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	14	135.000	46.000	46.000	70.500	114.000	213.000	236.000	236.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	11	94.455	7.000	7.000	51.000	92.000	155.000	182.000	182.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	90	158.167	53.000	81.900	120.750	156.500	198.000	221.700	237.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	10	128.200	90.000	90.000	107.000	130.000	147.500	162.000	162.000
				Chloride, dissolved, in mg/L as Cl [00940]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	4	--	25.900	--	--	--	--	--	46.700
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	16	33.881	6.000	6.000	16.350	29.500	45.500	101.000	101.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	1	--	--	--	--	--	--	--	88.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	19	52.589	1.700	1.700	9.200	43.000	67.600	160.000	160.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	20	34.980	8.600	8.670	16.000	20.900	55.575	95.900	96.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	18	30.889	3.000	3.000	15.250	22.500	54.350	79.200	79.200
				Dissolved solids, residue at 105 degrees Celsius, in mg/L [00515]							
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	10	276.000	78.000	78.000	157.000	227.000	418.000	500.000	500.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	11	376.727	132.000	132.000	210.000	280.000	500.000	1050.000	1050.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	89	386.084	140.000	194.000	338.000	378.000	452.000	530.500	1240.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	14	242.929	45.000	45.000	156.000	215.000	322.500	528.000	528.000
				Suspended solids, residue at 105 degrees Celsius, in mg/L [00530]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	19	47.053	1.000	1.000	5.000	9.000	36.000	444.000	444.000
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	25	213.800	3.000	3.300	10.500	63.000	382.000	878.400	984.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	16	6.688	1.000	1.000	2.500	6.500	8.750	18.000	18.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	37	196.784	1.000	1.900	6.000	46.000	239.000	1109.000	1370.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	15	37.333	1.000	1.000	4.000	6.000	53.000	230.000	230.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	94	127.559	1.000	1.875	4.000	8.000	39.750	813.000	2720.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	41	296.902	1.000	2.000	5.500	88.000	424.000	1646.001	1820.000

Appendix 4. Statistical summary of constituent concentrations and water-quality characteristics measured at selected locations in the Chenoweth Run Basin, Jefferson County, Kentucky, 1991–97—*Continued*

Station number	Station name	Period analyzed	N	Mean	Minimum	Value at indicated percentile 5	25	50	75	95	Maximum
				Suspended solids, nonvolatile on ignition, in mg/L [00540]							
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	10	147.800	2.000	2.000	17.250	85.000	283.500	534.000	534.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	11	293.727	3.000	3.000	12.000	82.000	694.000	1010.000	1010.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	83	61.614	1.000	1.000	2.000	4.000	19.000	291.200	1120.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	14	424.357	2.000	2.000	61.250	121.000	790.000	1660.000	1660.000
				Residue, volatile nonfilterable, in mg/L [00535]							
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	10	87.800	2.000	2.000	16.000	33.000	167.000	290.000	290.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	11	31.273	2.000	2.000	2.000	20.000	60.000	74.000	74.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	90	39.188	0.100	0.500	2.000	3.000	13.500	236.800	880.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	14	115.286	2.000	2.000	9.500	62.500	186.000	378.000	378.000
				Nitrogen, nitrate, total, in mg/L as N [00620]							
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	4	--	0.770	--	--	--	--	--	2.400
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	10	2.890	1.200	1.200	1.475	2.700	4.225	5.200	5.200
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	79	3.765	0.140	0.640	2.000	3.200	4.800	9.800	12.400
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	9	2.589	1.200	1.200	1.700	2.400	3.300	4.700	4.700
				Nitrogen, nitrite, total, in mg/L as N [00615]							
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	9	0.071	0.010	0.010	0.020	0.040	0.130	0.230	0.230
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	10	0.147	0.002	0.002	0.005	0.065	0.245	0.500	0.500
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	86	0.109	0.010	0.013	0.040	0.070	0.172	0.340	0.420
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	9	0.492	0.009	0.009	0.120	0.330	1.050	1.200	1.200
				Nitrogen, nitrite + nitrate, total, in mg/L as N [00630]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	18	1.021	0.260	0.260	0.653	1.130	1.325	1.700	1.700
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	20	1.493	0.580	0.587	0.875	1.550	1.875	2.617	2.630
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	15	9.452	0.880	0.880	4.600	9.600	13.000	19.000	19.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	36	5.216	1.200	1.200	2.075	4.135	7.800	13.640	15.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	15	5.040	1.100	1.100	2.800	3.500	6.700	14.000	14.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	85	3.889	0.310	0.909	2.010	3.270	4.660	10.512	13.800
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	36	4.074	0.940	1.229	1.900	2.950	4.852	12.575	13.000

Appendix 4. Statistical summary of constituent concentrations and water-quality characteristics measured at selected locations in the Chenoweth Run Basin, Jefferson County, Kentucky, 1991–97—*Continued*

Station number	Station name	Period analyzed	N	Mean	Minimum	Value at indicated percentile 5	25	50	75	95	Maximum
				Nitrogen, ammonia, total, in mg/L as N [00610]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	19	0.077	0.020	0.020	0.040	0.050	0.070	0.240	0.240
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	25	0.246	0.027	0.031	0.055	0.160	0.255	1.672	2.200
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	16	0.449	0.030	0.030	0.065	0.195	0.842	1.700	1.700
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	37	0.343	0.020	0.020	0.100	0.250	0.530	0.972	1.800
03298145	Chenoweth Run at Easum Road	01/95-01/96	15	0.161	0.010	0.010	0.040	0.100	0.260	0.600	0.600
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	93	0.167	0.010	0.020	0.070	0.100	0.200	0.489	0.760
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	41	0.153	0.010	0.021	0.075	0.110	0.200	0.605	0.690
				Nitrogen, ammonia, total, in mg/L as NH4 [71845]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	19	0.099	0.030	0.030	0.050	0.060	0.090	0.310	0.310
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	25	0.314	0.030	0.036	0.070	0.210	0.325	2.131	2.800
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	16	0.584	0.040	0.040	0.085	0.250	1.115	2.200	2.200
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	37	0.440	0.030	0.030	0.130	0.320	0.680	1.220	2.300
03298145	Chenoweth Run at Easum Road	01/95-01/96	15	0.207	0.010	0.010	0.050	0.130	0.330	0.770	0.770
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	93	0.216	0.010	0.030	0.090	0.130	0.255	0.632	0.980
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	41	0.197	0.010	0.031	0.095	0.140	0.260	0.775	0.890
				Nitrogen, organic, dissolved, in mg/L as N [00605]							
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	10	1.119	0.120	0.120	0.428	1.135	1.885	2.000	2.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	11	1.279	0.440	0.440	0.800	0.970	1.600	2.500	2.500
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	85	0.912	0.040	0.106	0.400	0.630	0.890	2.610	13.100
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	10	1.703	0.570	0.570	0.660	1.055	2.675	4.700	4.700
				Phosphorus, total, in mg/L as P [00665]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	15	0.103	0.010	0.010	0.020	0.040	0.120	0.360	0.360
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	25	0.176	0.020	0.020	0.045	0.130	0.225	0.544	0.550
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	12	2.430	0.860	0.860	1.500	2.500	3.325	4.000	4.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	34	1.288	0.340	0.340	0.485	0.820	2.050	3.207	3.530
03298145	Chenoweth Run at Easum Road	01/95-01/96	12	1.183	0.310	0.310	0.427	0.625	2.150	2.700	2.700
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	91	1.181	0.140	0.202	0.420	0.760	2.000	3.240	4.800
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	39	0.863	0.060	0.090	0.320	0.490	1.300	2.920	3.400

Appendix 4. Statistical summary of constituent concentrations and water-quality characteristics measured at selected locations in the Chenoweth Run Basin, Jefferson County, Kentucky, 1991–97—*Continued*

Station number	Station name	Period analyzed	N	Mean	Minimum	Value at indicated percentile 5	25	50	75	95	Maximum
				Phosphate, total, in mg/L as P04 [00650]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	3	--	0.020	--	--	--	--	--	0.020
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	10	0.230	0.010	0.010	0.030	0.105	0.438	0.860	0.860
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	1	--	--	--	--	--	--	--	7.970
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	14	3.211	0.460	0.460	0.798	2.745	5.905	7.360	7.360
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	85	2.753	0.370	0.499	1.040	1.990	4.600	6.440	8.340
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	18	2.174	0.180	0.180	0.800	1.150	3.750	6.130	6.130
				Phosphorus, dissolved, in mg/L as P [00666]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	10	0.041	0.010	0.010	0.020	0.035	0.060	0.100	0.100
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	20	0.042*	--	*0.008	*0.014	*0.030	*0.060	*0.156	0.160
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	9	2.556	1.200	1.200	1.500	2.600	3.700	3.800	3.800
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	26	0.917	0.030	0.034	0.183	0.420	1.325	3.715	4.100
03298145	Chenoweth Run at Easum Road	01/95-01/96	10	1.132	0.120	0.120	0.268	0.990	2.025	2.600	2.600
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	19	0.441	0.070	0.070	0.170	0.260	0.580	1.900	1.900
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	28	0.497	0.020	0.029	0.080	0.175	0.673	2.055	2.100
				Phosphorus, orthophosphate, total, in mg/L as P [70507]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	3	--	0.005	--	--	--	--	--	0.006
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	10	0.075	0.004	0.004	0.010	0.035	0.142	0.280	0.280
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	1	--	--	--	--	--	--	--	2.600
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	14	1.047	0.150	0.150	0.260	0.895	1.925	2.400	2.400
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	85	0.898	0.120	0.163	0.340	0.650	1.500	2.100	2.720
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	18	0.709	0.060	0.060	0.260	0.375	1.223	2.000	2.000
				Arsenic, total, in ug/L as As [01002]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	2	--	--	--	--	--	--	--	--
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	--	--	--	--	--	--	--	--
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	2	--	--	--	--	--	--	--	--
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	19	6.246*	--	*1.298	*2.603	*4.430	*10.000	*16.000	16.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	2	--	--	--	--	--	--	--	--
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	44	3.798*	--	*0.120	*0.519	*1.434	*3.941	*24.000	31.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	23	7.678*	--	*2.433	*4.459	*6.372	*11.000	*18.200	19.000

Appendix 4. Statistical summary of constituent concentrations and water-quality characteristics measured at selected locations in the Chenoweth Run Basin, Jefferson County, Kentucky, 1991–97—*Continued*

Station number	Station name	Period analyzed	N	Mean	Minimum	Value at indicated percentile 5	25	50	75	95	Maximum
				Barium, total, in ug/L as Ba [01007]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	2	--	78.000	--	--	--	--	--	79.000
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	74.529	41.000	41.000	64.000	70.000	93.000	110.000	110.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	2	--	26.000	--	--	--	--	--	64.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	19	88.211	35.000	35.000	43.000	71.000	129.000	231.000	231.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	2	--	47.000	--	--	--	--	--	59.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	44	76.568	26.000	26.750	36.000	42.000	83.500	324.750	568.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	24	89.167	40.000	40.000	43.750	67.500	119.750	225.500	234.000
				Beryllium, total, in ug/L as Be [01012]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	1	--	--	--	--	--	--	--	--
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	--	--	--	--	--	--	--	--
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	1	--	--	--	--	--	--	--	--
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	18	--	--	--	--	--	--	--	--
03298145	Chenoweth Run at Easum Road	01/95-01/96	1	--	--	--	--	--	--	--	1.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	44	0.244*	--	*0.003	*0.016	*0.056	*0.192	*1.000	4.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	23	1.000*	--	*1.000	*1.000	*1.000	*1.000	*1.000	1.000
				Cadmium, total, in ug/L as Cd [01027]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	2	--	--	--	--	--	--	--	--
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	--	--	--	--	--	--	--	--
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	2	--	--	--	--	--	--	--	--
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	19	--	--	--	--	--	--	--	--
03298145	Chenoweth Run at Easum Road	01/95-01/96	2	--	--	--	--	--	--	--	--
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	44	--	--	--	--	--	--	--	--
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	24	--	--	--	--	--	--	--	--
				Chromium, total, in ug/L as Cr [01034]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	2	--	--	--	--	--	--	--	--
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	2.354*	--	*0.205	*0.608	*1.334	*3.500	*10.000	10.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	2	--	--	--	--	--	--	--	--
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	19	--	--	--	--	--	--	--	--
03298145	Chenoweth Run at Easum Road	01/95-01/96	2	--	--	--	--	--	--	--	--
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	44	4.681*	--	*0.007	*0.072	*0.315	*1.615	*45.750	82.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	24	1.571*	--	*0.029	*0.158	*0.485	*1.442	*12.250	15.000

Appendix 4. Statistical summary of constituent concentrations and water-quality characteristics measured at selected locations in the Chenoweth Run Basin, Jefferson County, Kentucky, 1991–97—*Continued*

Station number	Station name	Period analyzed	N	Mean	Minimum	Value at indicated percentile 5	25	50	75	95	Maximum
				Copper, total recoverable, in ug/L as Cu [01042]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	2	--	--	--	--	--	--	--	--
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	7.183*	--	*1.269	*2.556	*7.000	*11.500	*14.000	14.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	2	--	8.000	--	--	--	--	--	17.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	19	16.158	7.000	7.000	13.000	15.000	21.000	30.000	30.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	2	--	7.000	--	--	--	--	--	11.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	44	11.896*	--	*3.920	*4.360	*8.000	*15.000	*42.250	73.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	24	15.083	5.000	5.500	8.250	10.500	18.750	39.000	41.000
				Iron, total, in ug/L as Fe [01045]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	2	--	249.000	--	--	--	--	--	10300.000
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	5325.647	94.000	94.000	864.000	2250.000	9665.000	16700.000	16700.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	2	--	47.000	--	--	--	--	--	257.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	19	9669.685	90.000	90.000	312.000	6130.000	20400.000	25000.000	25000.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	2	--	128.000	--	--	--	--	--	6940.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	44	4722.227	68.000	78.750	122.750	424.500	7797.500	22500.000	24600.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	24	11755.708	75.000	75.000	3925.000	7805.000	15575.000	41925.000	43100.000
				Lead, total, in ug/L as Pb [01051]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	1	--	--	--	--	--	--	--	23.000
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	--	--	--	--	--	--	--	--
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	1	--	--	--	--	--	--	--	3.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	18	23.792*	--	*10.753	*15.898	*20.000	*31.750	*40.000	40.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	1	--	--	--	--	--	--	--	13.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	44	14.477*	--	*2.611	*5.537	*9.780	*17.520	*45.000	90.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	23	18.972*	--	*2.754	*7.113	*12.471	*20.000	*58.400	60.000
				Mercury, total recoverable, in ug/L as Hg [71900]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	2	--	--	--	--	--	--	--	--
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	0.109*	--	*0.081	*0.099	*0.100	*0.114	*0.200	0.200
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	2	--	--	--	--	--	--	--	--
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	19	0.095*	--	*0.022	*0.040	*0.070	*0.108	*0.300	0.300
03298145	Chenoweth Run at Easum Road	01/95-01/96	2	--	--	--	--	--	--	--	--
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	45	0.147*	--	*0.016	*0.043	*0.083	*0.200	*0.470	1.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	24	0.127*	--	*0.031	*0.056	*0.099	*0.200	*0.300	0.300

Appendix 4. Statistical summary of constituent concentrations and water-quality characteristics measured at selected locations in the Chenoweth Run Basin, Jefferson County, Kentucky, 1991–97—*Continued*

Station number	Station name	Period analyzed	N	Mean	Minimum	Value at indicated percentile 5	25	50	75	95	Maximum
				Nickel, total, in ug/L as Ni [01067]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	2	--	--	--	--	--	--	--	--
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	5.314*	--	*2.004	*3.254	*4.626	*8.000	*11.000	11.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	2	--	--	--	--	--	--	--	--
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	19	8.343*	--	*2.430	*4.592	*6.602	*13.000	*20.000	20.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	2	--	--	--	--	--	--	--	--
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	44	11.078*	--	*1.328	*3.112	*7.530	*9.750	*52.500	70.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	24	8.414*	--	*1.146	*2.958	*6.000	*12.000	*26.750	27.000
				Selenium, total, in ug/L as Se [01147]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	1	--	--	--	--	--	--	--	--
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	--	--	--	--	--	--	--	--
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	1	--	--	--	--	--	--	--	--
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	18	--	--	--	--	--	--	--	--
03298145	Chenoweth Run at Easum Road	01/95-01/96	1	--	--	--	--	--	--	--	--
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	44	--	--	--	--	--	--	--	--
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	23	--	--	--	--	--	--	--	--
				Silver, total, in ug/L as Ag [01077]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	2	--	--	--	--	--	--	--	--
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	--	--	--	--	--	--	--	--
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	2	--	--	--	--	--	--	--	--
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	19	--	--	--	--	--	--	--	--
03298145	Chenoweth Run at Easum Road	01/95-01/96	2	--	--	--	--	--	--	--	--
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	44	--	--	--	--	--	--	--	--
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	24	--	--	--	--	--	--	--	--
				Zinc, total, in ug/L as Zn [01092]							
03298129	Chenoweth Run at Old Watterson Trail	01/95-03/97	2	--	10.000	--	--	--	--	--	50.000
03298135	Chenoweth Run at Ruckriegel Parkway	02/96-09/97	17	49.320*	--	*7.447	*24.500	*39.000	*77.500	*132.000	132.000
03298138	Chenoweth Run at Jeffersontown WWTP	01/95-01/96	2	--	28.000	--	--	--	--	--	63.000
03298140	Chenoweth Run at Taylorsville Road	01/95-09/97	19	67.526	25.000	25.000	34.000	42.000	102.000	148.000	148.000
03298145	Chenoweth Run at Easum Road	01/95-01/96	2	--	29.000	--	--	--	--	--	35.000
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	44	58.500	13.000	18.000	31.000	49.500	63.000	144.500	225.000
03298160	Chenoweth Run at Seatonville Road	01/95-09/97	24	62.250	16.000	16.250	27.250	45.000	95.750	173.000	190.000

Appendix 4. Statistical summary of constituent concentrations and water-quality characteristics measured at selected locations in the Chenoweth Run Basin, Jefferson County, Kentucky, 1991–97—*Continued*

Station number	Station name	Period analyzed	N	Mean	Minimum	Value at indicated percentile 5	25	50	75	95	Maximum
					Cyanide, total, in mg/L as Cn [00720]						
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	19	--	--	--	--	--	--	--	--
					2,4-D, total, in ug/L [39730]						
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	18	0.209*	--	*0.003	*0.008	*0.030	*0.213	*1.800	1.800
					2,4,5-T, total, in ug/L [39740]						
03298150	Chenoweth Run at Gelhaus Lane	01/91-12/97	18	--	--	--	--	--	--	--	--

*Value is estimated by use of a log-probability regression to predict the values of data below the detection limit.

```
***  HSPF model for Chenoweth Run - Louisville, Ky.
***  Modelers: Phil Zarriello, Ithaca N.Y.; Gary Martin, Louisville, Ky.
***  Run Date: 3/2/2000
***
***  References to HSPF manual V10
***
***  NOTE: Three or more asterisks indicate a model comment statement.
***
***  General Conversions
***   ac-ft/hr x 12.1 = mean cfs/sec  (ac-ft * 43560ft/ac * 1/60min/hr *1/60sec/
***   ac-ft/day x 0.50417 = mean cfs/sec
***   mean cfs/hr  x 0.0826446 = ac-ft/hr   (1/43560ac * 60min/hr * 60sec/min)
***   mean cfs/day x 1.9834711 = ac-ft/day
***
***   1 hour simulation:  flow, sediment, and PO4
***
***  Module  Sub-module  Purpose
***  ------  ----------  -----------------------------------
***  PERLND  PWATER      Flow from pervious areas
***          SEDMNT      Sediment generation
***          PQUAL       PO4 yield associated with sediment + overland flow
***  IMPLND  IWATER      Runoff from impervious surfaces
***          SLD         Solids generation
***          IQUAL       Buildup and washoff of PO4 on a surface
***  RCHRES  HYDR        Flow in Channels
***          SEDTRN      Sediment transport in channels
***          RQUAL       River quality
***            OXRX      Simulate DO and BOD
***            NUTRX     Nutrient flux (PO4 only) in channels

RUN

GLOBAL
  Chenoweth Run Watershed - Jeffersontown, KY 2/96 to 1/98 [QUAL run]
  START       1996/02/01 00:00  END    1998/01/31 24:00
  RUN INTERP OUTPUT LEVEL    9
  RESUME    0 RUN      1
END GLOBAL

********************************************************************************
***    FILES Block 4.2   pg 277                                              ***
********************************************************************************
FILES
<FILE>  <UN#>***<----FILE NAME------------------------------------------------->
WDM        20   C:\WRDAPP\GENWORK\ky\chen.wdm
ERROR      25   C:\WRDAPP\GENWORK\ky\qual.err
MESSU      22   C:\WRDAPP\GENWORK\ky\qual.ech
           15   C:\WRDAPP\GENWORK\ky\qual.out
END FILES

********************************************************************************
***  OPN Sequence Block  4.3  pg 279                                         ***
********************************************************************************
OPN SEQUENCE
***                 Select Time step:
*** INGRP             INDELT 00:05
    INGRP             INDELT 01:00
      IMPLND       1
      IMPLND       2

      PERLND       1
      PERLND       2
      PERLND       3
      PERLND       4
      PERLND       5
      PERLND       6
      PERLND       7
      PERLND       8
      PERLND       9
      PERLND      10
      PERLND      11
      PERLND      12
      PERLND      13
      PERLND      14
      PERLND      15
      PERLND      16
      PERLND      17
```

```
*** Process pond RCHRES (lakes/ponds) before channel RCHRES
      RCHRES      15
      RCHRES      16
      RCHRES      17
      RCHRES      18
      RCHRES      19
      RCHRES      20
      RCHRES      21
      RCHRES      22
      RCHRES      23

***   COPY         1

*** Channels
      RCHRES       1
      RCHRES       2
      RCHRES       3
      RCHRES       4
      RCHRES       5
      RCHRES       6
      RCHRES       7
      RCHRES       8
      RCHRES       9
      RCHRES      10
      RCHRES      11
      RCHRES      12
      RCHRES      13
      RCHRES      14

      COPY       100
      COPY       101
      COPY       102
      COPY       105
      COPY       106
      COPY       107
      COPY       108
      COPY       109
***   COPY       110
***   COPY       111

      GENER        1
      GENER        2
      GENER        3
      GENER        4
    END INGRP
END OPN SEQUENCE


*******************************************************************************
***          PERLND - Pervious land surface  Princ  4.2(1).1  pg 38         ***
***                                          Coding 4.4(1)    pg 284        ***
*******************************************************************************

PERLND
  ACTIVITY
    <PLS >          Active Sections (1=Active, 0=Inactive)             ***
  ### -### ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ***
    1   17              1    1    0         1    0              0
  END ACTIVITY

  PRINT-INFO
    <PLS > <-*** Print-flags: 2-PIVL, 3-dy, 4-mn, 5-yr, 6-never  ***-> PIVL  PYR
  ### -### ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ****   **
    1   17              6    5    6         6    6              6         1    1
  END PRINT-INFO
```

```
  GEN-INFO
    <PLS ><-------Name------->NBLKS   Unit-systems   Printer ***
  ###--###                          User  t-series Engl Metr ***
           LULC,Dainage,SLOPE              in  out           ***
    1      Agr, poor <5%         1    1    1    1   15    0
    2      Agr, poor >5%         1    1    1    1   15    0
    3      Agr, mod              1    1    1    1   15    0
    4      Agr, well             1    1    1    1   15    0

    5      Forest, poor, <5%     1    1    1    1   15    0
    6      Forest, poor, >5%     1    1    1    1   15    0
    7      Forest, mod           1    1    1    1   15    0
    8      Forest, well          1    1    1    1   15    0

    9      Open                  1    1    1    1   15    0

   10      Open R/C,poor,<5%     1    1    1    1   15    0
   11      Open R/C,poor,>5%     1    1    1    1   15    0
   12      Open R/C,mod, <5%     1    1    1    1   15    0
   13      Open R/C,mod, >5%     1    1    1    1   15    0
   14      Open R/C,well         1    1    1    1   15    0

   15      Dist R, poor          1    1    1    1   15    0
   16      Dist R, mod           1    1    1    1   15    0

   17      Dist C                1    1    1    1   15    0
  END GEN-INFO

***------------------------------------------------------------------------*
***  PERLND -  Section PWATER   Princ. 4.2(1).3   pg 54                    *
***                             Coding 4.4(1).4   pg 300                   *
***    Water Budget                                                        *
***------------------------------------------------------------------------*

  PWAT-PARM1
***                     1=varies monthly 0=does not
*** <PLS > <PWATER flags><monthly parameter value flags>
***## -### CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE
    1   17    0    0    0    1    1    1    1    1    1
  END PWAT-PARM1

  PWAT-PARM2
    <PLS > ***  PWATER input info: Part 2
  ### -### ***FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
           ***(none)      (in)   (in/hr)      (ft)    (none)    (l/in)    (l/in)
    1             0       5.67     0.037     1200.     0.025      0.45     0.994
    2             0       4.77     0.035      550.     0.075      0.45     0.998
    3             0       7.65     0.097     1200.     0.050      0.45     0.992
    4             0       3.60     0.356      400.     0.050      0.45     0.990

    5             0       5.67     0.037     1200.     0.025      0.45     0.998
    6             0       4.77     0.035      650.     0.075      0.45     0.994
    7             0       7.65     0.097     1200.     0.050      0.45     0.990
    8             0       3.60     0.356      400.     0.050      0.45     0.990

    9             0       5.76     0.073     1200.     0.050      0.45     0.994

   10             0       4.89     0.033     1300.     0.025      0.45     0.995
   11             0       4.38     0.032     1200.     0.075      0.45     0.994
   12             0       5.50     0.079     1200.     0.025      0.45     0.993
   13             0       5.50     0.075      600.     0.075      0.45     0.992
   14             0       3.24     0.152      800.     0.055      0.45     0.991

   15             0       2.30     0.038      200.     0.030      0.45     0.640
   16             0       2.90     0.058      200.     0.030      0.45     0.640
   17             0       2.05     0.028      100.     0.025      0.40     0.400
  END PWAT-PARM2
```

```
  PWAT-PARM3
    <PLS > ***  PWATER input info: Part 3
  ### -### ***PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
    1    4       40.       35.       2.5       2.0      0.00      0.00     0.070
    5    8       40.       35.       2.5       2.0      0.00      0.00     0.100
    9            40.       35.       2.5       2.0      0.00      0.00     0.070
   10   14       40.       35.       2.5       2.0      0.00      0.00     0.040
   15   16       40.       35.       3.0       2.0      0.00      0.00     0.020
   17            40.       35.       3.5       2.0      0.00      0.00     0.010
  END PWAT-PARM3

  PWAT-PARM4
    <PLS >     PWATER input info: Part 4                                  ***
    Flag PARM1   VCS       VUZ       VUR       VMN      VIFW       VLE ***
  ### -###     CEPSC      UZSN      NSUR     INTFW       IRC     LZETP ***
                (in)      (in)    (none)    (none)    (l/da)    (none) ***
    1   17
  END PWAT-PARM4

***  Monthly parameter values for flag set in PWAT-PARM1                  ***
***    Values represent the start of each month and interpolated          ***
***    to the value of the start of the next month                        ***

  MON-INTERCEP
    Monthly interception storage capacity                                 ***
    <PLS>                                                                 ***
  ### -###   Required if VCSFG=1 in PWAT-PARM1                            ***
            JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1    9 0.03 0.03 0.03 0.03 0.05 0.07 0.07 0.07 0.07 0.05 0.04 0.03
   10   14 0.02 0.02 0.02 0.02 0.03 0.05 0.05 0.05 0.05 0.05 0.03 0.03
   15   16 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.03 0.04 0.05 0.03 0.02
   17      0.01 0.01 0.01 0.02 0.02 0.02 0.02 0.02 0.04 0.05 0.03 0.01
  END MON-INTERCEP

  MON-UZSN
    Upper zone nominal storage                                            ***
    UZSN inversely affects peak flow - as UZSN goes up, peaks go down  ***
    <PLS>   Required if VUZFG=1                                           ***
  ### -###  Upper zone storage at start of each month                     ***
            JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1    4  .80  .80  .80  .80  .80  .80  .85  .85  .95  .95  .82  .80
    5    8  .84  .84  .84  .84  .84  .84  .86  .87  .97  .98  .88  .84
    9       .80  .80  .80  .80  .80  .80  .82  .86  .96  .96  .85  .83
   10   14  .82  .82  .82  .82  .82  .83  .84  .86  .97  .98  .90  .82
   15   16  .35  .35  .35  .35  .35  .35  .38  .38  .50  .50  .35  .35
   17       .10  .10  .10  .10  .10  .10  .12  .18  .28  .28  .14  .10
  END MON-UZSN

  MON-MANNING
    Manning's "n" for overland flow                                       ***
    <PLS >  Required if VNNFG=1                                           ***
  ### -###  Manning's n for overland flow at start of each month          ***
            JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1   14 0.25 0.25 0.25 0.25 0.26 0.26 0.26 0.26 0.28 0.28 0.27 0.25
    15  16 0.23 0.23 0.23 0.23 0.24 0.24 0.24 0.24 0.27 0.27 0.25 0.23
    17     0.22 0.22 0.22 0.22 0.22 0.22 0.22 0.22 0.24 0.24 0.23 0.22
  END MON-MANNING

  MON-INTERFLW
*** Monthly interflow  (inc INTFW flattens peak by creating more interflow)
    <PLS >  Required if VIFWFG=1                                          ***
  ### -###  Monthly interflow  at start of each month                     ***
            JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1    9 2.90 2.90 2.90 2.90 2.90 2.90 2.90 2.90 2.90 2.90 2.90 2.90
   10   14 2.80 2.80 2.80 2.80 2.80 2.85 2.85 2.85 2.85 2.85 2.85 2.80
   15   16 1.05 1.05 1.05 1.05 1.05 1.05 1.00 1.10 1.10 1.10 1.10 1.05
   17      0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.75 0.75 0.75 0.70
  END MON-INTERFLW

  MON-IRC
    Monthly interflow recession  (inc IRC dec peak)                       ***
    <PLS >  Required if VIRCFG=1  (max < 1.0)                             ***
  ### -###  Monthly interflow  at start of each month                     ***
            JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1    9 0.45 0.45 0.45 0.45 0.47 0.50 0.53 0.53 0.52 0.49 0.47 0.45
   10   14 0.35 0.35 0.35 0.36 0.40 0.42 0.44 0.45 0.45 0.44 0.43 0.35
   15   16 0.18 0.18 0.18 0.18 0.18 0.18 0.19 0.19 0.19 0.20 0.19 0.18
   17      0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.09 0.09 0.09 0.09 0.08
  END MON-IRC
```

```
  MON-LZETPARM
    Lower zone ET - index of deep-rooted veg density                   ***
    <PLS >  Required if VLEFG=1   (max < 1.0)                          ***
  ### -###  Lower zone ET parameter at start of each month             ***
            JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1       .12  .12  .12  .12  .13  .14  .14  .14  .14  .14  .13  .12
    2       .25  .25  .25  .26  .27  .28  .28  .28  .28  .28  .27  .25
    3       .12  .12  .12  .12  .13  .14  .14  .14  .14  .14  .13  .12
    4       .27  .27  .27  .27  .28  .29  .29  .29  .29  .29  .28  .27
    5       .56  .56  .56  .56  .58  .60  .62  .62  .62  .62  .59  .56
    6       .81  .81  .81  .81  .86  .91  .98  .98  .98  .98  .90  .81
    7       .72  .72  .72  .72  .76  .79  .79  .79  .79  .79  .76  .72
    8       .89  .89  .89  .89  .89  .91  .98  .98  .98  .98  .94  .89
    9       .22  .22  .22  .22  .23  .24  .24  .24  .24  .24  .23  .22

   10       .18  .18  .18  .18  .19  .22  .22  .22  .21  .20  .19  .18
   11       .34  .34  .34  .34  .38  .40  .40  .40  .38  .34  .34  .34
   12       .23  .23  .23  .23  .26  .28  .28  .28  .28  .27  .25  .23
   13       .30  .30  .30  .30  .34  .36  .36  .36  .34  .30  .30  .30
   14       .38  .38  .38  .38  .40  .42  .42  .42  .42  .42  .40  .38
   15   16  .05  .05  .05  .07  .10  .24  .24  .24  .25  .24  .18  .11
   17       .02  .02  .03  .03  .08  .15  .16  .17  .17  .17  .04  .03
  END MON-LZETPARM

  PWAT-STATE1
    <PLS > *** Initial conditions at start of simulation
  ### -### ***  CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
    1          0.030     0.000     1.547     0.104     8.946     2.529     0.911
    2          0.030     0.000     1.458     0.080     6.479     5.091     1.083
    3          0.030     0.000     1.412     0.063    13.426     3.032     1.489
    4          0.030     0.000      .868     0.002     5.889     4.008     3.003

    5          0.030     0.000     1.466     0.057     7.122     6.046     1.219
    6          0.030     0.000     1.460     0.056     5.859     2.722     1.163
    7          0.030     0.000     1.184     0.016     9.869     3.040     1.952
    8          0.030     0.000     0.692     0.001     5.007     3.867     2.854

    9          0.030     0.000     1.380     0.053     8.816     3.297     1.553
   10          0.020     0.000     1.594     0.096     7.600     2.534     0.904
   11          0.020     0.000     1.521     0.081     6.043     2.472     1.030
   12          0.020     0.000     1.593     0.106    12.003     2.056     0.980
   13          0.020     0.000     1.518     0.083     9.970     2.794     1.306
   14          0.020     0.000     1.286     0.028     5.430     3.243     2.216

   15          0.020     0.003     0.772     0.070     4.556     0.049     0.528
   16          0.020     0.001     0.727     0.070     4.746     0.106     1.054
   17          0.000     0.000     0.118     0.000     3.419     0.005     0.378
  END PWAT-STATE1

***** Section SEDMNT coding pg 315 4.4(1).5  -------------------------------

  SED-PARM1
  <  PLS > ***                SDOP= 0 new method less dependent on time step
  ### -###  CRV VSIV SDOP *** SDOP= 1 ARM & NPS method
    1    4    1    0    1
    5    8    1    0    1
    9   17    1    0    1
  END SED-PARM1

  SED-PARM2
    soil detachment DET = DELT60*(1.0-CR)*SMPF*KRER(RAIN/DETL60)^JRER  ***
  <  PLS >      mgt       coef      exp     reattach   veg      verticl***
  ### -###      SMPF      KRER      JRER     AFFIX     COVER      NVSI ***
    1    4       1.0      0.86      1.95      .020                 0.0
    5    8       1.0      0.14      2.30      .035       .95       0.0
    9            1.0      1.38      1.70      .015       .60       0.0
   10   14       1.0      1.95      1.55      .015       .60       0.0
   15            1.0      0.96      1.90      .010       .70       0.0
   16   17       1.0      0.45      1.90      .010       .70       0.0
  END SED-PARM2
```

```
  SED-PARM3
*** SDOP -flg determines (SED-PARAM1) washoff and scour equation used
***  1 Washoff = DELT60*KSER((SURS +SURO)/DELT60)^JSER
***  0 Washoff = DELT60*KSER(       SURO /DELT60)^JSER
***  1 Scour = SURO/[(SURS + SURO)*DELT60*KGER*((SURS + SURO)/DELT60)^JGER]
***  0 Scour =                     DELT60*KGER*( SURS + SURO)/DELT60^JGER
***                Washoff              Scour      ***
***  PLS >      coeff      exp       coeff      exp  ***
***## -###      KSER      JSER      KGER      JGER ***
    1    4      5.45      0.76      0.19      1.40
    5    8      2.95      1.05      0.10      2.30
    9           3.96      0.68      0.12      1.65
   10   14      5.46      0.25      0.18      1.35
   15           3.22      1.05      0.18      1.45
   16   17      2.62      1.25      0.08      2.40
  END SED-PARM3

  MON-COVER
  <  PLS >  Monthly values for erosion-related veg cover (CRV=1)       ***
  ### -###  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1    4  .55  .55  .55  .60  .70  .75  .85  .85  .84  .82  .70  .55
    5    8  .88  .88  .88  .92  .93  .95  .95  .95  .95  .93  .92  .91
    9   14  .65  .65  .70  .75  .85  .90  .92  .92  .85  .80  .78  .75
   15   17  .65  .65  .70  .75  .85  .90  .92  .92  .92  .92  .92  .75
  END MON-COVER

  SED-STOR
  <  PLS >  Detached sediment storage (tons/acre)            ***
  ### -###    BLOCK1      BLK2      BLK3      BLK4      BLK5 ***
    1    4      .010         0         0         0         0
    5    8      .005         0         0         0         0
    9   14      .008         0         0         0         0
   15   17      .010         0         0         0         0
  END SED-STOR

***  SOIL TEMP SIM TURNED OFF--NOT NEEDED BECAUSE AG-CHEM MODULE NOT USED


***** Section PSTEMP  coding pg 323 4.4(1).6  -----------------------------

  PSTEMP-PARM1
  ###  ### SLTV ULTV LGTV TSOP  ***
    1   17    1    1    1    1
  END PSTEMP-PARM1

***  PSTEMP-PARM2
***  ###  ###      ALST      BLST     ULTP1     ULTP2     LGTP1     LGTP2 ***
***    1   17        33       .80       .15        2.       .10        6.
***  END PSTEMP-PARM2

  MON-ASLT
  < PLS  >  Surface temperature when air temp is 32F  (TSOP = 1)       ***
  ###  ###  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1    4  34.  34.  35. 38.0 45.0 52.0 62.0 60.0 48.0 42.0  36. 35.0
    5    8  32.  32.  34. 38.0 40.0 48.0 58.0 58.0 44.0 38.0  36. 35.0
    9   14  34.  34.  35. 38.0 43.0 50.0 60.0 59.0 47.0 38.0  36. 35.0
   15   17  36.  36.  38. 41.0 46.0 53.0 64.0 63.0 52.0 44.0  39. 37.0
  END MON-ASLT

  MON-BSLT
  < PLS  >  Surface soil temperature slope (TSOP = 1)                  ***
  ###  ###  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1    4 0.28 0.28 0.28 0.29 0.31 0.38 0.42 0.45 0.42 0.38 0.28 0.28
    5    8 0.28 0.28 0.28 0.29 0.31 0.34 0.36 0.37 0.35 0.34 0.28 0.28
    9   14 0.28 0.28 0.28 0.29 0.31 0.38 0.42 0.45 0.42 0.38 0.28 0.28
   15   17 0.30 0.30 0.30 0.31 0.33 0.42 0.47 0.49 0.46 0.40 0.30 0.30
  END MON-BSLT

  MON-ULTP1
  < PLS  >  Upper zone soil temperature intercept (TSOP = 1)           ***
  ###  ###  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1    4  42.  42.  44.  47.  50.  54.  57.  58.  56.  46.  44.  42.
    5    8  44.  44.  44.  45.  47.  49.  51.  53.  52.  45.  44.  44.
    9   14  43.  43.  44.  45.  49.  53.  56.  57.  56.  46.  44.  44.
   15   17  45.  45.  45.  49.  53.  58.  62.  60.  58.  47.  45.  45.
  END MON-ULTP1
```

```
  MON-ULTP2
  < PLS  >  Upper zone soil temperature slope (TSOP = 1)               ***
  ###  ###  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1   17  .25  .25  .25  .30  .30  .30  .35  .35  .30  .25  .25  .25
   15   17  .30  .30  .30  .35  .35  .35  .40  .40  .35  .30  .30  .30
  END MON-ULTP2

  MON-LGTP1
  < PLS  >  Lower zone soil temperature (TSOP = 1)                     ***
  ###  ###  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1   17 57.5 57.5 58.8 60.0 60.4 60.8 61.3 62.4 61.5 60.5 59.3 58.1
  END MON-LGTP1

  PSTEMP-TEMPS
  < PLS  >  Initial temperatures                    ***
  ###  ###     AIRTC     SLTMP     ULTMP     LGTMP  ***
    1   14      29.5      33.0      43.0      57.5
   15   17      29.5      32.0      44.0      59.0
  END PSTEMP-TEMPS

*** Section PQUAL coding pg 363 4.4(1).8 -------------------------------------

  NQUALS
    <PLS >      ***
    # -  #NQUAL ***
    1   17    1
  END NQUALS

  QUAL-PROPS
    <PLS >*** Identifiers and flags
    # -  #<--qualid-->*** QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC
    1   17   PO4            LB    1              1         0         0
  END QUAL-PROPS

  QUAL-INPUT
    <PLS >  Storage on surface and nonseasonal parameters                   ***
    # -  #     SQO   POTFW   POTFS   ACQOP  SQOLIM   WSQOP    IOQC    AOQC ***
    1    4    1.00   0.045   0.035  0.0002   0.003     1.9  .00001 .000001
    5    8    2.00   0.008   0.008  0.0001   0.001     2.7  .00001 .000001
    9   14    1.10   0.070   0.040  0.0002   0.003     2.7  .00001 .000001
   15   16    0.20   0.460   0.058  0.0002   0.006     3.8  .00001 .000001
   17         0.20   0.820   0.062  0.0002   0.006     5.4  .00001 .000001
  END QUAL-INPUT


END PERLND

***==============================================================================
***==============================================================================

*************************************************************************
***   IMPLND  - Impervious land  4.2(2)    Prin.  4.2(2)  pg 104       ***
***                                        Coding 4.4(2)  pg 403       ***
*************************************************************************
IMPLND
  ACTIVITY
    <ILS >  Active Sections (1-active, 0-inactive)                     ***
  ### -### ATMP SNOW IWAT  SLD  IWG IQAL                               ***
    1                  1    1        1
    2                  1    1        1
  END ACTIVITY

  PRINT-INFO
    2-PIVL, 3-dy, 4-mn, 5-yr, 6-never    user  end                     ***
    <ILS > <------ Print-flags --------> PIVL  PYR                     ***
  ### -### ATMP SNOW IWAT  SLD  IWG IQAL ####   ##                     ***
    1                  6    5        6    1    1
    2                  6    5        6    1    1
  END PRINT-INFO

  GEN-INFO
    <ILS ><-------Name------->   Unit-systems   Printer                ***
  ### -###                     User  t-series Engl  Met                ***
                                       in  out i/o#                    ***
    1      Residential            1    1    1   15    0
    2      Comm/Indust/Mfam       1    1    1   15    0
  END GEN-INFO
```

```
*** ----------------------------------------------------------------------
***   IMPLND - Section IWATER input  Prin.  4.2(2).3  pg 104
***                                Coding 4.4(2).4  pg 408
***   retention, routing and evap from impervious surfaces
*** ----------------------------------------------------------------------

  IWAT-PARM1
    <ILS >          Flags          ***
  ### -### CSNO RTOP  VRS  VNN RTLI ***
    1         0    1              0
    2         0    1              0
  END IWAT-PARM1

  IWAT-PARM2
    <ILS >                                         ***
  ### -###      LSUR     SLSUR      NSUR     RETSC ***
    1           400.      .014      .010       .01
    2           200.      .010      .010       .03
  END IWAT-PARM2

  IWAT-PARM3
    <ILS >                    ***
  ### -###    PETMAX    PETMIN ***
    1            40.       35.
    2            40.       35.
  END IWAT-PARM3

  IWAT-STATE1
    <ILS >  IWATER state variables ***
  ### -###      RETS      SURS     ***
    1            .01       .00
    2            .03       .00
  END IWAT-STATE1

****  Section Solids  coding pg 416 4.4(2).6 ----------------------------

  SLD-PARM1
    <PLS > Accu remov   flgs ***
    # -  # VASD VRSD SDOP ***
    1    2    1    0    0
  END SLD-PARM1

  SLD-PARM2
                 Washoff      Accumulation        ***
    <PLS >      coef      exp            Removal    ***
  ### -###      KEIM      JEIM    ACCSDP    REMSDP  ***
    1           0.10      1.85      0.01         0
    2           0.12      1.90      0.01         0
  END SLD-PARM2

  MON-SACCUM
    <PLS >  Monthly solids accumulation rate (VASD= 1) ton/acre/day    ***
  ### -###  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1      .012 .012 .010 .003 .001 .001 .001 .001 .001 .001 .001 .005
    2      .011 .011 .008 .003 .001 .001 .001 .001 .001 .001 .001 .007
  END MON-SACCUM

  MON-REMOV  ***
    <PLS >  Monthly values for solids removal rate  (VRSD flg = 1)     ***
  ### -###  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
*** 1    2 .003 .003 .003 .003 .003 .003 .003 .003 .003 .003 .003 .003
  END MON-REMOV  ***

  SLD-STOR
    <PLS >  initial slds storage     (tons/acre)            ***
  ### -###     #####                                        ***
    1           .095
    2           .142
  END SLD-STOR
```

```
*** Section IQUAL  coding pg 428 4.4(2).7 ---------------------------------
***     because IMPLND has no explicit subroutines for PHOS

  NQUALS
    <PLS >      ***
  ### -###NQUAL ***
    1    2    1
  END NQUALS

  QUAL-PROPS
    <PLS > consituent     Unit Sed  Mon. Wash  mon.  ***
  ### -###<--qualid-->    QTID QSDF VPFW QSOF  VQO   ***
    1    2         PO4      LB    1    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
    <PLS >  Storage on surface and nonseasonal parameters   ***
  ### -###   SQO   POTFW   ACQOP  SQOLIM   WSQOP            ***
    1       .010    1.55    .001   0.045     5.4
    2       .012    1.42    .001   0.035     5.4
  END QUAL-INPUT

END IMPLND

***=============================================================================
***=============================================================================

********************************************************************************
***      RCHRES Block      Prin.  4.2(3)  pg 117                             ***
***                        Coding 4.4(3)  pg 433                             ***
***      Channel Processes                                                   ***
********************************************************************************
RCHRES
  ACTIVITY
    RCHRES  Active Sections (1=Active, 0=Inactive)           ***
  ### -### HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG ***
    1   23    1    1              1         1    1
  END ACTIVITY

  PRINT-INFO
    RCHRES <-Print-flags: 2-PIVL,3-dy,4-mn,5-yr,6-never ***> PIVL  PYR
  ### -### HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB ****  ***
    1   23    6    6              5    6    6    6              1    1
  END PRINT-INFO

  GEN-INFO
    RCHRES<-------Name------->Nexit   Unit Systems   Printer      ***
  ### -###                         User t-series  Engl Metr LKFG ***
                                           in  out                ***
    1     Chenoweth   #39        1    1    1    1   15    0    0
    2     Chenoweth   #37        1    1    1    1   15    0    0
    3     Reach       #36        1    1    1    1   15    0    0
    4     Chenoweth   #35        2    1    1    1   15    0    0
    5     Chenoweth   #33        2    1    1    1   15    0    0
    6     Chenoweth   #31        2    1    1    1   15    0    0
    7     Chenoweth   #28        2    1    1    1   15    0    0
    8     Chenoweth   #25        2    1    1    1   15    0    0
    9     Chenoweth   #23        2    1    1    1   15    0    0
   10     Chenoweth   #21        2    1    1    1   15    0    0
   11     Razor Br.   #14        1    1    1    1   15    0    0
   12     Chenoweth   #13        2    1    1    1   15    0    0
   13     Shinks Br.  #12        1    1    1    1   15    0    0
   14     Chenoweth   #11        2    1    1    1   15    0    0
*** Pond reaches (Lakes/ponds)
   15     V12                    1    1    1    1   15    0    0
   16     V13                    1    1    1    1   15    0    0
   17     V14                    1    1    1    1   15    0    0
   18     V21                    1    1    1    1   15    0    0
   19     V22                    1    1    1    1   15    0    0
   20     V23                    1    1    1    1   15    0    0
   21     V24                    1    1    1    1   15    0    0
   22     V27                    1    1    1    1   15    0    0
   23     V41                    1    1    1    1   15    0    0

  END GEN-INFO
```

```
*** ---------------------------------------------------------------------- ***
***    RECHRES - Section HYDR input  Prin.  4.2(3).1 pg 121                ***
***                                  coding 4.4(3).2 pg 438                ***
***       HYDRA-PARM1   pg 439                                             ***
***       HYDRA-PARM2   pg 441                                             ***
***       HYDRA-INIT    pg 444   Inital conditions                         ***
*** ---------------------------------------------------------------------- ***

  HYDR-PARM1
    RCHRES  Flags for HYDR section                           ***
  ### -###  VC A1 A2 A3  ODFVFG for each     ODGTFG for each *** FUNCT  for each
            FG FG FG FG  possible   exit     possible   exit *** possible   exit
                           1  2  3  4  5       1  2  3  4  5 ***   1  2  3  4  5
    1    3   0  1  1  1    4
    4    7   0  1  1  1    0  4                1  0                2
    8   10   0  1  1  1    0  4                1  0                2
   11        0  1  1  1    4
   12        0  1  1  1    0  4                1  0                2
   13        0  1  1  1    4
   14        0  1  1  1    0  4                1  0                2
   15   23   0  1  1  1    4
  END HYDR-PARM1


  HYDR-PARM2
    RCHRES ***
  ### -###  FTB  FTA       LEN     DELTH     STCOR              SED  ***
  ### -###  DSN  BNO   (miles)    (feet)    (feet)        KS      DB50 ***
    1             39     0.705       26.        0.        .5     .008
    2             37     1.234       30.        0.        .5     .008
    3             36     1.994       39.        0.        .5     .008
    4             35     0.244       10.        0.        .5     .008
    5             33     0.458        3.        0.        .5     .008
    6             31     0.441        7.        0.        .5     .008
    7             28     0.215        3.        0.        .5     .008
    8             25     0.490       10.        0.        .5     .008
    9             23     1.358       23.        0.        .5     .008
   10             21     0.957       23.        0.        .5     .008
   11             14     1.016       59.        0.        .5     .008
   12             13     0.690       12.        0.        .5     .008
   13             12     1.179       66.        0.        .5     .008
   14             11     1.584       31.        0.        .5     .008
*** Pond reaches (Lakes/ponds)
   15            112     0.200       .01        0.        .5     .008
   16            113     0.200       .01        0.        .5     .008
   17            114     0.200       .01        0.        .5     .008
   18            121     0.200       .01        0.        .5     .008
   19            122     0.200       .01        0.        .5     .008
   20            123     0.200       .01        0.        .5     .008
   21            124     0.200       .01        0.        .5     .008
   22            127     0.200       .01        0.        .5     .008
   23            141     0.200       .01        0.        .5     .008
  END HYDR-PARM2

  HYDR-INIT
                         Initial  value  of COLIND *** Initial  value  of OUTDGT
  <RCHRES>       VOL     for  each  possible  exit *** for  each  possible  exit
  ### -###    (ac-ft)      EX1  EX2  EX3  EX4  EX5 ***   EX1  EX2  EX3  EX4  EX5
    1          0.284       4.0
    2          0.560       4.0
    3          0.851       4.0
    4          0.597       0.0  4.0                      0.0  0.0
    5          0.386       0.0  4.0                      0.0  0.0
    6          0.925       0.0  4.0                      0.0  0.0
    7          0.256       0.0  4.0                      0.0  0.0
    8          1.020       0.0  4.0                      0.0  0.0
    9          4.740       0.0  4.0                      0.0  0.0
   10          3.300       0.0  4.0                      0.0  0.0
   11          0.065       4.0
   12          2.590       0.0  4.0                      0.0  0.0
   13          0.254       4.0
   14          9.260       0.0  4.0                      0.0  0.0
```

```
*** Pond reaches (Lakes/ponds)
   15       226.000       4.0
   16        18.400       4.0
   17        43.800       4.0
   18        92.200       4.0
   19        32.400       4.0
   20        35.600       4.0
   21        38.600       4.0
   22         8.410       4.0
   23         6.710       4.0

  END HYDR-INIT

***  Section ADCALC coding pg 445 4.4(3).3 ----------------------------------
***  Prepare advection simulation
   ADCALC-DATA
   RCHRES  Data for ADCALC     ***
  ### -###     CRRAT       VOL ***
    1   14      1.80
    15  23      1.10
   END ADCALC-DATA

*** Section HTRCH coding pg 451 4.4(3).5 ------------------------------------
***  Not active - stream temp read in from external annie file
***  To simulate stream temp external files for cloud cov, dew pnt, sol rad,
***  and wind speed are required

  HEAT-PARM
  <RCHRES>      ELEV     ELDAT    CFSAEX    KATRAD     KCOND     KEVAP ***
  ### -###                                                             ***
    1   14     550.0       0.0       .85
   15   23     550.0       0.0       .95
  END HEAT-PARM

  HEAT-INIT
  <RCHRES>        TW    AIRTMP ***
  ### -###                     ***
    1   23       41.       46.
  END HEAT-INIT


*** Section SEDTRN coding pg 454 4.4.(3).6 -----------------------------------
*** Simulate sediment transport in RCHRES
  SANDFG
  <RCHRES>      ***
  ### -### SNDFG (sand load simul method; 1-Toffaletti,2-Colbely,3-user) ***
    1   14     3
   15   23     1
  END SANDFG

  SED-GENPARM
  <RCHRES>    BEDWID    BEDWRN       POR ***
  ###  ###      (ft)      (ft)           ***
    1    5        5.       1.5
    6   10       10.       1.5
   11             5.       1.5
   12            15.       1.5
   13             5.       1.0
   14            20.       1.0
   15   23       25.       2.5
  END SED-GENPARM

  SAND-PM
  <RCHRES>      Dia.         W       RHO     KSAND    EXPSND ***
  ###  ###      (in)    (in/s)                               ***
    1   14      .008      .770      2.45       2.5       0.8
   15   23      .008      .770      2.45
  END SAND-PM

*** Silt  Parameters (default parameters washthru)
  SILT-CLAY-PM
  <RCHRES>      Dia.         W       RHO     TAUCD     TAUCS         M ***
  ###  ###      (in)    (in/s)  (gm/cm3)  (lb/ft2)  (lb/ft2)  (lb/ft2) ***
*** 1   14
    1    8    .00145     .0320      2.35      .270       .29      4.10
    9   14    .00145     .0320      2.35      .265       .30      5.10
   15   23    .00145     .0320      2.35      .100       .35      1.10
  END SILT-CLAY-PM
```

```
*** Clay Parameters
  SILT-CLAY-PM
  <RCHRES>      Dia.         W       RHO     TAUCD     TAUCS         M ***
  ###  ###      (in)    (in/s)  (gm/cm3)  (lb/ft2)  (lb/ft2)  (lb/ft2) ***
*** 1   15
    1    8    .00012     .0034      2.20      .270       .28      4.10
    9   14    .00012     .0034      2.20      .265       .30      4.10
   15   23    .00012     .0034      2.20      .100       .35      1.10
  END SILT-CLAY-PM

  SSED-INIT
  <RCHRES>     Suspended sed concs (mg/l) ***
  ### -###      Sand      Silt      Clay  ***
    1   14        0.        5.        4.
   15   23        0.        1.        4.
  END SSED-INIT

  BED-INIT
  <RCHRES>    BEDDEP  Initial bed composition as % ***
  ### -###      (ft)      Sand      Silt      Clay ***
    1   23
*** 1   23       0.8      0.80      0.15      0.05
  END BED-INIT


*** Section RQUAL coding pg 497 4.4(3).8  ---------------------------------------

  BENTH-FLAG
  <RCHRES>  Flag benthic influences, 1-active, 0-inactive ***
  ### -### BENF  flag                                      ***
    1   23    1
  END BENTH-FLAG

  SCOUR-PARMS
  <RCHRES> benthic scour parameters (only used BENF = 1) ***
  ### -###    SCRVEL    SCRMUL                           ***
    1   23        5.       1.5
  END SCOUR-PARMS

*** Section OXRX (required for RQUAL which is required for NUTRX)------------------
***  coding pg 500 4.4(3).8.1
***  NOTE: Pond RCHRES (No. 15-23) are not specified as LAKE's in RCHRES GEN-INFO
***        if these are specified as LAKE's (LKFG = 1), then windspeed is required

  OX-FLAGS
  <RCHRES> flag type of oxygen reaeration method ***
*** Owen's/Churchill's/O'Connor-Dubbins' formua  ***
  ### -### REAM                                  ***
    1   23    2
  END OX-FLAGS

  OX-GENPARM
  <RCHRES>    KBOD20     TCBOD    KODSET    SUPSAT ***
  ### -###       /hr                               ***
    1    7        .1                  4.
    8   14        .1                  5.
   15   23        .1                  8.
  END OX-GENPARM

  ELEV
  <RCHRES>      ELEV ***  elevation of RCHRES above sea level
  ### -###      (ft) ***  (required becaue HTRCH inactive)
    1   23       550
  END ELEV

  OX-BENPARM
  <RCHRES>     BENOD     TCBEN     EXPOD  BRBOD(1)  BRBOD(2)    EXPREL ***
  ### -###  mg/m2.hr                      mg/m2.hr  mg/m2.hr           ***
    1    7        1.       1.1       1.2        1.        5.       2.5
    8   14        4.       1.1       1.2        3.        8.       2.5
   15   23        3.       1.2       1.5        8.       15.       2.8
  END OX-BENPARM

***  OX-CFOREA
***  <RCHRES>    CFOREA *** correction factor for reaeration in lakes
***  ### -###           *** (RCHRES 15-23 pond RCHRES for ponds GEN PARM LKFG=1
***   15   23       0.8
***  END OX-CFOREA
```

```
  OX-TCGINV
  <RCHRES>            ***stream RCHRES (GEN-PARM LKFG=0,OX-FLAGS REAM=2)
  ### -###    TCGINV  ***
    1   23     1.050
  END OX-TCGINV

  OX-INIT
  <RCHRES>       DOX       BOD     SATDO ***
  ### -###      mg/l      mg/l      mg/l ***
    1   14       10.        2.
   15   23        8.        7.
  END OX-INIT

  *** Section NUTRX coding pg 511 4.4(3).8.2 --------------------------------
  *** Simulate PO4 in RCHRES ***
  NUT-FLAGS
  <RCHRES>  TAM  NO2  PO4  AMV  DEN ADNH ADPO PHFL ***
  ### -###                                         ***
    1   23    0    0    1    0    0    0    1    0
  END NUT-FLAGS

***  NUT-AD-FLAGS *** Not used ***
***    Atmospheric Deposition Flags ***
***  <RCHRES>    NO3    NH3    PO4  ***
***  ### -###   F  C   F  C   F  C  ***
***    1   23  -1  0  -1  0   0  0
***  END NUT-AD-FLAGS

  NUT-BENPARM
  *** Release rates - Used only if BENF = 1 in RQUAL
  ***       aerobic anaerobic   aerobic anaerobic
  <RCHRES>  BRTAM(1)  BRTAM(2)  BRPO4(1)  BRPO4(2)     ANAER  ***
  ### -###  mg/m2.hr  mg/m2.hr  mg/m2.hr  mg/m2.hr      mg/l  ***
    1   23      11.0      33.0      0.95       1.2    0.0055
  END NUT-BENPARM

  NUT-NITDENIT
   *** nitrification- denitrification rates
  <RCHRES>    KTAM20    KNO220     TCNIT    KNO320     TCDEN    DENOXT ***
  ### -###       /hr       /hr                 /hr                mg/l ***
    1   23      .002      .004      1.07      .001      1.04       0.2
  END NUT-NITDENIT

  NUT-NH3VOLAT
  <RCHRES>    EXPNVG    EXPNVL ***
  ### -###                     ***
    1   23      0.50    0.6667
  END NUT-NH3VOLAT

  NUT-BEDCONC
  <RCHRES>       Bed concentrations of NH4 & PO4 (mg/mg)               ***
  ### -###  NH4-sand  NH4-silt  NH4-clay  PO4-sand  PO4-silt  PO4-clay ***
    1   23         0         0         0   0.00011   0.00211   0.02421
  END NUT-BEDCONC

  NUT-ADSPARM
  <RCHRES>    Kd Adsorbtion coefficients for NH4 AND PO4  (l/mg)       ***
  ### -###  NH4-sand  NH4-silt  NH4-clay  PO4-sand  PO4-silt  PO4-clay ***
    1   23                                  400.00    500.00    900.00
  END NUT-ADSPARM

  NUT-DINIT
  <RCHRES>       NO3       TAM       NO2       PO4            ***
  ### -###      mg/l      mg/l      mg/l      mg/l        pH  ***
    1   23        0.        0.        0.     0.025       8.1
  END NUT-DINIT

  NUT-ADSINIT
  <RCHRES>        Initial suspended NH4 and PO4 concentrations (mg/mg) ***
  ### -###  NH4-sand  NH4-silt  NH4-clay  PO4-sand  PO4-silt  PO4-clay ***
    1   23        0.        0.        0.      .001      .025      0.50
  END NUT-ADSINIT

END RCHRES
```

```
******************************************************************************
***    COPY     Block  4.4.(11)  page 536                                    ***
***           combines times series from mutiple PERLN's,IMPLD's, RCHRES    ***
******************************************************************************
COPY
  TIMESERIES
  Copy-opn           ***
  ### -###  NPT  NMN ***
  100  102    0    7
  105              1
  106  109         5
  END TIMESERIES
END COPY

GENER
  OPCODE
    # -  #  Op- ***  add two time series
           code ***
    1    4   16
  END OPCODE
END GENER


******************************************************************************
***        External Sources Block 4.6.2   Page 569                          ***
***             WDM input data                                              ***
******************************************************************************
***  HOURLY TIME STEP

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <tgrp> <-Member-> ***
<Name> ### <Name>## tem strg<-factor->strg <Name> ### ###        <Name> # # ***
WDM     28 PREC     ENGLZERO      1.00SUM  PERLND   1  17 EXTNL  PREC
WDM     28 PREC     ENGLZERO      1.00SUM  IMPLND   1   2 EXTNL  PREC
WDM     28 PREC     ENGLZERO      1.00SUM  RCHRES   1  23 EXTNL  PREC
WDM     32 PET      ENGL          1.00SAME PERLND   1  17 EXTNL  PETINP
WDM     32 PET      ENGL          1.00SAME IMPLND   1   2 EXTNL  PETINP
WDM     32 PET      ENGL          1.00SAME RCHRES   1  23 EXTNL  POTEV

WDM     34 ATMP     ENGL          1.00SAME PERLND   1  17 ATEMP  AIRTMP
WDM     36 WTMP     ENGL          1.00SAME RCHRES   1   8 HTRCH  TW
WDM     40 WTMP     ENGL          1.00SAME RCHRES   9  23 HTRCH  TW

*** WWTP flow input source is in ft^3/s; target unit in ac-ft/hr    0.0826446
WDM   9602 FLOW     ENGL      .0826446SAME RCHRES   8     INFLOW IVOL
WDM   9603 FLOW     ENGL      .0826446SAME RCHRES   8     INFLOW IVOL
WDM   9605 FLOW     ENGL      .0826446SAME RCHRES   9     INFLOW IVOL
WDM   9606 FLOW     ENGL      .0826446SAME RCHRES  10     INFLOW IVOL

***  same for both time steps input DSN in tons/day assumes all SED from
***  WWTP is clay size except for the Jeff bypass flows which are split
***  between clay and silt size particles
WDM   9712 SED      ENGL          1.00DIV  RCHRES   8     INFLOW ISED   3
WDM   9713 SED      ENGL          0.50DIV  RCHRES   8     INFLOW ISED   2
WDM   9713 SED      ENGL          0.50DIV  RCHRES   8     INFLOW ISED   3
WDM   9715 SED      ENGL          1.00DIV  RCHRES   9     INFLOW ISED   3
WDM   9716 SED      ENGL          1.00DIV  RCHRES  10     INFLOW ISED   3

*** WWTP PO4 loads-- assume the majority of the by PO4 load is suspended & on clay size fraction
WDM   9702 PO4      ENGL          1.00DIV  RCHRES   8     INFLOW NUIF1  4
WDM   9703 PO4      ENGL           .20DIV  RCHRES   8     INFLOW NUIF1  4
WDM   9703 PO4      ENGL           .30DIV  RCHRES   8     INFLOW NUIF2  2
WDM   9703 PO4      ENGL           .70DIV  RCHRES   8     INFLOW NUIF2  3
WDM   9705 PO4      ENGL          1.00DIV  RCHRES   9     INFLOW NUIF1  4
WDM   9706 PO4      ENGL          1.00DIV  RCHRES  10     INFLOW NUIF1  4
```

```
*** Hourly GW loss DSN 72 ranges 1.0-1.5 ft3/s June-November, zero otherwise.
*** GW loss estimated to be a maximum of 2 ft3/s between Ruckriegel and
*** Gelhaus, the same lineal loss rate dowstream from Gelhaus; and 0.5 ft3/s
*** maximum upstream from Ruckriegel. Outflow Demand Gate 1 is the estimated
*** channel loss from the system.

WDM     72 FLOW     ENGL         0.079SAME RCHRES   4     EXTNL  OUTDGT 1
WDM     72 FLOW     ENGL         0.148SAME RCHRES   5     EXTNL  OUTDGT 1
WDM     72 FLOW     ENGL         0.143SAME RCHRES   6     EXTNL  OUTDGT 1
     *** Base loss rate 0.37 ft3/s upstream from Ruckriegel Pkwy
WDM     72 FLOW     ENGL         0.130SAME RCHRES   7     EXTNL  OUTDGT 1
WDM     72 FLOW     ENGL         0.295SAME RCHRES   8     EXTNL  OUTDGT 1
WDM     72 FLOW     ENGL         0.819SAME RCHRES   9     EXTNL  OUTDGT 1
WDM     72 FLOW     ENGL         0.577SAME RCHRES  10     EXTNL  OUTDGT 1
     *** Base loss rate 1.82 ft3/s Ruckriegel Pkwy to Gelhaus Ln
WDM     72 FLOW     ENGL         0.416SAME RCHRES  12     EXTNL  OUTDGT 1
WDM     72 FLOW     ENGL         0.955SAME RCHRES  14     EXTNL  OUTDGT 1
     *** Base loss rate 1.37 ft3/s Gelhaus Ln to Seatonville Rd


END EXT SOURCES


********************************************************************************
***    EXTERNAL Block  4.6.5     page 581                                    ***
***    output                                                                ***
********************************************************************************
***  Area of Chenoweth Run 10579.47 ac  (16.530 mi2)
***
***
***  Mult factor for RCHRES convert ac-ft/tsstep to inches =(12in/ft)/DA(ac)
***  US Gage :   12/ 3445.14 = 0.0034832   (RCHRES #6)
***  Mid Gage:   12/ 7326.62 = 0.0016379   (RCHRES #10)
***  DS Gage :   12/10579.47 = 0.0011343   (RCHRES #14)
***
***   Convert   ac-ft/hr into ft3/s
***     ac-ft/hr * 1hr/60min * 1min/60sec * 43,560ft2/ac  = 12.1

***   PERLND & IMPLND
***     converts ac-in/tsstep to watershed inches/tsstep = 1/DA
***   US Gage:   0.0002903 for DA of  3445.14 ac
***   Mid Gage:  0.0001365 for DA of  7326.62 ac
***   DS Gage:   0.0000945 for DA of 10579.47 ac
***




*** Basin Reach ID    Model RCHRES No.
*** --------------   -----------------
***       Reach 11 - RCHRES #14 (DS Gage at Seatonville Rd)
***       Reach 21 - RCHRES #10 (Mid Gage at Gelhaus Lane)
***       Reach 25 - RCHRES #8 (DS JTown WWTP at Taylorsville Rd)
***       Reach 31 - RCHRES #6  (US Gage at Ruckriegel Pkwy)

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***
RCHRES   6 OFLOW  OVOL   2       12.1     WDM    556 SIMQ   1 ENGL      REPL
RCHRES   8 OFLOW  OVOL   2       12.1     WDM    558 SIMQ   1 ENGL      REPL
RCHRES  10 OFLOW  OVOL   2       12.1     WDM    560 SIMQ   1 ENGL      REPL
RCHRES  14 OFLOW  OVOL   2       12.1     WDM    564 SIMQ   1 ENGL      REPL


 *** OVOL  - outflow ac-ft/hr through individual exit
 *** ROSED - total outflow sediment tons/hr
 *** SSED  - Suspended Sed conc. mg/l (4 - all size fractions)
 *** TAU   - Bed shear stress
```

```
*** Output time series at Ruckriegel (US gage CHEN 6)
RCHRES   6 OFLOW  OVOL   2   0.0034832     WDM    500 SIMQ   1 ENGL      REPL

RCHRES   6 SEDTRN ROSED  4                 WDM    600 SED    1 ENGL      REPL
RCHRES   6 SEDTRN SSED   4                 WDM    601 SSED   1 ENGL      REPL
RCHRES   6 HYDR   TAU    1                 WDM    602 TAU    1 ENGL      REPL
RCHRES   6 SEDTRN DEPSCR 1                 WDM    603 SCOU   1 ENGL      REPL
RCHRES   6 SEDTRN DEPSCR 2                 WDM    604 SCOU   1 ENGL      REPL
RCHRES   6 SEDTRN DEPSCR 3                 WDM    605 SCOU   1 ENGL      REPL
RCHRES   6 SEDTRN RSED   7 ***             WDM    606 RSED   1 ENGL      REPL
RCHRES   6 SEDTRN RSED   8 ***             WDM    607 RSED   1 ENGL      REPL
RCHRES   6 SEDTRN RSED   9 ***             WDM    608 RSED   1 ENGL      REPL

RCHRES   6 OXRX   DOX    1 1               WDM    800 DO     1 ENGL      REPL

RCHRES   6 NUTRX  NUCF9  2 4               WDM    700 DPO4   1 ENGL      REPL
RCHRES   6 NUTRX  NUCF2  1 2               WDM    701 SPO4   1 ENGL      REPL
RCHRES   6 NUTRX  NUCF2  2 2               WDM    702 SPO4   1 ENGL      REPL
RCHRES   6 NUTRX  NUCF2  3 2               WDM    703 SPO4   1 ENGL      REPL
RCHRES   6 NUTRX  NUCF2  4 2               WDM    704 SPO4   1 ENGL      REPL
   *** Total PO4 load
GENER    1 OUTPUT TIMSER                   WDM    705 TPO4   1 ENGL      REPL

*** Output time series at Talyorsville Rd. (CHEN 8)
RCHRES   8 SEDTRN ROSED  4                 WDM    628 SED    1 ENGL      REPL
GENER    3 OUTPUT TIMSER                   WDM    728 TPO4   1 ENGL      REPL

***  Output time series at Gelhaus  (mid gage CHEN 10)
RCHRES  10 OFLOW  OVOL   2   0.0016379     WDM    510 SIMQ   1 ENGL      REPL

RCHRES  10 SEDTRN ROSED  4                 WDM    610 SED    1 ENGL      REPL
RCHRES  10 SEDTRN SSED   4                 WDM    611 SSED   1 ENGL      REPL
RCHRES  10 HYDR   TAU    1                 WDM    612 TAU    1 ENGL      REPL
RCHRES  10 SEDTRN DEPSCR 1                 WDM    613 SCOU   1 ENGL      REPL
RCHRES  10 SEDTRN DEPSCR 2                 WDM    614 SCOU   1 ENGL      REPL
RCHRES  10 SEDTRN DEPSCR 3                 WDM    615 SCOU   1 ENGL      REPL
RCHRES  10 SEDTRN RSED   7 ***             WDM    616 RSED   1 ENGL      REPL
RCHRES  10 SEDTRN RSED   8 ***             WDM    617 RSED   1 ENGL      REPL
RCHRES  10 SEDTRN RSED   9 ***             WDM    618 RSED   1 ENGL      REPL

RCHRES  10 OXRX   DOX    1 1               WDM    810 DO     1 ENGL      REPL

RCHRES  10 NUTRX  NUCF9  2 4               WDM    710 DPO4   1 ENGL      REPL
RCHRES  10 NUTRX  NUCF2  1 2               WDM    711 SPO4   1 ENGL      REPL
RCHRES  10 NUTRX  NUCF2  2 2               WDM    712 SPO4   1 ENGL      REPL
RCHRES  10 NUTRX  NUCF2  3 2               WDM    713 SPO4   1 ENGL      REPL
RCHRES  10 NUTRX  NUCF2  4 2               WDM    714 SPO4   1 ENGL      REPL
  *** Total PO4 load
GENER    2 OUTPUT TIMSER                   WDM    715 TPO4   1 ENGL      REPL

*** Output time series at Seatonville Rd-  downstream site (CHEN 14)
RCHRES  14 OFLOW  OVOL   2   0.0011343     WDM    534 SIMQ   1 ENGL      REPL

RCHRES  14 SEDTRN ROSED  4                 WDM    634 SED    1 ENGL      REPL
GENER    4 OUTPUT TIMSER                   WDM    734 TPO4   1 ENGL      REPL


*** Output time series via Copy for use with HSPEXP
COPY   100 OUTPUT MEAN   1 1 0.0002903     WDM    501 SURO   1 ENGL      REPL
COPY   100 OUTPUT MEAN   2 1 0.0002903     WDM    502 IFWO   1 ENGL      REPL
COPY   100 OUTPUT MEAN   3 1 0.0002903     WDM    503 AGWO   1 ENGL      REPL
COPY   100 OUTPUT MEAN   4 1 0.0002903     WDM    505 PETX   1 ENGL AGGR REPL
COPY   100 OUTPUT MEAN   5 1 0.0002903     WDM    506 SAET   1 ENGL AGGR REPL
COPY   100 OUTPUT MEAN   6 1 0.0002903AVER WDM    507 UZSX   1 ENGL AGGR REPL
COPY   100 OUTPUT MEAN   7 1 0.0002903AVER WDM    508 LZSX   1 ENGL AGGR REPL

COPY   101 OUTPUT MEAN   1 1 0.0001365     WDM    511 SURO   1 ENGL      REPL
COPY   101 OUTPUT MEAN   2 1 0.0001365     WDM    512 IFWO   1 ENGL      REPL
COPY   101 OUTPUT MEAN   3 1 0.0001365     WDM    513 AGWO   1 ENGL      REPL
COPY   101 OUTPUT MEAN   4 1 0.0001365     WDM    515 PETX   1 ENGL AGGR REPL
COPY   101 OUTPUT MEAN   5 1 0.0001365     WDM    516 SAET   1 ENGL AGGR REPL
COPY   101 OUTPUT MEAN   6 1 0.0001365AVER WDM    517 UZSX   1 ENGL AGGR REPL
COPY   101 OUTPUT MEAN   7 1 0.0001365AVER WDM    518 LZSX   1 ENGL AGGR REPL
```

```
COPY   102 OUTPUT MEAN   1 1 0.0000945     WDM    521 SURO   1 ENGL      REPL
COPY   102 OUTPUT MEAN   2 1 0.0000945     WDM    522 IFWO   1 ENGL      REPL
COPY   102 OUTPUT MEAN   3 1 0.0000945     WDM    523 AGWO   1 ENGL      REPL
COPY   102 OUTPUT MEAN   4 1 0.0000945     WDM    525 PETX   1 ENGL AGGR REPL
COPY   102 OUTPUT MEAN   5 1 0.0000945     WDM    526 SAET   1 ENGL AGGR REPL
COPY   102 OUTPUT MEAN   6 1 0.0000945AVER WDM    527 UZSX   1 ENGL AGGR REPL
COPY   102 OUTPUT MEAN   7 1 0.0000945AVER WDM    528 LZSX   1 ENGL AGGR REPL

*** GW channel seepage  (dsn 80- hourly , 81- 5 min)
COPY   105 OUTPUT MEAN   1                 WDM     80 GW     1 ENGL      REPL

***  Output average soil temps & SED yield by land-use type
***  soil surface temp F                         xxx1
***  soil upper-zone temp F                      xxx2
***  soil lower-zone temp F                      xxx3
***  Total removal of sediment from PERLND's     xxx4
***  Sed transport capacity (by surface runoff)  xxx5

*** Combined Agr PERLND's (No. 1 to 4)
COPY   106 OUTPUT MEAN   1 1               WDM   1061 SLTM   1 ENGL      REPL
COPY   106 OUTPUT MEAN   2 1               WDM   1062 ULTM   1 ENGL      REPL
COPY   106 OUTPUT MEAN   3 1               WDM   1063 LGTM   1 ENGL      REPL
COPY   106 OUTPUT MEAN   4 1               WDM   1064 PSED   1 ENGL      REPL
COPY   106 OUTPUT MEAN   5 1               WDM   1065 STCP   1 ENGL      REPL

*** Combined Forest PERLND's (No. 5 to 8)
COPY   107 OUTPUT MEAN   1                 WDM   1071 SLTM   1 ENGL      REPL
COPY   107 OUTPUT MEAN   2                 WDM   1072 ULTM   1 ENGL      REPL
COPY   107 OUTPUT MEAN   3                 WDM   1073 LGTM   1 ENGL      REPL
COPY   107 OUTPUT MEAN   4                 WDM   1074 PSED   1 ENGL      REPL
COPY   107 OUTPUT MEAN   5                 WDM   1075 STCP   1 ENGL      REPL

*** Combined Open PERLND's (No. 9 to 14)
COPY   108 OUTPUT MEAN   1                 WDM   1081 SLTM   1 ENGL      REPL
COPY   108 OUTPUT MEAN   2                 WDM   1082 ULTM   1 ENGL      REPL
COPY   108 OUTPUT MEAN   3                 WDM   1083 LGTM   1 ENGL      REPL
COPY   108 OUTPUT MEAN   4                 WDM   1084 PSED   1 ENGL      REPL
COPY   108 OUTPUT MEAN   5                 WDM   1085 STCP   1 ENGL      REPL

*** Combined disturbed PERLND's (No. 15 to 17)
COPY   109 OUTPUT MEAN   1                 WDM   1091 SLTM   1 ENGL      REPL
COPY   109 OUTPUT MEAN   2                 WDM   1092 ULTM   1 ENGL      REPL
COPY   109 OUTPUT MEAN   3                 WDM   1093 LGTM   1 ENGL      REPL
COPY   109 OUTPUT MEAN   4                 WDM   1094 PSED   1 ENGL      REPL
COPY   109 OUTPUT MEAN   5                 WDM   1095 STCP   1 ENGL      REPL

***  Output individual PERLND sediment characteristics
PERLND   1 SEDMNT DETS                     WDM   2001 DETS   1 ENGL      REPL
PERLND   1 SEDMNT STCAP                    WDM   2002 STCP   1 ENGL      REPL
PERLND   1 SEDMNT WSSD                     WDM   2003 WSSD   1 ENGL      REPL
PERLND   1 SEDMNT SCRSD                    WDM   2004 SCRS   1 ENGL      REPL
PERLND   1 SEDMNT SOSED                    WDM   2005 SOSE   1 ENGL      REPL
PERLND   1 SEDMNT DET                      WDM   2006 DET    1 ENGL      REPL

END EXT TARGETS
```

```
********************************************************************************
***         SCHEMATIC Block 4.6.4   page 574                                 ***
***         Global specifications of watershed structure                     ***
***         works in tandem with MASS-LINK                                   ***
********************************************************************************
SCHEMATIC
<-Source->                  <--Area-->     <-Target->  <ML->  ***
<Name> ###                  <-factor->     <Name> ###      #  ***
                               (acres)                        ***
*** Subbasin 1a to RCHRES 1 (fig. 29)
                            (241.95 ac - 226.74ac per,  15.21 ac imp)
PERLND   1                       20.64     RCHRES   1      1
PERLND   2                        0.30     RCHRES   1      1
PERLND   3                       10.66     RCHRES   1      1
PERLND   4                        5.28     RCHRES   1      1
PERLND   5                       11.63     RCHRES   1      1
PERLND   6                        2.49     RCHRES   1      1
PERLND   7                       28.44     RCHRES   1      1
PERLND   8                        8.91     RCHRES   1      1
PERLND   9                       11.15     RCHRES   1      1
PERLND  10                       13.69     RCHRES   1      1
PERLND  11                        1.62     RCHRES   1      1
PERLND  12                        4.84     RCHRES   1      1
PERLND  13                        1.12     RCHRES   1      1
PERLND  14                        9.96     RCHRES   1      1
PERLND  15                       17.95     RCHRES   1      1
PERLND  16                        8.67     RCHRES   1      1
PERLND  17                        2.62     RCHRES   1      1

IMPLND   1                        5.00     RCHRES   1      2
IMPLND   2                        0.07     RCHRES   1      2

*** Subbasin 1a to Pond RCHRES V23

PERLND   1                       28.26     RCHRES  23      1
PERLND   2                        0.81     RCHRES  23      1
PERLND   3                        0.10     RCHRES  23      1
PERLND   9                        8.83     RCHRES  23      1
PERLND  10                       13.00     RCHRES  23      1
PERLND  11                        0.60     RCHRES  23      1
PERLND  12                        0.45     RCHRES  23      1
PERLND  13                        0.02     RCHRES  23      1
PERLND  14                        1.59     RCHRES  23      1
PERLND  15                       10.24     RCHRES  23      1
PERLND  16                        0.66     RCHRES  23      1
PERLND  17                        2.21     RCHRES  23      1

IMPLND   1                       10.14     RCHRES  23      2

*** Subbasin 1b to RCHRES 1 (318.09 ac)
PERLND   7                        4.75     RCHRES   1      1
PERLND   8                        2.89     RCHRES   1      1
PERLND   9                       68.46     RCHRES   1      1
PERLND  10                       25.46     RCHRES   1      1
PERLND  11                        3.92     RCHRES   1      1
PERLND  12                       27.96     RCHRES   1      1
PERLND  13                       16.84     RCHRES   1      1
PERLND  14                       15.50     RCHRES   1      1
PERLND  15                        5.64     RCHRES   1      1
PERLND  16                       13.34     RCHRES   1      1
PERLND  17                       57.54     RCHRES   1      1

IMPLND   1                       28.76     RCHRES   1      2
IMPLND   2                       47.03     RCHRES   1      2

*** Subbasin 1c to RCHRES 1 (185.89 ac)
PERLND   5                        1.18     RCHRES   1      1
PERLND   7                       21.84     RCHRES   1      1
PERLND   8                        4.10     RCHRES   1      1
PERLND   9                       14.47     RCHRES   1      1
PERLND  10                        3.40     RCHRES   1      1
PERLND  11                        0.79     RCHRES   1      1
PERLND  12                       18.92     RCHRES   1      1
PERLND  13                        5.52     RCHRES   1      1
PERLND  14                        4.68     RCHRES   1      1
PERLND  15                       20.34     RCHRES   1      1
PERLND  16                       17.64     RCHRES   1      1
PERLND  17                       22.82     RCHRES   1      1

IMPLND   1                       16.57     RCHRES   1      2
IMPLND   2                       33.62     RCHRES   1      2
```

```
*** Subbasin 2a to RCHRES 2 (242.53 ac)
PERLND   1                        2.68     RCHRES   2      1
PERLND   2                        0.05     RCHRES   2      1
PERLND   3                        0.68     RCHRES   2      1
PERLND   5                        6.46     RCHRES   2      1
PERLND   6                        3.36     RCHRES   2      1
PERLND   9                        4.97     RCHRES   2      1
PERLND  10                       15.26     RCHRES   2      1
PERLND  11                       12.20     RCHRES   2      1
PERLND  12                       11.07     RCHRES   2      1
PERLND  13                       20.94     RCHRES   2      1
PERLND  14                        6.25     RCHRES   2      1
PERLND  15                        3.85     RCHRES   2      1
PERLND  17                       67.78     RCHRES   2      1

IMPLND   1                        2.19     RCHRES   2      2
IMPLND   2                       84.79     RCHRES   2      2

*** Subbasin 2b to RCHRES 2 (475.93 ac)
PERLND   9                        5.47     RCHRES   2      1
PERLND  10                        6.48     RCHRES   2      1
PERLND  11                        2.55     RCHRES   2      1
PERLND  12                       36.21     RCHRES   2      1
PERLND  13                       34.31     RCHRES   2      1
PERLND  14                       13.55     RCHRES   2      1
PERLND  15                       25.16     RCHRES   2      1
PERLND  16                       76.84     RCHRES   2      1
PERLND  17                      109.11     RCHRES   2      1

IMPLND   1                       20.49     RCHRES   2      2
IMPLND   2                      145.76     RCHRES   2      2

*** Subbasin 3  to RCHRES 3 (986.80 ac)
PERLND   1                        0.04     RCHRES   3      1
PERLND   2                        0.03     RCHRES   3      1
PERLND   5                        0.92     RCHRES   3      1
PERLND   6                        0.41     RCHRES   3      1
PERLND   7                        0.16     RCHRES   3      1
PERLND   9                       29.90     RCHRES   3      1
PERLND  10                       86.81     RCHRES   3      1
PERLND  11                       15.50     RCHRES   3      1
PERLND  12                       54.69     RCHRES   3      1
PERLND  13                       30.55     RCHRES   3      1
PERLND  14                        3.39     RCHRES   3      1
PERLND  15                      224.80     RCHRES   3      1
PERLND  16                      279.21     RCHRES   3      1
PERLND  17                       89.83     RCHRES   3      1

IMPLND   1                      117.21     RCHRES   3      2
IMPLND   2                       53.35     RCHRES   3      2

*** Subbasin 4  to RCHRES 4 (29.02 ac)
PERLND   9                        0.29     RCHRES   4      1
PERLND  10                        4.52     RCHRES   4      1
PERLND  11                       10.93     RCHRES   4      1
PERLND  12                        0.19     RCHRES   4      1
PERLND  13                        0.22     RCHRES   4      1
PERLND  15                        7.64     RCHRES   4      1
PERLND  17                        1.74     RCHRES   4      1

IMPLND   1                        1.64     RCHRES   4      2
IMPLND   2                        1.85     RCHRES   4      2

*** Subbasin 5a to RCHRES 5 (356.37 ac)
PERLND   1                        5.18     RCHRES   5      1
PERLND   2                        0.28     RCHRES   5      1
PERLND   3                        0.40     RCHRES   5      1
PERLND   5                       18.58     RCHRES   5      1
PERLND   6                       37.65     RCHRES   5      1
PERLND   7                       48.28     RCHRES   5      1
PERLND   9                       21.14     RCHRES   5      1
PERLND  10                        9.57     RCHRES   5      1
PERLND  11                       19.40     RCHRES   5      1
PERLND  12                       26.23     RCHRES   5      1
PERLND  13                       22.50     RCHRES   5      1
PERLND  15                        9.34     RCHRES   5      1
PERLND  16                       10.98     RCHRES   5      1
PERLND  17                       51.76     RCHRES   5      1

IMPLND   1                        8.34     RCHRES   5      2
IMPLND   2                       66.74     RCHRES   5      2
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*** Subbasin 5b to RCHRES 5 (51.37 ac)
PERLND   9                      2.67     RCHRES   5      1
PERLND  10                      4.48     RCHRES   5      1
PERLND  11                     15.27     RCHRES   5      1
PERLND  12                      1.93     RCHRES   5      1
PERLND  13                      1.02     RCHRES   5      1
PERLND  15                     12.51     RCHRES   5      1
PERLND  16                      1.16     RCHRES   5      1
PERLND  17                      4.87     RCHRES   5      1

IMPLND   1                      6.71     RCHRES   5      2
IMPLND   2                      0.75     RCHRES   5      2

*** Subbasin 6a to RCHRES 6 (437.52 ac)
PERLND   1                     15.24     RCHRES   6      1
PERLND   2                      9.54     RCHRES   6      1
PERLND   3                     22.28     RCHRES   6      1
PERLND   5                     40.58     RCHRES   6      1
PERLND   6                     82.40     RCHRES   6      1
PERLND   7                     60.48     RCHRES   6      1
PERLND   8                      4.97     RCHRES   6      1
PERLND   9                      2.31     RCHRES   6      1
PERLND  10                     14.87     RCHRES   6      1
PERLND  11                     23.29     RCHRES   6      1
PERLND  12                     29.33     RCHRES   6      1
PERLND  13                     22.03     RCHRES   6      1
PERLND  15                     19.24     RCHRES   6      1
PERLND  16                      5.61     RCHRES   6      1
PERLND  17                     35.27     RCHRES   6      1

IMPLND   1                     12.11     RCHRES   6      2
IMPLND   2                     37.97     RCHRES   6      2

*** Subbasin 6b to RCHRES 6 (119.67 ac)
PERLND   1                      4.32     RCHRES   6      1
PERLND   2                      8.65     RCHRES   6      1
PERLND   3                     15.18     RCHRES   6      1
PERLND   9                      4.16     RCHRES   6      1
PERLND  10                      3.24     RCHRES   6      1
PERLND  11                     18.36     RCHRES   6      1
PERLND  12                      5.39     RCHRES   6      1
PERLND  13                      3.99     RCHRES   6      1
PERLND  15                      9.89     RCHRES   6      1
PERLND  16                      8.45     RCHRES   6      1
PERLND  17                     18.96     RCHRES   6      1

IMPLND   1                      7.80     RCHRES   6      2
IMPLND   2                     11.28     RCHRES   6      2

**** Ruckriegel Parkway (Upper Gage) at outflow RCHRES 6--------------------

*** Subbasin 7  to RCHRES 7 (10.45 ac)
PERLND   1                      0.65     RCHRES   7      1
PERLND   2                      2.76     RCHRES   7      1
PERLND   3                      0.86     RCHRES   7      1
PERLND   9                      0.35     RCHRES   7      1
PERLND  10                      0.68     RCHRES   7      1
PERLND  11                      0.93     RCHRES   7      1
PERLND  13                      0.16     RCHRES   7      1
PERLND  14                      0.03     RCHRES   7      1
PERLND  15                      2.58     RCHRES   7      1
PERLND  16                      0.25     RCHRES   7      1

IMPLND   1                      1.20     RCHRES   7      2

*** Subbasin 8a to RCHRES 8 (253.07 ac)
PERLND   1                      5.12     RCHRES   8      1
PERLND   2                     28.42     RCHRES   8      1
PERLND   3                     17.79     RCHRES   8      1
PERLND   4                      6.62     RCHRES   8      1
PERLND   9                      6.81     RCHRES   8      1
PERLND  10                      3.68     RCHRES   8      1
PERLND  11                     11.45     RCHRES   8      1
PERLND  12                      9.07     RCHRES   8      1
PERLND  13                      5.88     RCHRES   8      1
PERLND  14                      3.95     RCHRES   8      1
PERLND  15                      8.72     RCHRES   8      1
PERLND  16                      6.64     RCHRES   8      1
PERLND  17                      6.83     RCHRES   8      1
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IMPLND   1                        4.51     RCHRES   8       2
IMPLND   2                        9.76     RCHRES   8       2

*** Subbasin 8a to Pond RCHRES V22
PERLND   1                        7.20     RCHRES  22       1
PERLND   2                        7.17     RCHRES  22       1
PERLND   3                       28.11     RCHRES  22       1
PERLND   4                        0.26     RCHRES  22       1
PERLND   9                        2.62     RCHRES  22       1
PERLND  10                        7.00     RCHRES  22       1
PERLND  11                        1.72     RCHRES  22       1
PERLND  12                       22.49     RCHRES  22       1
PERLND  13                       12.08     RCHRES  22       1
PERLND  14                        0.19     RCHRES  22       1
PERLND  15                        3.94     RCHRES  22       1
PERLND  16                        9.25     RCHRES  22       1
PERLND  17                        6.66     RCHRES  22       1

IMPLND   1                        2.89     RCHRES  22       2
IMPLND   2                        6.24     RCHRES  22       2

*** Subbasin 8b to RCHRES 8 (325.43 ac)
PERLND   1                       11.42     RCHRES   8       1
PERLND   2                       10.98     RCHRES   8       1
PERLND   3                       17.12     RCHRES   8       1
PERLND   4                        0.91     RCHRES   8       1
PERLND   9                        8.19     RCHRES   8       1
PERLND  10                       20.53     RCHRES   8       1
PERLND  11                       28.78     RCHRES   8       1
PERLND  12                       30.41     RCHRES   8       1
PERLND  13                       10.02     RCHRES   8       1
PERLND  14                        2.00     RCHRES   8       1
PERLND  15                       54.74     RCHRES   8       1
PERLND  16                       45.72     RCHRES   8       1
PERLND  17                       27.26     RCHRES   8       1

IMPLND   1                       44.47     RCHRES   8       2
IMPLND   2                       12.88     RCHRES   8       2

*** Subbasin 8c to RCHRES 8 (116.57 ac)
PERLND   5                        4.04     RCHRES   8       1
PERLND   6                        3.57     RCHRES   8       1
PERLND   7                        0.38     RCHRES   8       1
PERLND   9                       18.81     RCHRES   8       1
PERLND  10                        4.44     RCHRES   8       1
PERLND  11                       42.10     RCHRES   8       1
PERLND  12                        5.63     RCHRES   8       1
PERLND  13                        6.04     RCHRES   8       1
PERLND  14                        3.64     RCHRES   8       1
PERLND  15                       13.94     RCHRES   8       1
PERLND  16                        6.96     RCHRES   8       1
PERLND  17                        1.06     RCHRES   8       1

IMPLND   1                        5.96     RCHRES   8       2

*** Subbasin 9a to RCHRES 9 (969.95 ac)
PERLND   1                        0.63     RCHRES   9       1
PERLND   2                        0.69     RCHRES   9       1
PERLND   3                        9.28     RCHRES   9       1
PERLND   5                       11.17     RCHRES   9       1
PERLND   6                       42.87     RCHRES   9       1
PERLND   7                        0.32     RCHRES   9       1
PERLND   8                        3.79     RCHRES   9       1
PERLND  10                       50.22     RCHRES   9       1
PERLND  11                      203.90     RCHRES   9       1
PERLND  12                      234.84     RCHRES   9       1
PERLND  13                       93.18     RCHRES   9       1
PERLND  14                        8.60     RCHRES   9       1
PERLND  15                       21.74     RCHRES   9       1
PERLND  16                       31.22     RCHRES   9       1
PERLND  17                        1.83     RCHRES   9       1

IMPLND   1                       16.92     RCHRES   9       2
IMPLND   2                        0.22     RCHRES   9       2
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*** Subbasin 9a to Pond RCHRES V21
PERLND   2                        0.19     RCHRES  21      1
PERLND   3                        3.81     RCHRES  21      1
PERLND   5                        0.01     RCHRES  21      1
PERLND   9                        4.24     RCHRES  21      1
PERLND  10                       15.57     RCHRES  21      1
PERLND  11                       27.50     RCHRES  21      1
PERLND  12                      105.16     RCHRES  21      1
PERLND  13                       29.30     RCHRES  21      1
PERLND  15                        4.77     RCHRES  21      1
PERLND  16                       33.21     RCHRES  21      1
PERLND  17                        0.93     RCHRES  21      1

IMPLND   1                       13.84     RCHRES  21      2

*** Subbasin 9b to RCHRES 9 (699.96 ac)
                                           (Saratoga Woods in this subbasin)
PERLND   5                        3.21     RCHRES   9      1
PERLND   6                       14.67     RCHRES   9      1
PERLND   8                        9.86     RCHRES   9      1
PERLND   9                       35.19     RCHRES   9      1
PERLND  10                       33.21     RCHRES   9      1
PERLND  11                      115.95     RCHRES   9      1
PERLND  12                       14.40     RCHRES   9      1
PERLND  13                        3.17     RCHRES   9      1
PERLND  14                       73.65     RCHRES   9      1
PERLND  15                      154.06     RCHRES   9      1
PERLND  16                       23.23     RCHRES   9      1

IMPLND   1                       36.67     RCHRES   9      2

*** Subbasin 9b to Pond RCHRES V20
PERLND   3                        0.32     RCHRES  20      1
PERLND   5                        2.93     RCHRES  20      1
PERLND   6                       13.06     RCHRES  20      1
PERLND   8                        2.75     RCHRES  20      1
PERLND   9                       66.66     RCHRES  20      1
PERLND  10                       20.97     RCHRES  20      1
PERLND  11                       35.70     RCHRES  20      1
PERLND  12                       14.62     RCHRES  20      1
PERLND  13                        0.70     RCHRES  20      1
PERLND  14                        4.59     RCHRES  20      1
PERLND  15                       13.10     RCHRES  20      1
PERLND  16                        3.38     RCHRES  20      1

IMPLND   1                        3.91     RCHRES  20      2

*** Subbasin 10a to Pond RCHRES V19 (702.90 ac)
PERLND   5                       17.00     RCHRES  19      1
PERLND   6                       27.32     RCHRES  19      1
PERLND   7                       19.01     RCHRES  19      1
PERLND   8                        7.15     RCHRES  19      1
PERLND  10                       61.99     RCHRES  19      1
PERLND  11                      147.16     RCHRES  19      1
PERLND  12                       49.16     RCHRES  19      1
PERLND  13                       37.41     RCHRES  19      1
PERLND  14                       18.30     RCHRES  19      1
PERLND  15                      144.14     RCHRES  19      1
PERLND  16                      110.43     RCHRES  19      1
PERLND  17                       37.50     RCHRES  19      1

IMPLND   1                       26.33     RCHRES  19      2

*** Subbasin 10b to RCHRES 10 (803.15 ac)
PERLND   1                        1.23     RCHRES  10      1
PERLND   2                       14.32     RCHRES  10      1
PERLND   3                        0.08     RCHRES  10      1
PERLND   4                       22.12     RCHRES  10      1
PERLND   5                        4.29     RCHRES  10      1
PERLND   6                       25.92     RCHRES  10      1
PERLND   7                        0.88     RCHRES  10      1
PERLND   8                       33.88     RCHRES  10      1
PERLND   9                        2.29     RCHRES  10      1
PERLND  10                        7.95     RCHRES  10      1
PERLND  11                       26.00     RCHRES  10      1
PERLND  12                        4.38     RCHRES  10      1
PERLND  13                        3.74     RCHRES  10      1
PERLND  14                       46.72     RCHRES  10      1
PERLND  15                       19.79     RCHRES  10      1
PERLND  16                       15.86     RCHRES  10      1
IMPLND   1                        7.23     RCHRES  10      2
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*** Subbasin 10b to Pond RCHRES V18
PERLND   1                      21.31     RCHRES  18      1
PERLND   2                      36.56     RCHRES  18      1
PERLND   3                      50.50     RCHRES  18      1
PERLND   4                       5.61     RCHRES  18      1
PERLND   5                       6.05     RCHRES  18      1
PERLND   6                      36.19     RCHRES  18      1
PERLND   7                      43.73     RCHRES  18      1
PERLND   8                      14.45     RCHRES  18      1
PERLND   9                     112.20     RCHRES  18      1
PERLND  10                      25.07     RCHRES  18      1
PERLND  11                      68.31     RCHRES  18      1
PERLND  12                      18.67     RCHRES  18      1
PERLND  13                      10.56     RCHRES  18      1
PERLND  14                      22.49     RCHRES  18      1
PERLND  15                      53.35     RCHRES  18      1
PERLND  16                      17.20     RCHRES  18      1

IMPLND   1                      24.22     RCHRES  18      2


*** Gelhaus Lane (Lower Gage) at exit to RCHRES 10-----------------------------

*** Subbasin 11 to RCHRES 11 (756.41 ac)
PERLND   1                      27.31     RCHRES  11      1
PERLND   2                      91.05     RCHRES  11      1
PERLND   3                      82.08     RCHRES  11      1
PERLND   4                      12.82     RCHRES  11      1
PERLND   5                       3.45     RCHRES  11      1
PERLND   6                      49.82     RCHRES  11      1
PERLND   7                      14.45     RCHRES  11      1
PERLND   8                      58.63     RCHRES  11      1
PERLND   9                      17.44     RCHRES  11      1
PERLND  10                      11.04     RCHRES  11      1
PERLND  11                      60.82     RCHRES  11      1
PERLND  12                      32.72     RCHRES  11      1
PERLND  13                      12.81     RCHRES  11      1
PERLND  14                      41.58     RCHRES  11      1
PERLND  15                      17.86     RCHRES  11      1
PERLND  16                      17.07     RCHRES  11      1

IMPLND   1                       9.77     RCHRES  11      2

 *** Subbasin 11 to Pond RCHRES V17
PERLND   1                       5.29     RCHRES  17      1
PERLND   2                      17.93     RCHRES  17      1
PERLND   3                      33.37     RCHRES  17      1
PERLND   5                       2.15     RCHRES  17      1
PERLND   6                      12.77     RCHRES  17      1
PERLND   8                      11.95     RCHRES  17      1
PERLND   9                       2.84     RCHRES  17      1
PERLND  10                      13.59     RCHRES  17      1
PERLND  11                      40.01     RCHRES  17      1
PERLND  12                      15.55     RCHRES  17      1
PERLND  13                       2.47     RCHRES  17      1
PERLND  14                      13.75     RCHRES  17      1
PERLND  15                      13.18     RCHRES  17      1
PERLND  16                       6.74     RCHRES  17      1

IMPLND   1                       4.10     RCHRES  17      2

*** Subbasin 12 to RCHRES 12 (284.78 ac)
PERLND   1                       1.70     RCHRES  12      1
PERLND   2                      46.47     RCHRES  12      1
PERLND   3                      23.29     RCHRES  12      1
PERLND   4                      42.30     RCHRES  12      1
PERLND   5                       0.19     RCHRES  12      1
PERLND   6                       0.14     RCHRES  12      1
PERLND   8                       0.19     RCHRES  12      1
PERLND   9                       1.02     RCHRES  12      1
PERLND  10                       2.17     RCHRES  12      1
PERLND  11                      20.00     RCHRES  12      1
PERLND  12                       0.55     RCHRES  12      1
PERLND  13                       1.63     RCHRES  12      1
PERLND  14                      31.67     RCHRES  12      1
PERLND  15                       6.14     RCHRES  12      1
PERLND  16                       5.66     RCHRES  12      1

IMPLND   1                       5.36     RCHRES  12      2
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*** Subbasin 12 to Pond RCHRES V16
PERLND   1                        0.31     RCHRES  16      1
PERLND   2                        0.66     RCHRES  16      1
PERLND   3                        0.02     RCHRES  16      1
PERLND   4                        2.40     RCHRES  16      1
PERLND   5                        2.74     RCHRES  16      1
PERLND   6                        3.55     RCHRES  16      1
PERLND   7                        0.06     RCHRES  16      1
PERLND   8                        3.31     RCHRES  16      1
PERLND   9                        2.64     RCHRES  16      1
PERLND  10                        2.57     RCHRES  16      1
PERLND  11                       14.70     RCHRES  16      1
PERLND  12                        5.44     RCHRES  16      1
PERLND  13                        2.19     RCHRES  16      1
PERLND  14                       18.72     RCHRES  16      1
PERLND  15                        3.48     RCHRES  16      1
PERLND  16                        3.72     RCHRES  16      1

IMPLND   1                        2.30     RCHRES  16      2

*** Subbasin 13 to RCHRES 13 (1,401.30ac)
PERLND   1                       34.70     RCHRES  13      1
PERLND   2                       97.30     RCHRES  13      1
PERLND   3                       38.38     RCHRES  13      1
PERLND   4                       72.98     RCHRES  13      1
PERLND   5                       82.05     RCHRES  13      1
PERLND   6                      335.34     RCHRES  13      1
PERLND   7                        1.83     RCHRES  13      1
PERLND   8                      102.39     RCHRES  13      1
PERLND   9                        4.34     RCHRES  13      1
PERLND  10                       31.63     RCHRES  13      1
PERLND  11                       84.09     RCHRES  13      1
PERLND  12                        6.28     RCHRES  13      1
PERLND  13                        1.04     RCHRES  13      1
PERLND  14                       11.41     RCHRES  13      1
PERLND  15                       30.84     RCHRES  13      1
PERLND  16                        5.29     RCHRES  13      1
PERLND  17                        0.22     RCHRES  13      1

IMPLND   1                       32.85     RCHRES  13      2

*** Subbasin 13 to Pond RCHRES V15
PERLND   1                       16.20     RCHRES  15      1
PERLND   2                       35.74     RCHRES  15      1
PERLND   3                       21.63     RCHRES  15      1
PERLND   4                        6.91     RCHRES  15      1
PERLND   5                        7.69     RCHRES  15      1
PERLND   6                       20.76     RCHRES  15      1
PERLND   8                        0.01     RCHRES  15      1
PERLND  10                       77.56     RCHRES  15      1
PERLND  11                      174.75     RCHRES  15      1
PERLND  12                       20.40     RCHRES  15      1
PERLND  13                        2.95     RCHRES  15      1
PERLND  14                        1.42     RCHRES  15      1
PERLND  15                       30.07     RCHRES  15      1
PERLND  16                        5.04     RCHRES  15      1

IMPLND   1                        7.21     RCHRES  15      2

*** Subbasin 14 to RCHRES 14 (837.85 ac)
PERLND   1                       34.12     RCHRES  14      1
PERLND   2                      138.32     RCHRES  14      1
PERLND   3                       54.74     RCHRES  14      1
PERLND   4                      127.54     RCHRES  14      1
PERLND   5                       15.21     RCHRES  14      1
PERLND   6                      217.48     RCHRES  14      1
PERLND   7                        7.70     RCHRES  14      1
PERLND   8                      176.23     RCHRES  14      1
PERLND  10                        1.47     RCHRES  14      1
PERLND  11                        9.41     RCHRES  14      1
PERLND  12                       15.91     RCHRES  14      1
PERLND  13                        9.25     RCHRES  14      1
PERLND  14                        5.39     RCHRES  14      1
PERLND  15                        9.04     RCHRES  14      1
PERLND  16                        7.85     RCHRES  14      1

IMPLND   1                        8.19     RCHRES  14      2
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***  channel linkages
RCHRES  23                       1.00     RCHRES   1      4
RCHRES   1                       1.00     RCHRES   2      4
RCHRES   2                       1.00     RCHRES   4      4
RCHRES   3                       1.00     RCHRES   4      4
RCHRES   4                       1.00     RCHRES   5      5
RCHRES   5                       1.00     RCHRES   6      5
RCHRES   6                       1.00     RCHRES   7      5
RCHRES   7                       1.00     RCHRES   8      5
RCHRES  22                       1.00     RCHRES   8      4
RCHRES   8                       1.00     RCHRES   9      5
RCHRES  21                       1.00     RCHRES   9      4
RCHRES  20                       1.00     RCHRES   9      4
RCHRES   9                       1.00     RCHRES  10      5
RCHRES  19                       1.00     RCHRES  10      4
RCHRES  18                       1.00     RCHRES  10      4
RCHRES  10                       1.00     RCHRES  12      5
RCHRES  17                       1.00     RCHRES  11      4
RCHRES  16                       1.00     RCHRES  12      4
RCHRES  11                       1.00     RCHRES  12      4
RCHRES  12                       1.00     RCHRES  14      5
RCHRES  15                       1.00     RCHRES  13      4
RCHRES  13                       1.00     RCHRES  14      4

*** =========================================================
*** Copy operations for use with HSPEXP
*** ----------------------------------------------------------
****  Mfact is CUMULATIVE contributing area to:
***   Upper gage at Ruckriegel Parkway
****                          Area (ac)
PERLND   1                      76.36     COPY   100     90
PERLND   2                      19.66     COPY   100     90
PERLND   3                      49.30     COPY   100     90
PERLND   4                       5.28     COPY   100     90
PERLND   5                      79.35     COPY   100     90
PERLND   6                     126.31     COPY   100     90
PERLND   7                     163.95     COPY   100     90
PERLND   8                      20.87     COPY   100     90
PERLND   9                     173.82     COPY   100     90
PERLND  10                     200.78     COPY   100     90
PERLND  11                     124.43     COPY   100     90
PERLND  12                     217.21     COPY   100     90
PERLND  13                     159.06     COPY   100     90
PERLND  14                      54.92     COPY   100     90
PERLND  15                     366.60     COPY   100     90
PERLND  16                     422.56     COPY   100     90
PERLND  17                     464.51     COPY   100     90

IMPLND   1                     236.96     COPY   100     91
IMPLND   2                     483.21     COPY   100     91



***                            -------
***                     total  3445.14
*** ----------------------------------------------------------
***   Lower Gage at Gelhaus Lane
PERLND   1                     123.92     COPY   101     90
PERLND   2                     120.75     COPY   101     90
PERLND   3                     177.17     COPY   101     90
PERLND   4                      40.80     COPY   101     90
PERLND   5                     128.05     COPY   101     90
PERLND   6                     289.91     COPY   101     90
PERLND   7                     228.27     COPY   101     90
PERLND   8                      92.75     COPY   101     90
PERLND   9                     431.18     COPY   101     90
PERLND  10                     452.09     COPY   101     90
PERLND  11                     833.93     COPY   101     90
PERLND  12                     726.04     COPY   101     90
PERLND  13                     371.30     COPY   101     90
PERLND  14                     239.08     COPY   101     90
PERLND  15                     861.47     COPY   101     90
PERLND  16                     725.91     COPY   101     90
PERLND  17                     546.58     COPY   101     90
```

```
IMPLND   1                      425.11     COPY   101     91
IMPLND   2                      512.31     COPY   101     91


***                            -------
***                     total  7326.62
*** -------------------------------------------------------
***   DS at Seatonville Rd - Mouth
****                           Area (ac)
PERLND   1                      243.55     COPY   102     90
PERLND   2                      548.22     COPY   102     90
PERLND   3                      430.68     COPY   102     90
PERLND   4                      305.75     COPY   102     90
PERLND   5                      241.53     COPY   102     90
PERLND   6                      929.77     COPY   102     90
PERLND   7                      252.31     COPY   102     90
PERLND   8                      445.46     COPY   102     90
PERLND   9                      459.46     COPY   102     90
PERLND  10                      592.12     COPY   102     90
PERLND  11                     1237.71     COPY   102     90
PERLND  12                      822.89     COPY   102     90
PERLND  13                      403.64     COPY   102     90
PERLND  14                      363.02     COPY   102     90
PERLND  15                      972.08     COPY   102     90
PERLND  16                      777.28     COPY   102     90
PERLND  17                      546.80     COPY   102     90

IMPLND   1                      494.89     COPY   102     91
IMPLND   2                      512.31     COPY   102     91



***                             -------
***                     total  10579.47
***
***
*** ---------------------------------------------------------

*** "GW seepage" between Ruckriegel and Gelhaus gages
RCHRES   8                        1.00     COPY   105     95
RCHRES   9                        1.00     COPY   105     95
RCHRES  10                        1.00     COPY   105     95

*** GENER adds sus. and diss. PO4
RCHRES   6                        1.00     GENER    1     97
RCHRES  10                        1.00     GENER    2     97
RCHRES   8                        1.00     GENER    3     97
RCHRES  14                        1.00     GENER    4     97

**** Copy operation to check avg soil temps by land use type
***  the MFACT is the percent of PERLND area in each Land use class
PERLND   1                        0.16     COPY   106     96
PERLND   2                        0.36     COPY   106     96
PERLND   3                        0.28     COPY   106     96
PERLND   4                        0.20     COPY   106     96

PERLND   5                        0.13     COPY   107     96
PERLND   6                        0.50     COPY   107     96
PERLND   7                        0.13     COPY   107     96
PERLND   8                        0.24     COPY   107     96

PERLND   9                        0.14     COPY   108     96
PERLND  10                        0.15     COPY   108     96
PERLND  11                        0.31     COPY   108     96
PERLND  12                        0.21     COPY   108     96
PERLND  13                        0.10     COPY   108     96

PERLND  14                        0.09     COPY   108     96
PERLND  15                        0.42     COPY   109     96
PERLND  16                        0.34     COPY   109     96
PERLND  17                        0.24     COPY   109     96

END SCHEMATIC
```

```
******************************************************************************
***         MASS-LINK Block  4.6.4   page 574                                 ***
***         Specific TS transferred between operations                        ***
******************************************************************************
*** MFACT 0.08333333 = 1/12 ft/in (convert runoff in inches to ac-ft for routing

MASS-LINK

*** PERLND's  route water & QW  from pervious areas to channels  ---------------

  MASS-LINK        1
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> # #<-factor->strg <Name>                <Name> # #  ***

PERLND     PWATER PERO      0.08333333     RCHRES         INFLOW IVOL

   *** MFACT is the proportion of sand, silt, and clay
PERLND     SEDMNT SOSED     0.02           RCHRES         INFLOW ISED   1
PERLND     SEDMNT SOSED     0.38           RCHRES         INFLOW ISED   2
PERLND     SEDMNT SOSED     0.60           RCHRES         INFLOW ISED   3
   *** PO4 simulated as Agrchem
PERLND***  PHOS   TSP4S  1                 RCHRES         INFLOW NUIF1  4
PERLND***  PHOS   TSP4S  5                 RCHRES         INFLOW NUIF1  4
PERLND***  PHOS   SSP4S  3                 RCHRES         INFLOW NUIF1  4
PERLND***  PHOS   SEDP   2  0.01           RCHRES         INFLOW NUIF2  1 2
PERLND***  PHOS   SEDP   2  0.20           RCHRES         INFLOW NUIF2  2 2
PERLND***  PHOS   SEDP   2  0.79           RCHRES         INFLOW NUIF2  3 2
   *** PO4 simulated as PQUAL
PERLND     PQUAL  SOQO   1                 RCHRES         INFLOW NUIF1  4
PERLND     PQUAL  SOQS   1  0.01           RCHRES         INFLOW NUIF2  1 2
PERLND     PQUAL  SOQS   1  0.20           RCHRES         INFLOW NUIF2  2 2
PERLND     PQUAL  SOQS   1  0.79           RCHRES         INFLOW NUIF2  3 2

  END MASS-LINK    1


*** IMPLND's - route water & QW from impervious areas to channels ------------

  MASS-LINK        2
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
IMPLND     IWATER SURO      0.08333333     RCHRES         INFLOW IVOL

*** MFACT is the proportion of sand, silt, and clay
IMPLND     SOLIDS SOSLD     0.02           RCHRES         INFLOW ISED   1
IMPLND     SOLIDS SOSLD     0.38           RCHRES         INFLOW ISED   2
IMPLND     SOLIDS SOSLD     0.60           RCHRES         INFLOW ISED   3

*** sus. PO4 is porportioned: 1% on sand, 20% on silt, & 79% on clay
IMPLND     IQUAL  SOQO   1                 RCHRES         INFLOW NUIF1  4
IMPLND     IQUAL  SOQS   1  0.01           RCHRES         INFLOW NUIF2  1 2
IMPLND     IQUAL  SOQS   1  0.20           RCHRES         INFLOW NUIF2  2 2
IMPLND     IQUAL  SOQS   1  0.79           RCHRES         INFLOW NUIF2  3 2
  END MASS-LINK    2

*** RCHRES - route water & QW from channel to channel  with 1 outflow gate ----

  MASS-LINK        4
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
RCHRES     ROFLOW                  1.0     RCHRES         INFLOW
  *** NOTE: the above mass-link is equivalent to what follows since group
  ***         members are not specified all active members are targeted
RCHRES***  ROFLOW ROVOL            1.0     RCHRES         INFLOW IVOL
  ***      (1st mem# 1-sand, 2-silt, 3-clay, 4-total; 2nd mem#. 2- PO4)
RCHRES***  SEDTRN ROSED  1         1.0     RCHRES         INFLOW ISED   1
RCHRES***  SEDTRN ROSED  2         1.0     RCHRES         INFLOW ISED   2
RCHRES***  SEDTRN ROSED  3         1.0     RCHRES         INFLOW ISED   3
  ***(NUCF1 -diss 4-PO4;NUCF2 particulate 1-sand,2-silt,3-clay, 2nd mem# 2-PO4)
RCHRES***  NUTRX  NUCF1  4         1.0     RCHRES         INFLOW NUIF1  4
RCHRES***  NUTRX  NUCF2  1 2       1.0     RCHRES         INFLOW NUIF2  1 2
RCHRES***  NUTRX  NUCF2  2 2       1.0     RCHRES         INFLOW NUIF2  2 2
RCHRES***  NUTRX  NUCF2  3 2       1.0     RCHRES         INFLOW NUIF2  3 2
  END MASS-LINK    4
```

```
*** RCHRES's - route water & QW from channel to channel with 2 outflow gates --

  MASS-LINK        5
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
RCHRES     OFLOW  OVOL   2         1.0     RCHRES         INFLOW IVOL
  *** 2nd outflow gate - main flow
  *** route sus. sediments downstream                             )
RCHRES     SEDTRN OSED   2 1       1.0     RCHRES         INFLOW ISED   1
RCHRES     SEDTRN OSED   2 2       1.0     RCHRES         INFLOW ISED   2
RCHRES     SEDTRN OSED   2 3       1.0     RCHRES         INFLOW ISED   3
  *** route diss. and sus. PO4 downstream
RCHRES     NUTRX  NUCF9  2 4       1.0     RCHRES         INFLOW NUIF1  4
RCHRES     NUTRX  OSPO4  2 1       1.0     RCHRES         INFLOW NUIF2  1 2
RCHRES     NUTRX  OSPO4  2 2       1.0     RCHRES         INFLOW NUIF2  2 2
RCHRES     NUTRX  OSPO4  2 3       1.0     RCHRES         INFLOW NUIF2  3 2
  *** 1st outflow gate - "GW seepage"
  *** route sus. sediments downstream
RCHRES     SEDTRN OSED   1 1       1.0     RCHRES         INFLOW ISED   1
RCHRES     SEDTRN OSED   1 2       1.0     RCHRES         INFLOW ISED   2
RCHRES     SEDTRN OSED   1 3       1.0     RCHRES         INFLOW ISED   3
  *** route sus. PO4 downstream but not diss. PO4
RCHRES     NUTRX  OSPO4  1 1       1.0     RCHRES         INFLOW NUIF2  1 2
RCHRES     NUTRX  OSPO4  1 2       1.0     RCHRES         INFLOW NUIF2  2 2
RCHRES     NUTRX  OSPO4  1 3       1.0     RCHRES         INFLOW NUIF2  3 2
  END MASS-LINK    5

*** MASS-LINK for COPY operations for HSPEXP  --------------------------------

<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***

  MASS-LINK       90
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   4
PERLND     PWATER TAET                     COPY           INPUT  MEAN   5
PERLND     PWATER UZS                      COPY           INPUT  MEAN   6
PERLND     PWATER LZS                      COPY           INPUT  MEAN   7
  END MASS-LINK   90

  MASS-LINK       91
IMPLND     IWATER SURO                     COPY           INPUT  MEAN   1
IMPLND     IWATER PET                      COPY           INPUT  MEAN   4
IMPLND     IWATER IMPEV                    COPY           INPUT  MEAN   5
  END MASS-LINK   91

*** MASS LINK for other COPY operations -------------------------------------

***  Acummulate Channel loss to GW seepage to WDM file
***  NOTE GW Seepage loss is not routed to any other part of the watershed
  MASS-LINK       95
RCHRES     HYDR   O      1                 COPY           INPUT  MEAN   1
  END MASS-LINK   95

***  Soil temp. and sediment from PERLND's
  MASS-LINK       96
PERLND     PSTEMP SLTMP                    COPY           INPUT  MEAN   1
PERLND     PSTEMP ULTMP                    COPY           INPUT  MEAN   2
PERLND     PSTEMP LGTMP                    COPY           INPUT  MEAN   3
PERLND     SEDMNT SOSED                    COPY           INPUT  MEAN   4
PERLND     SEDMNT DETS                     COPY           INPUT  MEAN   5
  END MASS-LINK   96

*** Mass-link for GENER operation to calc total PO4 load -------------------
  MASS-LINK       97
RCHRES     NUTRX  NUCF9  2 4               GENER          INPUT  ONE
RCHRES     NUTRX  NUCF2  4 2               GENER          INPUT  TWO
  END MASS-LINK   97

END MASS-LINK
```

```
******************************************************************************
***       FTABLES Block  4.5     page 565                                   ***
***       Describes functional relation between area-storage-discharge      ***
******************************************************************************
FTABLES
  FTABLE     11
 ROWS COLS ***   (RCHRES 14)            Chenoweth #11
   20    4
     DEPTH      AREA    VOLUME     DISCH     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (CFS) ***
   494.800     0.000     0.000      0.00
   495.000     0.882     0.305      2.00
   495.500     3.086     1.068      7.00
   496.000     7.646     3.152     24.00
   496.500     9.457     5.567     54.00
   497.000    10.661     8.499     97.00
   497.500    11.526    11.609    154.00
   498.000    13.358    15.446    223.00
   498.500    14.790    17.936    268.00
   499.000    15.852    20.643    324.00
   499.500    19.937    27.755    462.00
   500.000    25.428    38.696    698.00
   500.500    31.935    57.742   1132.00
   501.000    41.677    78.785   1588.00
   501.500    54.226   111.002   2301.00
   502.000    62.733   146.911   3135.00
   502.500    69.885   186.059   4134.00
   503.000    75.604   228.889   5318.00
   504.000    85.176   322.198   8206.00
   505.000    91.923   423.101  11796.00
  END FTABLE 11

  FTABLE     12
 ROWS COLS ***  (RCHRES 13)         Shinks Branch #12
   16    4
     DEPTH      AREA    VOLUME     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS) ***
   530.000     0.000     0.000      0.00
   530.100     0.476     0.100      1.00
   530.600     3.846     1.785     27.00
   531.100     5.868     5.246    114.00
   531.600     9.260    10.194    256.00
   532.100    14.240    15.703    418.00
   532.600    18.830    27.779    804.00
   533.100    24.827    43.473   1347.00
   533.600    29.038    61.919   2032.00
   534.100    34.437    83.052   2859.00
   534.600    38.468   106.240   3830.00
   535.100    41.025   130.123   4931.00
   535.600    42.768   154.281   6158.00
   536.100    44.081   179.091   7534.00
   536.600    45.626   204.657   9034.00
   537.100    46.673   230.240  10651.00
  END FTABLE 12

  FTABLE     13
 ROWS COLS ***   (RCHRES 12)           Chenoweth #13
   20    4
     DEPTH      AREA    VOLUME     DISCH     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (CFS) ***
   524.000     0.000     0.000      0.00
   524.200     0.672     0.338      7.20
   524.500     1.679     0.846     18.00
   525.000     2.491     2.101     64.00
   525.500     2.849     3.445    132.00
   526.000     3.448     4.997    220.00
   526.500     4.391     6.808    325.00
   527.000     5.556     9.078    448.00
   527.500     6.636    11.508    588.00
   528.000     7.953    14.771    797.00
   528.500     9.515    18.558   1038.00
   529.000    11.403    24.020   1390.00
   529.500    13.584    31.265   1862.00
   530.000    15.530    40.031   2416.00
   530.500    17.200    49.596   3070.00
   531.000    18.858    59.783   3811.00
   531.500    19.949    69.721   4627.00
   532.500    21.503    90.044   6495.00
   533.500    22.637   111.139   8671.00
   534.500    23.802   130.456  10787.00
  END FTABLE 13
```

```
  FTABLE     14
 ROWS COLS ***   (RCHRES 11)   Razor Branch #14
   15    4
     DEPTH      AREA    VOLUME     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS) ***
   536.000     0.000     0.000      0.00
   536.200     1.842     0.689     12.00
   536.700     4.163     3.716    102.00
   537.200     6.321     7.950    254.00
   537.700     8.460    13.017    461.00
   538.200    10.931    19.071    718.00
   538.700    14.808    32.868   1342.00
   539.200    16.934    43.068   1860.00
   539.700    18.795    53.838   2450.00
   540.200    20.324    63.911   3040.00
   540.700    21.574    73.570   3642.00
   541.200    22.780    84.814   4380.00
   541.700    23.970    96.668   5198.00
   542.200    25.343   110.215   6169.00
   542.700    26.712   127.164   7458.00
  END FTABLE 14

  FTABLE     21
 ROWS COLS ***    (RCHRES 10)           Chenoweth #21
   20    4
     DEPTH      AREA    VOLUME     DISCH     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (CFS) ***
   536.000     0.000     0.000      0.00
   536.100     0.757     0.046      0.60
   536.500     0.787     0.228      3.00
   537.000     2.862     1.326     24.00
   537.500     4.599     3.335     81.00
   538.000     5.739     5.846    172.00
   538.500     7.501     9.244    306.00
   539.000    10.143    13.677    486.00
   539.500    12.762    19.057    714.00
   540.000    15.064    25.044    989.00
   540.500    17.737    32.260   1313.00
   541.000    20.690    42.531   1784.00
   541.500    23.445    53.823   2328.00
   542.000    25.426    65.646   2964.00
   542.500    28.206    79.423   3699.00
   543.000    30.145    93.722   4539.00
   543.500    32.067   108.791   5466.00
   544.000    34.085   125.233   6509.00
   545.000    37.268   160.216   8938.00
   545.500    39.377   179.196  10290.00
  END FTABLE 21

  FTABLE     23
 ROWS COLS ***     (RCHRES 9)           Chenoweth #23
   20    4
     DEPTH      AREA    VOLUME     DISCH     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (CFS) ***
   560.100     0.000     0.000      0.00
   560.200     0.260     0.087      0.75
   560.500     1.039     0.351      3.00
   561.000     4.729     2.518     28.00
   561.500     7.136     5.688     84.00
   562.000     8.851    10.027    182.00
   562.500    10.955    15.441    321.00
   563.000    17.026    23.290    494.00
   563.500    23.454    31.320    657.00
   564.000    27.448    41.245    887.00
   564.500    32.216    55.357   1223.00
   565.000    36.995    74.639   1724.00
   565.500    44.557    98.209   2344.00
   566.000    47.789   123.228   3097.00
   566.500    50.803   151.146   4001.00
   567.000    53.674   180.548   5018.00
   567.500    56.234   210.879   6141.00
   568.000    58.477   241.964   7368.00
   568.500    60.379   273.623   8699.00
   569.000    62.134   305.930  10126.00
  END FTABLE 23
```

```
  FTABLE     25
 ROWS COLS ***    (RCHRES 8)            Chenoweth #25
   20    4
     DEPTH      AREA    VOLUME     DISCH     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (CFS) ***
   580.000     0.000     0.000      0.00
   580.100     0.470     0.118      4.60
   580.500     1.176     0.592     23.00
   581.000     1.890     1.575     80.00
   581.500     2.617     2.858    171.00
   582.000     3.430     4.300    290.00
   582.500     4.226     6.143    441.00
   583.000     5.534     8.237    619.00
   583.500     6.723    10.676    821.00
   584.000     8.200    13.914   1068.00
   584.500     9.444    17.178   1329.00
   585.000    10.308    20.643   1635.00
   585.500    11.103    24.489   1993.00
   586.000    11.813    28.702   2405.00
   586.500    12.399    33.300   2890.00
   587.000    12.911    38.152   3431.00
   588.000    13.957    48.431   4653.00
   589.000    15.256    60.102   6129.00
   590.000    16.156    72.122   7818.00
   591.000    16.915    85.784   9915.00
  END FTABLE 25

  FTABLE     28
 ROWS COLS ***   (RCHRES 7)    Chenoweth #28
   20    4
     DEPTH      AREA    VOLUME     DISCH     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (cfs) ***
   590.000     0.000     0.000      0.00
   590.100     0.049     0.022      2.00
   590.500     0.245     0.109     10.00
   591.000     0.408     0.321     43.00
   591.500     0.503     0.565     95.00
   592.000     0.607     0.849    163.00
   592.500     0.705     1.172    249.00
   593.000     0.923     1.629    367.00
   593.500     1.089     2.120    499.00
   594.000     1.366     2.693    644.00
   594.500     1.704     3.439    820.00
   595.000     1.895     4.311   1045.00
   595.500     2.060     5.239   1300.00
   596.000     2.242     6.205   1575.00
   597.000     2.807     8.518   2216.00
   598.000     3.317    11.541   3117.00
   599.000     3.830    15.165   4283.00
   600.000     4.155    19.386   5823.00
   601.000     4.535    24.057   7633.00
   601.500     4.668    26.435   8637.00
  END FTABLE 28

  FTABLE     31
 ROWS COLS ***   (RCHRES 6)    Chenoweth #31
   20    4
     DEPTH      AREA    VOLUME     DISCH     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (cfs) ***
   594.000     0.000     0.000      0.00
   594.100     0.252     0.103      2.30
   594.300     0.758     0.309      7.00
   594.800     1.291     1.007     35.00
   595.300     1.668     1.893     83.00
   595.800     2.089     2.966    148.00
   596.300     2.590     4.502    246.00
   596.800     3.268     6.168    359.00
   597.300     3.706     7.984    488.00
   597.800     4.352    10.223    637.00
   598.300     4.861    12.585    809.00
   598.800     5.226    14.960   1001.00
   599.300     6.087    17.795   1215.00
   599.800     6.929    20.941   1453.00
   600.800     8.367    27.093   1924.00
   601.800    10.428    37.890   2775.00
   602.800    13.234    52.416   3947.00
   603.800    16.268    69.791   5399.00
   604.800    18.627    89.211   7168.00
   605.300    19.920   100.090   8174.00
  END FTABLE 31
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  FTABLE     33
 ROWS COLS ***  (RCHRES 5)     Chenoweth #33
   20    4
     DEPTH      AREA    VOLUME     DISCH     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (cfs) ***
   600.400     0.000     0.000      0.00
   600.500     0.047     0.008      0.20
   601.000     0.428     0.174      8.00
   601.500     0.580     0.425     28.00
   602.000     0.742     0.776     63.00
   602.500     0.881     1.169    110.00
   603.000     0.971     1.618    172.00
   603.500     1.092     2.139    252.00
   604.000     1.225     2.733    348.00
   604.500     1.356     3.335    453.00
   605.000     1.543     4.069    583.00
   605.500     1.798     5.036    759.00
   606.000     2.113     6.313    996.00
   606.500     2.378     7.786   1286.00
   607.000     2.662     9.427   1625.00
   607.500     3.097    11.335   2007.00
   608.000     3.652    13.696   2431.00
   609.000     5.044    19.285   3405.00
   610.000     6.516    25.069   4514.00
   611.000     7.237    31.308   5836.00
  END FTABLE 33

  FTABLE     35
 ROWS COLS ***  (RCHRES 4)     Chenoweth #35
   17    4
     DEPTH      AREA    VOLUME     DISCH     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (cfs) ***
   606.000     0.000     0.000      0.00
   606.100     0.180     0.094      2.80
   606.500     0.899     0.447     14.00
   607.000     1.770     1.278     50.00
   607.500     2.411     2.394    108.00
   608.000     3.621     4.445    212.00
   608.500     4.717     6.633    334.00
   609.000     5.967     9.558    515.00
   609.500     7.380    13.425    761.00
   610.000     8.320    17.664   1070.00
   610.500     9.289    22.079   1407.00
   611.000    10.300    28.159   1917.00
   611.500    11.731    35.628   2568.00
   612.000    13.291    44.612   3393.00
   612.500    15.196    55.254   4384.00
   613.000    17.880    67.897   5512.00
   613.500    19.174    79.386   6754.00
   614.000    20.283    91.101   8083.00
  END FTABLE 35

  FTABLE     36
 ROWS COLS ***   (RCHRES 3)        Reach #36
    8    4
     DEPTH      AREA    VOLUME     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS) ***
   710.000     0.000     0.000      0.00
   710.100     1.346     0.306      2.00
   710.600     6.523     5.049     60.00
   711.100    13.634    14.289    193.00
   711.600    20.460    27.132    389.00
   712.100    26.299    43.038    659.00
   712.600    39.327    86.551   1473.00
   713.100    45.407   120.847   2243.00
  END FTABLE 36
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  FTABLE     37
 ROWS COLS ***   (RCHRES 2)    Chenoweth #37
   21    4
     DEPTH      AREA    VOLUME     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS) ***
   624.000     0.000     0.000      0.00
   624.200     0.400     0.144      2.00
   624.700     1.480     1.148     23.00
   625.200     2.171     2.493     62.00
   625.700     3.095     4.433    129.00
   626.200     5.232     7.152    216.00
   626.700     6.537    10.490    330.00
   627.200     7.501    14.295    472.00
   627.700     8.658    18.672    642.00
   628.200     9.991    23.752    846.00
   628.700    11.563    29.673   1086.00
   629.200    12.386    35.689   1361.00
   629.700    13.315    41.884   1652.00
   630.200    14.483    48.921   1988.00
   630.700    16.177    56.548   2350.00
   631.200    17.882    65.027   2750.00
   631.700    19.156    73.876   3186.00
   632.200    21.130    84.260   3686.00
   632.700    22.822    95.385   4245.00
   633.200    24.440   107.074   4846.00
   633.700    25.981   119.123   5480.00
  END FTABLE 37

  FTABLE     39
 ROWS COLS ***   (RCHRES 1)    Chenoweth #39
   22    4
     DEPTH      AREA    VOLUME     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS) ***
   643.900     0.000     0.000      0.00
   644.300     0.569     0.201      4.00
   644.800     1.458     0.806     22.00
   645.300     2.203     1.631     54.00
   645.800     2.970     2.688    102.00
   646.300     3.654     4.036    179.00
   646.800     4.741     5.785    276.00
   647.300     6.144     8.139    397.00
   647.800     7.460    10.806    537.00
   648.300     8.671    13.525    698.00
   648.800     9.540    16.383    880.00
   649.300    10.669    21.221   1210.00
   649.800    11.412    24.845   1469.00
   650.300    12.238    28.774   1758.00
   650.800    13.165    33.039   2079.00
   651.300    14.440    37.732   2430.00
   651.800    14.998    42.453   2814.00
   652.300    15.534    47.373   3229.00
   652.800    16.208    52.696   3680.00
   653.300    16.962    58.315   4166.00
   653.800    17.695    64.346   4707.00
   654.300    18.580    70.239   5231.00
  END FTABLE 39


***  NOTE: Pond RCHRES used when drainage area to ponds is >10% of the subbasin

  FTABLE    112
 ROWS COLS *** (Pond RCHRES 15, Subbasin 13, fig. 28)  Chenoweth V12
    8    4
     DEPTH      AREA    VOLUME     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS) ***
     0.000     0.000     0.000      0.00
     8.000    41.900   124.000      0.01
    10.000    44.300   172.000      0.02
    12.000    47.110   226.000      0.03
    13.000    48.100   251.000    250.00
    14.000    49.500   283.000    750.00
    15.000    50.400   310.000   1500.00
    16.000    51.800   339.000   3000.00
  END FTABLE112
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  FTABLE    113
 ROWS COLS *** (Pond RCHRES 16, Subbasin 12)     Chenoweth V13
    9    4
     DEPTH      AREA    VOLUME     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS) ***
     0.000     0.000     0.000      0.00
     8.000     3.400    10.100      0.01
    10.000     3.600    14.000      0.02
    12.000     3.800    18.400      0.03
    12.500     3.850    19.400     35.00
    13.000     3.900    20.400     75.00
    14.000     4.000    23.000    200.00
    15.000     4.100    25.200    400.00
    16.000     4.200    27.600    800.00
  END FTABLE113

  FTABLE    114
 ROWS COLS ***  (Pond RCHRES 17, Subbasin 11)     Chenoweth V14
    8    4
     DEPTH      AREA    VOLUME     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS) ***
     0.000     0.000     0.000      0.00
     8.000     8.100    24.000      0.01
    10.000     8.600    33.200      0.02
    12.000     9.100    43.700      0.03
    13.000     9.300    48.500     75.00
    14.000     9.600    54.600    200.00
    15.000     9.800    60.000    400.00
    16.000    10.000    65.600    800.00
  END FTABLE114

  FTABLE    121
 ROWS COLS ***  (Pond RCHRES 18, Subbasin 10b)    Chenoweth V21
    8    4
     DEPTH      AREA    VOLUME     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS) ***
     0.000     0.000     0.000      0.00
     8.000    17.100    50.700      0.01
    10.000    18.100    70.000      0.02
    12.000    19.200    92.100      0.03
    13.000    19.600   102.000    250.00
    14.000    20.200   115.000    750.00
    15.000    20.500   126.000   1500.00
    16.000    21.100   138.000   3000.00
  END FTABLE121

  FTABLE    122
 ROWS COLS ***  (Pond RCHRES 19, Subbasin 10a)    Chenoweth V22
    8    4
     DEPTH      AREA    VOLUME     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS) ***
     0.000     0.000     0.000      0.00
     8.000     6.000    17.800      0.01
    10.000     6.300    24.500      0.02
    12.000     6.700    32.300      0.03
    13.000     6.900    35.900    250.00
    14.000     7.100    40.400    750.00
    15.000     7.200    44.300   1500.00
    16.000     7.400    48.400   3000.00
  END FTABLE122

  FTABLE    123
 ROWS COLS ***  (Pond RCHRES 20, Subbasin 9b)      Chenoweth V23
   10    4
     DEPTH      AREA    VOLUME     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS) ***
     0.000     0.000     0.000      0.00
     8.000     6.600    19.500      0.01
    10.000     6.900    27.000      0.02
    12.000     7.400    35.500      0.03
    12.500     7.450    37.500     35.00
    13.000     7.500    39.400     75.00
    14.000     7.800    44.400    200.00
    15.000     7.900    48.600    400.00
    16.000     8.100    53.200    800.00
    17.000     8.300    57.800   1600.00
  END FTABLE123
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  FTABLE    124
 ROWS COLS *** (Pond RCHRES 21, Subbasin 9a)        Chenoweth V24
    8    4
     DEPTH      AREA    VOLUME     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS) ***
     0.000     0.000     0.000      0.00
     8.000     7.100    21.200      0.01
    10.000     7.500    29.300      0.02
    12.000     8.000    38.500      0.03
    13.000     8.200    42.700     75.00
    14.000     8.400    48.100    200.00
    15.000     8.600    52.700    400.00
    16.000     8.800    57.800    800.00
  END FTABLE124

  FTABLE    127
 ROWS COLS ***  (Pond RCHRES 22, Subbasin 8a)       Chenoweth V27
    8    4
     DEPTH      AREA    VOLUME     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS) ***
     0.000     0.000     0.000      0.00
     8.000     1.600     4.600      0.01
    10.000     1.700     6.400      0.02
    12.000     1.760     8.400      0.03
    13.000     1.800     9.400     75.00
    14.000     1.850    10.600    200.00
    15.000     1.880    11.600    400.00
    16.000     1.940    12.700    800.00
  END FTABLE127

  FTABLE    141
 ROWS COLS *** (Pond RCHRES 23, Subbasin 1a)        Chenoweth V41
    8    4
     DEPTH      AREA    VOLUME     DISCH ***
      (FT)   (ACRES)   (AC-FT)     (CFS) ***
     0.000     0.000     0.000      0.00
     8.000     1.250     3.700      0.01
    10.000     1.320     5.110      0.02
    12.000     1.400     6.700      0.03
    13.000     1.430     7.500     75.00
    14.000     1.470     8.400    200.00
    15.000     1.500     9.200    400.00
    16.000     1.540    10.100    800.00
  END FTABLE141
END FTABLES


END RUN
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Martin and others—HYDROLOGIC AND WATER-QUALITY CHARACTERIZATION AND MODELING OF THE CHENOWETH RUN BASIN, JEFFERSON COUNTY, KENTUCKY—U.S. Geological Survey Water-Resources Investigations Report 00-4239

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