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Continuous Hydrologic Simulation of Runoff for the Middle Fork and South Fork of the Beargrass Creek Basin in Jefferson County, Kentucky

Water-Resources Investigations Report 98–4182

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By G. Lynn Jarrett, University of Louisville, Aimee C. Downs, U.S. Geological Survey, and
Patricia A. Grace–Jarrett, Louisville and Jefferson County Metropolitan Sewer District

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Louisville, Kentucky
1998

U.S. DEPARTMENT OF THE INTERIOR

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U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	2.540	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer

DEM	Digital elevation model
GIS	Geographic information system
HRU's	Hydrologic response units
HSPEXP	Hydrological Simulation Program—FORTRAN Expert System
HSPF	Hydrological Simulation Program—FORTRAN
IMPLND	Impervious land cover
INFILT	Infiltration capacity
LOJIC	Louisville and Jefferson County Information Consortium
LZETP	Lower-zone evapotranspiration parameter
LZSN	Lower-zone nominal storage capacity
MSD	Louisville and Jefferson County Metropolitan Sewer District
NWS	National Weather Service
PERLND	Pervious land cover
SWM	Stanford Watershed Model
UCI	User-control input
USGS	U.S. Geological Survey

Continuous Hydrologic Simulation of Runoff for the Middle Fork and South Fork of Beargrass Creek Basin in Jefferson County, Kentucky

By G. Lynn Jarrett, Aimee C. Downs, *and* Patricia A. Grace–Jarrett

Abstract

The Hydrological Simulation Program—FORTRAN (HSPF) was applied to an urban drainage basin in Jefferson County, Ky. to integrate the large amounts of information being collected on water quantity and quality into an analytical framework that could be used as a management and planning tool. Hydrologic response units were developed using geographic data and a K-means analysis to characterize important hydrologic and physical factors in the basin. The Hydrological Simulation Program—FORTRAN Expert System (HSPEXP) was used to calibrate the model parameters for the Middle Fork Beargrass Creek Basin for 3 years (June 1, 1991, to May 31, 1994) of 5-minute streamflow and precipitation time series, and 3 years of hourly pan-evaporation time series. The calibrated model parameters were applied to the South Fork Beargrass Creek Basin for confirmation. The model confirmation results indicated that the model simulated the system within acceptable tolerances. The coefficient of determination and coefficient of model-fit efficiency between simulated and observed daily flows were 0.91 and 0.82, respectively, for model calibration and 0.88 and 0.77, respectively, for model confirmation. The model is most sensitive to estimates of the area of effective impervious land in the basin; the spatial distribution of rainfall; and the lower-zone evapotranspiration, lower-zone nominal storage, and infiltration-capacity parameters during recession and low-flow periods. The error contribution from these sources varies with season and antecedent conditions.

INTRODUCTION

Urban streams have often been a neglected ecological and cultural resource in an otherwise densely populated landscape. The quality of urban-stream systems is an integral part of the activities in the surrounding watershed and airshed. Changes in water quantity, quality, and fluvial geomorphology are influenced by the original nature of the watershed and the type and intensity of basin activities. Consequently, management of a stream system such that economic, aesthetic, and ecologic goals are achieved requires that the potential for changes to a stream be considered when changes in land-use activities are being planned (Delleur and others, 1976).

The Louisville and Jefferson County Metropolitan Sewer District (MSD) is responsible for managing the streams and drainage basins in and around Louisville, Ky. The MSD has a long history of collecting water-quantity data associated with flood studies and urban development. In 1988, the MSD, in cooperation with the U.S. Geological Survey (USGS), began systematically collecting water-quality data from Jefferson County streams. Systematic evaluation of this expanding data base has been hampered, however, by the lack of a formal conceptual framework and appropriate computer model.

In 1994, the MSD decided to evaluate the utility of using a comprehensive river-basin model to interpret the data and provide guidance on future data-collection efforts. The model also is expected to provide a means of evaluating the water-quality and -quantity consequences of alternative management decisions. The primary objective of the study reported here was to develop a more refined and accurate representation of basin hydrology and water quality by efficiently integrating the large amounts of available information into a model. The second objective required that the model adequately represent the important hydrologic processes.

This report describes the effectiveness of the Hydrological Simulation Program—FORTRAN (HSPF) model in simulating a 3-year hydrologic record for the period June 1, 1991, to May 31, 1994, in the South Fork and Middle Fork Subbasins of Beargrass Creek in Jefferson County, Ky. Although simulations were made for a model of the Muddy Fork Subbasin, those results are not reported here because of a lack of observed record for both the calibration and confirmation periods.

Background

The HSPF version 10.0 (Bicknell and others, 1993) was selected as the most appropriate basin model. The HSPF is capable of continuous simulation of river-basin hydrology and water quality for conventional and toxic organic pollutants. The model is classified as a physically based conceptual model (Wurbs, 1995) that is capable of simulating important hydrologic and water-quality processes. The HSPF model has extensive input data requirements. It is, however, within the model's capacity to manipulate large amounts of hydrologic data.

The HSPF is a collection of FORTRAN source-coded modules that represent water-quantity and -quality processes dependent on a time-series management system. Model parameters are used to adapt the source codes to a wide range of river-basin conditions. The output parameters in the model correlate to physically based properties or process-oriented conditions (Donigian and others, 1984).

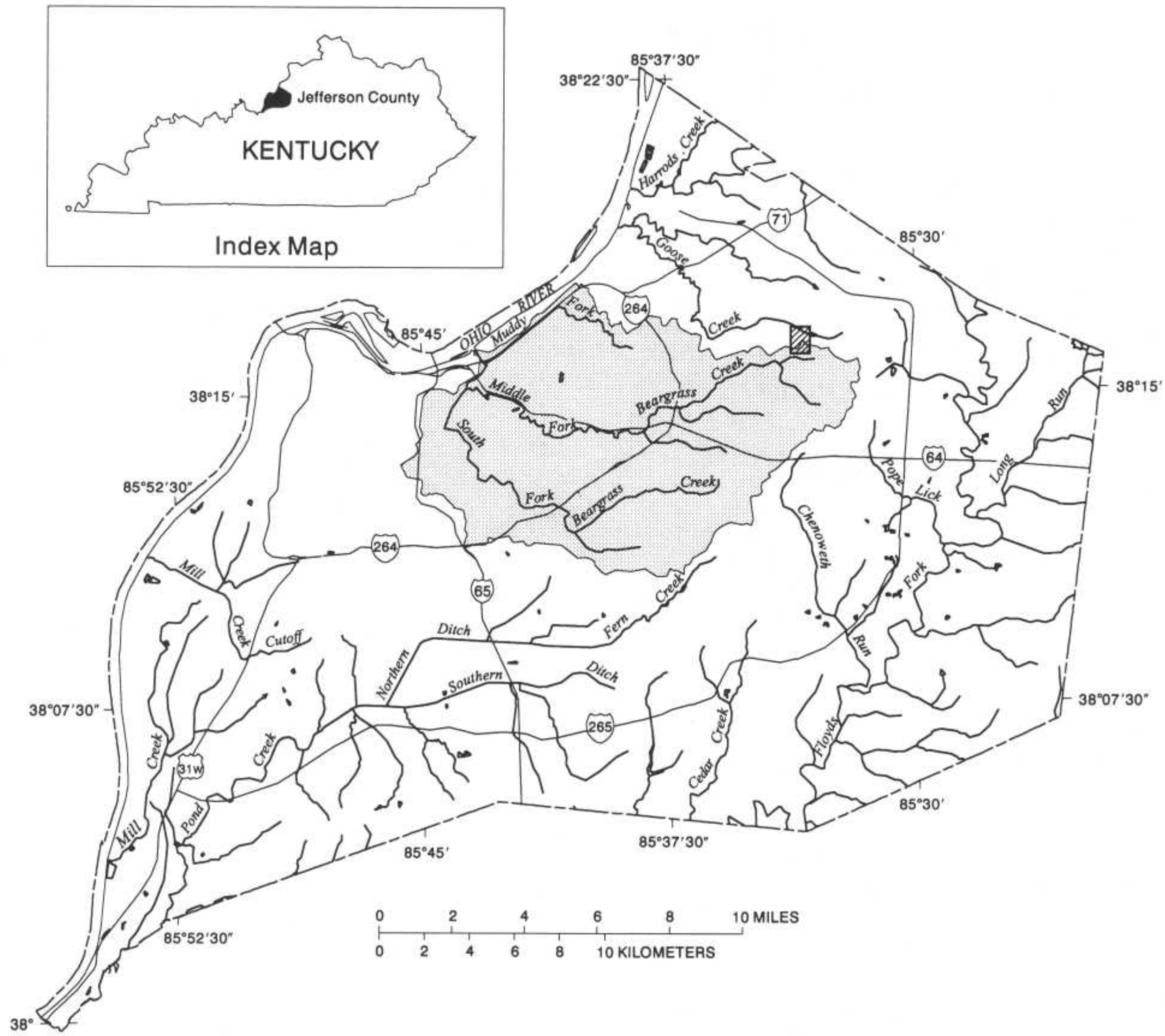
Previous Work

The HSPF model has been widely applied to evaluate agricultural runoff (Moore and others, 1988; Chew and others, 1991; Laroche and others, 1996) and for planning purposes in urban and suburban environments (Ng and Marsalek, 1989; Dinicola, 1989; Duncker and others, 1995). The model also has been used to characterize the effects of changing land uses on channel expansion and channel incision (Booth, 1990). Fontaine (1995) reported that the HSPF model was more accurate than the traditional event-based model (HEC-1) in predicting extreme floods in the upper Midwest. The hydrologic component of the HSPF is based on the Stanford Watershed Model (SWM) (Crawford and Linsley, 1966). One of the early applications of this model (Crawford and Linsley, 1966) was in the Beargrass Creek Basin in Louisville, Ky. Crawford and Linsley's simulations were for the period from 1950 to 1953, prior to extensive urban development in the basin.

Description of Study Area

The Beargrass Creek Basin borders the Ohio River in Jefferson County in north-central Kentucky (fig. 1). The county is the most densely populated area of the State. Streams in the Beargrass Creek Basin drain 61.0 mi^2 of eastern Jefferson County, Ky. The drainage comprises three tributary subbasins: the South Fork, the Middle Fork, and the Muddy Fork. Subbasin sizes for the South Fork, Middle Fork, and Muddy Fork are 27.0 mi^2, 25.1 mi^2, and 8.9 mi^2, respectively (fig. 2). The HSPF model was developed to simulate the entire Middle Fork Basin and 22.04 mi^2 (81.6 percent) of the South Fork Basin to downstream point indicated as number 1 (approximately Logan Street) as shown in figure 2. The HSPF user-control input (UCI) files (included in the appendixes to this report) describe the model for the full part of the simulated basin; however, subareas and reaches downstream from the streamflow gages were deactivated in the model code, and use of these UCI files would yield discharge and average depth at the streamflow-gage locations. Instructions are given in the UCI file for simulation of the full basins. The drainage areas up to the streamflow gages are 18.9 and 17.2 mi^2 for the Middle Fork and South Fork, respectively.

Jefferson County has a moist-continental climate with moderately cold winters and hot, humid summers. Average annual precipitation is approximately 43 in., mostly as rainfall. Average annual snowfall is slightly less than 17 in. and may occur between November and April. Historical rainfall records indicate that March is the wettest month of the year, and October is the driest. Frontal systems moving from the southwest provide the precipitation during most of the year, but, in



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

EXPLANATION

BEARGRASS CREEK BASIN

MIDDLE FORK DIVERSION TO GOOSE CREEK

Figure 1. Location of Beargrass Creek Basin in Jefferson County, Kentucky.

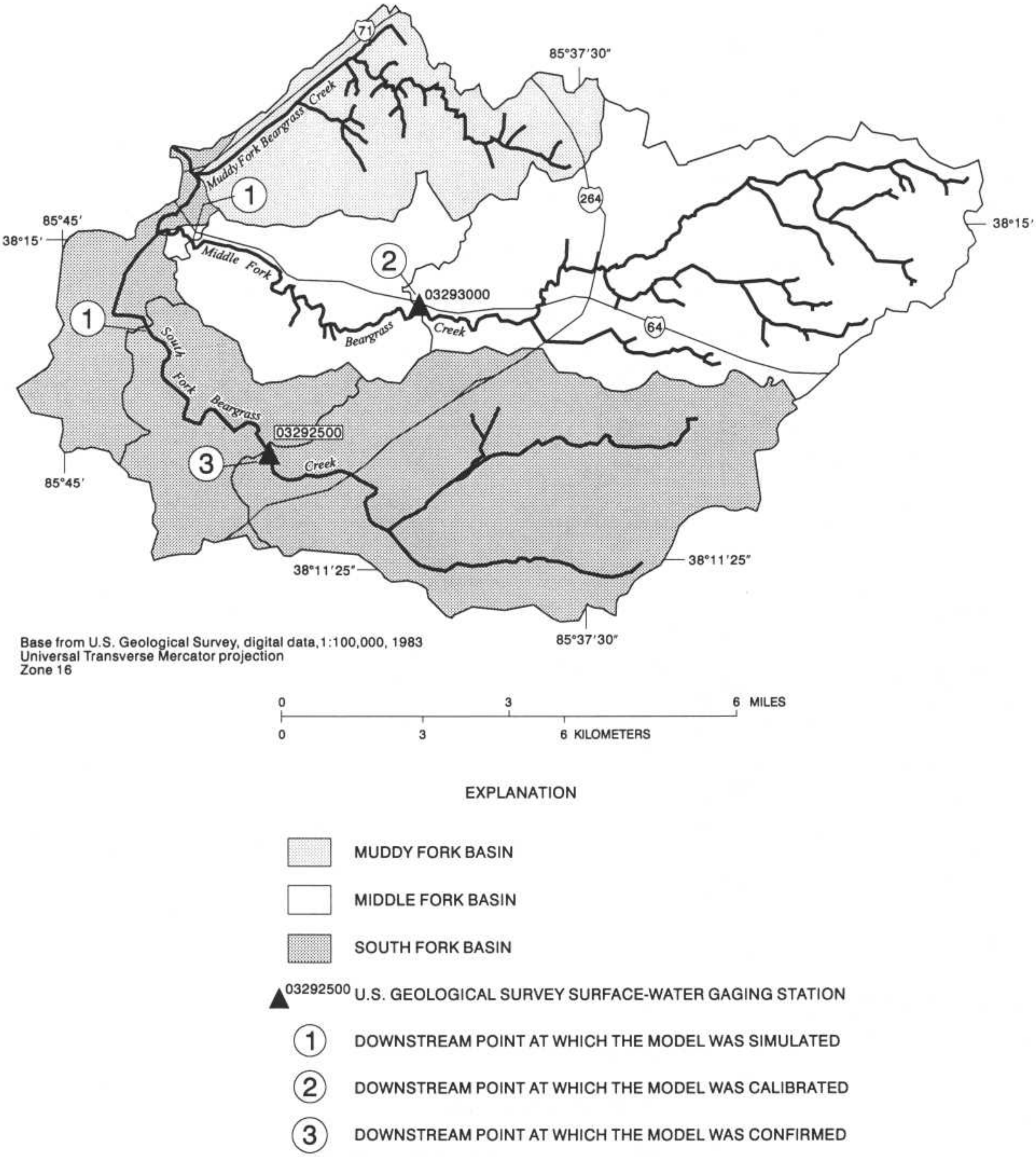


Figure 2. Location of Muddy Fork, Middle Fork, and South Fork Subbasins of the Beargrass Creek Basin, Jefferson County, Kentucky; two surface-water gaging stations; and points at which the Hydrological Simulation Program-FORTRAN (HSPF) model was simulated, calibrated, and confirmed.

late summer, convective storms may produce locally heavy rainfall. Evaluation of a local 45-year-long hourly rainfall record indicated that approximately 70 storms occur each year. These storms are defined as 0.1 in. of precipitation with at least 0.01 in. occurring within each hour of the storm's duration.

The headwaters of Beargrass Creek drain Silurian age dolomite, shale, and minor amounts of limestone. The creek cuts into Devonian age limestone and shale before flowing into the Ohio River. A more detailed description of the basins can be found in Evaldi and Moore (1992). Land use in the basins varies from single-family residential to light industrial. The dominant land use in all three subbasins is single-family residential, followed by paved (impervious) surfaces (roads and parking lots), parks, and cemeteries (table 1). The land-use percentages given in table 1 are for the entire basin, which is different from the simulated basin for the South Fork and subbasins used for calibration and confirmation for the Middle Fork and South Fork, respectively. Most of the basin is sewered with separate sanitary and storm sewers. Combined sewers are present in the lower part of each basin. The combined systems periodically overflow to surface waters. Part of the flow in the Middle Fork is diverted to Goose Creek (fig. 1) during high-flow conditions south of Anchorage, Ky., near Whipps Mill Road, east of Hurstbourne Lane.

Table 1. Distribution of land uses in the South and Middle Forks of the Beargrass Creek Basin in Jefferson County, Kentucky

Type of land use	South Fork (percent)	Middle Fork (percent)
Single-family residence	46.7	43.8
Multiple-family residence	4.7	5.8
Commercial	7.6	8.7
Industrial	4.1	1.0
Churches, schools, and other non-commercial facilities	5.8	6.1
Parks, cemeteries, and other public open space	9.8	11.2
Vacant or undeveloped	6.2	9.8
Roads and other paved areas	15.1	13.6

STUDY METHODS

Two long-term stream-discharge-measuring sites are located in the Middle Fork and South Fork Basins of Beargrass Creek (fig. 2). Continuous discharge data collected and computed at these sites were used to calibrate and confirm the HSPF model. In addition, precipitation and pan-evaporation data were compiled. A wide variety of Geographic Information System (GIS) data layers were developed and analyzed to delineate the Hydrologic Response Units (HRU's), which were critical to the basic analysis of the hydrologic system.

Collection of Meteorological Data

Meteorological data were compiled from the USGS/MSD precipitation network and the National Weather Service (NWS). The seven rain gages in the basin that were used to simulate runoff from the Middle Fork and South Fork are described in table 2. Five other rain gages operated by the USGS, in cooperation with the MSD, are outside the basin but within 5 mi of the center of the basin. The locations of the seven rain gages also are shown in figure 3. Precipitation data were available at 5-minute intervals for the calibration period of midnight June 1, 1991, to midnight May 31, 1994. Daily pan-evaporation data were obtained from the NWS for a station located at Nolin River Lake, Ky., approximately 75 mi south of Louisville, Ky. Missing data were filled in with data collected at Patoka Lake, Ind., approximately 80 mi northwest of Louisville.

Development of Geographic Information System (GIS) Data Base

The hydrologic properties of the contributing areas were quantified using ARC/INFO GRID (Environmental Systems Research Institute, Inc., 1992), a raster-based tool for correlating and overlaying multiple GIS data bases. Data layers, obtained from the Louisville and Jefferson County Information Consortium (LOJIC), included land use, hydrography (streams, lakes, and holding ponds), soils (Zimmerman and others, 1966), pavement (roads, sidewalks, and recreational areas), tree cover, catchment basins, buildings, and elevation data. The data were digitized at a resolution of 1:100 from low-altitude aerial photography.

Table 2. Station number, name, and location of the precipitation gages used in the simulation of runoff from the Middle Fork and South Fork Beargrass Creek Basins in Jefferson County, Kentucky

[RG, rain gage; SF, South Fork Beargrass Creek Basin; MF, Middle Fork Beargrass Creek Basin]

Rain gage number	Name	Latitude[1]	Longitude[1]	Basin in which raingage data were used
RG6	Seneca Golf Course along Bon Air Avenue	381353	854018	SF, MF
RG8	McMahan Fire Station at Taylorsville Road	381306	853636	SF, MF
RG11	East County Government Center	381457	853154	MF
RG19	South Fork Beargrass Creek at Trevilian Way	381239	854207	SF, MF
RG22	South Fork Beargrass Creek at Bardstown Road	381200	853946	SF
RG24	South Fork Beargrass Creek Tributary at Bardstown Road	381112	853935	SF
RG27	Middle Fork Beargrass Creek at Shelbyville Road	381456	853616	MF

[1]Degree, minute, and second symbols omitted.

The foundation layer for the analysis was a digital elevation model (DEM) that was generated from the elevation data using the grid-based elevation model, TOPOGRID (Hutchinson and Dowling, 1991). TOPOGRID is unique in that it creates a hydrologically correct elevation surface that takes into consideration known locations of hydrologic features rather than interpolating their location from the contour coverage alone. All data layers, except for catchment basins, swimming pools, parking lots, and tree cover, were converted from vector to raster data. The cell sizes for all the raster data layers were 65.6 by 65.6 ft, an area of 4,305 ft^2.

Raster coverages defining the characteristics of the (1) stream reach, (2) rain gage Thiessen polygon, (3) riparian zone, (4) land use, and (5) land slope were aggregated into one coverage (hereafter referred to as the composite-coverage) that represented the unique combinations of these five characteristics. The composite-coverage yielded 390 unique polygons for the Middle Fork and 318 unique polygons for the South Fork. Some polygons contained identical values known as zones. In GRID calculations, zones do not need to be contiguous. ARC/INFO's statistical capabilities were used to compute area per stream reach; area of each of the composite-coverage zones; and percent of hydrology, soils, pavement, and buildings for each of the composite-coverage zones. Other source data were represented as points instead of polygons, such as stormwater catchment basins and swimming pools, or arcs, such as tree cover and parking lots. Because these point features have no area, frequency was used to estimate density per composite-coverage zone. Arc length was used for arc features to estimate area per composite-cover zone.

Delineation of Hydrologic Response Units (HRU's)

Many factors affect how precipitation is converted into streamflow within a drainage basin. The spatial variability of these factors can be incorporated into the HSPF by subdividing the drainage basin into small subunits, which may then be characterized by a system of Hydrologic Response Units (HRU's). Each of the HRU's are simulated with unique parameter configurations. Initially, four HRU's—three pervious and one impervious—were developed from the GIS data bases for the Middle Fork Basin. These units were hypothesized to convert precipitation to streamflow in different ways and at different rates. Dinicola (1989) attributed physical significance to the parameter sets developed in a regional calibration of the HSPF in the northwestern part of the State of Washington. After developing hypotheses regarding the distinct hydrologic responses occurring in the modeled watersheds, parameter sets were developed to test those hypotheses.

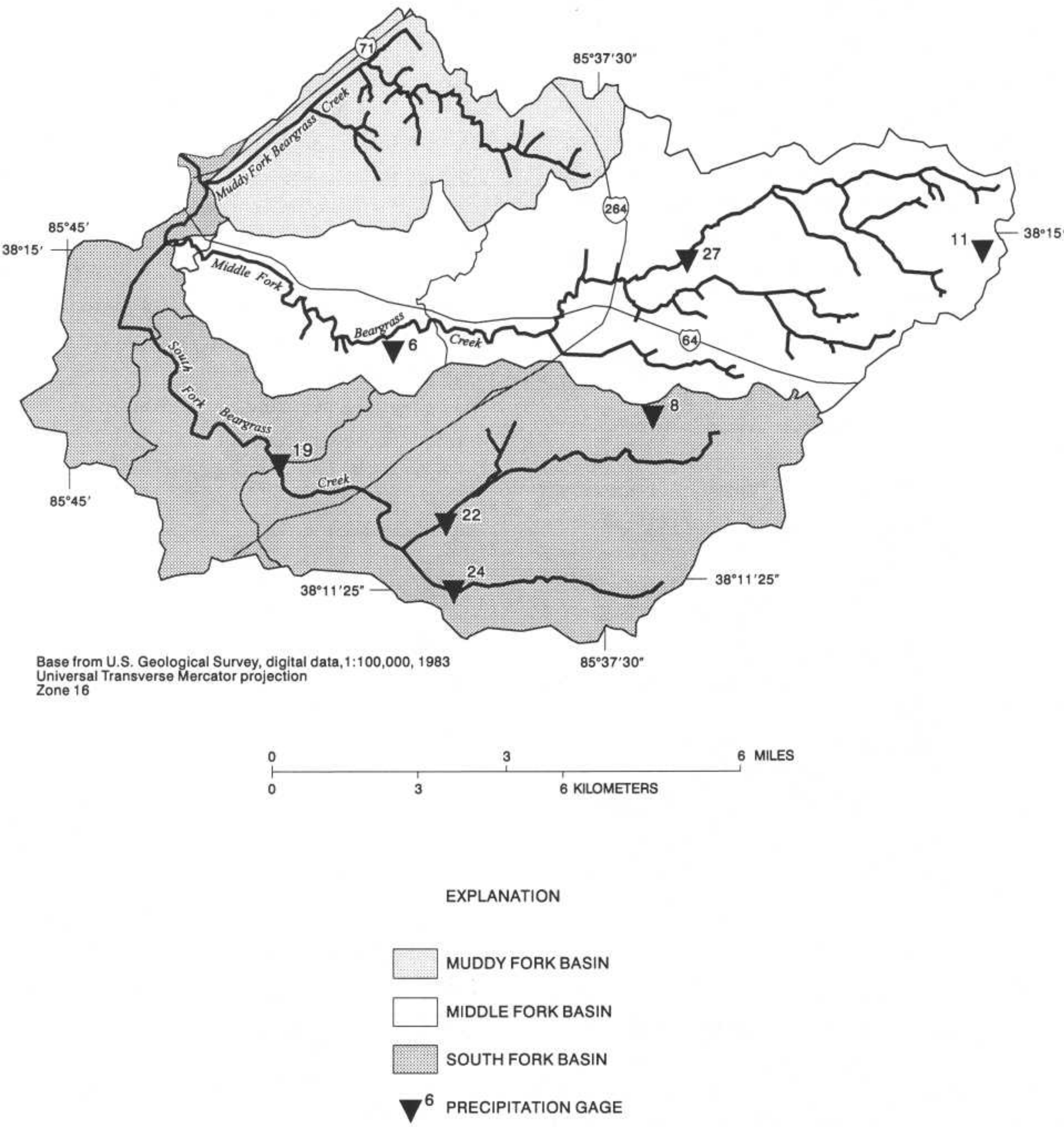


Figure 3. Location of precipitation gages used for runoff simulation in the Middle Fork and South Fork Subbasins of the Beargrass Creek Basin, Jefferson County, Kentucky.

Similar to Dinicola's (1989) method, the HRU's for this study were developed around physically based concepts; however, the parameter sets were developed from empirical and spatial data.

A K-means cluster analysis was used to aggregate four basic groups of data based on the hydrologically relevant information associated with each of the polygons. The K-means technique is a nonhierarchical grouping procedure that is used to associate multidimensional data. Details on and examples of the K-means technique are given in Hartigan (1975); Wilkinson and Hill (1994); Hair and others (1987); and Haag and others (1995). The classification variables used to group the pervious land components of the polygons were as follows: (1) X_{infilt} = soil permeability (inches per hour), (2) X_{lzs} = soil-storage capacity (inches of water per inch of soil times the depth in inches to the seasonally high water table), and (3) X_{tree} = area of tree canopy (square feet). The correlation of these variables produced three distinct clusters for pervious areas that form the basis of the HRU's. The clusters (HRU's) are a lawn cluster, a wooded cluster, and a riparian cluster. The riparian cluster (HRU) was primarily characterized by its close proximity to streams. A fourth cluster was identified as impervious but is not shown in figure 4. The impervious cluster (and IMPLND's in HSPF) are characterized as completely impervious surfaces such as roads and parking lots. Each of the classification variables contributed significantly at the 5-percent level to differentiating the clusters as determined by an analysis of variance applying the F-test. Notched box plots illustrate the separation of the pervious clusters as a function of the classification variables (fig. 4).

The three pervious clusters of polygons became the basis for each of the three pervious (PERLND) HRU's used as input to the Middle Fork model. The three pervious units were further subdivided into one of three slope classes: (1) 0 to 5 percent, (2) greater than 5 percent to 12 percent, and (3) greater than 12 percent.

Impervious (IMPLND) areas were clustered in an attempt to define another group of HRU's, but this attempt was not successful. Information on slope, the density of catch basins leading to storm sewers, and the type of imperviousness did not produce unique clusters; subsequently, only one IMPLND surface unit was identified with input parameters developed for each of the three previously mentioned slope classes.

The HRU's in the South Fork Basin were generated on the basis of a linear discriminant-function equation developed for the Middle Fork Basin. Surrogate information on soil permeability, soil storage capacity, and area of tree canopy were used to identify the HRU's. As previously stated, 318 polygons were delineated in the South Fork Basin after aggregating the multiple GIS data coverages. The classification variables of soil permeability, soil storage capacity, and area of tree canopy were assigned to each polygon in the South Fork Basin. An equation was developed on the basis of the results of cluster analysis for the Middle Fork Basin to predict what HRU a particular polygon would be assigned based on the three previously mentioned variables.

The 318 polygons in the South Fork Basin were assigned to either one of the three PERLND or the one IMPLND HRU on the basis of the following equation:

$$HRU = b_0 + b_1 X_{infilt} + b_2 X_{lzs} + b_3 X_{tree}, \qquad (1)$$

where

HRU	is assigned a value of 1, 2, or 3 for each of the 318 polygons in the basin,
X_{infilt}	is soil permeability (inches per hour),
X_{lzs}	is soil storage capacity (inches),
X_{tree}	is area of tree canopy (square feet), and
b_0, b_1, b_2, and b_3	are weighing coefficients (table 3).

For the three pervious Hydrologic Response Units (HRU's)—Lawn, Riparian, and Wooded—the following equations apply:

$$Lawn = (-4.715) + 1.468 X_{infilt} + 2.083 X_{lzs} + 0.003 X_{tree}, \qquad (2)$$

$$Riparian = (-56.099) + 1.450 X_{infilt} + 8.361 X_{lzs} + (-0.002) X_{tree}, \quad \text{and} \qquad (3)$$

$$Wooded = (-19.004) + 1.296 X_{infilt} + 4.749 X_{lzs} + 0.001 X_{tree}. \qquad (4)$$

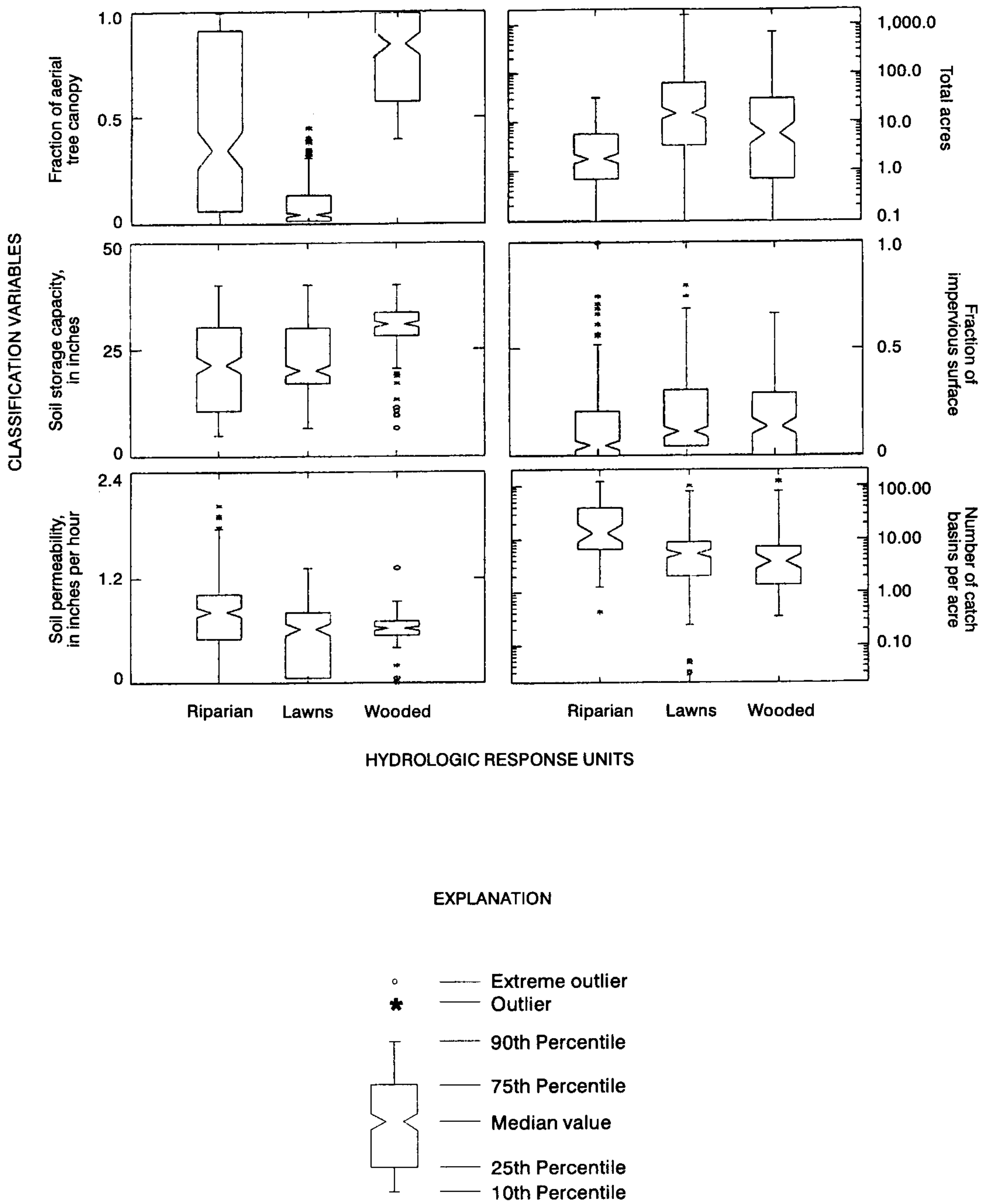


Figure 4. Classification of land-use data into three distinct pervious Hydrolologic Response Units for the Middle Fork Beargrass Creek Basin in Jefferson County, Kentucky. (Impervious Hydrologic Response Unit not shown)

Table 3. Weighing coefficient values for estimating hydrologic response units (HRU's) in the South Fork Beargrass Creek Basin in Jefferson County, Kentucky

[infilt, soil permeability in inches per hour; lzs, soil storage capacity in inches; tree, area of tree canopy in square feet]

Coefficient	Lawn	Riparian	Wooded
b_0	-4.715	-56.099	-19.004
b_1 for infilt	1.468	1.450	1.296
b_2 for lzs	2.083	8.361	4.749
b_3 for tree	.003	-.002	.001

The authors acknowledge that this procedure for establishing the HRU's in the South Fork Basin may be a potential source of error in the confirmation of the model; however, in the event that sufficient GIS coverages are not available, this is considered an acceptable technique. This conclusion is supported by the generally good confirmation results obtained for the South Fork Beargrass Creek that are described later. The distribution of land cover in terms of the various PERLND's and IMPLND's in the Middle Fork and South Fork Basins are listed in tables 4 and 5, respectively.

HYDROLOGIC SIMULATION

The HSPF model was initially setup and calibrated to data for the Middle Fork Basin of Beargrass Creek because of data availability. The model was confirmed by simulating runoff for the South Fork Basin. Although statistical results indicate that the model did not simulate the hydrologic system as well in the South Fork Basin as in the Middle Fork Basin, the confirmation results indicate the calibrated HSPF model is still applicable and transferable to other similar basins.

Table 4. Percentage of pervious (PERLND) and impervious (IMPLND) land cover in the Hydrological Simulation Program—FORTRAN (HSPF) model for the Middle Fork Beargrass Creek Basin in Jefferson County, Kentucky

[HRU, Hydrologic Response Unit; %, percent; ≤, less than or equal to; <, less than; >, greater than]

Land-cover type (HRU)	Low slope (≤5%)	Medium slope (5%<slope≤12%)	High slope (>12%)	Total
		Above streamflow gage		
Pervious				
Lawn	7.55	0.91	0.43	8.89
Riparian	30.73	5.76	.75	37.24
Wooded	31.86	.82	.33	33.01
Impervious	18.26	2.10	.50	20.86
		Total basin modeled		
Pervious				
Lawn	19.32	5.02	3.79	28.13
Riparian	22.64	4.24	.55	27.45
Wooded	23.47	.61	.24	24.32
Impervious	16.48	2.42	1.20	20.10

Table 5. Percentage of pervious (PERLND) and impervious (IMPLND) land cover in the Hydrological Simulation Program—FORTRAN (HSPF) model for the South Fork Beargrass Creek Basin in Jefferson County, Kentucky

[HRU, Hydrologic Response Unit; %, percent; ≤, less than or equal to; <, less than; >, greater than]

Land-cover type (HRU)	Low slope (≤5%)	Medium slope (5%<slope≤12%)	High slope (>12%)	Total
		Above streamflow gage		
Pervious				
Lawn	5.06	0.75	2.48	8.29
Riparian	24.55	.16	.0	24.71
Wooded	34.54	5.53	.06	40.13
Impervious	25.10	1.24	.53	26.87
		Total basin modeled		
Pervious				
Lawn	4.0	.82	4.97	9.79
Riparian	18.70	.12	.0	18.82
Wooded	36.32	7.75	.05	44.12
Impervious	23.95	2.22	1.10	27.27

Model Setup

Seventeen parameters are included in the HSPF source code for simulating the rainfall-runoff process for PERLND surfaces, and four parameters are included for IMPLND surfaces (table 6). The three most sensitive PERLND surface parameters for controlling the annual and monthly water balances in a basin are lower-zone evapotranspiration (LZETP), lower-zone nominal storage capacity (LZSN), and infiltration capacity (INFILT). The effect of INFILT on the annual and monthly water balances is indirect (Lumb and others, 1994). Initial estimates of these parameters were obtained using spatially distributed digital data coverages for trees and soils.

The LZETP parameter, an index value that ranges from 0.01 to 0.99, was calculated as the sum of the fractional area of tree cover within each grid cell for each polygon. This value was then allowed to vary monthly either as a function of the monthly potential evapotranspiration or pan evaporation.

The moisture-holding capacity (LZSN) for the soil was estimated by multiplying the available water capacity by the depth to the seasonally high water table. This produced an estimate of pore volume for each soil. An areal-weighted storage volume was computed for each polygon by the same methods used for infiltration.

The soil information was obtained from the Jefferson County Soil Survey (Zimmerman and others, 1966). INFILT was estimated for each polygon by computing an areally weighted mean permeability value by use of the following equation:

$$I = \frac{\sum_{i=1}^{n} (a_i P_i)}{\sum_{i=1}^{n} a_i} , \qquad (5)$$

where

I is areal-weighted minimum infiltration value,
a_i is area in acres for soil i,
P_i is minimum permeability value for soil i, and
n is the number of polygons in the basin.

Table 6. Hydrological Simulation Program—FORTRAN (HSPF) parameters used to simulate hydrology

Abbreviation	Explanation
LZETP	Lower-zone evapotranspiration. An index value (ranging from 0 to 0.99) representing the density of deep-rooted vegetation in PERLND's.
INFILT	Infiltration capacity. An index to the infiltration capacity of the soils. This parameter also affects percolation to the ground-water zone.
INFEXP	Exponent for the infiltration equation. Controls rate of infiltration decrease as a function of increasing soil moisture.
INFILD	Ratio of maximum to mean infiltration rate.
INTFW	Interflow index. An index that controls the amount of infiltrated water that flows as shallow subsurface runoff.
IRC	Interflow recession coefficient. An index for the rate of shallow subsurface flow.
CEPSC	Interception storage capacity of PERLND's.
RETSC	Retention storage capacity for IMPLND's.
LZSN	Lower-zone nominal storage. An index to the soil moisture holding capacity.
UZSN	Upper-zone nominal storage. An index to the amount of surface storage in depressions and the upper few inches of soil.
BASETP	Fraction of available potential-evapotranspiration demand that can be met from ground-water outflow. Simulates evapotranspiration from riparian vegetation.
AGWETP	Fraction of available potential-evapotranspiration demand that can be met from stored ground water. Simulates evapotranspiration from phreatophytes, in general.
AGWRC	Ground-water recession parameter. An index of the rate at which ground water drains from the land.
KVARY	Ground-water outflow modifier. An index of how much affect recent recharge has on ground-water outflow.
DEEPFR	Fraction of ground water that does not discharge to the surface within the boundaries of the modeled area.
LSUR	Average length of the overland flow plane (PERLND or IMPLND).
SLSUR	Average slope of the overland flow plane (PERLND or IMPLND).
NSUR	Average roughness of the overland flow plane (PERLND or IMPLND).

Values for parameters without physically measurable surrogates or for parameters that were not measured were initially estimated from literature values. A model-sensitivity analysis was done after the initial calibration. This analysis indicated what aspect of the hydrograph was affected by varying each of these parameters and the magnitude of the effects. On the basis of the results of the sensitivity analysis, the values of most of the parameters obtained from the literature were adjusted only slightly during the calibration process.

Model Calibration

The hydrologic model was calibrated by using the Hydrological Simulation Program—FORTRAN Expert System (HSPEXP) (Lumb and others, 1994), various statistical techniques, and visual techniques to relate simulated discharge to observed discharge (James and Burges, 1982). The model was calibrated using data for a 5-minute time step for a 3-year period.

The HSPEXP provides an alternative to numerical optimization (Liou, 1970; Shanholtz and Carr, 1975; Mein and Brown, 1978; Jacomino and Fields, 1997; Magette and others, 1976; Pierre, 1986) for refining parameter estimates. Numerical optimization tends to remove the modeler from the process of relating the model to the physical environment. In addition, multiple numerical solutions may be found for the same conditions. As a result, it is important that historical information about and the physical constraints of the hydrologic system be considered during model calibration. The HSPEXP source code provides a means to incorporate expert modeling experience with the HSPF system and knowledge of the prototype system into the calibration process.

The convergence criteria used in application of the HSPEXP to minimize error differences of selected runoff characteristics and the respective acceptable differences between simulated and observed characteristic values are presented in table 7. In the calculation of the storm statistics, 10 storms were identified as follows: March 5-9, 1992; March 17-21, 1992; May 2-5, 1992; May 29-June 3, 1992; June 15-20, 1992; July 26-31, 1992; August 5-10, 1992; September 15-20, 1992; August 1-6, 1993; and October 16-21, 1993. The acceptable differences applied in the calibration to runoff for the Middle Fork Beargrass Creek Basin are more stringent than the default values recommended by Lumb and others (1994); thus, the calibration obtained in this model is considered very good. The simulated and observed daily discharges for the Middle Fork Beargrass Creek Basin are shown in figures 5a-c.

Model Confirmation

The calibrated model parameters of the Middle Fork Basin were applied in the South Fork Basin of Beargrass Creek. The time period (June 1, 1991, to May 31, 1994) for calibration and confirmation were the same; however, the two basins had only three precipitation gages in common, and those gages had different areal weightings for each basin (table 2). The geometry and land uses also differed between basins (tables 4 and 5). The simulated and observed daily discharges for the South Fork Beargrass Creek Basin are shown in figures 6a-c. In the calculation of the storm statistics, 10 storms were identified as follows: March 5-14, 1992; March 17-27, 1992; May 2-13, 1992; May 28-June 5, 1992; June 17-25, 1992; July 26-August 5, 1992; August 7-15, 1992; September 17-24, 1992; August 1-7, 1993; and October 16-21, 1993. As indicated in table 8, figures 5a-c, and figures 6a-c, the confirmation simulation for the South Fork Basin cannot be considered as statistically accurate as the calibration simulation in the Middle Fork Basin.

Table 7. Minimized error in the difference of selected runoff characteristics during calibration of the Hydrological Simulation Program—FORTRAN (HSPF) to the Middle Fork Beargrass Creek at Louisville, Kentucky, from June 1, 1991, to May 31, 1994

Minimized error characteristic	Error difference between simulated and observed values (percent)	Target criteria applied in this study (percent)	Suggested default criteria[1]
Error in total volume	3.74	5.0	10.0
Error in low-flow recession	-.02	.030	.030
Error in the 50-percent lowest flows	-.74	5.0	10.0
Error in the 10-percent highest flows	-2.09	5.0	15.0
Error in storm volumes	-7.71	20.0	20.0
Seasonal volume error	7.23	20.0	30.0
Summer-storm volume error	-10.70	50.0	50.0

[1]Lumb and others (1994), p. 56, 58.

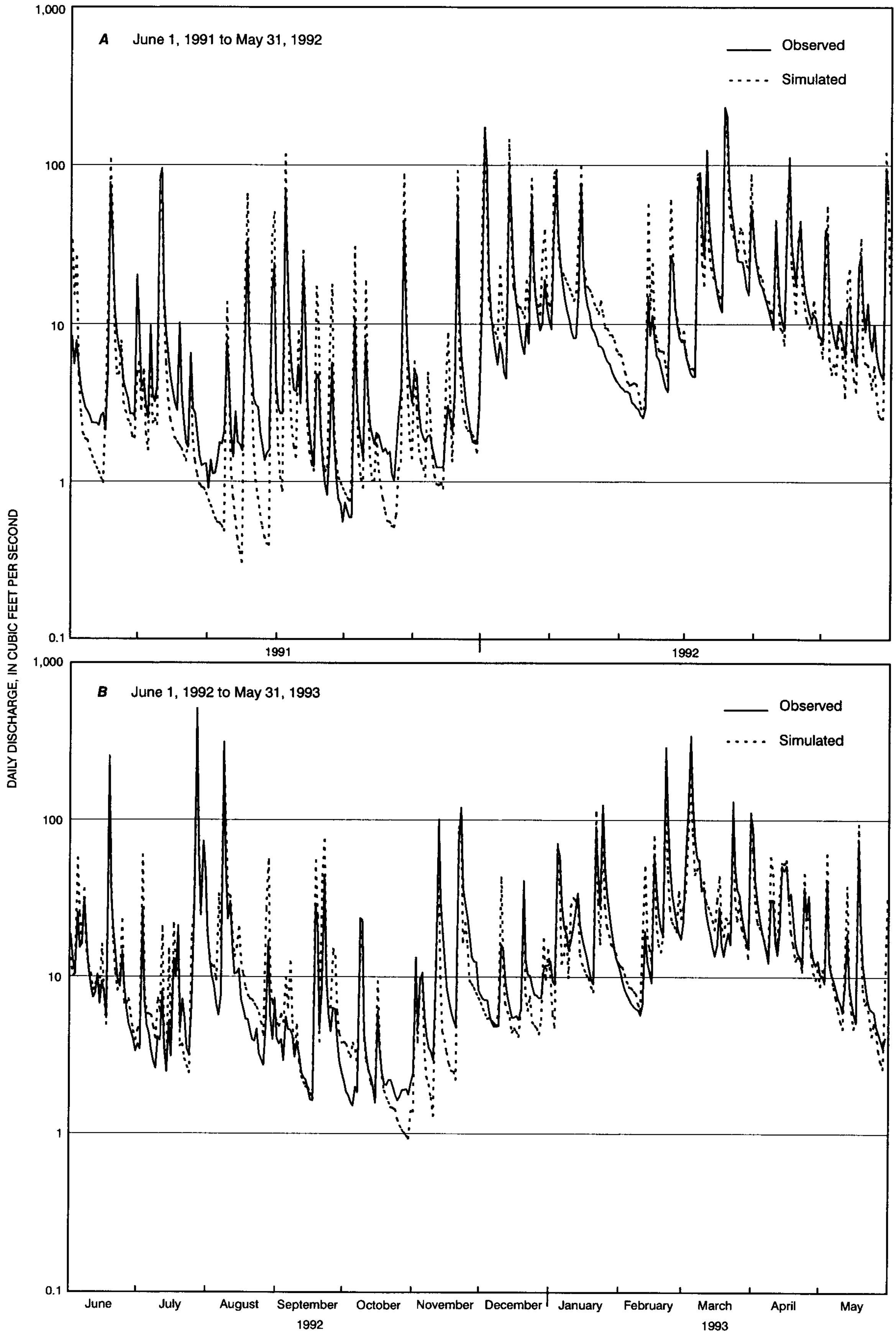


Figure 5. Observed and simulated (from model calibration) daily discharge for the Middle Fork Beargrass Creek at Louisville, Kentucky.

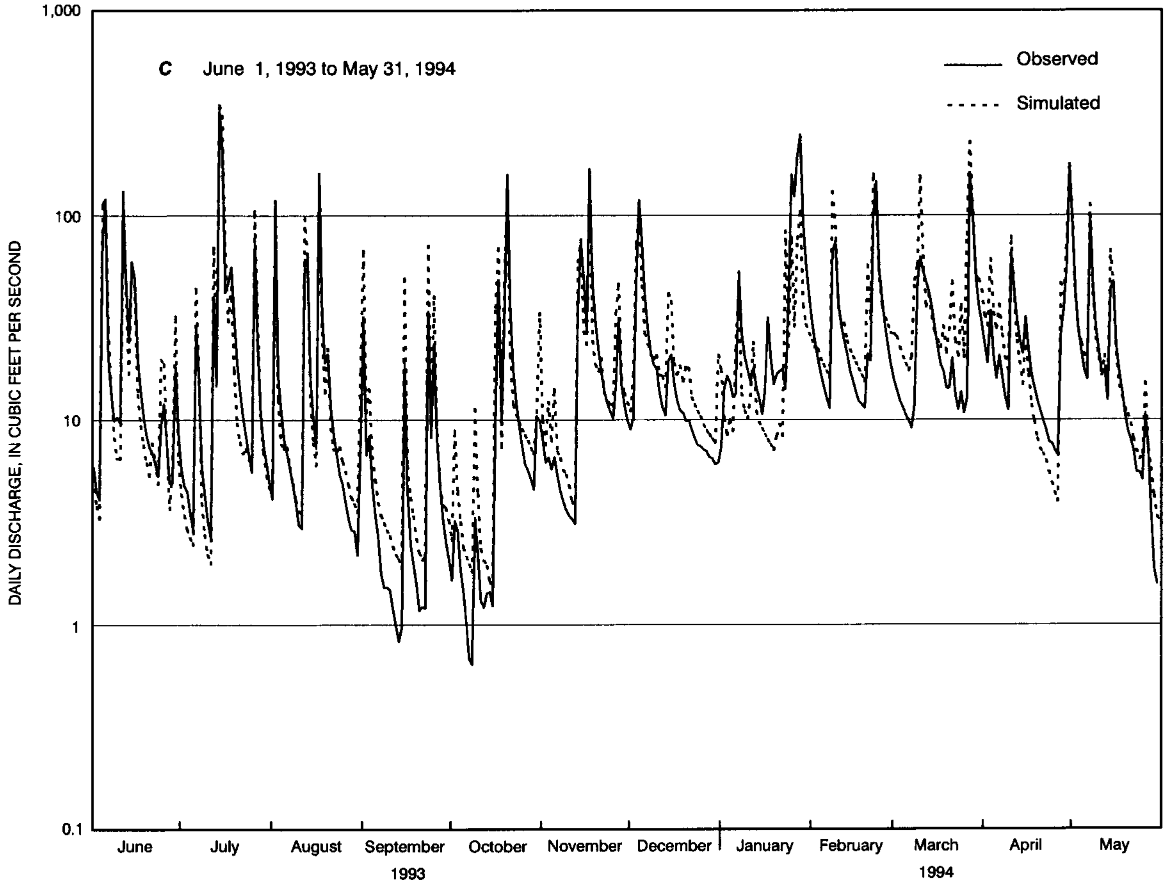


Figure 5. Observed and simulated (from model calibration) daily discharge for the Middle Fork Beargrass Creek at Louisville, Kentucky—Continued.

Simulation Results and Errors

Several model-fit statistics were calculated for the model calibration and confirmation (table 8). The absolute error is defined as the simulated value minus the observed value, and the relative error as the simulated value minus the observed value divided by the observed value (James and Burges, 1982). Two other statistics—the coefficient of model-fit efficiency (Nash and Sutcliffe, 1970) and the coefficient of determination (Mosteller and Tukey, 1977)—are provided principally as a basis to compare the models developed and applied here to other published models. The calibrated model for Middle Fork Basin was made to fit the observed streamflow data. Of the eight characteristics of the hydrograph compared, the differences between the observed and simulated runoff characteristics are all less than about 8 percent (table 9). Differences in the observed and simulated low flows (lowest 50 percent of flows) of the confirmed South Fork model are nearly 10 times greater than these differences for the calibrated Middle Fork model. The differences in the observed and simulated summer storm volume for the confirmed South Fork model are nearly twice as large as those for the calibrated Middle Fork model. Still, errors in the simulated runoff for the South Fork model are not unreasonable considering that no calibration was done and all criteria were within the limits suggested by Lumb and others (1994). The other model fit statistics would generally classify the model results as good relative to the results of other studies summarized by Duncker and others (1995).

Evaluation of the residuals indicates that large errors are predominantly associated with convective storms in summer and late snowfall events in the winter of 1994 (January 16 to February 10, 1994). The convective storms often produce locally heavy rainfall that may not be adequately estimated by the discrete rainfall network used in this study. Snowstorms of the magnitude observed in the winter of 1994 are rare in the Louisville area and do not justify incorporating simulation of snowmelt; their occurrence however, does have

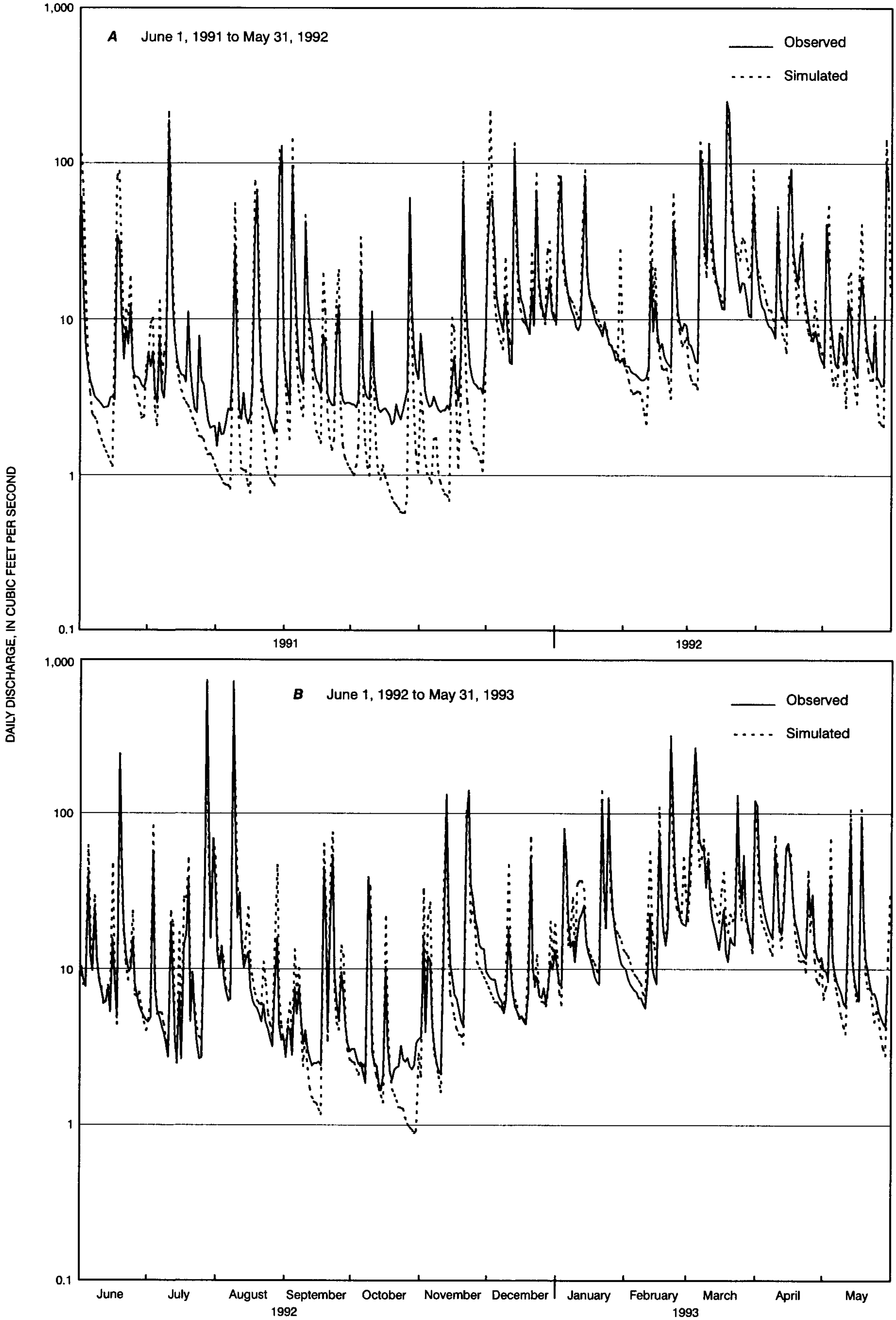


Figure 6. Observed and simulated (from model confirmation) daily discharge for the South Fork Beargrass Creek at Louisville, Kentucky.

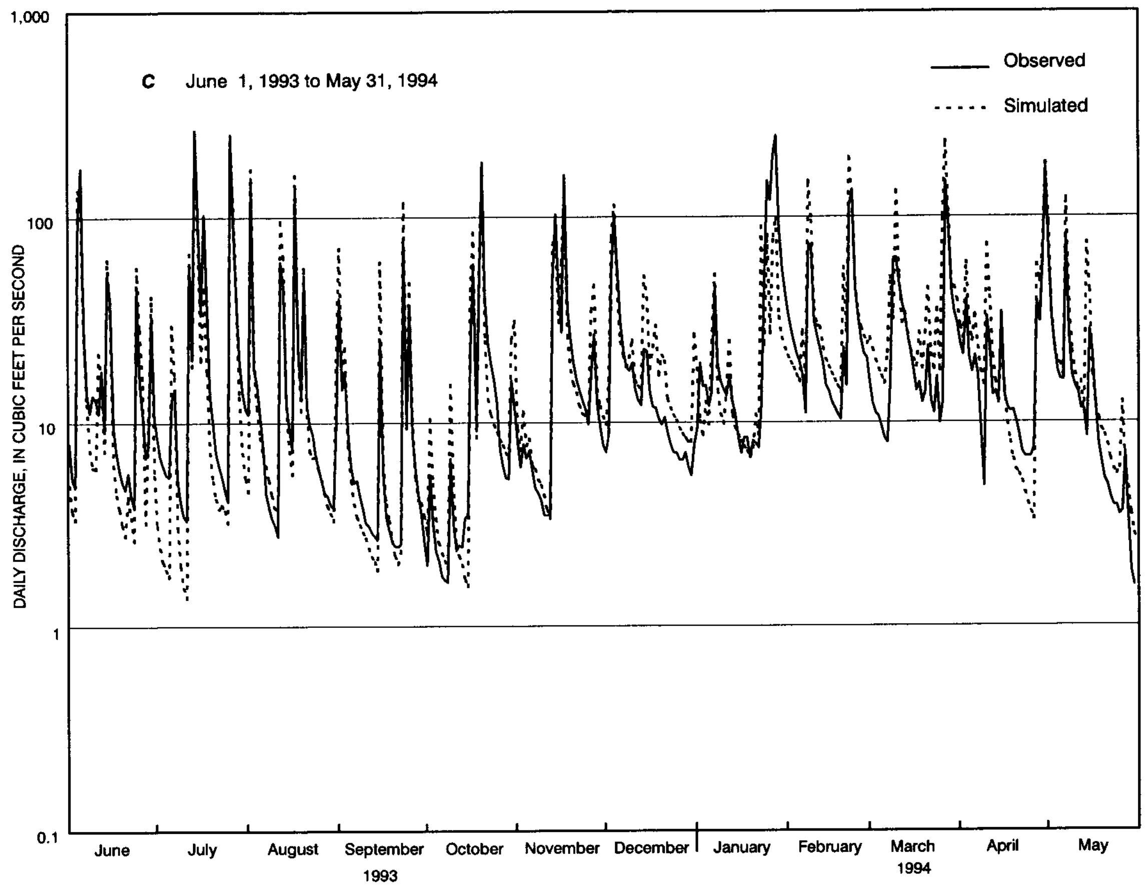


Figure 6. Observed and simulated (from model confirmation) daily discharge for the South Fork Beargrass Creek at Louisville, Kentucky—Continued.

Table 8. Statistical summary for observed and simulated daily streamflow and relative and absolute error series for the Middle Fork and South Fork Basins of Beargrass Creek at Louisville, Kentucky, from June 1, 1991, to May 31, 1994

[---, not applicable]

	Middle Fork		South Fork	
	Mean	**Standard deviation**	**Mean**	**Standard deviation**
Observed streamflow, in cubic feet per second	20.2	37.1	21.2	45.2
Simulated streamflow, in cubic feet per second	20.9	33.5	22.3	37.2
Absolute error (simulated–observed)	.76	15.7	1.09	21.7
Relative error (percent difference) (simulated–observed)/observed, in percent	15.3	64.3	8.3	63.5
Coefficient of model-fit efficiency	.82	---	.77	---
Coefficient of determination	.91	---	.88	---

Table 9. Statistics for the criteria used in the hydrologic calibration and confirmation of the Hydrological Simulation Program—FORTRAN (HSPF) model applied to the Middle Fork and South Fork Basins of Beargrass Creek at Louisville, Kentucky, from June 1, 1991, to May 31, 1994

	Observed	Simulated	Percent error (simulated/ observed -1) (percent)
Middle Fork (calibration)			
Total annual runoff, in inches	45.5	47.2	3.7
Total highest 10 percent flows, in inches	22.8	22.4	-1.8
Total lowest 50 percent flows, in inches	5.10	5.14	-.8
Total storm volume, in inches	6.47	5.97	-7.7
Average storm peaks, in cubic feet per second	653.6	699.6	7.0
Summer flow volume, in inches	10.8	11.4	5.6
Winter flow volume, in inches	13.2	13.0	-1.5
Summer storm volume, in inches	3.48	3.11	-10.6
South Fork (confirmation)			
Total annual runoff, in inches	51.6	56.0	8.5
Total highest 10 percent flows, in inches	27.3	27.9	2.0
Total lowest 50 percent flows, in inches	6.0	5.6	-7.7
Total storm volume, in inches	10.3	9.4	-8.0
Average storm peaks, in cubic feet per second	914.9	910.8	-.5
Summer flow volume, in inches	14.3	14.3	.0
Winter flow volume, in inches	13.7	15.2	10.3
Summer storm volume, in inches	5.7	4.6	-20.5

ramifications for model efficiency that may persist for several weeks as observed in this study.

SUMMARY AND CONCLUSIONS

A Hydrological Simulation Program—FORTRAN (HSPF) river-basin model was developed for the Middle Fork Basin and South Fork Basin in the Beargrass Creek Basin in Jefferson County, Ky. The simulated period was June 1, 1991, to May 31, 1994. The Hydrological Simulation Program—FORTRAN Expert System (HSPEXP) was used to calibrate the model parameters.

Meteorological data including precipitation and pan-evaporation were compiled. A variety of Geographic Information System (GIS) data coverages were developed and analyzed to delineate unique polygons within each model-grid cell. The polygons were aggregated using a K-means cluster analysis technique into four primary clusters (or groups). The clusters were classified according to their pervious (PERLND) or impervious (IMPLND) land uses and were defined as Hydrologic Response Units (HRU's). In the Middle

Fork Basin, 390 polygons were assigned to the 4 HRU's. The HRU's designated as PERLND areas were lawn, wooded, and riparian areas. A fourth HRU, designated as IMPLND, included surfaces such as roads, parking lots, buildings, and similar structures. Each of the HRU's was further divided on the basis of land slope such that 12 land-cover/land-slope combinations were applied in the model.

In the South Fork Basin, a surrogate method was devised to assign an HRU to a polygon based on an equation developed in the Middle Fork Basin that related the HRU to classification variables of soil permeability, soil-moisture storage capacity, and tree-canopy cover. A total of 318 polygons in the South Fork Basin were assigned to the 4 previously defined HRU's.

An HSPF model was developed and calibrated for the Middle Fork Basin. The simulation results indicated that the calibration was adequate—model-simulated runoff characteristics were within acceptable default criteria limits. The model calibrated for Middle Fork Basin was confirmed by applying it to the South Fork Basin. Though the confirmation results were not as good as for the Middle Fork Basin, the model was still adequate to evaluate simulation of daily flows in ungaged basins. This model could be used to calculate daily streamflow in an ungaged basin with similar land use/land cover where water-quality data are available to improve basin-load estimations.

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