U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Recd 9/14/98

In cooperation with Du Page County Department of Environmental Concerns

Regional Rainfall-Runoff Relations for Simulations of Streamflow for Watersheds in Du Page County, Illinois

Water-Resources Investigations Report 98–4035

USGS
science for a changing world

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Regional Rainfall-Runoff Relations for Simulation of Streamflow for Watersheds in Du Page County, Illinois

By James J. Duncker and Charles S. Melching

Water-Resources Investigations Report 98–4035

In cooperation with
the DU PAGE COUNTY DEPARTMENT OF ENVIRONMENTAL CONCERNS

Urbana, Illinois
1998

USGS
science for a changing world

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Thomas J. Casadevall, Acting Director

For additional information write to:

District Chief
U.S. Geological Survey
221 North Broadway Avenue
Urbana, Illinois 61801

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286, Building 810
Denver, CO 80225

CONTENTS

Abstract 1
Introduction 1
Purpose and Scope 3
Acknowledgments 3
Description of Study Area 3
Geology 3
Climate 5
Watersheds 5
Sawmill Creek 5
St. Joseph Creek 7
Kress Creek 7
Data-Collection Methods 10
Hydrologic Data 14
Land-Cover Data 15
Development of Regional Rainfall-Runoff Relations 15
Model-Calibration Procedures 16
Model-Verification Procedures 20
Results of Model Calibration 20
Best-Fit Calibration 21
Regional Calibration 21
Results of Model Verification 29
Results of Model Recalibration 30
Regional Rainfall-Runoff Relations 46
Summary and Conclusions 51
References Cited 52
Appendix 1: User Control Input Files 57

FIGURES

1-6. Maps showing:
1. Location of Du Page County, Ill., and surrounding counties 2
2. Locations of the study watersheds, watershed boundaries, and U.S. Geological Survey streamflow-and rainfall-gaging stations, and National Oceanic and Atmospheric Administration rain gages utilized in the development of rainfall-runoff relations for Du Page County, Ill. 4
3. Natural Resources Conservation Service soil associations in Du Page County, Ill. 6
4. Sawmill Creek watershed, stream channel, and U.S. Geological Survey streamflow-and rainfall-gaging stations 8
5. St. Joseph Creek watershed, stream channel, and U.S. Geological Survey streamflow-and rainfall-gaging stations, and National Oceanic and Atmospheric Administration rainfall-gaging station 9
6. Kress Creek watershed, stream channel, and U.S. Geological Survey streamflow- and rainfall-gaging stations 13
7. Diagram of the Hydrological Simulation Program—Fortran model 17
8. Daily runoff-duration curves for observed data and Hydrological Simulation Program—Fortran simulation with the application of the best-fit and regional parameter sets for a 45-month calibration period (January 1990–September 1993) for Kress Creek at West Chicago, Ill. 23
9. Daily runoff-duration curves for observed data and Hydrological Simulation Program—Fortran simulation with application of the best-fit and regional parameter sets for a 45-month calibration period (January 1990–September 1993) for St. Joseph Creek at Route 34 at Lisle, Ill. 24

10. Daily runoff-duration curves for observed data and Hydrological Simulation Program—Fortran simulation with application of the best-fit and regional parameter sets for a 45-month calibration period (January 1990–September 1993) for Sawmill Creek near Lemont, Ill. 25
11. Runoff-frequency plots for observed data and Hydrological Simulation Program—Fortran simulation with application of the best-fit and regional parameter sets for storms producing greater than 0.5 inch of runoff in a 3-day period for Kress Creek at West Chicago, Ill. (January 1990–September 1993) 26
12. Runoff-frequency plots for observed data and Hydrological Simulation Program—Fortran simulation with application of the best-fit and regional parameter sets for storms producing greater than 0.6 inch of runoff in a 3-day period for St. Joseph Creek at Route 34 at Lisle, Ill., (January 1990–September 1993) 27
13. Runoff-frequency plots for observed data and Hydrological Simulation Program—Fortran simulation with application of the best-fit and regional parameter sets for storms producing greater than 0.7 inch of runoff in a 3-day period for Sawmill Creek near Lemont, Ill., (January 1990–September 1993) 28
14. Observed and Hydrological Simulation Program—Fortran simulated (with application of the regional parameter set) monthly runoff for a 39-month verification period for Kress Creek at West Chicago, Ill. 31
15. Observed and Hydrological Simulation Program—Fortran simulated (with application of the regional parameter set) monthly runoff for a 39-month verification period for St. Joseph Creek at Route 34 at Lisle, Ill 32
16. Observed and Hydrological Simulation Program—Fortran simulated (with application of the regional parameter set) monthly runoff for a 39-month verification period for Sawmill Creek near Lemont, Ill. 33
17. Daily runoff-duration curves for observed data and Hydrological Simulation Program—Fortran simulation with the application of the regional parameter set for an 87-month recalibration period (July 1986–September 1993) for Kress Creek at West Chicago, Ill. 35
18. Daily runoff-duration curves for observed data and Hydrological Simulation Program—Fortran simulation with application of the regional parameter set for an 87-month recalibration period (July 1986–September 1993) for St. Joseph Creek at Route 34 at Lisle, Ill. 36
19. Daily runoff-duration curves for observed data and Hydrological Simulation Program—Fortran simulation with application of the regional parameter set for an 87-month recalibration period (July 1986–September 1993) for Sawmill Creek near Lemont, Ill. 37
20. Runoff-frequency plots for observed data and Hydrological Simulation Program—Fortran simulation with application of the regional parameter set for an 87-month recalibration period (July 1986–September 1993) for storms producing greater than 0.8 inch of runoff in a 3-day period for Kress Creek at West Chicago, Ill. 38
21. Runoff-frequency plots for observed data and Hydrological Simulation Program—Fortran simulation with application of the regional parameter set for an 87-month recalibration period for storms producing greater than 1.0 inch of runoff in a 3-day period for St. Joseph Creek at Route 34 at Lisle, Ill., (July 1986–September 1993) 39
22. Runoff-frequency plots for observed data and Hydrological Simulation Program—Fortran simulation with application of the regional parameter set for an 87-month recalibration period for storms producing greater than 1.0 inch of runoff in a 3-day period for Sawmill Creek near Lemont, Ill., (July 1986–September 1993) 40
23. Observed and Hydrological Simulation Program—Fortran simulated (with application of the regional parameter set) monthly runoff for Kress Creek at West Chicago, Ill., for an 87-month recalibration period 42
24. Observed and Hydrological Simulation Program—Fortran simulated (with application of the regional parameter set) monthly runoff for St. Joseph Creek at Route 34 at Lisle, Ill., for an 87-month recalibration period 43
25. Observed and Hydrological Simulation Program—Fortran simulated (with application of the regional parameter set) monthly runoff for Sawmill Creek near Lemont, Ill., for an 87-month recalibration period 44
26. Relation between the interflow recession constant in the Hydrological Simulation Program—Fortran and watershed area for three watersheds in Du Page County, Ill., and five watersheds in Lake County, Ill. 50

TABLES

1. Land-cover characteristics derived from 1990 data for three watersheds in Du Page County, Ill 7
2. Common soil types and (or) soil/urban complexes in the Kress Creek watershed and their properties 11

3. Model-calibration statistics for three watersheds in Du Page County, Ill., simulated with application of the best-fit parameter set for the Hydrological Simulation Program—Fortran for a 45-month calibration period (January 1990–September 1993) 21
4. Observed and simulated annual and grand total runoff from three watersheds in Du Page County, Ill. 22
5. Model-calibration statistics for three watersheds in Du Page County, Ill., simulated for a 45-month calibration period (January 1990–September 1993) 29
6. Model-verification statistics for three watersheds in Du Page County, Ill., for a 39-month verification period (July 1986–September 1989) 30
7. Observed and Hydrological Simulation Program—Fortran simulated with application of the regional parameter set for a 39-month verification period (July 1986–September 1989) annual and grand total runoff from three watersheds in Du Page County, Ill 30
8. Model-recalibration statistics for Hydrological Simulation Program—Fortran simulation of rainfall-runoff relations for three watersheds in Du Page County, Ill., with application of the regional parameter set for an 87-month recalibration period (July 1986–September 1993) 34
9. Observed and Hydrological Simulation Program—Fortran simulated with application of the regional parameter set for an 87-month period (July 1986–September 1993) annual and grand total runoff from three watersheds in Du Page County, Ill 41
10. Rainfall-runoff coefficients for storms producing greater than 0.8 inch of observed runoff during a 3-day period in the Kress Creek watershed in Du Page County, Ill., (July 1986–September 1993) 45
11. Rainfall-runoff coefficients for storms producing greater than 1.0 inch of observed runoff during a 3-day period for the St. Joseph Creek watershed in Du Page County, Ill., (July 1986–September 1993) 45
12. Rainfall-runoff coefficients for storms producing greater than 1.0 inch of observed runoff during a 3-day period for the Sawmill Creek watershed in Du Page County, Ill., (July 1986–September 1993) 46
13. Model-parameter values for a 45-month (January 1990–September 1993) regional calibration period and an 87-month (July 1986–September 1993) regional recalibration of three watersheds in Du Page County, Ill., simulated with the Hydrological Simulation Program—Fortran 47
14. Monthly variable model-parameter values for the best-fit calibration, 45-month (January 1990–September 1993) regional calibration, and 87-month (July 1986–September 1993) recalibration of three watersheds in Du Page County, Ill., simulated with the Hydrological Simulation Program—Fortran 48

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch per hour (in/h)	0.0254	meter per hour
inch per year (in/yr)	25.4	millimeter per year

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

$$°C = (°F - 32) / 1.8$$

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.

Regional Rainfall-Runoff Relations for Simulation of Streamflow for Watersheds in Du Page County, Illinois

By James J. Duncker *and* Charles S. Melching

ABSTRACT

Rainfall and streamflow data collected from July 1986 through September 1993 were utilized to calibrate and verify a continuous-simulation rainfall-runoff model for three watersheds (11.8–18.0 square miles in area) in Du Page County. Classification of land cover into three categories of pervious (grassland, forest/wetland, and agricultural land) and one category of impervious subareas was sufficient to accurately simulate the rainfall-runoff relations for the three watersheds. Regional parameter sets were obtained by calibrating jointly all parameters except fraction of ground-water inflow that goes to inactive ground water (DEEPFR), interflow recession constant (IRC), and infiltration (INFILT) for runoff from all three watersheds. DEEPFR and IRC varied among the watersheds because of physical differences among the watersheds. Two values of INFILT were obtained: one representing the rainfall-runoff process on the silty and clayey soils on the uplands and lake plains that characterize Sawmill Creek, St. Joseph Creek, and eastern Du Page County; and one representing the rainfall-runoff process on the silty soils on uplands that characterize Kress Creek and parts of western Du Page County.

Regional rainfall-runoff relations, defined through joint calibration of the rainfall-runoff model and verified for independent periods, presented in this report, allow estimation of runoff for watersheds in Du Page County with an error in the total water balance less than 4.0 percent; an average absolute error in the annual-flow estimates of 17.1 percent with the error rarely exceeding 25 percent for annual flows; and correlation coefficients and coefficients of model-fit efficiency for monthly flows of at least 87 and 76 percent, respectively. Close reproduction of the runoff-volume duration curves was obtained. A frequency analysis of storm-runoff volume indicates a tendency of the model to undersimulate large storms, which may result from underestimation of the amount of impervious land cover in the watershed and errors in measuring rainfall for convective storms. Overall, the results of regional calibration and verification of the rainfall-runoff model indicate the simulated rainfall-runoff relations are adequate for stormwater-management planning and design for watersheds in Du Page County.

INTRODUCTION

Du Page County is located in the Chicago metropolitan area of northeastern Illinois, approximately 10 mi west of the city of Chicago (fig. 1). Du Page County has one of the fastest-growing populations of any county in the Midwest, and urban development is proceeding rapidly, resulting in changes in the physical conditions of watersheds within the area. Negative effects associated with development in a watershed (such as increases in the magnitudes and frequencies of damaging floods, an increase in stream-channel erosion, and an overall degradation of water quality) emphasize the need for mitigation of current stormwater problems, and better-informed planning and design for future watershed development.

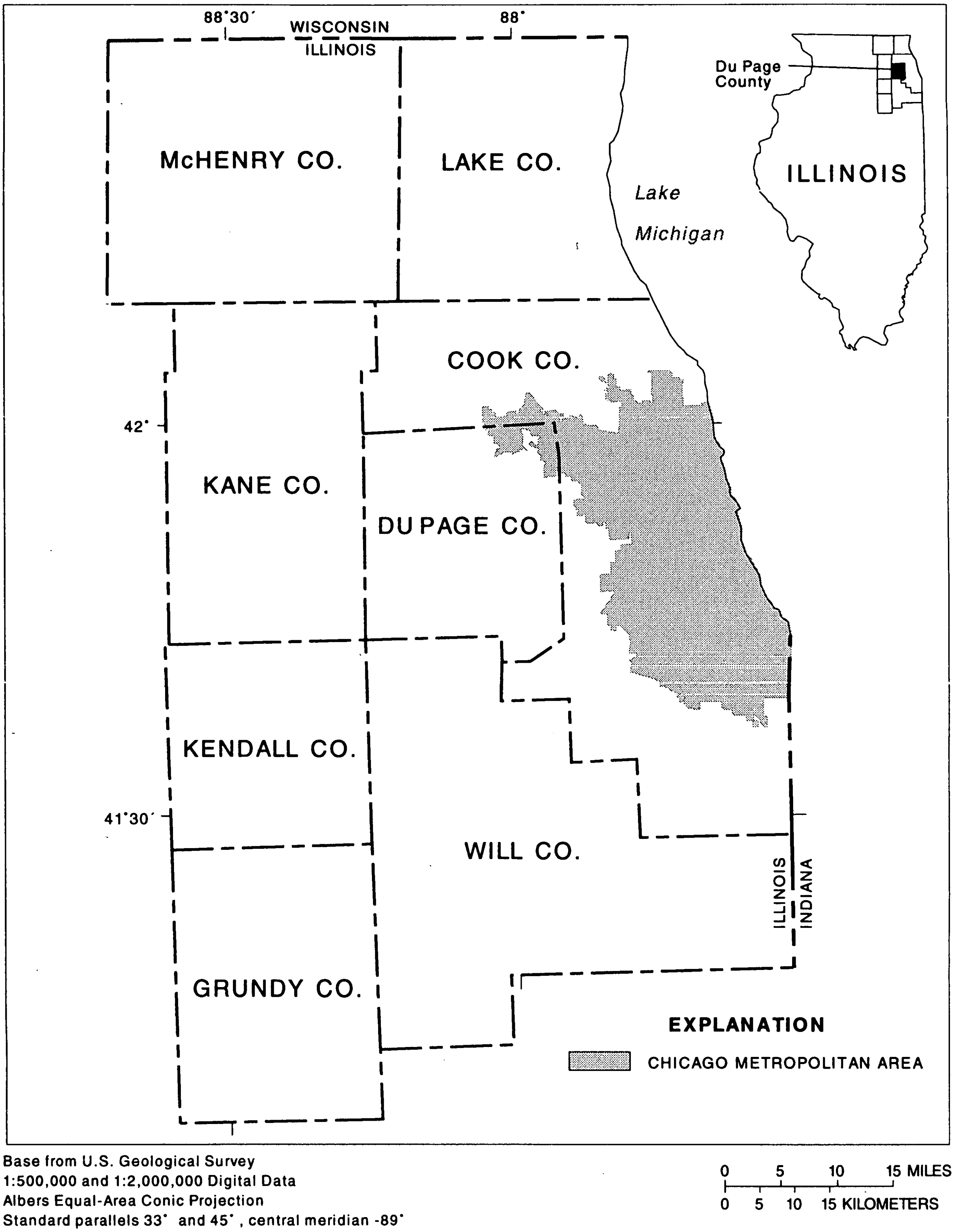


Figure 1. Location of Du Page County, Ill., and surrounding counties.

Hydrologic information on the temporal and areal variations in storm-runoff quantity provides the technical basis for design of urban-drainage facilities, the planning of stormwater-management alternatives, and the establishment of realistic regulations. Designers use the information to ensure properly sized and located storm drains and storm-runoff storage reservoirs.

Available information concerning the variation in time and space of the flow rates and volumes of storm runoff in Du Page County is limited, especially on small (less than 25 mi^2) watersheds. Lacking reliable data, planners, designers, engineers, regulators, and researchers seeking solutions to hydrologic and hydraulic problems for urban areas have resorted to various assumptions and models that may or may not be technically supportable.

The Du Page County Department of Environmental Concerns (DEC) currently is implementing a Stormwater Management Program (SMP). This program was initiated in 1982 in response to "increased flooding; flood-plain mapping errors; lack of coordination within watersheds; and the need for better management, information, and planning tools" (L.M. Mele, Du Page County Department of Environmental Concerns, written commun., 1985). As a part of this program, a distributed-parameter, rainfall-runoff model coupled with a dynamic open-channel flow model is utilized to simulate stormflow hydrographs and route the simulated flows through the channel system. The U.S. Geological Survey (USGS), in cooperation with the Du Page County DEC, began collecting hydrologic data on three watersheds in February 1986 to calibrate the distributed parameter rainfall-runoff model. These hydrologic and hydraulic models are utilized for mapping flood plains, regulating future development, and evaluating flood- and stormwater-control projects.

Purpose and Scope

This report describes the results of a study to define and simulate regional (countywide in this study) rainfall-runoff relations for small watersheds in Du Page County, Ill. The report includes (1) a description of the methods of hydrologic and land-cover data collection, (2) a description of the calibration and verification procedures used for the rainfall-runoff model, and (3) the results of calibration and verification of the rainfall-runoff model.

The information in this report is based primarily on rainfall and streamflow data collected by the USGS from February 1986 to September 1993 in three watersheds in Du Page County, Ill. The watersheds have areas of 11.8, 13.3, and 18.0 mi^2, with land use ranging from predominately urban to predominately rural. Rainfall data were collected at 16 sites in and near Du Page County. Land-cover data were supplied by the Du Page County DEC from a county geographic information system (GIS) data base. Rainfall-runoff relations were developed with the Hydrological Simulation Program—Fortran (HSPF) model (Bicknell and others, 1993) for each watershed.

Acknowledgments

The authors are grateful to Ms. Linda M. Mele, Du Page County Department of Environmental Concerns, for her assistance with project planning and data collection. Thomas Price, Northeastern Illinois Planning Commission, provided valuable coordination, advice in modeling, and review of this report. In addition, Dr. Norbert Golchert of Argonne National Laboratory supplied some of the meteorological data utilized in the study.

DESCRIPTION OF STUDY AREA

The study area consists of three watersheds in and near Du Page County in northeastern Illinois (fig. 2). The understanding of the geology and climate of the county, in addition to the physical characteristics of gaged watersheds, is necessary to the development of rainfall-runoff relations for ungaged streams.

Geology

Du Page County is subdivided into the Wheaton Morainal Region and the Bloomington Ridged Plain physiographic divisions (fig. 2) (Leighton and others, 1948). The two physiographic divisions have contrasting differences in glacial morphology. The Wheaton Morainal Region is characterized by a series of closely spaced glacial moraines formed by a relatively stagnant ice front, which produced an undulating topography. The Bloomington Ridged Plain is characterized by low, widely spaced moraines alternating with generally flat, featureless,

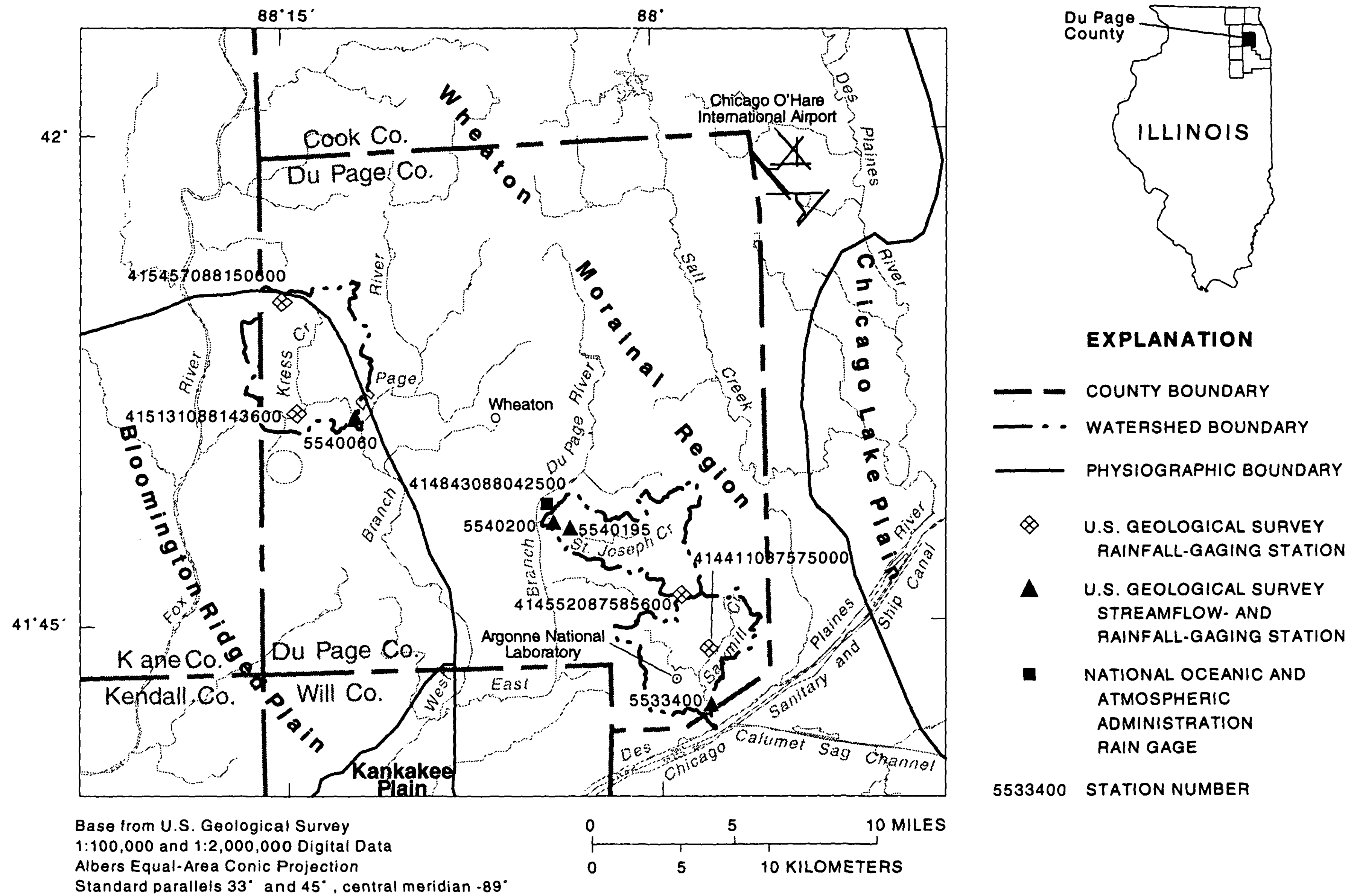


Figure 2. Locations of the study watersheds, watershed boundaries, and U.S. Geological Survey streamflow- and rainfall-gaging stations, and National Oceanic and Atmospheric Administration rain gages utilized in the development of rainfall-runoff relations for Du Page County, Ill.

ground moraine formed by an ice front, which had advanced and retreated several times.

The geology of the study area can be generalized as consisting of unconsolidated glacial deposits overlying thick sequences of Paleozoic dolomite, sandstone, and shale bedrock. The bedrock sequences lie unconformably upon Precambrian crystalline basement rocks. The unconsolidated glacial deposits were deposited by ice of the Lake Michigan glacial lobe during the Wisconsinan Stage. The deposits range in thickness from 0 to 200 ft within the study area and form primarily terminal and ground-moraine features.

Several aquifers are recognized within the Paleozoic bedrock (Zeizel and others, 1962). Shale formations within the bedrock form confining units in some places. The fractured Silurian dolomite that underlies the unconsolidated glacial deposits throughout the study area forms the principal aquifer. Groundwater recharge to the Silurian dolomite aquifer has been estimated at 1.2–2.9 in/yr and recharge rates for the glacial drift aquifers are estimated to be 2.9–4.7 in/yr (Zeizel and others, 1962).

The U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) (formerly the Soil Conservation Service) soil survey of Du Page County (Mapes, 1979) indicates that soils in the study area were formed mainly in glacial material and consist of poorly drained silts and clays. Well-drained silty soils are found in some upland areas in the western part of Du Page County. Eight predominant soil associations are identified by the NRCS in Du Page County (fig. 3). These soil associations are placed into three broad categories for planning purposes in Du Page County: 1) silty and clayey soils on uplands and lake plains, 2) silty soils on uplands, 3) silty and loamy soils on terraces and bottom lands. The majority of the soils in Du Page County are categorized by the NRCS as hydrologic soil types B and C. The hydrologic characteristics of the NRCS soil types B and C are sufficiently similar for most stormwater-modeling purposes such that the soils in the watersheds studied can be considered uniform, except for soils in the Kress Creek watershed. Soils in the Kress Creek watershed (and elsewhere in western Du Page County as shown in fig. 3) are substantially different than those found elsewhere in Du Page County. The approach used to account for the different soil types in the Kress Creek watershed is described in the "Kress Creek" section.

Climate

The study area has a temperate, humid, continental climate that is slightly modified by Lake Michigan. Long-term daily climatic data are available for the National Oceanic and Atmospheric Administration (NOAA) gage at Wheaton, Ill. (fig 2). The long-term (1927–93) average annual precipitation for the study area is approximately 35 in., and the long-term (1948–93) mean annual temperature for the study area is approximately 49°F (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1986–1993).

The climate of the study area results in storms with general seasonal characteristics. Storms in the spring, autumn, and winter tend to be associated with fronts that move through the area and produce widespread, relatively uniform amounts of precipitation. Summer storms tend to develop as smaller, isolated convective storm cells that produce widely scattered and varying amounts of precipitation.

The climate during the period of study can be considered typical for the Midwest. Average annual temperature and average annual precipitation during the study (February 1986–September 1993) were close to the long-term averages for the Wheaton NOAA station (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1986–1993). Two extreme climatic periods should be noted. A series of storms during August 1987 produced record rainfall in parts of Du Page County and peak discharges in excess of the 60-year flood discharge at some sites. In addition to the record floods of August 1987, record droughts occurred in much of Du Page County during the summers of 1988 and 1990.

Watersheds

Three watersheds with drainage areas of 11.8, 13.3, and 18.0 mi^2 were selected for instrumentation to determine rainfall-runoff relations (fig. 2). The watersheds include a good representation of land cover and drainage features typical of most of Du Page County.

Sawmill Creek

The Sawmill Creek watershed is 13.3 mi^2 in area and is in southern Du Page County (fig. 2). Sawmill Creek is a tributary to the Des Plaines River. Land-cover data indicate a mix of urban and rural/open space

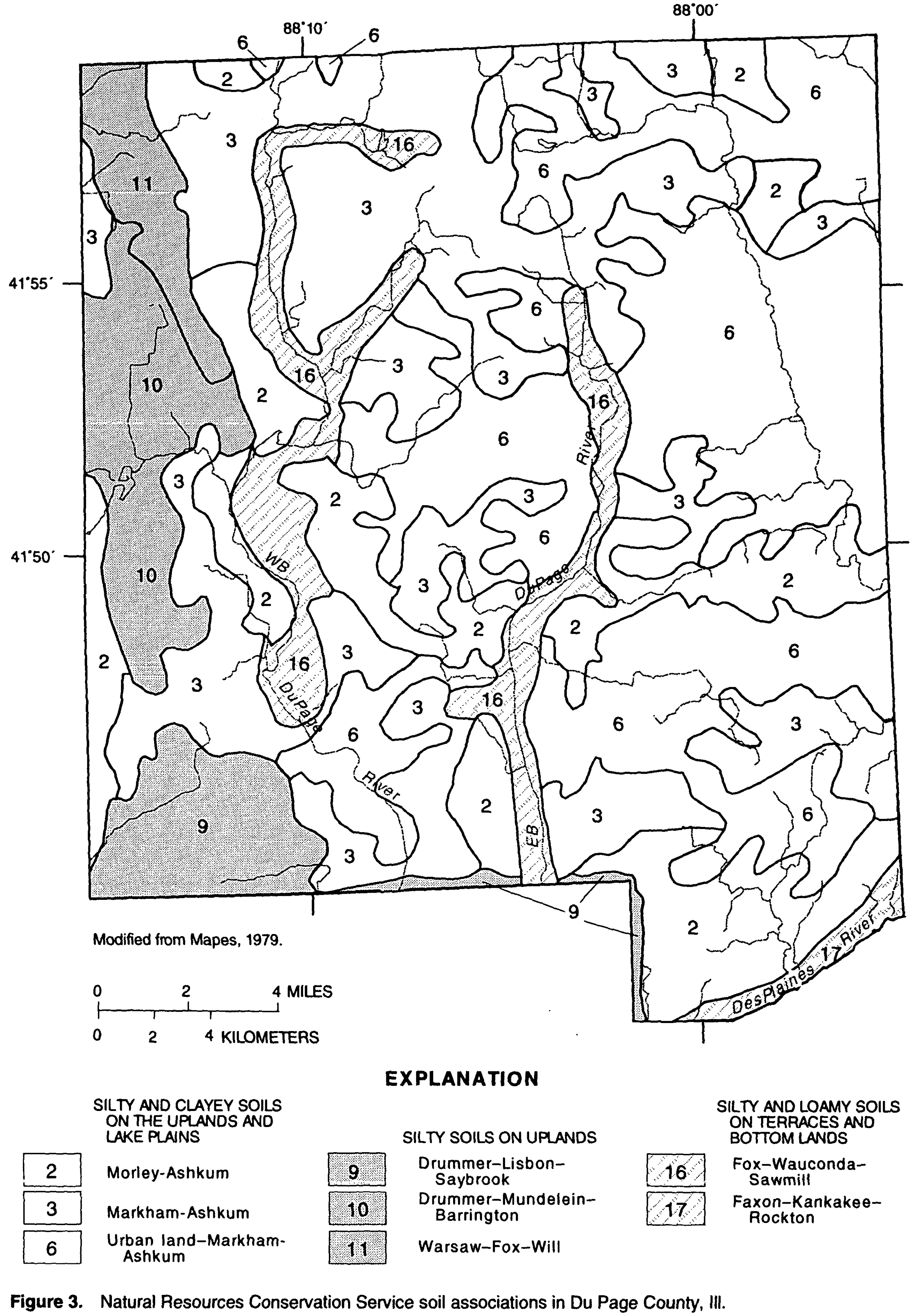


Figure 3. Natural Resources Conservation Service soil associations in Du Page County, Ill.

with 17.2 percent impervious area. A mix of swales and storm sewers provide drainage for the urban areas of the watershed. Relatively large tracts of forest are present in the lower part of the watershed on forest preserve land and on Argonne National Accelerator Laboratory property. The land-cover percentages for impervious and three types of pervious area (grassland, forest/wetland, and agricultural land) are listed in table 1.

A wastewater-treatment facility discharged effluent to Sawmill Creek until February 1986, when operation of the facility was discontinued. Discharge records from the treatment facility were obtained to subtract the effluent flows from the gaging-station record. Storm hydrographs from Sawmill Creek have moderately steep rising limbs because of the impervious land cover within the watershed. Base flow within Sawmill Creek is a result of ground-water discharge from shallow, glacial drift aquifers. The Sawmill Creek watershed and USGS streamflow- and rainfall-gaging stations utilized in the hydrologic modeling are shown in figure 4.

St. Joseph Creek

The St. Joseph Creek watershed is 11.8 mi^2 in area and is in central Du Page County bordering on the northern boundary of the Sawmill Creek watershed (fig. 2). St. Joseph Creek is a tributary of the East Branch of the Du Page River. Land-cover data indicate 22.3 percent of impervious area, which is associated with the predominately urban part of the watershed. The land-cover percentages for impervious and three types of pervious area (grassland, forest/wetland, and agricultural land) are listed in table 1.

Runoff in the St. Joseph Creek watershed is affected by the large amount of impervious land cover. The primary drainage features within the urban part of the watershed are storm sewers. Storm hydrographs from St. Joseph Creek have a steep rising limb. The time lag between rainfall peak and streamflow peak is short. Little topographic relief is present within the watershed. Watershed boundaries are obscure in places and have been modified at times by construction activities. Storm-sewer maps were used to help define the watershed boundaries. Base flow within the St. Joseph Creek watershed is a result of ground-water discharge from shallow, glacial drift aquifers. Zero-flow periods result during dry weather almost every year. The St. Joseph Creek watershed, USGS streamflow- and rainfall-gaging stations, and National Oceanic and Atmospheric Administration rainfall-gaging station utilized in the hydrologic modeling are shown in figure 5.

High stages in the East Branch of the Du Page River produced variable-backwater conditions at the original St. Joseph Creek at Lisle, Ill., gaging station (station number 05540200) at State Route 53. Variable backwater results in uncertainty in the stage-discharge relation at this station. Because of the uncertainty in the stage-discharge relation, a second gaging station (station number 05540195) was established in July 1989 approximately 1 mi upstream at the State Route 34 bridge over St. Joseph Creek, a site unaffected by the variable-backwater conditions. The relocation of the St. Joseph Creek station reduced the drainage area by 0.7 mi^2 (11.8 to 11.1 mi^2) but did not appreciably alter the overall composition of the watershed land cover (table 1).

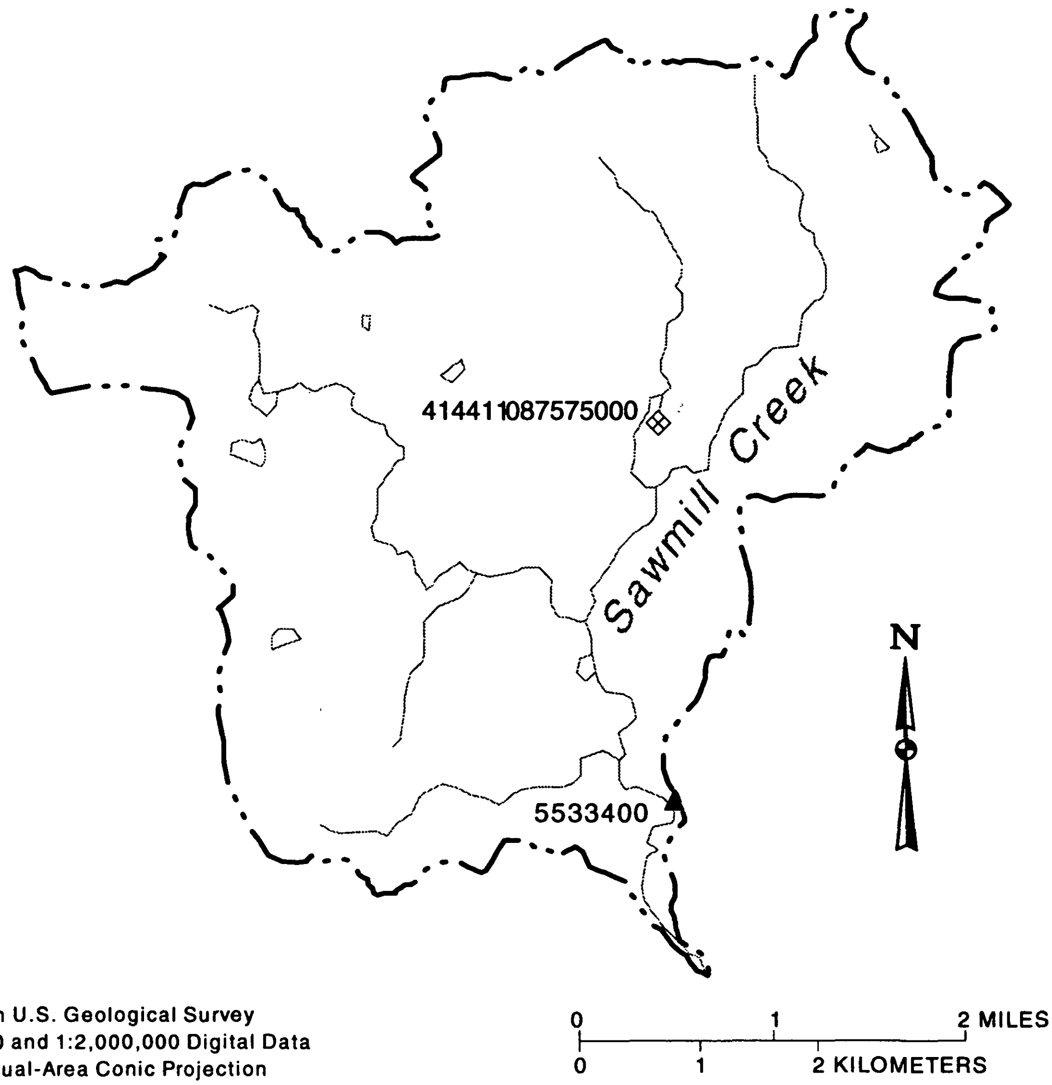
Kress Creek

The Kress Creek watershed is 18.0 mi^2 in area and is in northwest Du Page County (fig. 2). Kress

Table 1. Land-cover characteristics derived from 1990 data for three watersheds in Du Page County, Ill.

[mi^2, square miles]

Watershed and station number	Drainage area (mi^2)	Impervious area (percent)	Pervious area		
			Grassland (percent)	Forest/wetland (percent)	Agricultural land (percent)
St. Joseph Creek at Lisle, Ill. 05540200	11.8	21.90	70.90	7.00	0.20
St. Joseph Creek at Route 34 at Lisle, Ill. 05540195	11.1	22.33	70.63	6.79	.25
Kress Creek at West Chicago, Ill. 05540060	18.0	14.38	32.07	7.18	46.37
Sawmill Creek near Lemont, Ill. 05533400	13.3	17.16	62.68	17.42	2.74



Base from U.S. Geological Survey
1:100,000 and 1:2,000,000 Digital Data
Albers Equal-Area Conic Projection
Standard parallels 33° and 45°, central meridian -89°

EXPLANATION

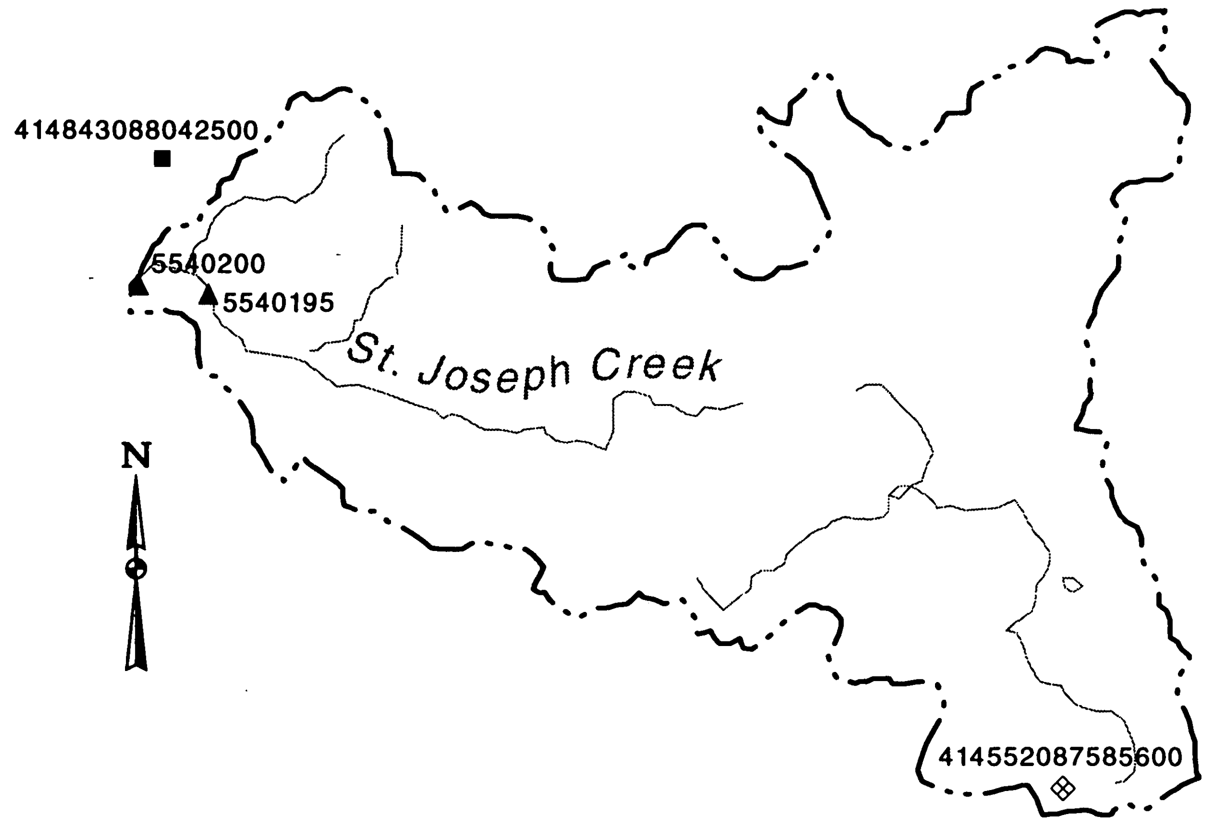
—— - - WATERSHED BOUNDARY

⊕ U.S. GEOLOGICAL SURVEY RAINFALL-GAGING STATION

▲ U.S. GEOLOGICAL SURVEY STREAMFLOW- AND RAINFALL-GAGING STATION

5533400 STATION NUMBER

Figure 4. Sawmill Creek watershed, stream channel, and U.S. Geological Survey streamflow- and rainfall-gaging stations.



Base from U.S. Geological Survey
1:100,000 and 1:2,000,000 Digital Data
Albers Equal-Area Conic Projection
Standard parallels 33° and 45°, central meridian -89°

0 1 2 MILES
0 1 2 KILOMETERS

EXPLANATION

— · ·	WATERSHED BOUNDARY
◈	U.S. GEOLOGICAL SURVEY RAINFALL-GAGING STATION
▲	U.S. GEOLOGICAL SURVEY STREAMFLOW- AND RAINFALL-GAGING STATION
■	NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION RAINFALL GAGE
5540195	STATION NUMBER

Figure 5. St. Joseph Creek watershed, stream channel, and U.S. Geological Survey streamflow- and rainfall-gaging stations, and National Oceanic and Atmospheric Administration rainfall-gaging station.

Creek is a tributary to the West Branch of the Du Page River. The land-cover data indicate the watershed includes 14.4 percent impervious area but also includes a substantial area of agricultural land (46.4 percent). Within the study period (February 1986–September 1993), urban development substantially modified the land cover within the watershed. The land-cover used in the modeling was derived from 1990 tax parcel data and is considered to be representative of median conditions during the study period. The land-cover percentages for impervious and three types of pervious area (grassland, forest/wetland, and agricultural land) are listed in table 1.

As indicated in figure 3, the Kress Creek watershed is characterized by silty soils on uplands that are not present in the Sawmill Creek and St. Joseph Creek watersheds and are rare in the remainder of Du Page County. The properties of the soils in Kress Creek were reviewed to determine if Kress Creek should be represented with two soil groups in rainfall-runoff simulation: one representing the silty and clayey soils on uplands and lake plains (which characterize Sawmill Creek and St. Joseph Creek) and the other representing the silty soils on uplands. The 15 most common soil types and or soil/urban complexes (representing 87.9 percent of the watershed) in the Kress Creek watershed and their properties are listed in table 2. As indicated in table 2, the differences in the hydrologic properties among the soils in the Kress Creek watershed are small. Most soils in the Kress Creek watershed have NRCS hydrologic soil classification B, permeabilities between 0.6 and 2.0 in/h, high available moisture capacity, and moderate transmission rates. The primary differences among the soils relate to drainage and, consequently, the depth to the water table during wet periods (that is, the highest water table depth). Under natural conditions, the two main soils—Drummer silty clay loam and Mundelein silt loam—in the Kress Creek watershed are poorly drained with substantially higher water tables than the other soils in the watershed, which could result in a smaller Upper-Zone Storage in HSPF simulation of runoff from these soils. However, it is likely that these soils include agricultural tile drains. Thus, the physical difference among the soils in the watershed under natural conditions is negated by agricultural drainage, and it seems likely that two different hydrologic soil groups in the Kress Creek watershed cannot be distinguished.

Considering the percentages of the given soil types in the Kress Creek watershed relative to the percentages of these soils in Du Page County, it is clear that the Kress Creek watershed includes substantially different soil types than Du Page County as a whole. For example, the percentages of the five most common soil types in the Kress Creek watershed are 4.8, 5.8, 6.2, 0.5, and 8.6 times the respective percentages in Du Page County. Thus, it is clear that the Kress Creek watershed includes considerably different soils than the Sawmill Creek and St. Joseph Creek watersheds, and derivation of different sets of soil-runoff parameters for simulation of the rainfall-runoff process for Kress Creek, Sawmill Creek, and St. Joseph Creek is justified.

Further, justification for simulating the rainfall-runoff process on Kress Creek with a separate set of soil-runoff parameters results from observation of base-flow characteristics. The Kress Creek watershed has the largest base flow of the three watersheds considered in this study. A single day of zero flow was observed during the study period, which may have resulted from unmeasured withdrawals by irrigation pumps for a sod farm during an extended period of dry weather flow. The substantially higher base flow in Kress Creek reflects higher infiltration and greater replenishment of the shallow, glacial drift aquifers that provide base flow. Simulation of the higher infiltration requires a different set of soil-runoff parameters than is appropriate for Sawmill Creek and St. Joseph Creek.

Primary drainage features within the Kress Creek watershed include a retention storage facility adjacent to the stream channel in the extreme upper reaches of the watershed. A combination of grassed swales and storm sewers provide drainage throughout the watershed. Storm hydrographs for Kress Creek have the least-steep rising limb of the three watersheds considered in this study. These least-steep rising limbs on the hydrographs for Kress Creek may result from the effects of the retention storage facility, the larger drainage area, and the lower percentage of impervious area relative to the other watersheds. The Kress Creek watershed and USGS streamflow- and rainfall-gaging stations utilized in the hydrologic modeling are shown in figure 6.

DATA-COLLECTION METHODS

The hydrologic cycle is a conceptual framework that describes the movement of water within a watershed and between land, water bodies, and the atmosphere. Rainfall-runoff relations that define the

Table 2. Common soil types and (or) soil/urban complexes in the Kress Creek watershed and their properties

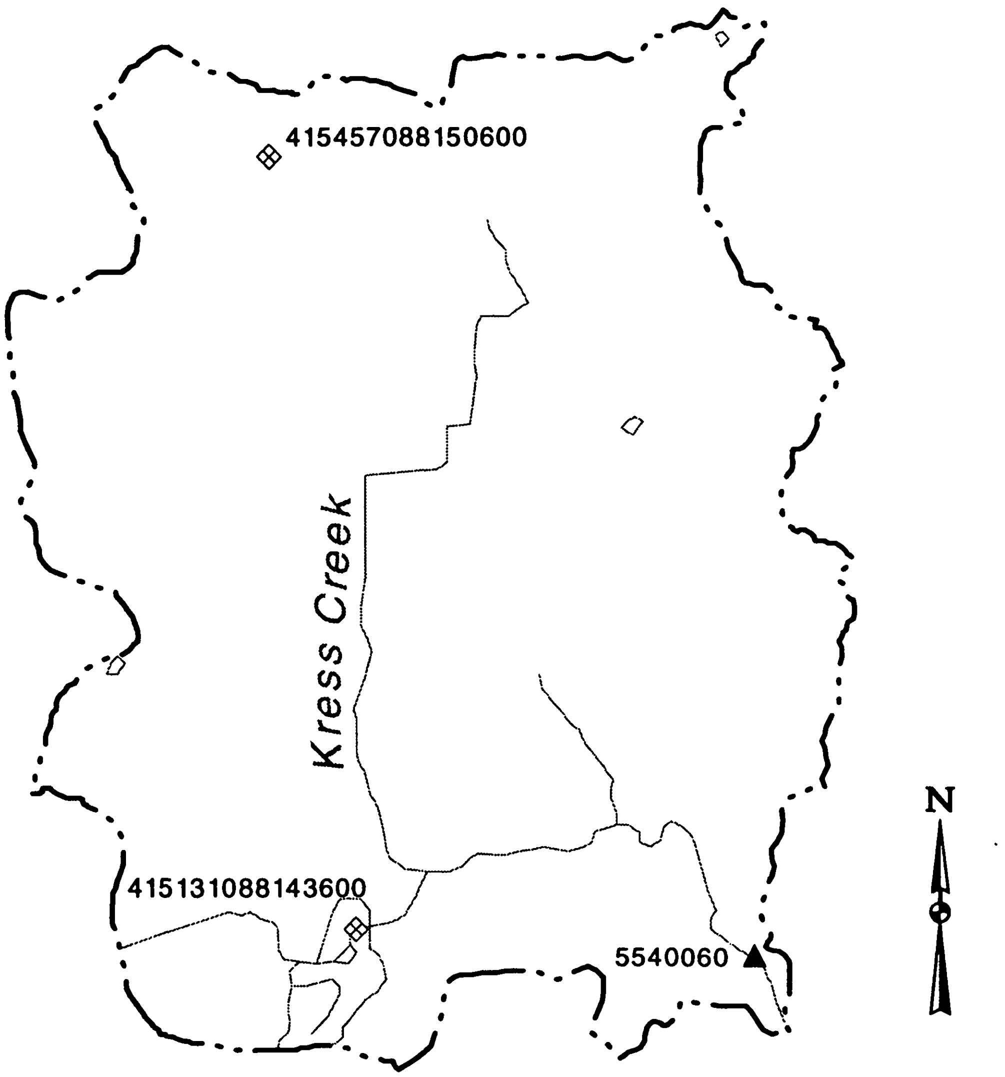
[NRCS, Natural Resources Conservation Service; in/h, inch per hour; in., inch; <, less than; ---, not available; N/A, not applicable; %, percent]

NRCS soil code	Soil name	Percent in basin	Percent in Du Page County	NRCS soil type	Permeability (in/h)	Available moisture capacity	Drainage	Transmission rate	Highest water-table depth	Organic matter content
152	Drummer Silty Clay Loam	32.28	6.67	B/D	0.6–2.0	High (0.21–0.24 in.)	Poorly drained	Moderate	<1 foot (undrained)	High
442	Mundelein Silt Loam	13.22	2.28	B	0.6–2.0	High (0.18–0.24 in.)	Somewhat poorly drained	Moderate	1–3 feet (undrained)	High
698B	Grays Silt Loam	5.8	.94	B	0.6–2.0	High (0.18–0.24 in.)	Moderately well drained	Moderate	4–6 feet	Moderate
531	Markham Silt Loam	5.52	11	C	0.6–2.0 (1–12 in.), 0.06–0.6 (12–60 in.)	High (0.22–0.24 in.), Moderate (0.11–0.2 in.)	Moderately well drained	Moderately slow to slow	---	Moderate
926B	Urban land, Drummer-Barrington Complex	4.65	.54	B/D	0.6–2.0	High (0.18–0.24 in.)	Poorly drained (Drummer), Well drained to moderately well drained (Barrington)	---	Depends on constructed drainage system	---
696	Zurich Silt Loam	3.94	.47	B	0.6–2.0	High (0.18–0.24 in.)	Moderately well drained	Moderate (upper), Moderately rapid (lower)	4–6 feet	Moderately low
1903	Muskego and Houghton mucks	3.4	.93	A/D	0.6–2.0	Very high (0.35–0.45 in.)	Very poorly drained	Moderate to rapid (upper), Slow to rapid (lower)	Surface	Very high
534	Urban land, Orthents complex, clayey	3.22	9.21	([1])	N/A	N/A	N/A	N/A	N/A	N/A

Table 2. Common soil types and (or) soil/urban complexes in the Kress Creek watershed and their properties—Continued

NRCS soil code	Soil name	Percent in basin	Percent in Du Page County	NRCS soil type	Permeability (in/h)	Available moisture capacity	Drainage	Transmission rate	Highest water-table depth	Organic matter content
327B	Fox Silt Loam	2.79	1.26	B	0.6–2.0	Moderate (0.15–0.24 in.)	Well drained	Moderate	---	Moderately low
533	Urban land	2.77	3.51	([2])	Consists of pavement and buildings	N/A	N/A	N/A	N/A	N/A
223B	Varna Silt Loam	2.6	3.45	C	0.6–2.0 (0.8 in.), 0.06–0.6 (8–60 in.)	High (0.22–0.24 in.) Moderate (0.09–0.2 in.)	Moderately well drained	Moderately slow (upper), Slow to moderately slow (lower)	---	Moderate to high
697	Wauconda Silt Loam	2.38	.68	B	0.6–2.0	High (0.18–0.24 in.)	Somewhat poorly drained	Moderate	1–3 feet (undrained)	Moderate
1330	Peotone Silty Clay Loam	1.91	.61	B/D	0.2–0.6	High (0.11–0.23 in.)	Very poorly drained	Moderately slow	Surface	High
443B	Barrington Silt Loam	1.75	1.29	B	0.6–2.0	High (0.18–0.24 in.)	Well drained	Moderate	---	Moderate to high
923B	Urban land, Markham-Ashkum Complex	1.69	15.51	C, B/D	N/A	N/A	N/A	N/A	N/A	N/A

[1]Nearly 75 percent urban.
[2]More than 85 percent.



Base from U.S. Geological Survey
1:100,000 and 1:2,000,000 Digital Data
Albers Equal-Area Conic Projection
Standard parallels 33° and 45°, central meridian -89°

EXPLANATION

—— • • WATERSHED BOUNDARY

◈ U.S. GEOLOGICAL SURVEY RAINFALL-GAGING STATION

▲ U.S. GEOLOGICAL SURVEY STREAMFLOW- AND RAINFALL-GAGING STATION

5540060 STATION NUMBER

Figure 6. Kress Creek watershed, stream channel, and U.S. Geological Survey streamflow- and rainfall-gaging stations.

land-based part of the hydrologic cycle are quantified in the study described in this report for three watersheds in Du Page County, Ill. To define rainfall-runoff relations, data are collected to observe the processes that make up the hydrologic cycle. Data collection defines watershed characteristics (such as, soils and land cover) and provides measured inputs (rainfall), estimates of internal fluxes (potential evapotranspiration, ground-water recharge, and others), and measured outputs (runoff) necessary for the calibration of a simulation model.

Hydrologic Data

Runoff data were collected at streamflow-gaging stations located within each drainage basin. Electronic data loggers provided continuous-recording stage data at a 5-minute interval. Telemetry at each streamflow-gaging station provided near real-time data acquisition and aided data collection during storms. Stage-discharge relations were developed for each streamflow-gaging station based on current-meter discharge measurements and methods described by Rantz and others (1982). Stage-discharge ratings were confirmed by current-meter discharge measurements during storms and periodically during the study. Special emphasis was made to confirm stage-discharge ratings during high-flow conditions. Indirect measurements of peak discharge were utilized to help define the stage-discharge relation at high flow at each streamflow-gaging station. Streamflow records for the three watersheds are rated as good (within 10 percent error) for the full period of record, except for estimated periods (such as, winter periods when the stream is ice-covered or periods of missing record), which are rated poor (within 15 percent error). Daily streamflow data for the three watersheds were published in USGS annual water data reports for Illinois (Fitzgerald and others, 1987; Fitzgerald and others, 1988; Coupe and others, 1989; Sullivan and others, 1990; Richards and others, 1991; Richards and others, 1992; La Tour and others, 1993; and Zuehls and others, 1994).

Rainfall data were collected at 14 gaging stations in and near Du Page County (fig. 2). The data from only six of these stations were utilized for simulation of the rainfall-runoff process in the three watersheds. Data from the other 8 stations were utilized at times to estimate rainfall values for periods of missing rainfall data from the rain gages within the watersheds. Tipping-bucket rain gages were installed to collect rainfall data at a resolution of 0.01 in. and a 5-minute recording interval. Daily rainfall data collected from February 1986 through September 1991 are given in Duncker and others (1992), and data collected from October 1991 to September 1993 are given in Straub and others (1998). Data collected at the rainfall-gaging stations were augmented by rainfall data from the NOAA rain gage located at O'Hare International Airport, Chicago, Ill., and a rainfall-gaging station located at Argonne National Laboratory, Lemont, Ill. (fig. 2).

The meteorological data required for the hydrologic modeling include rainfall, potential evapotranspiration, snow depth, air temperature, dew-point temperature, wind speed, cloud cover, and net solar radiation. Meteorological data were thoroughly analyzed prior to model simulation. The meteorological data included those data collected at study stations and at NOAA stations. Mean aerial rainfall is determined from point measurements of rainfall at several locations within the watershed. Theissen polygons were determined to distribute the point measurements of rainfall over the study watersheds.

Rainfall data collected during intense storms was corrected according to the rain gage manufacturer specifications. This correction was needed to account for overspill as water pours from the funnel to the tipping-bucket mechanism. The correction has a relatively minor effect on rainfall totals.

Thirteen of the 14 rainfall-gaging stations in and near Du Page County had periods of missing record. The periods of missing record generally resulted from mechanical malfunctions, or ice or debris clogging the rain-gage funnel. Rainfall data for periods of missing record were estimated by applying a distance-weighted average method and data from three surrounding rainfall-gaging stations (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1972).

Cumulative-mass plots and double-mass plots of rainfall were used to analyze the data for periods of inconsistencies. Trends and changes in the slope of the double-mass curve were examined in detail. Field notes that correspond with the periods in question were reviewed to determine causative factors for inconsistencies in the data.

Three methods were reviewed for estimating the potential evapotranspiration (PET): Hamon method (Hamon, 1961), Penman-Monteith method (Monteith, 1965), and a modified Penman method described by

Kohler and others (1955). The Penman-Monteith method was applied in this study as it was considered the most accurate of the methods reviewed and the PET time series was readily available from the Midwest Climate Information System (Kunkel and others, 1990).

Land-Cover Data

A GIS data base maintained by Du Page County provided plat, parcel, and topographical information from which land-cover categories applied in the hydrologic modeling could be delineated. The area of a watershed consisting of each land-cover category was determined by accessing the GIS data base. The area delineated as a particular land-cover category within a watershed was then expressed as a percentage of the total drainage area.

> "Land-use information (that is, residential, commercial, and others) is available from the Du Page County Planning Division on a tax parcel basis based on 1990 conditions. The entire county is divided into tax parcels and a single land use is assigned to each parcel. Thirty-one different land-use categories are identified on the basis of tax parcel information. For practical hydrologic simulation, these 31 land-use categories must be reduced to a small number of land-cover categories that reasonably represent the hydrologic response of the watershed. Lumb and James (1976) found that subdividing watersheds into pervious and impervious land-cover categories provided reasonable accuracy in runoff simulation with the Stanford Watershed Model for storm-water management in De Kalb County, Ga. For applications of HSPF in the Chicago area, division of the pervious land-cover category into several categories has resulted in reliable simulations, for example, Price, (1994a) in Du Page County, and Duncker and others (1995) in Lake County. In this case, four categories of land cover were applied to rainfall-runoff simulation in Du Page County: impervious land, grassland, forest/wetland, and agricultural land. Percentages of these cover categories were developed for each of the 31 land-use types in the tax parcel data base and programmed into the GIS data base so that land-cover percentages can be computed automatically for any watershed selected (Price, 1996)."

The four land-cover categories were selected by county engineers in previous (unpublished) watershed-modeling studies. The land-cover data are derived from a county GIS data base. The previous modeling studies identified the impervious areas as the primary source of storm runoff. These studies also hypothesized a relation between connected and unconnected hydraulically impervious areas to differentiate areas that drain onto pervious land cover.

The amount of hydraulically connected impervious land cover in each watershed was determined from the Du Page County parcel-based, land-use GIS data base. First, estimates of the amount and type of land cover associated with each land-use category were made by Du Page County personnel. The amount of hydraulically connected impervious area was then estimated for each land-cover category. This approach provides an estimate of the hydraulically connected impervious land cover that is consistent when applied correctly throughout the county. The part of the impervious land cover that is hydraulically connected to the stream can be difficult to measure accurately.

DEVELOPMENT OF REGIONAL RAINFALL-RUNOFF RELATIONS

An enhanced version of the Stanford Watershed Model (Crawford and Linsley, 1966), HSPF (Bicknell and others, 1993), was selected for simulation of runoff from the three watersheds. Prior to this study, Du Page County applied another version of the Stanford Watershed Model, the LANDS model (Hydrocomp International, Inc., 1970), for stormwater management (Price, 1993). The county has applied HSPF for more recent stormwater-management work. The LANDS model and HSPF, like the Stanford Watershed Model, are continuous-simulation models. Continuous-simulation models are well suited for stormwater-management applications because the models account for water stored in the watershed over time. This accounting capability enables more realistic simulation of antecedent moisture conditions and flood sequences than can be done in event-based models, in which antecedent conditions are assumed. Annual and monthly water balances must be accurately simulated for this premise to be correct.

The primary purpose of modeling for stormwater management is to estimate the infrequent (once, on average, in 5-100 years), large peak discharges and runoff volumes to be controlled and (or) mitigated by stormwater facilities. Because of the small, spatial extent of high-intensity convective storms, errors in the rainfall input to models and the runoff estimate from models can be very large, even for small watersheds with several rainfall-gaging stations. For example, Schilling and Fuchs (1986) demonstrated that the magnitude of error in urban-runoff calculations for small watersheds resulting from rainfall spatial variability may be greater than 100 percent in peak-discharge and runoff-volume estimation. Therefore, matching observed and simulated storm-runoff volumes for all storms is difficult. At best, the specific storm-runoff volumes can be examined to eliminate bias (that is, tendencies to overestimate or underestimate) in the simulated runoff volumes. Matching the observed and simulated runoff frequency relations is a good criterion for calibration of continuous-simulation models for use in stormwater management. In addition, comparing observed and simulated runoff-duration curves provides an indication of model performance over the entire range of observed flows. Thus, model calibration was achieved in a stepwise manner; first obtaining acceptable annual and monthly mass balances, then adjusting parameters to obtain good agreement between the observed and simulated frequency of storm-runoff volumes; and then further adjusting parameters to obtain a good fit between the observed and simulated flow-duration curves. Calibration is facilitated by the hierarchical structure of HSPF, in which the annual balance is most affected by one set of parameters, the monthly balances by another set, and the storm runoff by a third set (Donigian and others, 1984).

HSPF is a conceptual model that approximates the terrestial part of the hydrologic cycle by a series of interconnected water storage zones: an upper zone, a lower zone, and a ground-water zone. The amounts of water in these zones and the flux of water between the zones and to the stream or atmosphere are simulated on a continuous basis for a subarea of a given land cover and precipitation input. The fluxes of water between storage zones and to the stream or atmosphere are affected by a large number of model parameters. The model parameters have physical meaning conceptually but are not physically measurable and must be determined by calibration. The model parameters include threshold values, partition coefficients, and linear-reservoir release coefficients. Model parameters and their function are listed in figure 7.

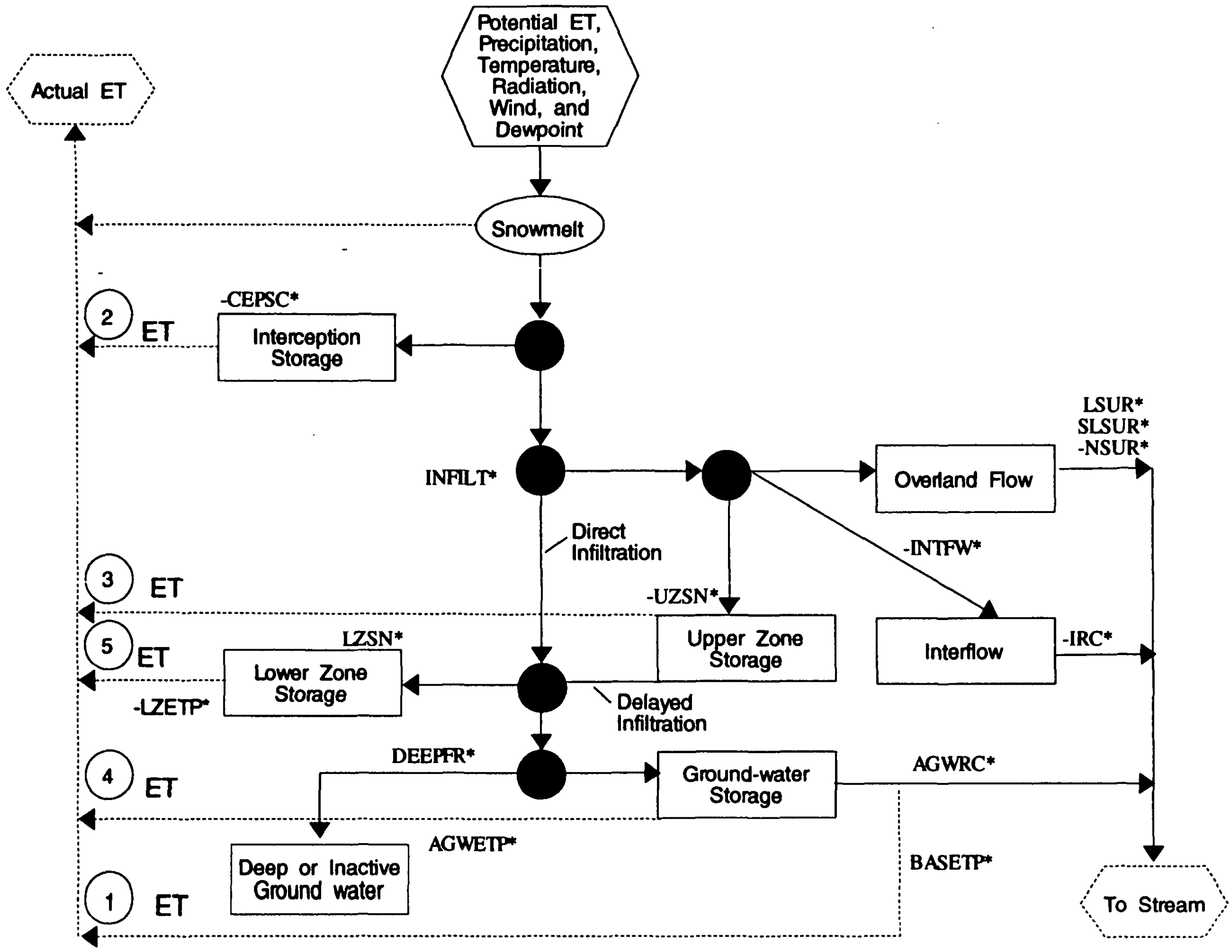
The flow paths through the upper, lower, and ground-water zones and the relations among the storage in the zones, streamflow, and evapotranspiration are shown in figure 7. The upper zone usually consists of surface vegetation, ground litter, and the upper several inches of soil. Surface runoff and prompt subsurface flow (interflow) are affected by storage in the upper zone. The lower zone is the zone from which deeply rooted vegetation draws water. This water is then lost to the atmosphere through evapotranspiration. The lower zone does not discharge flow to the stream. The ground-water zone stores the water that supports base flow during periods of no rainfall. Water also can be lost to deep ground water that does not flow to the stream from the ground-water zone.

Each watershed studied was subdivided on the basis of rain-gage locations and land-cover categories. Rainfall data from the rain-gage network were distributed on the basis of the Theissen polygon method. Application of the Theissen polygon method divides a watershed into several polygons that represent the part of the watershed nearest a given rain gage. Rainfall data for the station within each polygon is applied uniformly to the area covered by each polygon. Two broad categories of land cover are utilized in HSPF: pervious land cover (PERLNDS) and impervious land cover (IMPLNDS). A wide range of physical attributes can be assigned to a PERLND or IMPLND to represent various land-cover conditions. Land-cover data were aggregated into pervious and impervious categories for each of the Theissen polygons. The pervious category was further subdivided into grass, agriculture, and forest/wetland land-cover categories.

Initial values for model parameters were selected on the basis of previous studies (Donigian and Davis, 1978), watershed characteristics, and preliminary model simulations. In the preliminary simulations, initial values for storage parameters were selected by setting the values to zero and simulating 3 years of streamflow. Storage values are equilibrated in model simulation over time. Values for the storage parameters for the initial month of model simulation were then determined from the storage-parameter values for the same month in subsequent years.

Model-Calibration Procedures

The calibration of a simulation model is the primary means of developing rainfall-runoff relations (Troutman, 1985). In addition to an understanding of rainfall-runoff relations, the model calibration process also provides engineers and planners with useful insight on the runoff process in the watershed for



EXPLANATION

FLOW PATH SYMBOLS	
→ (arrow)	Model flow direction
(2) ET	Order taken to meet ET demand
Hexagon	Input
Ellipse	Process
Filled circle	Model decision point
Rectangle	Storage
Dotted hexagon	Output

	PARAMETER
CEPSC*	Interception storage
INFILT*	Infiltration
LSUR*	Length of overland flow plane
NSUR*	Manning's *n* for the overland flow plane
SLSUR*	Slope of overland flow plane
INTFW*	Interflow
UZSN*	Upper zone storage
IRC*	Interflow recession constant
LZSN*	Lower zone nominal storage
LZETP*	Lower zone evapotranspiration
DEEPFR*	Fraction of ground-water inflow which goes to inactive ground water
BASETP*	Baseflow evapotranspiration
AGWETP*	Active ground-water evapotranspiration
AGWRC*	Active ground-water recession constant

Figure 7. Diagram of the Hydrological Simulation Program—Fortran model.

stormwater management. The observed-data set was divided into a calibration period and a verification period. The calibration period (January 1990–September 1993) was selected to include several large floods as well as extended dry periods. The period of record available for calibration (45 months) is sufficiently long enough to provide an adequate calibration (Donigian and others, 1984, p. 84). Total, annual, seasonal, and monthly mass balances were determined to evaluate the quality of fit of each calibration. Simulated runoff generated in each watershed was not routed in the model, but rather delivered instantaneously to the streamflow-gaging station. Hydraulic routing of simulated runoff was determined to be beyond the scope of this study because the Du Page County DEC utilizes a separate model for hydraulic routing of simulated runoff, which incorporates a full, dynamic-wave, unsteady-flow model.

Three formats were used for the calibration of the three watersheds. First, a best-fit calibration was obtained by calibrating each watershed independently for the 45-month calibration period. The best-fit calibration provides a means of evaluating the quality of fit for the second format (regional calibration). In regional calibration, a single calibration parameter set was developed by calibrating all parameters except fraction of ground-water inflow that goes to inactive ground water (DEEPFR), interflow recession constant (IRC), and infiltration (INFILT) for all three watersheds jointly. DEEPFR and IRC are directly related to physical characteristics of the watersheds and are not necessarily uniform across Du Page County. The value of INFILT determined by joint calibration for Sawmill Creek and St. Joseph Creek is representative of the rainfall-runoff process for the silty and clayey soils on the uplands and lake plains that characterize these watersheds in eastern Du Page County (fig. 3). The value of INFILT determined in calibration for Kress Creek is representative of the rainfall-runoff process on the silty soils on uplands that characterize parts of western Du Page County (fig. 3). Following the verification of the calibrated parameter sets, a third calibration was done utilizing the full period of record of July 1986–September 1993 (87 months) to determine parameter sets appropriate for the different soil groups in Du Page County. The third calibration, utilizing the full period of record, increases the confidence level and range of applicability of the regional parameter set. Substantial differences between the verified, 45-month regional parameter set and the calibrated 87-month regional parameter set were analyzed closely. The objective of this regional recalibration is to develop parameter sets suitable for simulation of rainfall-runoff relations on ungaged watersheds in Du Page County.

Many commonly used rainfall-runoff models have built-in calibration routines that estimate the best values of the model parameters as the parameter values that result in a minimization of an objective measure of the agreement between the simulated and observed runoff. The objective measures commonly used include the sum of the squared differences, sum of absolute differences, and weighted sum of squared differences (for example, more weight is given to matching high flows). An automatic calibration routine was developed for the Stanford Watershed Model (James, 1972). Because of the size of the model output file and the complexity of the model, however, calibration could be performed for only 1 year of data at a time, and the optimum parameter values for each year in the calibration would be averaged to determine the best overall parameter set. Averaging optimum parameters for several years is not a suitable approach when year-to-year variations in rainfall and runoff are large. Thus, no formal calibration routines have been developed or advocated for HSPF, and HSPF calibration must be accomplished by trial and error. An expert system has recently been developed to assist in the trial-and-error calibration of HSPF (Lumb and others, 1994). This system had not been fully implemented, however, until after a substantial amount of calibration experience had been gained for the watersheds in Du Page County. Thus, the expert system was not applied in this study.

Because the HSPF calibration is performed in a stepwise manner—matching the overall water balance, the annual water balances, the monthly water balances, and finally, considering storm-runoff volumes and frequencies—several criteria must be considered to determine if the quality of the fit between the simulated and observed runoff is acceptable. James and Burgess (1982) recommend that graphical and statistical means be used to assess the quality of fit because trends and biases can be easily detected on graphs, and statistics provide an objective measure of whether one simulation is an improvement over another. A combination of graphical and statistical measures of the quality of fit was used in this study.

For the overall and annual water balances, only the percent error was considered. Donigian and others (1984, p. 114) state that for HSPF, the annual or monthly fit is very good when the error is less than

10 percent, good when the error is from 10 to 15 percent, and fair when the fit is from 15 to 25 percent.

Plots of observed and simulated runoff were prepared for the monthly water balance and checked for periods of consistent oversimulation or undersimulation. The quality of fit for monthly values also was examined by three statistics: (1) the correlation coefficient between simulated and observed flows, (2) the coefficient of model-fit efficiency (Nash and Sutcliffe, 1970) between simulated and observed flows, and (3) the number of months for which the percentage error was less than a specified percentage (10 and 25 percent were used in this study). The average relative percent error in monthly flows over the calibration period also was considered, but relatively small overestimates in months with very low flows made this statistic a poor indicator of the overall quality of the fit.

The correlation coefficient, C, is calculated as

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

where,

Qo_i is the observed runoff volume for month i,
Qs_i is the simulated runoff volume for month i,
Qo is the average observed monthly runoff volume,
Qs is the average simulated monthly runoff volume,
N is the number of months in the calibration period, and
$*$ is the dot product.

The coefficient of model-fit efficiency, E, is calculated as

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

The coefficient of model-fit efficiency is a direct measure of the fraction of the variance of the original data series explained by the model. If the data and model residuals are normally distributed, the coefficient of model-fit efficiency should nearly equal the square of the correlation coefficient. The coefficient of model-fit efficiency provides a more rigorous evaluation of fit quality than the correlation coefficient because the correlation coefficient only indicates that the series being compared have similar patterns of being greater than and less than their respective mean values. However, the correlation coefficient does not consider the magnitude of differences between the observed and simulated values. Thus, the simulated series may increase and decrease in the same pattern as the observed series, thus yielding a high correlation coefficient, but the two series may have poor agreement. This relation is illustrated in the verification results for Sawmill Creek discussed in the "Results of Model Verification" section.

James and Burgess (1982) suggest that an excellent calibration is obtained if the coefficient of model-fit efficiency exceeds 0.97 and present an example of an HSPF application in which the correlation coefficient and the coefficient of model-fit efficiency for daily flows exceeds 0.98. For the Stanford Watershed Model, Crawford and Linsley (1966) reported correlation coefficients for daily flows from 0.94 to 0.98 for seven watersheds ranging in size from 18 to 1,342 mi^2 and with 4 to 8 years of data. Other researchers studying monthly flows have accepted calibration results with lower correlation coefficient and coefficient of model-fit efficiency values. Ligon and Law (1973) applied the Stanford Watershed Model to a 561-acre experimental agricultural watershed in South Carolina and obtained a correlation coefficient and a coefficient of model-fit efficiency for monthly flows of 0.966 and 0.931, respectively, for a 60-month calibration period. Chiew and others (1991) applied HSPF to a 56.4 mi^2 agricultural watershed in west Tennessee and obtained a correlation coefficient for monthly flows of 0.8 for a 54-month calibration period. Price (1994a) applied HSPF to four watersheds in Du Page County, Ill., ranging in size from 28.2 to 115.6 mi^2. For a 108-month calibration period, the correlation coefficients for monthly flows ranged from 0.88 to 0.95. Duncker and others (1995) applied HSPF to five watersheds in Lake County, Ill., ranging in size from 6.3 to 59.9 mi^2. For a 43-month calibration period, the correlation coefficients for monthly flows ranged from 0.93

to 0.97 and the coefficient of model-fit efficiency for monthly flows ranged from 0.86 to 0.92 for best-fit calibrations, whereas for regional calibrations and verification the correlation coefficient ranged from 0.93 to 0.95 and the coefficient of model-fit efficiency ranged from 0.86 to 0.91.

The daily flows were checked graphically by comparing the observed and simulated runoff-duration curves and time series. General agreement between the observed and simulated runoff-duration curves indicates adequate simulation over the range of the flow conditions modeled. Substantial or consistent departures between the observed and simulated runoff-duration curves indicate inadequate calibration. Certain characteristics of the model could contribute to departure between the simulated and observed runoff-duration curves. For example, the effects of impervious areas that are not hydraulically connected to the drainage system are not explicitly simulated in the model. These are impervious areas that generate runoff that does not directly enter the stream channel or other parts of the drainage system (swales, gutters, sewers, and others). Runoff from these areas drains across adjacent pervious areas and may infiltrate before reaching the drainage system. Departure among the runoff-duration curves also could result from the absence of channel routing of flows. Channel routing of flows was considered to be beyond the scope of this study. Because routing is not done, all simulated runoff is delivered to the stream channel instantaneously so that simulated flows could tend to be larger than the observed flows in runoff-duration curve analysis of daily runoff. Potential problems in runoff-frequency analyses were avoided by utilizing 3-day storm volumes.

The quality of fit for the larger storms was measured graphically by the agreement between the simulated and observed partial-duration series of runoff volumes. Runoff volumes were used instead of peak discharges because the hydraulic routing required for peak discharge simulation in HSPF was not applied. Three-day runoff volumes were used to ensure consistency in the definition of the runoff resulting from a storm. For example, Bradley and Potter (1992) used 3-day runoff volumes in a frequency analysis of observed and HSPF-simulated runoff series for the 30.5 mi^2 Salt Creek watershed at Rolling Meadows, Ill. Further, for most of the storms studied on five watersheds in Lake County, Ill., by Duncker and others (1995), the runoff had returned to near base-flow conditions in 3 days. The storms in the partial-duration series analysis were initially selected such that no storms resulting in less than 1.0 in. of runoff would be used. The threshold value of 1.0 in. of runoff did not provide a suitable number of storms for analyses in the 45-month calibration period. The threshold value was reduced to 0.4 in. for the Kress Creek watershed and to 0.7 in. for the St. Joseph Creek and Sawmill Creek watersheds. The annual probability of exceedance of each storm was determined according to Langbein (1949).

Model-Verification Procedures

Verification of the calibrated parameter set provides a means of evaluating the model calibration. An acceptable verification indicates that the calibrated parameter set is suitable for the intended applications. In this study, a successful verification would indicate that given certain restrictions (outlined in the "Regional Rainfall-Runoff Relations" section), the parameter set is suitable for simulating runoff from watersheds in Du Page County for stormwater management.

The regional parameter sets for the two soil groups in Du Page County, derived from the three watersheds, was verified utilizing a part of the streamflow records of each watershed that was not used in the calibration process. The verification period (July 1986–September 1989) includes several large storms from August 1987 and a prolonged period of drought (1988, 1989). As such, the verification period provides a rigorous evaluation of the model calibration. Verification of the calibrated parameter set consisted of simulating the verification period for each watershed with application of the calibrated parameter set. An acceptable verification was achieved if statistical results from the verification simulation were close to those statistical results for the best-fit model simulations, and graphical results from the verification simulation indicated no bias or trends in the simulated runoff.

Results of Model Calibration

Model-calibration results for the watersheds are presented in three formats: best-fit calibration results for each watershed, 45-month regional calibration results, and the results of regional calibration to the full 87-month period of record. Statistical results of the best-fit calibrations are summarized in table 3. The grand total and annual water balances for the observed data and the best-fit and regional simulations during the study are summarized in table 4.

Best-Fit Calibration

Best-fit model calibration of the three watersheds produced good results. Best-fit model calibration statistics were similar to reported results from similar studies that applied the Stanford Watershed Model or HSPF (Ligon and Law, 1973; Dinicola, 1989; Chiew and others, 1991; Price and Dreher, 1991; Duncker and others, 1995). For simulations with the best-fit model-parameter sets, correlation coefficients ranged from 0.9292 to 0.9570 and coefficients of model-fit efficiency ranged from 0.8565 to 0.9157 (table 3). Close reproduction of the observed runoff-duration curves (figs. 8–10) indicates that the best-fit calibration parameter sets provide an acceptable simulation of rainfall-runoff relations on the study watersheds in Du Page County, Ill.

Following the criteria of Donigian and others (1984, p. 114), the best-fit simulations provided very good (less than 10 percent error) results for watershed total water balances and fair (15 to 25 percent error) to good (10 to 15 percent error) results for annual water balances (table 4). The margin of error for total water balances was within 0.7 percent. Annual water balances were simulated with average absolute errors from 6.4 to 11.3 percent. Many of the greater absolute percentage errors in the annual and monthly water balances reflect years and months with relatively low amounts of runoff. These periods yield absolute errors with large percent differences but fairly small actual differences. The grand total water balance and annual water balances were most sensitive to changes in the upper zone nominal storage parameter (UZSN) and the parameter controlling recharge to deep aquifers, DEEPFR.

Close reproduction of runoff-duration curves (figs. 8–10) with application of the best-fit parameter sets indicates that the model provides acceptable simulation of rainfall-runoff relations on the watersheds over a wide range of hydrologic conditions. Variation in the low-flow parts of the runoff-duration curves among the three watersheds reflects the different base-flow characteristics of the streams. A sustained base flow is most evident in the runoff-duration curve for Kress Creek (fig. 8), which terminates at approximately 4 ft^3/s at the lower end of the curve. This contrasts with the low end of the runoff-duration curve at zero flow for St. Joseph Creek (fig. 9). These observed discharges in cubic feet per second were converted to inches per day for comparison with the unrouted simulated discharges in figures 8–10.

Runoff-frequency plots (utilizing a partial-duration series of 3-day storm volumes) for the larger storms (figs. 11–13) indicate that HSPF simulation with application of the best-fit parameter set tended to undersimulate the observed runoff-frequency plots. The possible reasons for the undersimulation of the runoff from large storms are discussed in the "Results of Model Recalibration" section.

Regional Calibration

The objective of regional calibration is to develop parameter sets based on data from gaged watersheds for simulation of rainfall-runoff relations for the two soil groups on ungaged watersheds in Du Page County. To evaluate the quality of fit achieved for simulations applying the regional parameter set, model-performance statistics from simulations applying the regional parameter set were compared with model-performance statistics from simulations

Table 3. Model-calibration statistics for three watersheds in Du Page County, Ill., simulated with application of the best-fit parameter set for the Hydrological Simulation Program—Fortran for a 45-month calibration period (January 1990–September 1993)

Watershed	Coefficient of model-fit efficiency	Correlation coefficient	Number of months when the difference between simulated and observed average monthly discharge was less than 10 percent	Number of months when the difference between simulated and observed average monthly discharge was less than 25 percent
Kress Creek	0.9157	0.9570	15	27
St. Joseph Creek	.8565	0.9292	10	21
Sawmill Creek	.8755	0.9364	10	22

Table 4. Observed and simulated annual and grand total runoff from three watersheds in Du Page County, Ill.

[Results simulated with the Hydrological Simulation Program—Fortran with application of the best-fit and regional parameter sets for a 45-month period; observed refers to observed data; best-fit refers to simulated data with the best-fit parameter set; regional refers to simulated data with the regional parameter set; 1990 data for all watersheds represent a partial year, January 1990–September 1990]

Watershed	Runoff (in inches) by water year[1] 1990	1991	1992	1993	Grand total
Kress Creek					
Observed	11.29	14.26	9.27	18.01	52.83
Best-fit	11.31	13.97	12.06	15.73	53.07
Regional	10.24	11.97	11.00	14.34	47.55
St. Joseph Creek					
Observed	13.64	13.31	8.05	15.60	50.60
Best-fit	12.25	12.82	8.08	17.38	50.53
Regional	10.25	12.05	7.38	16.58	46.25
Sawmill Creek					
Observed	14.77	14.40	8.83	19.04	57.03
Best-fit	12.93	14.28	11.21	18.98	57.41
Regional	10.05	13.68	10.63	18.42	52.78

[1]The water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends and which includes 9 of the 12 months.

applying the best-fit parameter set of each watershed. As expected, the application of the regional parameter set results in lower model-performance statistics than the application of the best-fit parameter set because the calibration of a regional parameter set must apply to all three watersheds for all parameters except DEEPFR, IRC, and INFILT. Although the quality of fit is poorer when applying the regional parameter set, the statistics indicate that the regional calibration parameter set results in acceptable simulations for the intended applications. For simulations applying the regional parameter set, correlation coefficients range from 0.9226 to 0.9423 (table 5). The coefficients of model-fit efficiency range from 0.8345 to 0.8625. The results of annual and grand total water balances are presented in table 4. Grand-total water balances for the study period were within 8.6 percent for all three watersheds. Average absolute errors in annual flows were 20.4 percent for the Kress Creek watershed, 12.2 percent for the St. Joseph Creek watershed, and 15.2 percent for the Sawmill Creek watershed. The reduction in the overall model performance resulting from the derivation of the regional parameter set is relatively small and the model-fit statistics are within the range of values considered acceptable in previous studies discussed earlier. These results indicate the regional calibration is satisfactory.

Analysis of the runoff-frequency plots indicates that application of the regional parameter set tends to result in undersimulation of runoff from larger storms (figs. 11–13). Ideally, the simulated runoff volumes would match the observed runoff volumes closely or undersimulate and oversimulate in a random, yet close, manner. Instead, application of the regional parameter set developed in this study consistently undersimulates runoff from larger storms, as did the application of the best-fit parameter set. Several factors, which may contribute to the undersimulation of large storms, are discussed in the "Results of Model Recalibration" section.

The runoff-duration curves (figs. 8–10) provide for an overall analysis of the simulation quality with the application of the regional parameter set over the full range of flows during the calibration period. Although application of the regional parameter set results in undersimulation of larger storms as indicated in the runoff-frequency plots (figs. 11–13) over the full range of flows in the study period, application of the regional parameter set results in adequate simulation of the full range of observed runoff. For the most part, the runoff-duration curves for the simulated data closely match the runoff-duration curves for the observed data for all three watersheds. The high flow or upper end of the runoff-duration curves in all three watersheds reflects the undersimulation of large storms seen in the runoff-frequency analysis. Medium flows are slightly oversimulated in the St. Joseph Creek and Sawmill Creek watersheds and are closely simulated in the

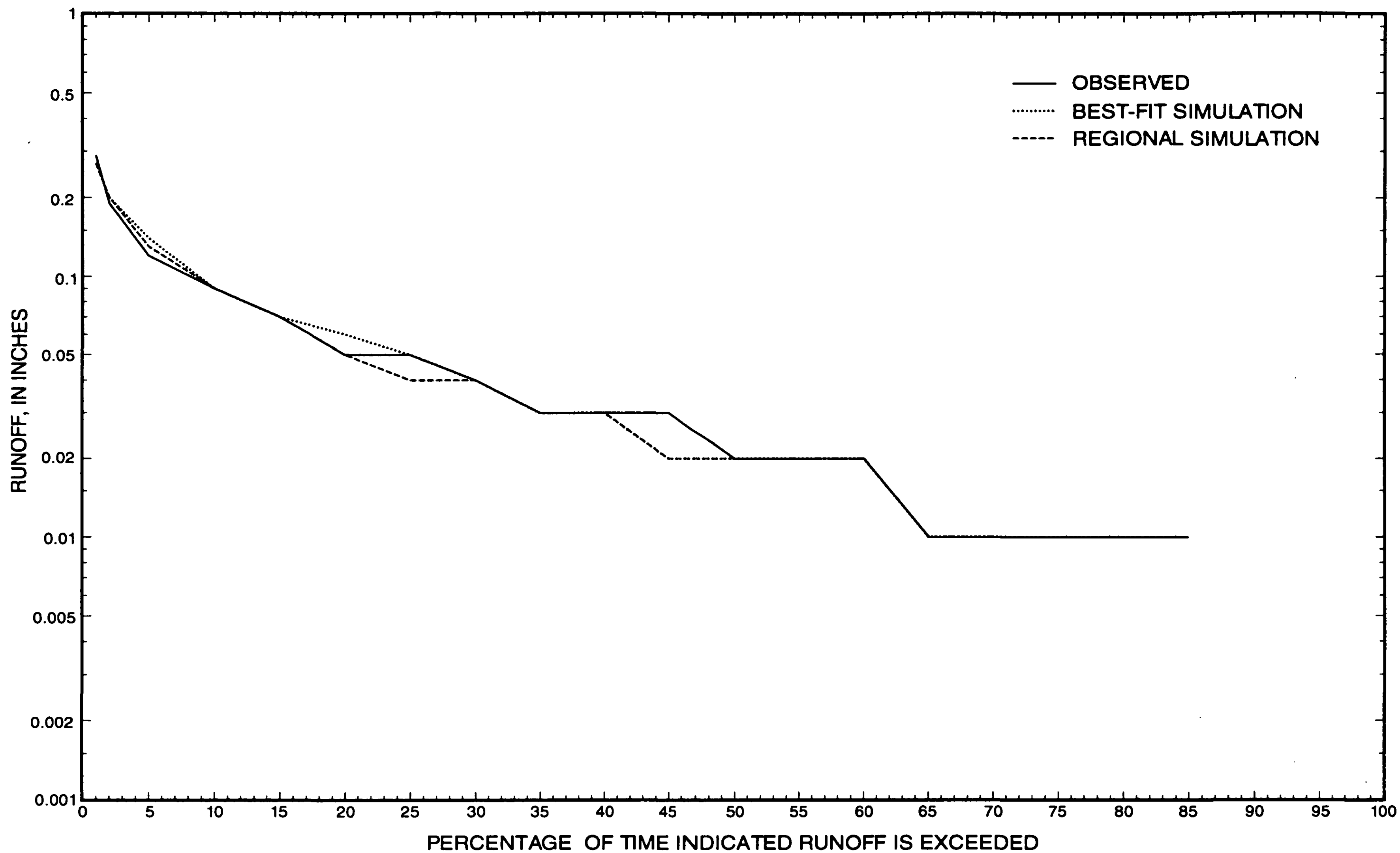


Figure 8. Daily runoff-duration curves for observed data and Hydrological Simulation Program—Fortran simulation with the application of the best-fit and regional parameter sets for a 45-month calibration period (January 1990–September 1993) for Kress Creek at West Chicago, Ill.

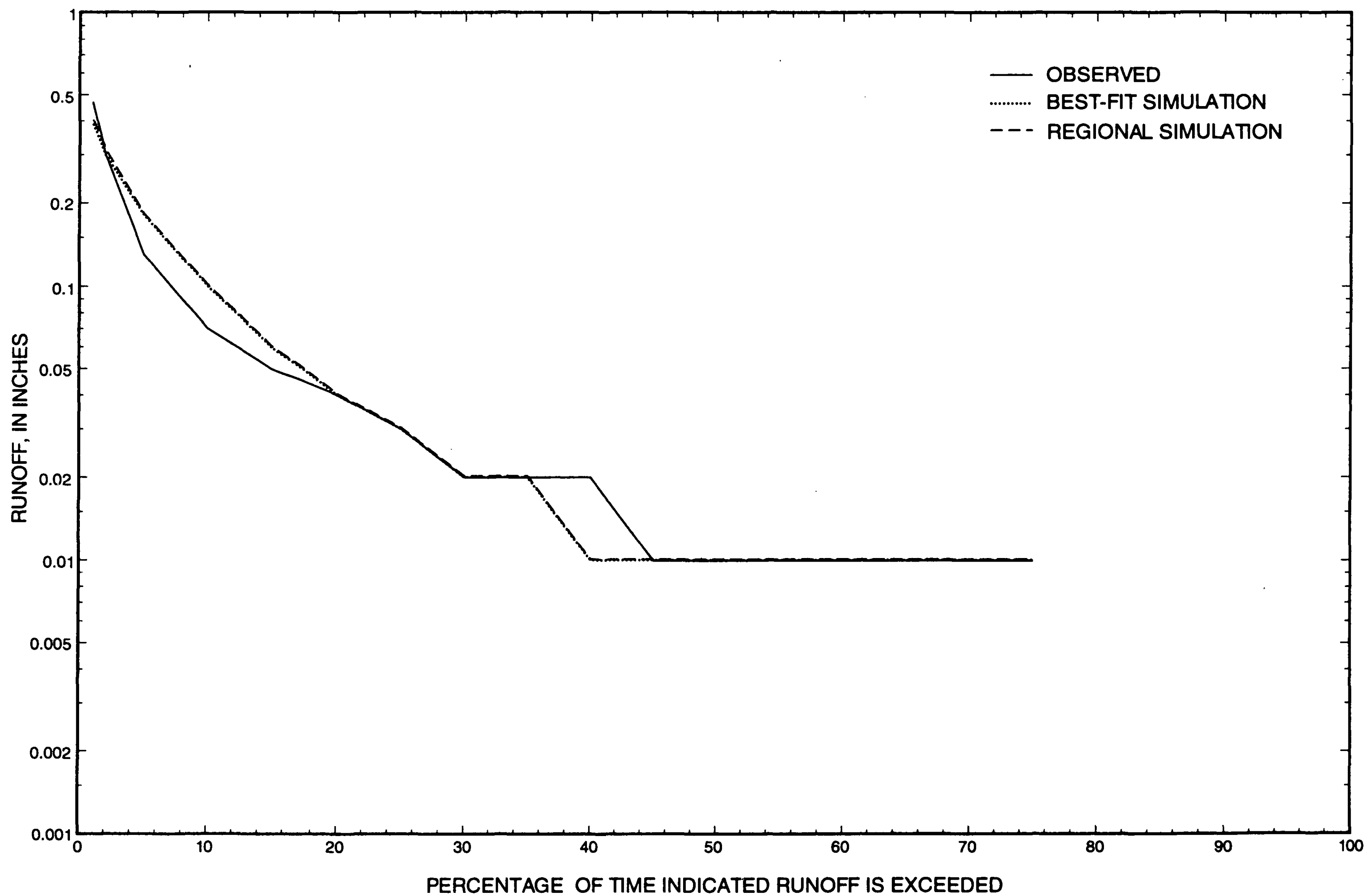


Figure 9. Daily runoff-duration curves for observed data and Hydrological Simulation Program—Fortran simulation with application of the best-fit and regional parameter sets for a 45-month calibration period (January 1990–September 1993) for St. Joseph Creek at Route 34 at Lisle, Ill.

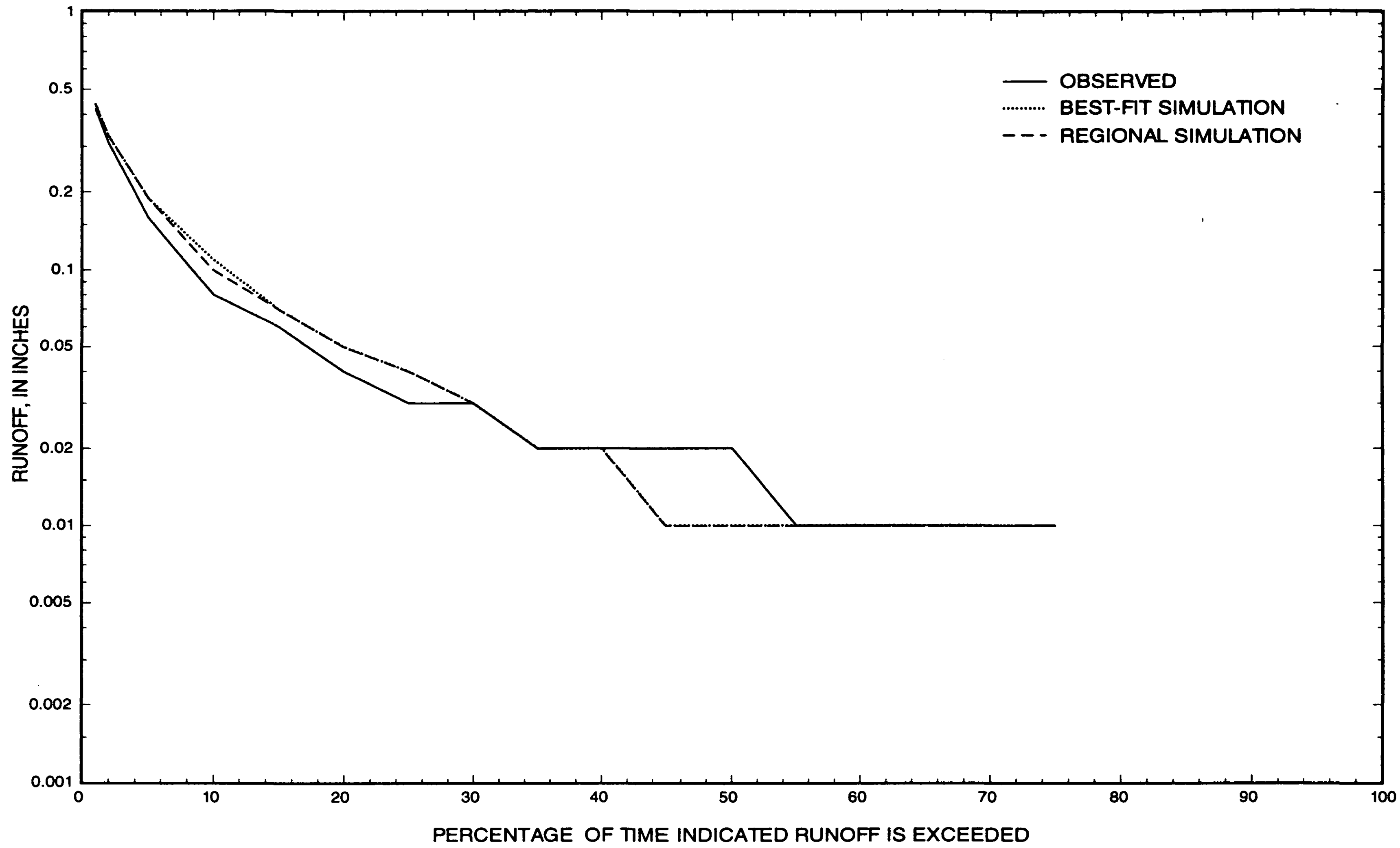


Figure 10. Daily runoff-duration curves for observed data and Hydrological Simulation Program—Fortran simulation with application of the best-fit and regional parameter sets for a 45-month calibration period (January 1990–September 1993) for Sawmill Creek near Lemont, Ill.

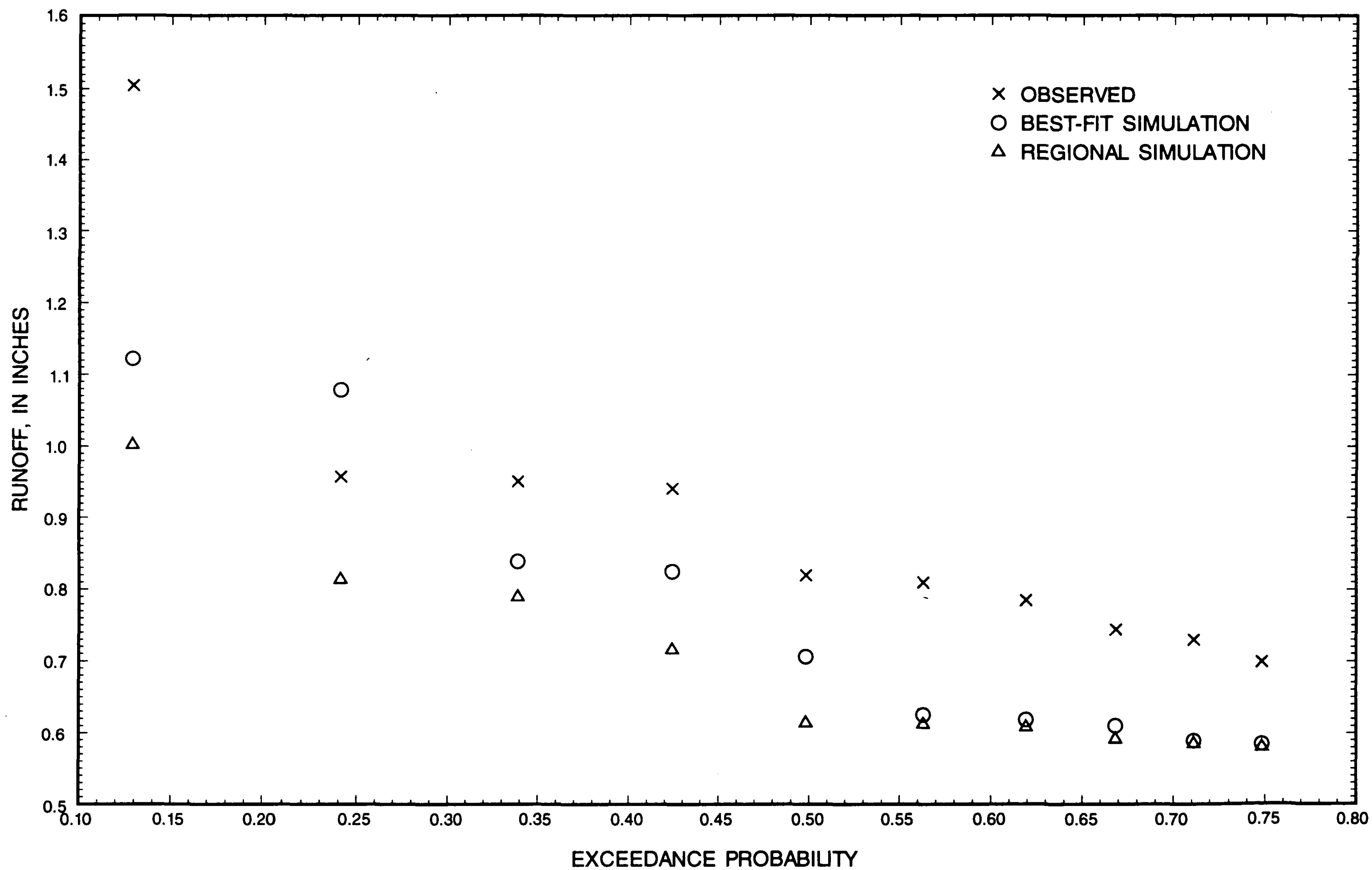


Figure 11. Runoff-frequency plots for observed data and Hydrological Simulation Program—Fortran simulation with application of the best-fit and regional parameter sets for storms producing greater than 0.5 inch of runoff in a 3-day period for Kress Creek at West Chicago, Ill. (January 1990–September 1993).

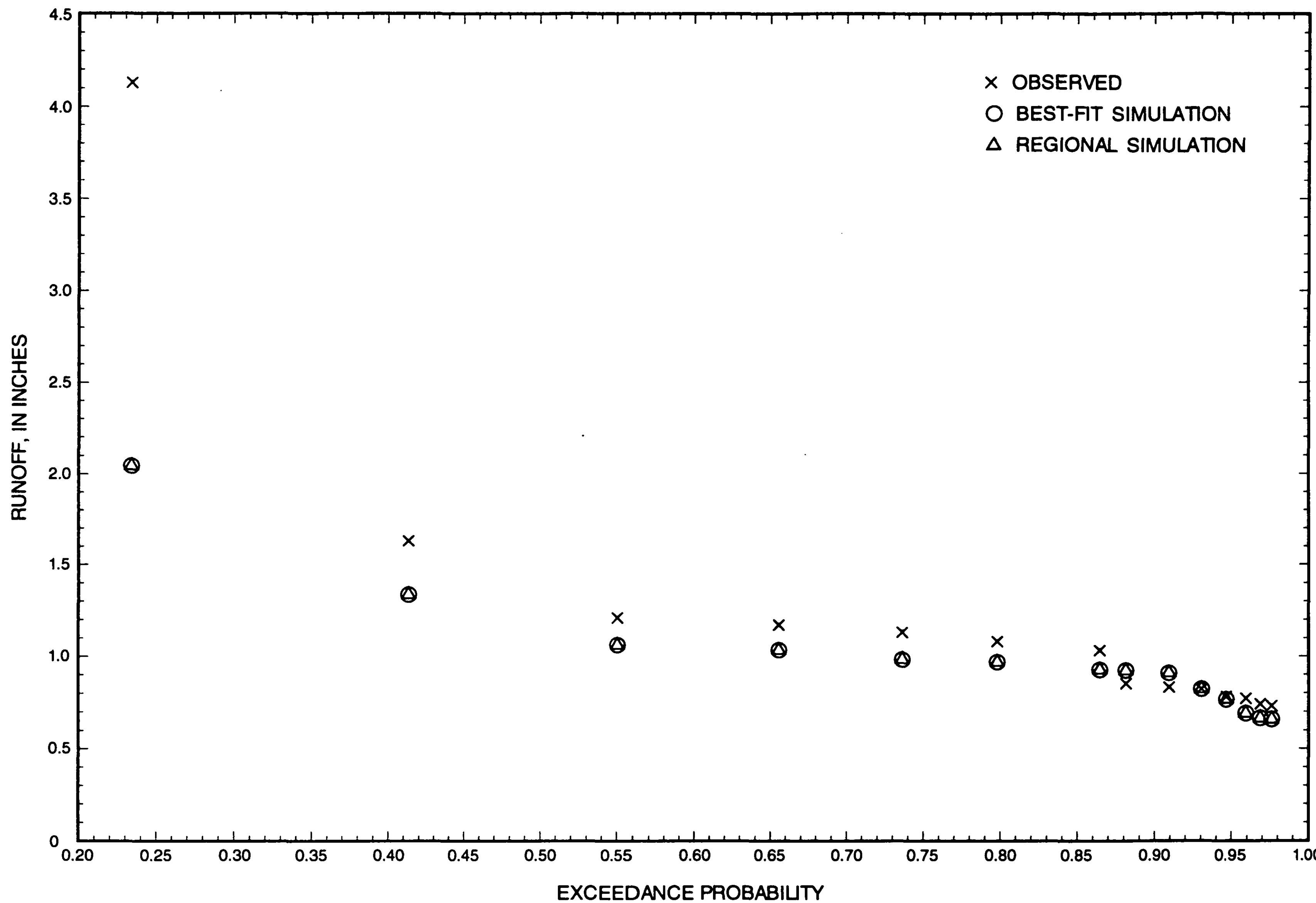


Figure 12. Runoff-frequency plots for observed data and Hydrological Simulation Program—Fortran simulation with application of the best-fit and regional parameter sets for storms producing greater than 0.6 inch of runoff in a 3-day period for St. Joseph Creek at Route 34 at Lisle, Ill., (January 1990–September 1993).

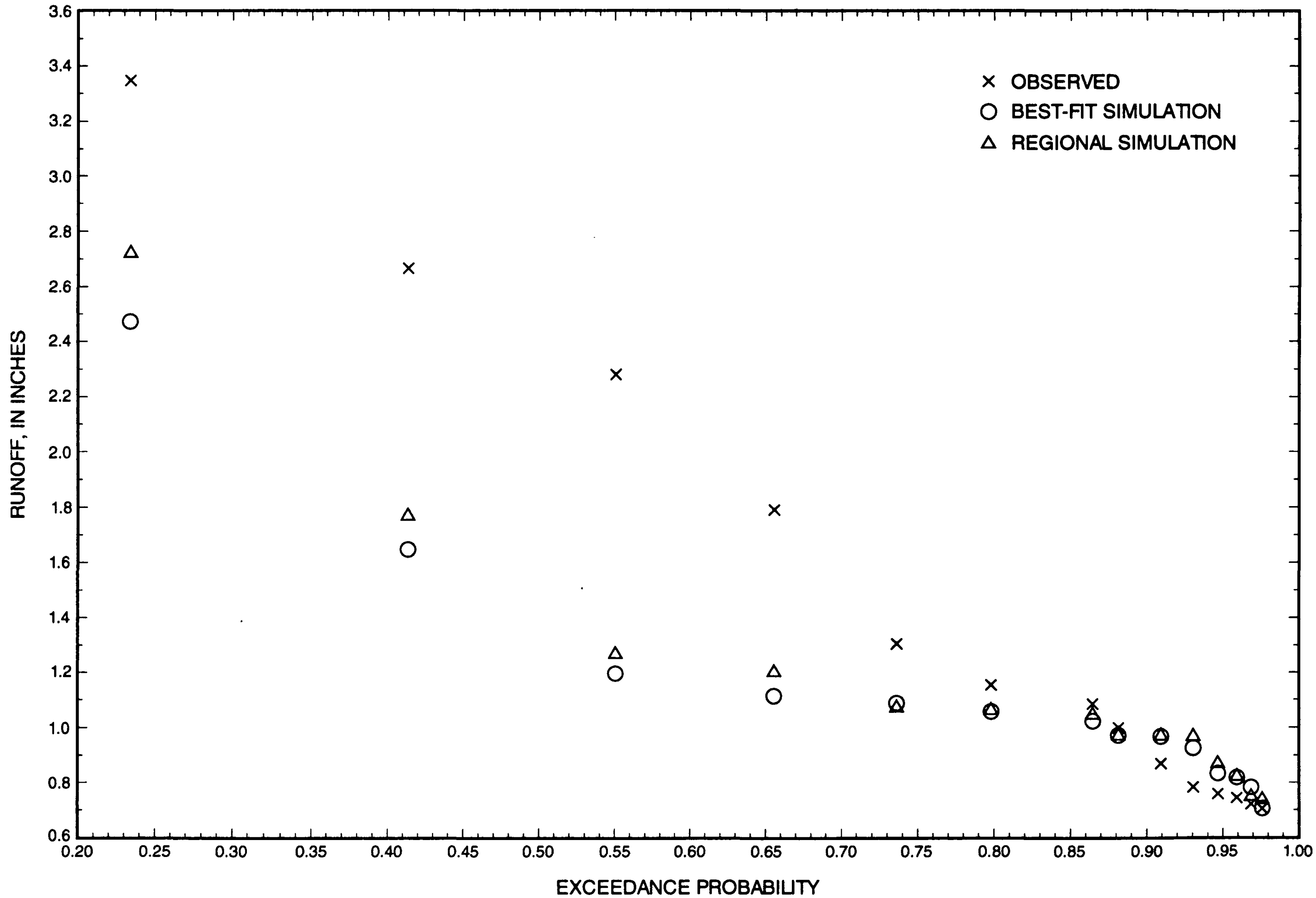


Figure 13. Runoff-frequency plots for observed data and Hydrological Simulation Program—Fortran simulation with application of the best-fit and regional parameter sets for storms producing greater than 0.7 inch of runoff in a 3-day period for Sawmill Creek near Lemont, Ill., (January 1990–September 1993).

Table 5. Model-calibration statistics for three watersheds in Du Page County, Ill., simulated for a 45-month calibration period (January 1990–September 1993)

[Results simulated with the application of the regional calibration parameter set for the Hydrological Simulation Program—Fortran]

Watershed	Coefficient of model-fit efficiency	Correlation coefficient	Number of months when the difference between simulated and observed average monthly discharge was less than 10 percent	Number of months when the difference between simulated and observed average monthly discharge was less than 25 percent
Kress Creek	0.8625	0.9423	11	25
St. Joseph Creek	.8345	0.9229	13	28
Sawmill Creek	.8485	0.9226	10	21

Kress Creek watershed. Most of the departure in the runoff-duration curves is evident in the medium- to low-flow parts of the curves.

Results of Model Verification

The results of model verification of the regional parameter set are presented in tables 6–7 and figures 14–16. Correlation coefficients for simulations applying the regional parameter set (calibrated to data from January 1990–September 1993) during the verification period (July 1986–September 1989) ranged from 0.7810 to 0.9304. Coefficients of model-fit efficiency for simulations applying the regional parameter set during the verification period ranged from 0.3414 to 0.8247. Statistical results for the model verification are worse than statistical results for the model calibration, which indicates an overall decrease in simulation quality. The decrease in simulation quality was expected because of the wider range of hydrologic conditions during the verification period (July 1986–September 1989) than during the calibration period (January 1990–September 1993). Although the simulation quality has decreased from the calibration results for the Kress Creek and St. Joseph Creek watersheds as measured by the correlation coefficients and coefficients of model-fit efficiency, the verification statistics still indicate an acceptable level of simulation quality for stormwater-management applications relative to the results of previous HSPF studies reported in the "Model-Calibration Procedures" section. The large decrease in model-fit efficiency for the verification of the Sawmill Creek calibration indicates an unacceptable verification.

Following an unacceptable verification for the Sawmill Creek watershed, numerous attempts at recalibration were made in an effort to produce acceptable verification results without a substantial decrease in calibration quality. Initially, minor adjustments to the monthly UZSN values were made in an effort to improve the verification without compromising the calibration quality. After this adjustment proved unsuccessful in improving the verification results, an attempt was made to define the parameter changes that were needed to adequately simulate the verification period. In general, large increases to monthly UZSN values throughout the year were needed to produce an adequate simulation of the verification period. The model-parameter set with the large increases in monthly UZSN was used to simulate the calibration period but resulted in an unsatisfactory simulation. The large differences in model-parameter sets needed to produce adequate simulation of the calibration and verification periods precludes the development of a single parameter set that would accurately simulate both periods.

To simulate the calibration period, the parameters in HSPF must be set to generate substantial runoff. To simulate the verification period, however, the parameters in HSPF must be set to enhance moisture storage and evapotranspiration (decreased runoff). In the calibration of the three watersheds in this study, increases and decreases in the monthly UZSN value are utilized to either store rainfall for evapotranspiration or generate runoff and, thus, reflect the general climatic conditions in the watershed. The 1986–89 period was selected to provide a more rigorous verification, but the conditions were such that an acceptable verification was not achieved. The simulation quality for all three watersheds during the verification period is illustrated in the monthly flow time series in figures 14–16.
In the Sawmill Creek watershed, runoff for 34 of the 39 months was oversimulated.

Table 6. Model-verification statistics for three watersheds in Du Page County, Ill., for a 39-month verification period (July 1986–September 1989)

[Results simulated with application of the regional calibration parameter set for the Hydrological Simulation Program—Fortran]

Watershed	Coefficient of model-fit efficiency	Correlation coefficient	Number of months when the difference between simulated and observed average monthly discharge was less than 10 percent	Number of months when the difference between simulated and observed average monthly discharge was less than 25 percent
Kress Creek	0.8247	0.9304	7	21
St. Joseph Creek	.6728	0.8776	5	13
Sawmill Creek	.3414	0.7810	6	11

Table 7. Observed and Hydrological Simulation Program—Fortran simulated with application of the regional parameter set for a 39-month verification period (July 1986–September 1989) annual and grand total runoff from three watersheds in Du Page County, Ill.

[Observed refers to observed data; regional refers to simulated data using the regional parameter set; 1986 data for all watersheds represents a partial year, July 1986–September 1986]

Watershed	Runoff (in inches) by water year[1]				Grand total
	1986	1987	1988	1989	
Kress Creek					
Observed	1.49	13.38	10.77	7.00	32.64
Regional	2.14	11.91	9.64	7.15	30.84
St. Joseph Creek					
Observed	1.99	10.72	10.00	9.02	31.73
Regional	3.11	16.14	9.41	11.08	39.74
Sawmill Creek					
Observed	3.77	9.04	8.12	10.23	31.16
Regional	3.28	14.28	8.06	11.76	37.38

[1]The water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends and which includes 9 of the 12 months.

Results of Model Recalibration

In an ideal situation, a model is calibrated to as long a period as possible to ensure that the model is evaluated for and the model parameters represent a wide range of hydrologic conditions. In typical model applications to independently verify the calibration, a part of the available period of record is reserved for the verification, which then reduces the period of record available for calibration. Once the basic structure of and procedures applied in the model have been shown to adequately simulate the rainfall-runoff process of a watershed through calibration and verification, the model may be recalibrated by using the full period of record. The joint recalibration of the three watersheds to the full period of record available (87 months) provides for improved confidence in the applicability of the calibrated regional parameter set.

In the case of Sawmill Creek, the simulation model was not adequately verified. However, the average annual error (bias) was –6.9 percent for the calibration period (January 1990–September 1993) and 11 percent for the verification period. The negative and positive biases for the calibration and verification periods probably are a consequence of differences in general climatic conditions between the two periods discussed previously. When the two periods are combined in recalibration, the differences are averaged and a relatively neutral bias is expected for the entire recalibration period. Thus, it is reasonable to recalibrate for Sawmill Creek, as well as for Kress Creek

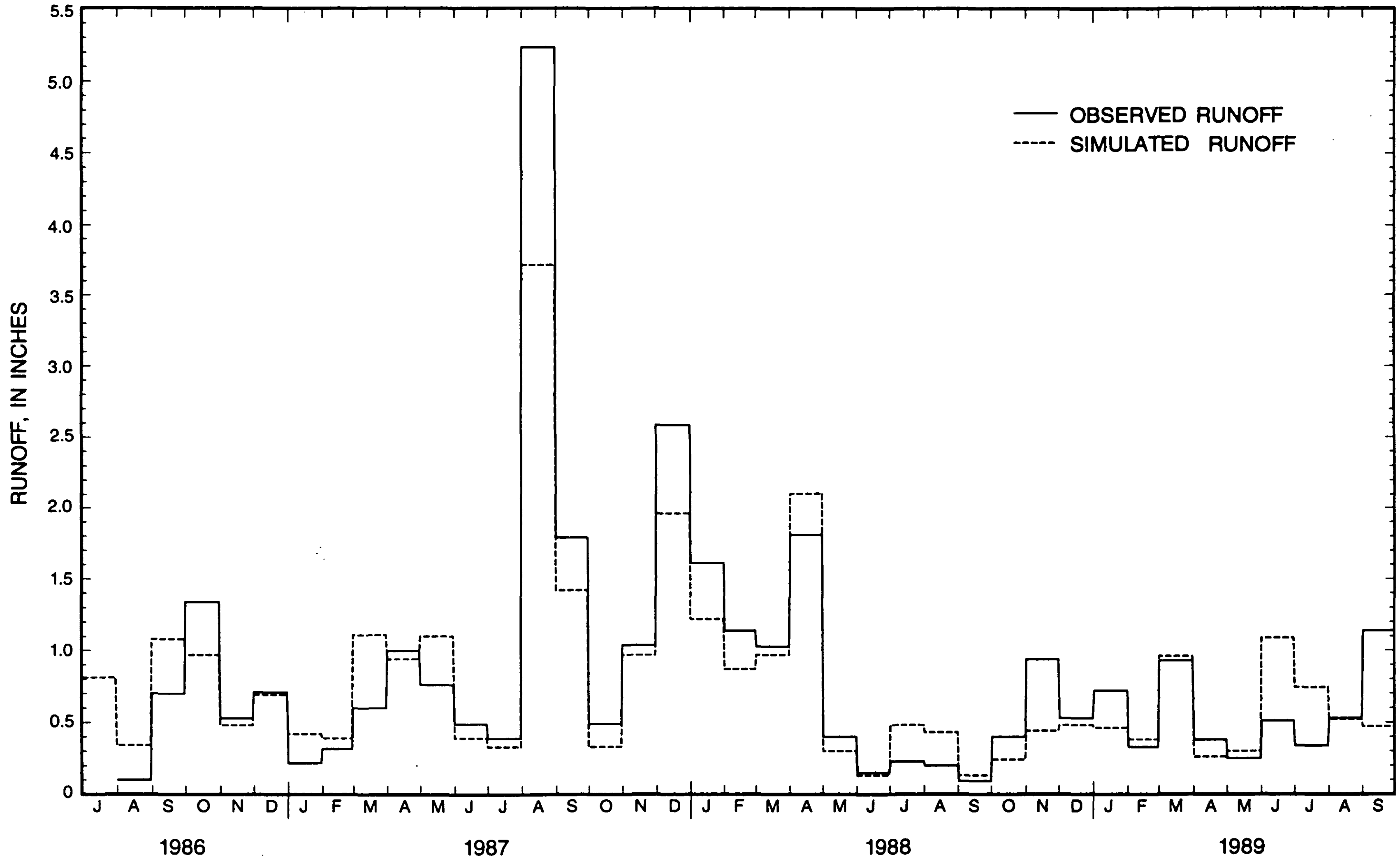


Figure 14. Observed and Hydrological Simulation Program—Fortran simulated (with application of the regional parameter set) monthly runoff for a 39-month verification period for Kress Creek at West Chicago, Ill.

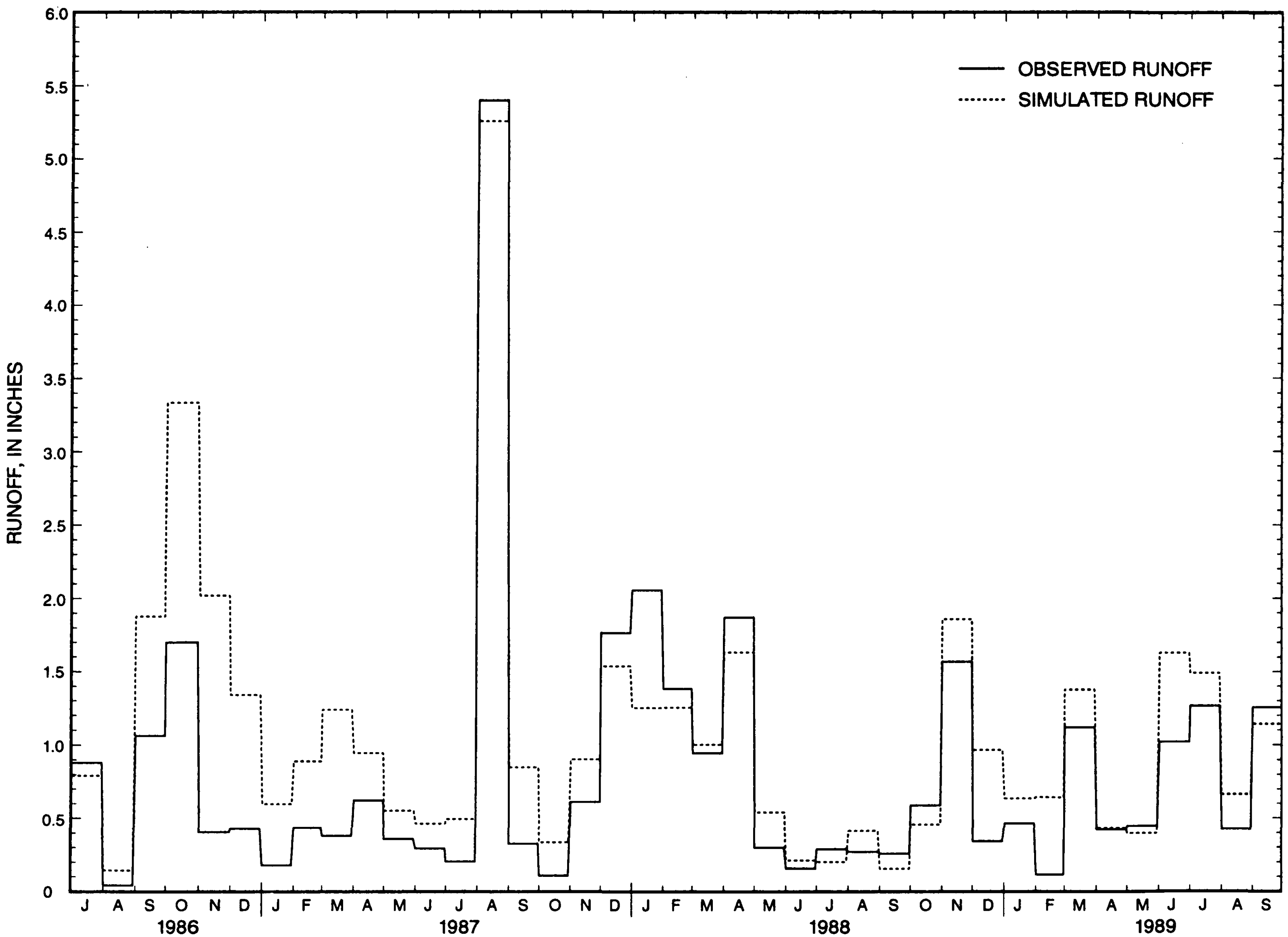


Figure 15. Observed and Hydrological Simulation Program—Fortran simulated (with application of the regional parameter set) monthly runoff for a 39-month verification period for St. Joseph Creek at Route 34 at Lisle, Ill.

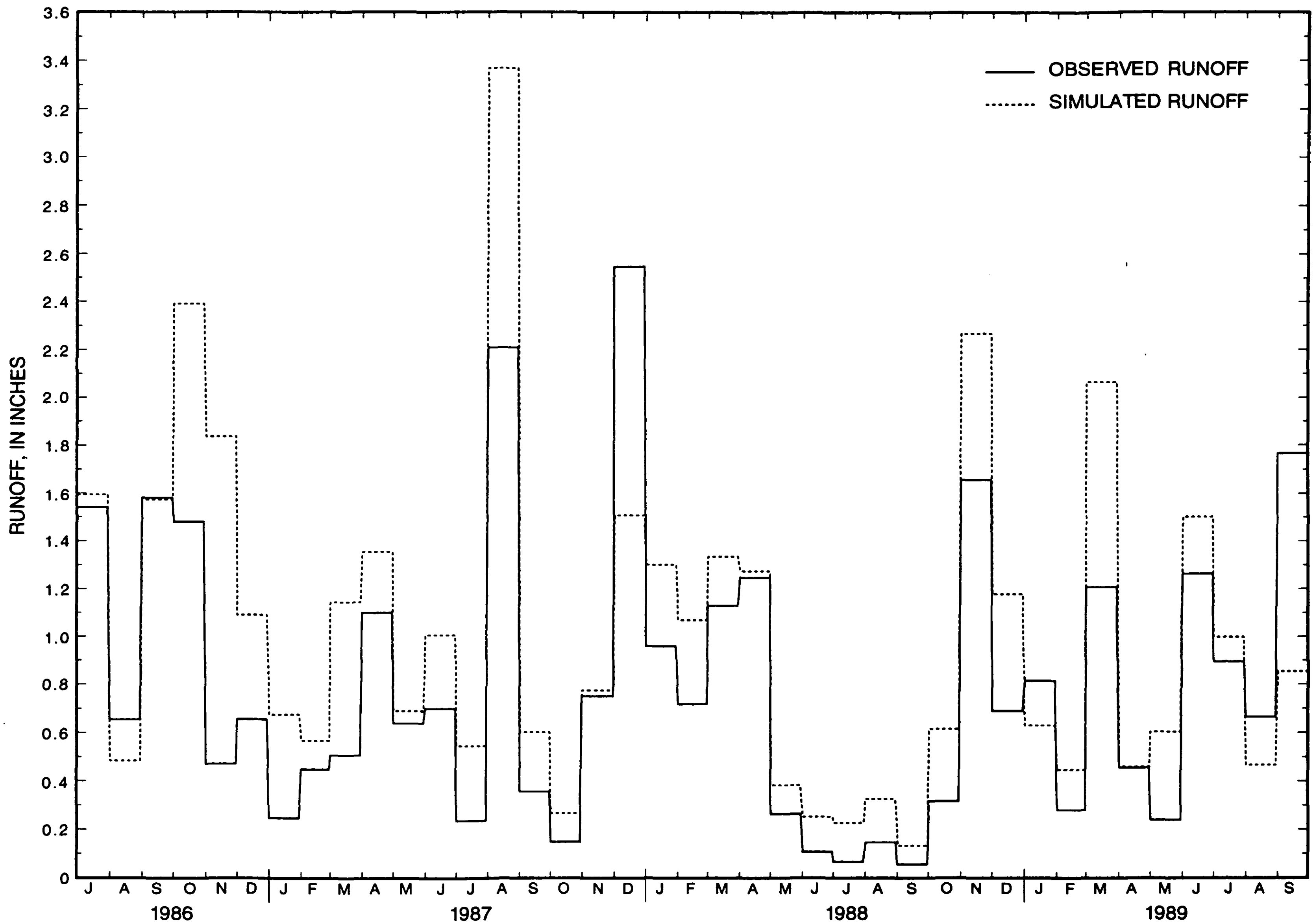


Figure 16. Observed and Hydrological Simulation Program—Fortran simulated (with application of the regional parameter set) monthly runoff for a 39-month verification period for Sawmill Creek near Lemont, Ill.

and St. Joseph Creek, for which the verification results were good.

Statistical results for the recalibration are presented in table 8. The observed and simulated runoff-duration curves for the 87-month recalibration period are shown in figures 17–19. The observed and simulated runoff-frequency plots for the 87-month recalibration period are shown in figures 20–22. For simulations applying the regional parameter set, correlation coefficients with the regional parameter set range from 0.8742 to 0.9150. The coefficients of model-fit efficiency ranged from 0.7612 to 0.8348. The results of annual and grand total water balances are presented in table 9. Grand total water balances for the study period were within 4.0 percent for all three watersheds. Average absolute errors in the full-year annual flows were 15.2 percent for the Kress Creek watershed, 18.4 percent for the St. Joseph Creek watershed, and 19.1 percent for the Sawmill Creek watershed. The results of the recalibration indicated that only minor changes to the calibrated regional parameter set were necessary as described in the "Regional Rainfall-Runoff Relations" section.

The overall quality of the simulation utilizing the parameter set from regional recalibration decreased from that for the best-fit calibration, but the results indicate that the parameter set from regional recalibration is suitable for the intended stormwater-management applications relative to the criteria for acceptable calibration results discussed previously. The simulation quality for the 87-month regional recalibration of the Kress Creek and St. Joseph Creek watersheds decreased as expected when compared to the 45-month regional calibration, yet resulted in coefficients of model-fit efficiency greater than 0.80 and correlation coefficients greater than 0.90. The simulation quality for the 87-month regional recalibration of the Sawmill Creek watershed is indicated by a coefficient of model-fit efficiency greater than 0.76 and a correlation coefficient greater than 0.87. Although, the quality of the 87-month regional recalibration for the Sawmill Creek watershed decreased substantially compared to the 45-month regional calibration, and the statistics indicate acceptable results that are greatly improved compared to the verification results. The observed and simulated total monthly runoff during the 87-month regional recalibration are shown in figures 23–25. A graphical indication of the simulation quality is illustrated in these figures. In the 87-month recalibration for the Kress Creek watershed, the regional parameter set resulted in oversimulation of runoff for 45 months and undersimulation of runoff for 42 months. In the St. Joseph Creek watershed, the regional parameter set resulted in oversimulation of runoff for 49 months and undersimulation of runoff for 38 months. In the Sawmill Creek watershed, the regional parameter set resulted in oversimulation of runoff for 49 months and undersimulation for 38 months.

With the exception of 3 storms in the Kress Creek watershed, all of the storms analyzed in the runoff-frequency analysis were undersimulated. Three factors that may contribute to the undersimulation of large storms are discussed in the following paragraphs.

1. The rainfall data may not be representative of the true rainfall over the entire watershed. Relatively small, intense, convective storm cells can produce large amounts of rain over a watershed, yet miss the rain gages entirely or produce more rainfall over the watershed than the amount that is recorded at the rain gages. Typically, the spatial variability of rainfall should result in random errors in the estimated runoff. In this case, however, the argument that spatial variability of rainfall is a potential source of error is valid because of the position of the rain gages in the watersheds. For each watershed, one rain gage is

Table 8. Model-recalibration statistics for Hydrological Simulation Program—Fortran simulation of rainfall-runoff relations for three watersheds in Du Page County, Ill., with application of the regional parameter set for an 87-month recalibration period (July 1986–September 1993)

Watershed	Coefficient of model-fit efficiency	Correlation coefficient	Number of months when the difference between simulated and observed average monthly discharge was less than 10 percent	Number of months when the difference between simulated and observed average monthly discharge was less than 25 percent
Kress Creek	0.8348	0.9150	13	40
St. Joseph Creek	.8056	0.9001	16	36
Sawmill Creek	.7612	0.8742	15	32

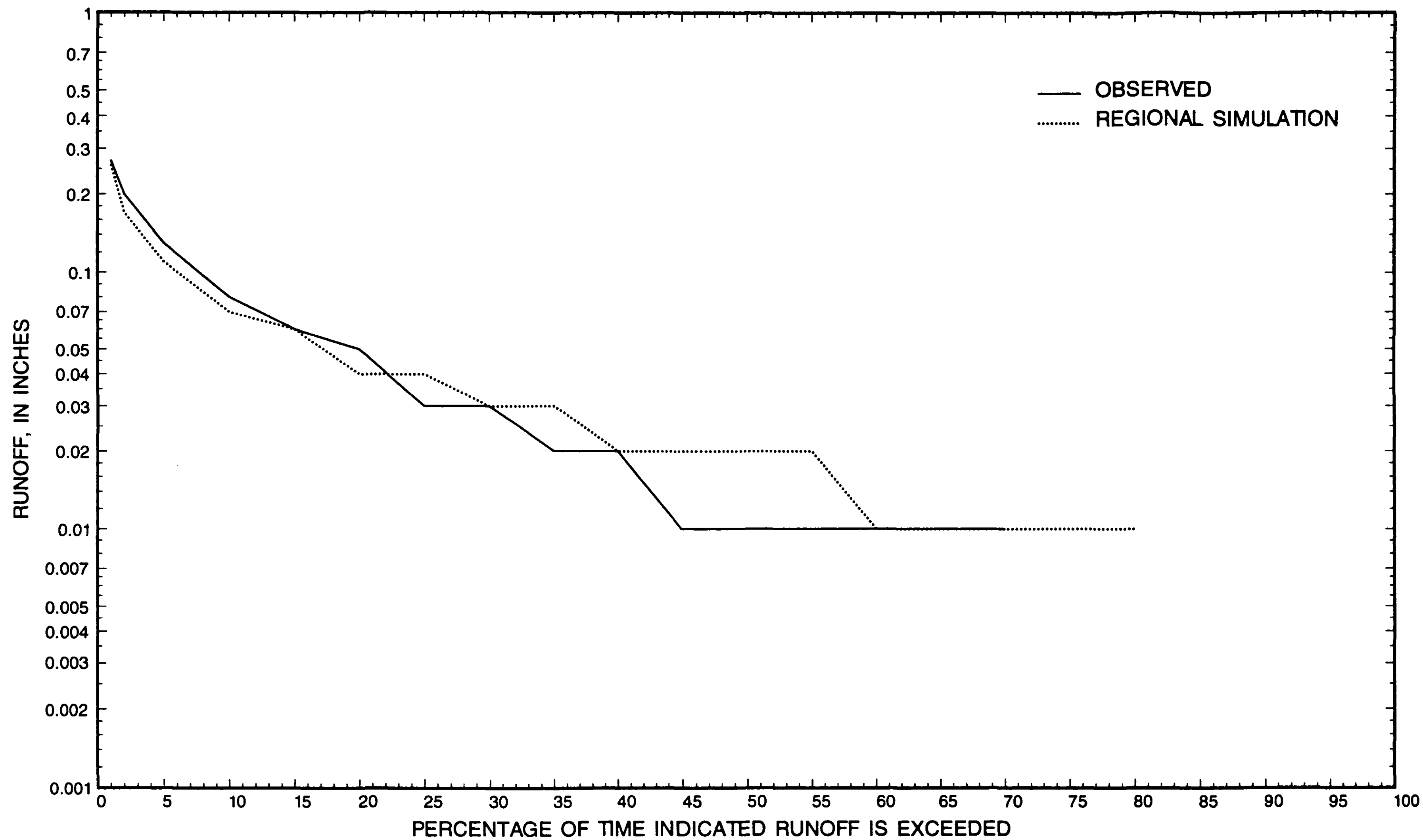


Figure 17. Daily runoff-duration curves for observed data and Hydrological Simulation Program—Fortran simulation with the application of the regional parameter set for an 87-month recalibration period (July 1986–September 1993) for Kress Creek at West Chicago, Ill.

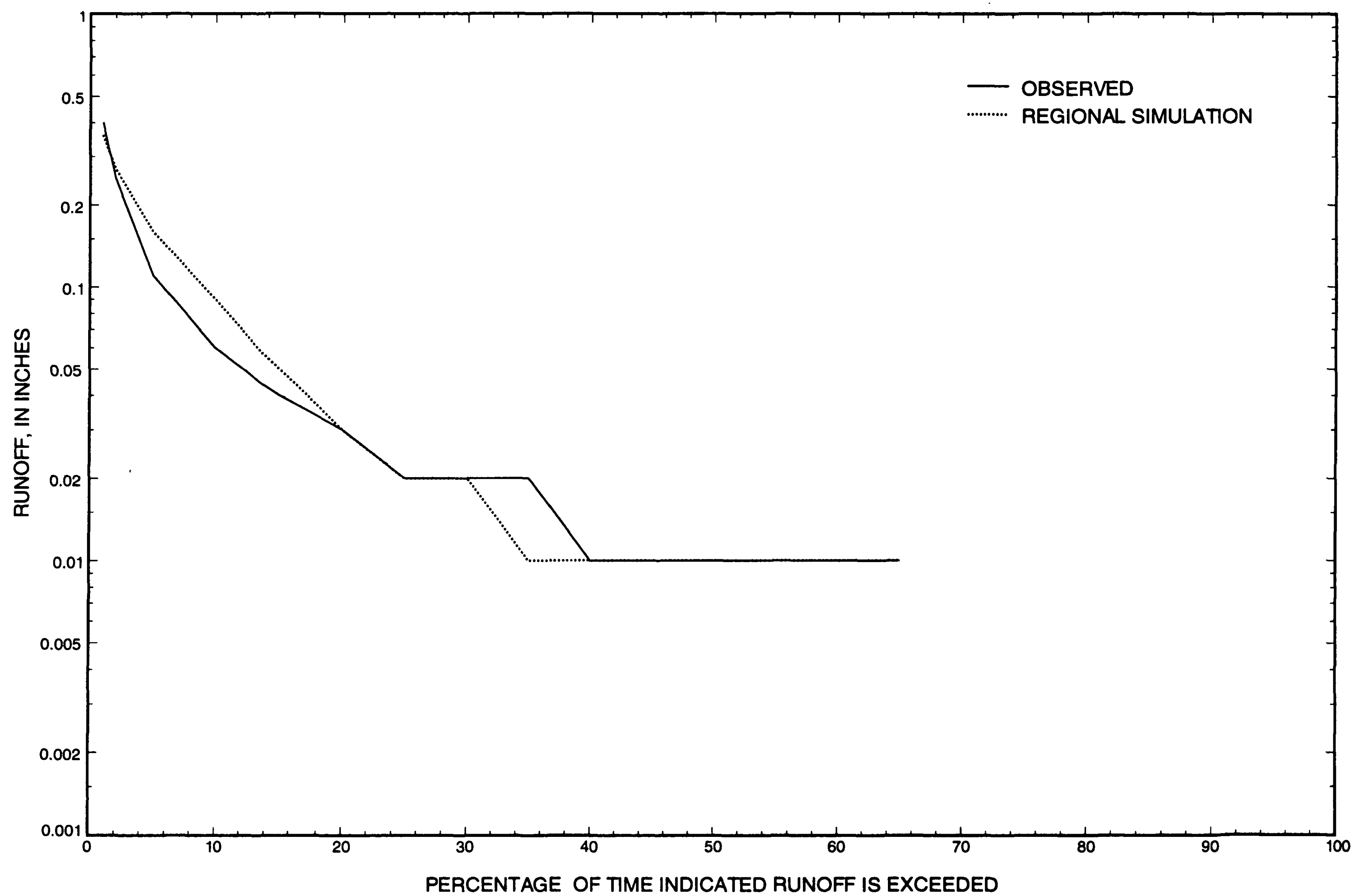


Figure 18. Daily runoff-duration curves for observed data and Hydrological Simulation Program—Fortran simulation with application of the regional parameter set for an 87-month recalibration period (July 1986–September 1993) for St. Joseph Creek at Route 34 at Lisle, Ill.

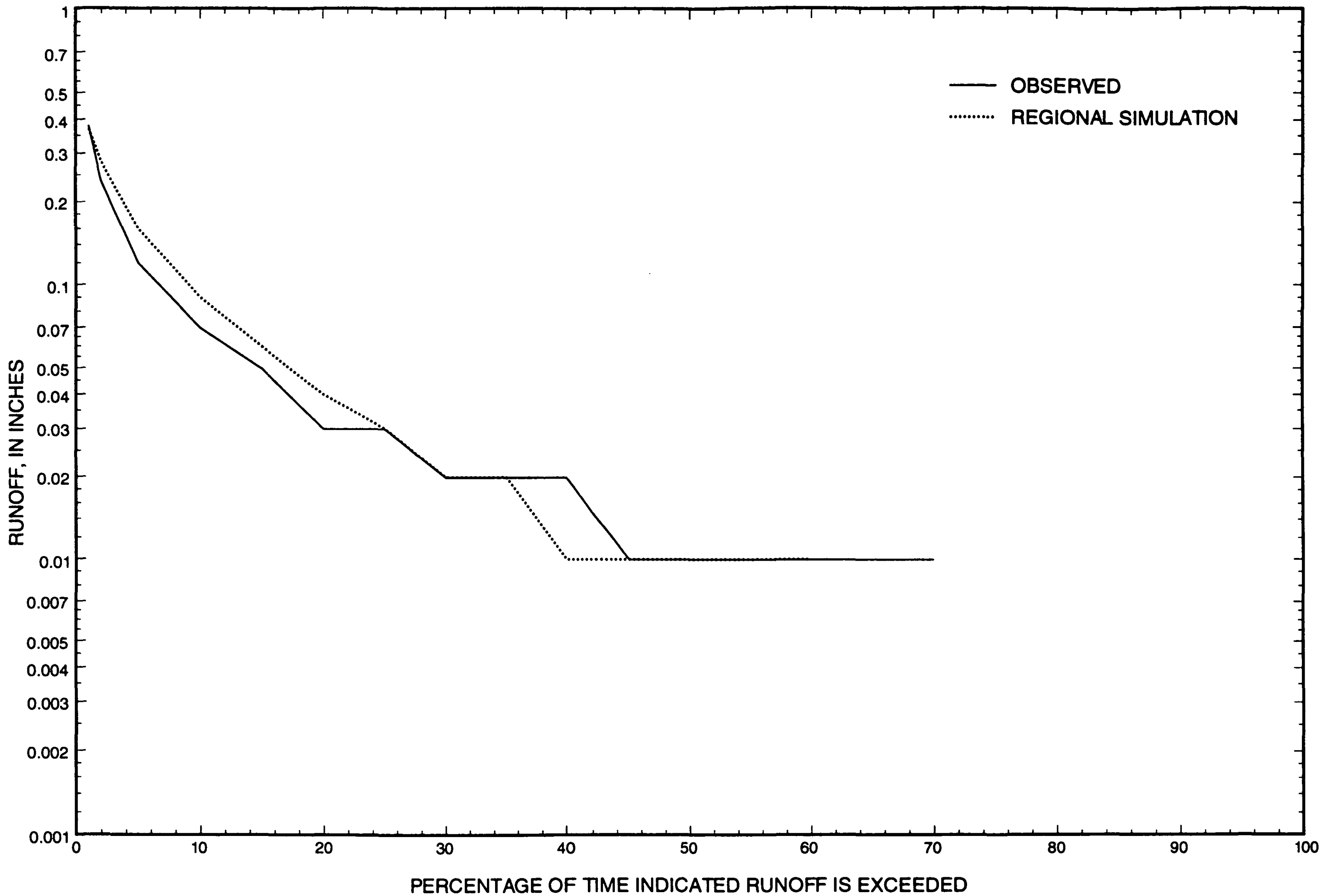


Figure 19. Daily runoff-duration curves for observed data and Hydrological Simulation Program—Fortran simulation with application of the regional parameter set for an 87-month recalibration period (July 1986–September 1993) for Sawmill Creek near Lemont, Ill.

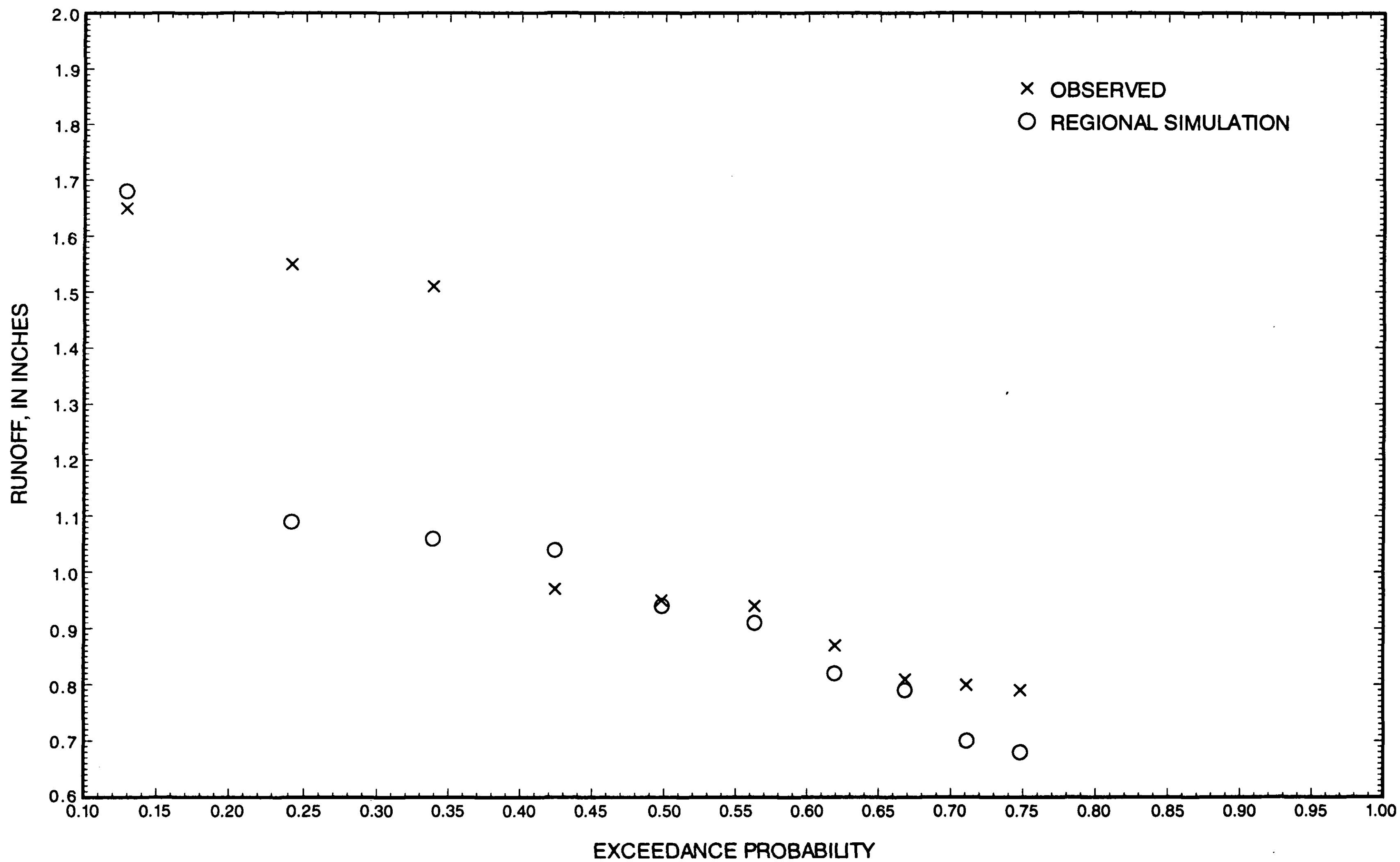


Figure 20. Runoff-frequency plots for observed data and Hydrological Simulation Program—Fortran simulation with application of the regional parameter set for an 87-month recalibration period (July 1986–September 1993) for storms producing greater than 0.8 inch of runoff in a 3-day period for Kress Creek at West Chicago, Ill.

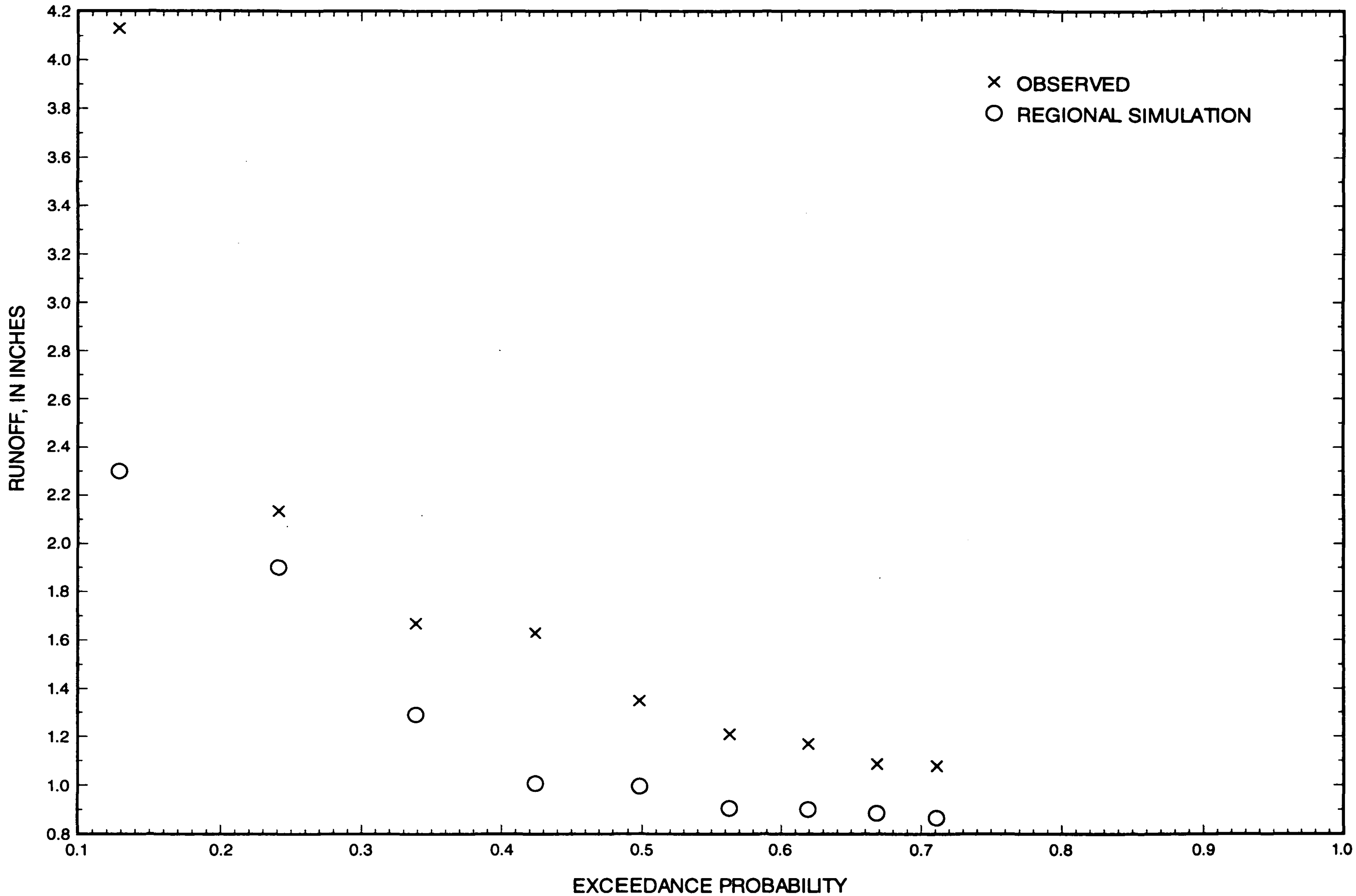


Figure 21. Runoff-frequency plots for observed data and Hydrological Simulation Program—Fortran simulation with application of the regional parameter set for an 87-month recalibration period for storms producing greater than 1.0 inch of runoff in a 3-day period for St. Joseph Creek at Route 34 at Lisle, Ill., (July 1986–September 1993)

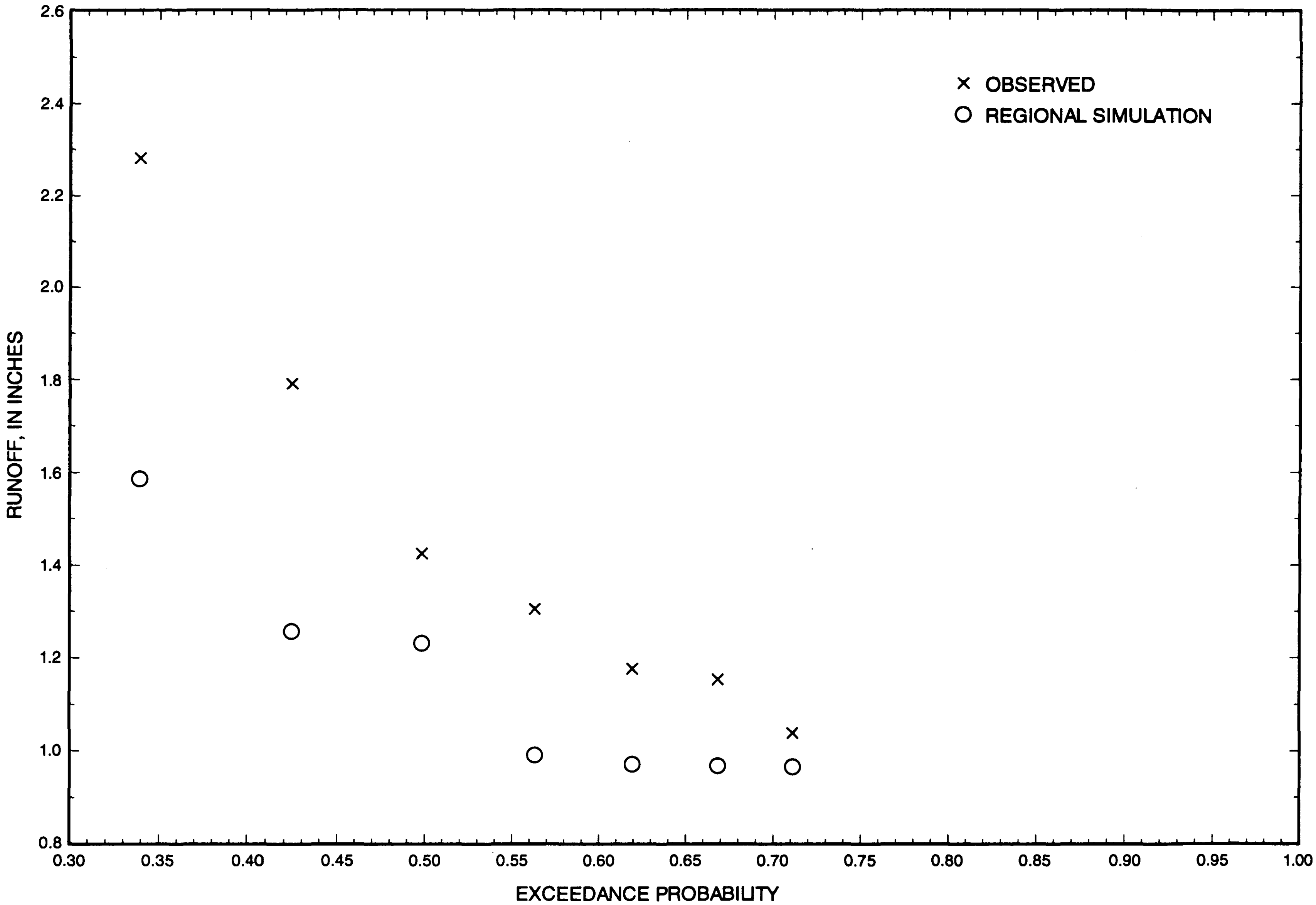


Figure 22. Runoff-frequency plots for observed data and Hydrological Simulation Program—Fortran simulation with application of the regional parameter set for an 87-month recalibration period for storms producing greater than 1.0 inch of runoff in a 3-day period for Sawmill Creek near Lemont, Ill., (July 1986–September 1993)

Table 9. Observed and Hydrological Simulation Program—Fortran simulated with application of the regional parameter set for an 87-month period (July 1986–September 1993) annual and grand total runoff from three watersheds in Du Page County, Ill.

[Observed refers to observed data; regional refers to simulated data using the regional parameter set; 1986 data for all watersheds represents a partial year, July 1986 through September 1986]

Watershed	Runoff (in inches) by water year[1]								Grand total
	1986	1987	1988	1989	1990	1991	1992	1993	
Kress Creek									
Observed	1.49	13.38	10.77	7.00	12.02	14.26	9.27	18.01	86.20
Regional	2.14	11.91	9.64	7.15	9.00	15.63	13.06	16.76	85.30
St. Joseph Creek									
Observed	1.99	10.72	10.00	9.02	14.22	13.31	8.05	15.60	82.91
Regional	3.11	16.14	9.41	10.48	11.08	12.05	7.38	16.58	86.23
Sawmill Creek									
Observed	3.77	9.04	8.12	10.23	15.63	14.40	8.83	19.04	89.05
Regional	3.28	14.28	8.06	11.76	10.69	13.68	10.63	18.42	90.80

[1]The water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends and which includes 9 of the 12 months.

at the streamflow-gaging station and the other is near the boundary of the watershed on the opposite side of the watershed (the rain gage in the middle of Sawmill Creek operated for only a relatively short period). Therefore, if a large storm went through the center of the watershed, the rain gages on the boundaries might record rainfall totals much less than occurred over the watershed. Conversely, if a large storm passed directly over the rain gage, the high rainfall total at that gage would be balanced by the lower rainfall total of the other side of the watershed, and a relatively reasonable average rainfall might be obtained. Thus, the simulation results might be biased toward undersimulation of runoff from large storms.

This condition is evident in the data when rainfall-runoff coefficients exceed 1.00. Rainfall-runoff coefficients that were calculated for each of the storms in the runoff-frequency analysis are listed in tables 10–12. An example of this problem is the May 9–11, 1990, storm in the St. Joseph Creek watershed. The two rainfall-gaging stations in the watershed recorded 3.76 and 4.04 in. of rain, yet the observed streamflow data indicate that the storm produced 4.13 in. of runoff.

2. The rain-gage network in Du Page County consists of tipping-bucket rain gages, which have been shown to under-record during periods of intense rainfall. The rainfall data used in this study were corrected for intense periods of rainfall according to manufacturer specifications. Price (1994b) found a consistent bias in the rainfall data when compared with data from the National Weather Service weighing-bucket rain-gage network in and near Du Page County. This bias is unlikely to be the sole source of the undersimulation of large events, however, because in a similar study applying HSPF to runoff simulation for watersheds in Lake County, Ill. (fig. 1), and utilizing rainfall data from tipping-bucket rain gages, storm-runoff volumes were oversimulated for 2 watersheds and mixed over- and undersimulations were obtained for 3 watersheds (Duncker and others, 1995). The USGS is currently studying this possible bias by locating tipping-bucket and weighing-bucket rain gages together at two sites in Du Page County.
3. The land-cover data used in the study may not truly represent the amount of impervious land cover in a watershed. In particular, determination of the percentage of impervious land cover that is hydraulically connected to the drainage system is difficult. For example, Allen and Bejcek (1979) did a detailed study of impervious areas in 15 watersheds in northeastern Illinois by applying a grid-sampling technique to aerial photographs of the watersheds taken in 1970. The grid density was 900 points per square mile. The St. Joseph Creek watershed upstream from Belmont Avenue (8.8 mi^2 in area, 80 percent of the study watershed) was determined to include 29.3 percent impervious land cover. The percentage of

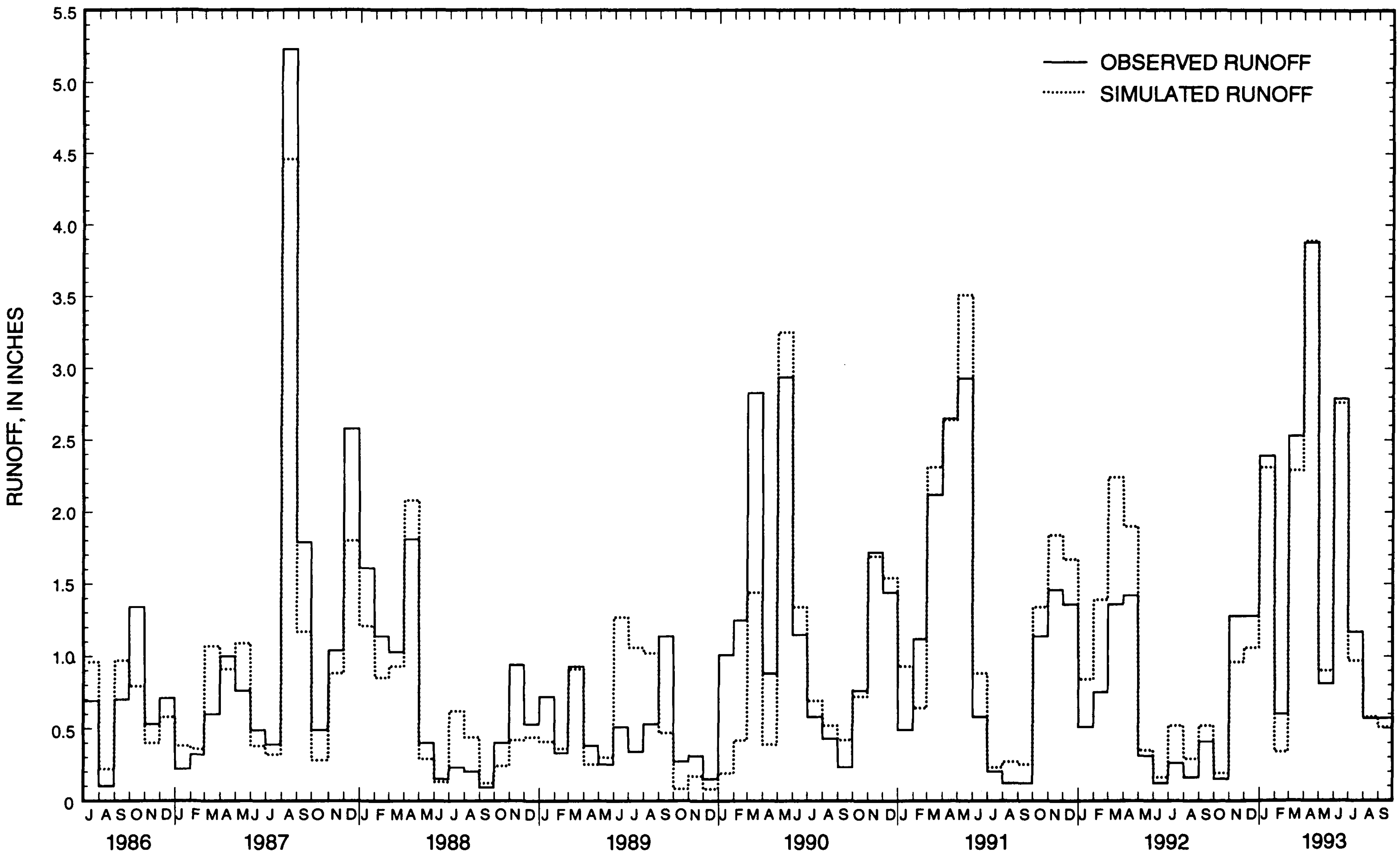


Figure 23. Observed and Hydrological Simulation Program—Fortran simulated (with application of the regional parameter set) monthly runoff for Kress Creek at West Chicago, Ill., for an 87-month recalibration period.

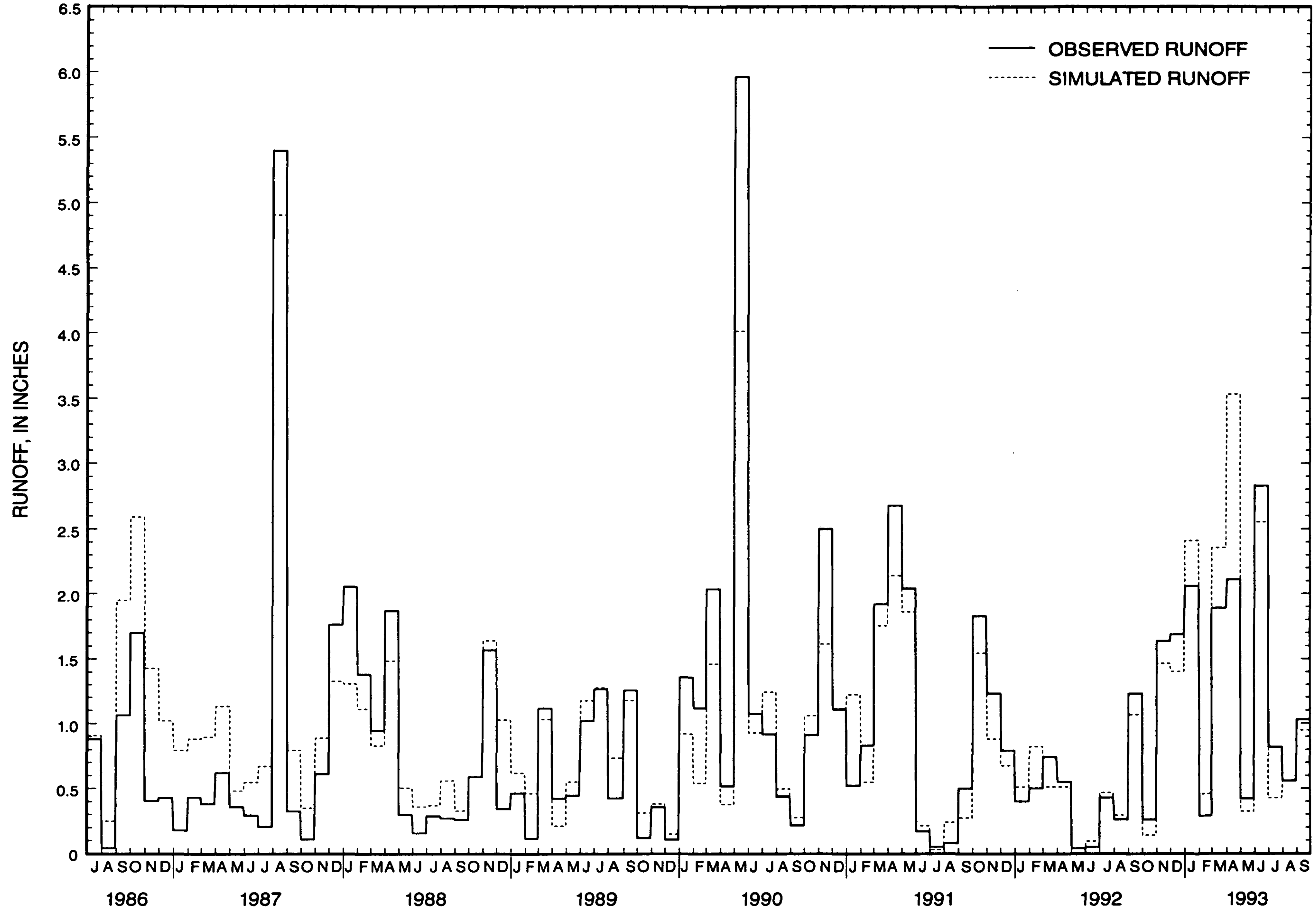


Figure 24. Observed and Hydrological Simulation Program—Fortran simulated (with application of the regional parameter set) monthly runoff for St. Joseph Creek at Route 34 at Lisle, Ill., for an 87-month recalibration period.

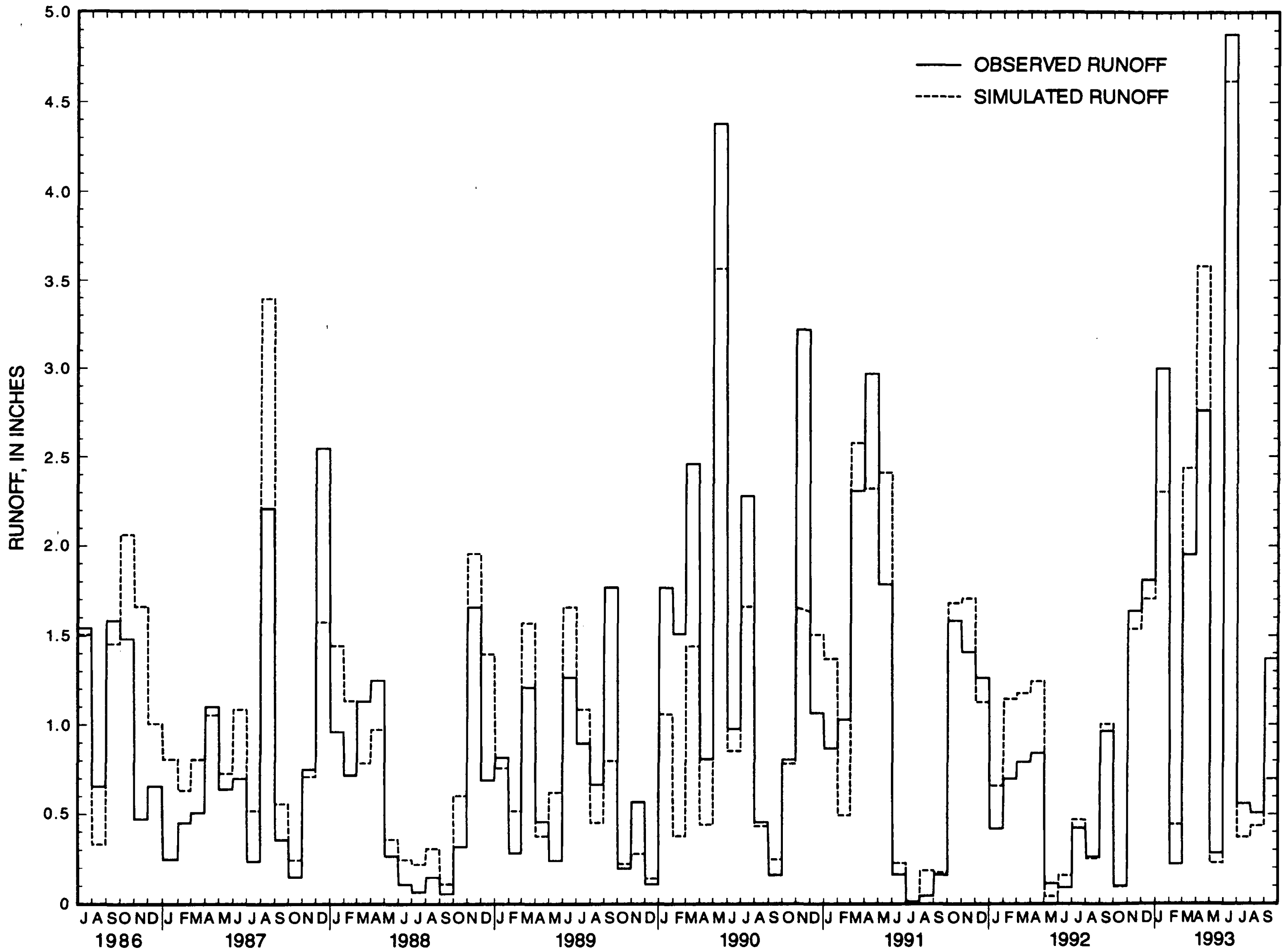


Figure 25. Observed and Hydrological Simulation Program—Fortran simulated (with application of the regional parameter set) monthly runoff for Sawmill Creek near Lemont, Ill., for an 87-month recalibration period.

Table 10. Rainfall-runoff coefficients for storms producing greater than 0.8 inch of observed runoff during a 3-day period in the Kress Creek watershed in Du Page County, Ill., (July 1986–September 1993)

[Rainfall amounts shown are totals for the two rain gages in the watershed; rainfall-runoff coefficients are calculated for the recorded rainfall at each rain gage]

Date	Rainfall (inches)	Observed runoff (inches)	Rainfall-runoff coefficient
August 14–16, 1987	1.95/1.95	1.55	0.80/0.80
August 17–19, 1987	.48/.48	.87	1.81/1.81
August 26–28, 1987	2.68/3.43	1.65	0.62/0.48
March 9–11, 1990	1.54/1.72	.78	0.51/0.46
May 10–12, 1990	2.42/3.77	.95	0.39/0.25
November 27–29, 1990	2.98/3.30	.82	0.28/0.25
April 14–16, 1991	1.91/2.21	.96	0.50/0.43
May 25–27, 1991	2.53/2.88	1.50	0.59/0.52
March 23–25, 1993	1.31/1.73	.81	0.62/0.47
June 8–10, 1993	1.25/1.34	.94	0.75/0.70

Table 11. Rainfall-runoff coefficients for storms producing greater than 1.0 inch of observed runoff during a 3-day period for the St. Joseph Creek watershed in Du Page County, Ill., (July 1986–September 1993)

[Rainfall amounts shown are totals for the two rain gages in the watershed; rainfall-runoff coefficients are calculated for the recorded rainfall at each rain gage]

Date	Rainfall (inches)	Observed runoff (inches)	Rainfall-runoff coefficient
October 3–5, 1986	2.70/2.17	1.24	0.46/0.57
August 14–16, 1987	3.77/5.35	2.14	0.57/0.49
August 26–28, 1987	3.75/5.22	1.67	0.45/0.32
April 5–7, 1988	1.55/2.61	1.35	0.86/0.52
March 8–10, 1990	1.87/1.91	1.09	0.58/0.57
May 9–11, 1990	3.76/4.04	4.13	1.10/1.02
November 27–29, 1990	2.94/2.95	1.63	0.55/0.55
April 14–16, 1991	1.97/2.05	1.17	0.59/0.57
May 25–27, 1991	1.63/1.05	1.08	0.66/1.03
June 7–9, 1993	3.31/2.52	1.21	0.37/0.48

impervious land cover determined from the parcel-based Du Page County land-cover data set (22.33 percent) closely matches the USGS side-looking airborne radar (SLAR) land-cover data (described in Duncker and others (1995)) for the St. Joseph Creek watershed, and, thus, appears reasonable for rainfall-runoff simulation. Recent work by Price (1996) in the Sawmill Creek watershed, however, increased the amount of impervious land cover from 17.16 percent indicated in the Du Page County land-cover data set to 20.7 percent on the basis of a revision of assumptions concerning the amount of hydraulically connected impervious land cover associated with single-family residential areas without storm sewers. Without a consistent and reliable means of estimating hydraulically connected impervious area, development of accurate and reliable simulation models will be difficult.

Additional model simulations were made in an attempt to resolve the problem of consistent undersimulation of large storms. Increasing the amount of impervious land cover substantially increased the simulated runoff volumes but had adverse effects on the overall mass balance, and medium- and low-flow parts of the flow-duration curves. The models could have

Table 12. Rainfall-runoff coefficients for storms producing greater than 1.0 inch of observed runoff during a 3-day period for the Sawmill Creek watershed in Du Page County, Ill., (July 1986–September 1993)

[Rainfall amounts shown are totals for the two rain gages in the watershed; rainfall-runoff coefficients are calculated for the recorded rainfall at each rain gage]

Date	Rainfall (inches)	Observed runoff (inches)	Rainfall-runoff coefficient
August 26–28, 1987	3.81/3.75	1.42	0.37/0.38
December 20–22, 1987	1.22/1.62	1.04	0.85/0.64
September 1–3, 1989	2.04/2.22	1.18	0.58/0.53
March 9–11, 1990	3.02/3.76	2.67	0.88/0.71
July 19–21, 1990	4.30/3.65	1.79	0.42/0.49
November 27–29, 1990	3.63/3.16	2.28	0.63/0.72
April 14–16, 1991	.71/1.97	1.30	1.84/0.66
January 3–5, 1993	1.26/1.31	1.15	0.92/0.88
June 8–10, 1993	6.16/3.31	3.35	0.54/1.01

been recalibrated to compensate for the increase in impervious land cover; however, land-cover data are not available to support or guide this approach. Storms with resulting rainfall-runoff ratios greater than 1.00 could have been excluded from the analysis but were retained to illustrate the problems encountered in the rainfall-runoff simulation.

REGIONAL RAINFALL-RUNOFF RELATIONS

Simulation of runoff from a watershed provides insight to the processes that affect runoff. Although most parameters in HSPF cannot be physically measured, the parameter values should define the general relations between the processes that affect runoff. A conceptualization of the runoff process was developed prior to simulation to guide the calibration procedure. The conceptualization is important in guiding the calibration process because the number of parameters in HSPF may permit similar results with different parameter sets. Thus, the model-parameter values (shown in tables 13 and 14, and the User Control Input files in appendix 1) developed in this study reflect the conceptualization of the watersheds and the hydrologic processes that affect runoff.

The conceptualized model for the three watersheds is based on an analysis of the physical setting in each watershed. The county GIS land-cover data base provided the model input to quantitatively represent the physical setting in each watershed. The urban land cover in these watersheds plays an important role in the generation of runoff to the stream. The amount of impervious land cover associated with urban areas was thought to be the primary factor in generating runoff.

Five categories of pervious land covers were defined by the county GIS data base. The five categories consisted of three slopes of grassland, forest, and agricultural land. The three slope categories defined by the county for the grassland land-cover category are 0–2 percent, 3–5 percent, and 6 percent and greater. Initial model simulations indicated that the model was insensitive to the different slope classifications for the grassland land cover. Thus, to simplify the model simulations, the three categories of grassland were combined into one grassland category.

Agricultural land within the three watersheds was differentiated from other pervious land covers by seasonal variations in the interception storage parameter (CEPSC) to reflect the different stages of vegetative growth for crops such as corn and soybeans. Except for the seasonal variation in interception storage, the agricultural land cover was simulated with similar model parameters as the grassland land-cover category.

Forested land cover was represented in a similar manner. Different seasonal variations in the foliage of deciduous trees was simulated by monthly variation in CEPSC.

The conceptualized model for the three watersheds also recognized significant differences within the ground-water-flow regimes of the three streams. Streamflow records from Kress Creek show a higher base flow than either St. Joseph Creek or Sawmill Creek. During low-flow periods, Kress Creek would maintain a significant base flow, whereas flow in Sawmill Creek diminishes and St. Joseph Creek would

Table 13. Model-parameter values for a 45-month (January 1990–September 1993) regional calibration period and an 87-month (July 1986–September 1993) regional recalibration of three watersheds in Du Page County, Ill., simulated with the Hydrological Simulation Program—Fortran

[HSPF, Hydrological Simulation Program—Fortran; ----, indicates the regional value for the interflow recession constant parameter is variable depending on watershed drainage area]

HSPF parameters: INFILT, infiltration; INTFW, interflow; IRC, interflow recession constant; LZSN, lower zone nominal storage; AGWRC, active ground-water recession constant; DEEPFR, fraction of ground-water inflow, which goes to inactive ground water; AGWETP, active ground-water evapotranspiration, BASETP, baseflow evapotranspiration

HSPF parameters	45-Month regional calibration	87-Month regional recalibration
INFILT	0.02 (Sawmill, St Joseph) .09 (Kress)	0.02 (Sawmill, St. Joseph) .09 (Kress)
INTFW	7.0	7.0
IRC	------	-------
LZSN	.1	.1
AGWRC	.99	.99
DEEPFR	.33 (Sawmill, St. Joseph) .34 (Kress)	.33 (Sawmill, St. Joseph) .34 (Kress)
AGWETP	.02	.02
BASETP	.03	.03

become a dry channel for extended periods of time. The low-flow characteristics of the three streams were simulated using the model parameters that controlled the ground-water flow regime, such as DEEPFR, base flow evapotranspiration (BASETP), and active ground-water recession constant (AGWRC).

The conceptualized model also recognized the importance of generally high water tables throughout the county and the effects of agricultural drainage tiles. No model parameters directly account for these factors, but the model parameters that define the overall ground-water flow regime reflect the presence of these factors.

Model parameter values for the initial simulations were obtained from the parameter values listed in a table of the User's Manual for the Agricultural Runoff Management (ARM) Model (Donigian and Davis, 1978, p. 58). The initial values for the DEEPFR parameter, which controls the amount of recharge to deep aquifers that do not affect streamflow in the basin simulated, was selected based on Zeizel and others (1962); where the average amount of recharge to the glacial aquifers in the study area was determined. The DEEPFR value was then refined to match the low-flow part of the runoff-duration curves for each watershed.

The infiltration parameter, INFILT, was initially set to a single value for the three watersheds to simulate relatively uniform soil conditions throughout the county. The single INFILT value (INFILT equal to 0.02) followed the original conceptualized model for each of the watersheds that soil types did not vary substantially within Du Page County. After further calibration of runoff from the three watersheds, the simulation quality improved for the Kress Creek watershed when the differences among soil types (discussed in the "Kress Creek" section) were recognized and the INFILT parameter value was increased to 0.09. The improved quality of the simulation using a higher value for the INFILT parameter confirmed the affect on runoff resulting from the previously discussed difference in the soils among the Kress Creek watershed and the other watersheds. This separate calibration of INFILT necessitated a revision to the conceptualized model for the three watersheds.

The simulation model for each of the watersheds incorporated a method to account for seasonal variation in runoff resulting from fluctuations of the water table. Seasonal fluctuation of the water table (high water table in the winter and low water table in the summer) is a common occurrence in northeastern Illinois. The most logical approach to simulate water-table fluctuations would be to apply a monthly variable lower zone nominal storage (LZSN) parameter (a small LZSN value in winter to increase water to ground-water storage and a large LZSN value in summer to reduce water to ground-water storage). Because LZSN is assigned a single value throughout the year, an alternative means of obtaining monthly variability was needed. By constricting INFILT and reducing LZSN to a very small value, the model was simplified to

Table 14. Monthly variable model-parameter values for the best-fit calibration, 45-month (January 1990–September 1993) regional calibration, and 87-month (July 1986–September 1993) recalibration of three watersheds in Du Page County, Ill., simulated with the Hydrological Simulation Program—Fortran

[UZSN, upper zone nominal storage parameter; LZETP, lower zone evapotranspiration parameter; CEPSC, interception storage parameter]

Parameter	Watershed, regional parameter set, or land cover[1]	January	February	March	April	May	June	July	August	September	October	November	December
UZSN													
	Kress	2.5	1.5	0.9	0.5	0.2	0.4	0.8	3.0	4.5	4.3	3.8	3.0
	St. Joseph	3.2	1.6	.9	1.1	.4	.8	.5	3.1	4.3	3.7	3.1	3.1
	Sawmill	3.6	2.3	1.6	1.2	1.1	1.0	.8	1.5	3.2	4.0	4.1	3.5
	45-Month regional calibration	3.6	2.3	1.4	1.2	1.0	.7	.8	1.3	3.2	3.8	3.9	3.3
	87-Month regional recalibration	3.2	1.7	2.3	1.7	1.5	.9	1.0	1.2	3.6	5.0	4.6	5.0
LZETP													
	Grass	.02	.02	.07	.16	.21	.30	.32	.32	.27	.16	.07	.02
	Forest	.02	.02	.10	.25	.35	.45	.50	.50	.40	.25	.10	.02
	Agricultural	.02	.02	.10	.25	.35	.45	.45	.45	.45	.30	.10	.02
CEPSC													
	Grass	.01	.01	.02	.02	.03	.04	.04	.04	.03	.02	.01	.01
	Forest	.02	.03	.04	.06	.08	.10	.10	.10	.09	.07	.03	.02
	Agricultural	.00	.00	.00	.02	.03	.08	.08	.08	.08	.04	.01	.00

[1]Kress, St. Joseph, and Sawmill refer to watersheds. 45-month and 87-month regional refers to the regional parameter sets developed during the calibration phase of modeling, and grass, forest, and agricultural refer to land covers.

effectively contain only one subsurface zone. The simplified subsurface zone was developed during the calibration process as simulation quality improved as LZSN was systematically reduced. The interflow (INTFW) and IRC parameters were then calibrated to simulate the natural interflow process. The monthly variable UZSN parameter provided a means of adjusting the amount of water in the redefined "lower zone" (that is, the functionally combined lower zone and upper zone). This type of simplification of the model is not unprecedented in that a similar approach was adopted by Gupta and Sorooshian (1983) in work with the National Weather Service-River Forecast System (NWSRFS) soil moisture accounting model. The soil moisture accounting model of the NWSRFS is basically a modification of HSPF, in which the subsurface is simulated by a lower zone nominal storage, a primary base-flow storage, and a secondary base-flow storage. Gupta and Sorooshian (1983) noted that whereas the physical rationale behind this soil moisture accounting model is sound, their calibration experiments indicated that the interacting parameters were difficult to calibrate properly, and the calibration problems could lead to substantial errors when the model is used in forecasting. Therefore, they advocated merging the three lower zones in the NWSRFS into a single lower zone with some of the lower zone functions partly absorbed by the upper zone to improve parameter identifiability (that is, to make calibrations more consistent) and the accuracy of the model in forecasting. Duncker and others (1995) applied the combined lower zone and upper zone approach to HSPF model simulation of runoff from watersheds in nearby Lake County, Ill., with satisfactory results.

Because most of the runoff from the pervious land segments was directed through interflow storage, the 3-day storm volumes were sensitive to changes of the interflow inflow parameter, INTFW, and the interflow recession constant, IRC. A previous study (Duncker and others, 1995) utilizing HSPF to simulate rainfall-runoff relations on watersheds in nearby Lake County, Ill. (fig. 1), developed a relation between the IRC parameter and the watershed drainage area. The relation is

$$IRC = 0.0939 \ln A + 0.504\,, \qquad (3)$$

where A is the watershed drainage area in square miles. The relation is physically reasonable because interflow should reach the stream sooner in small watersheds than in large watersheds. Model calibration of the three watersheds in this study proceeded with a prior assumption of the IRC-drainage area relation as valid, yet provisional, because it was developed from a limited data base (five simulated watersheds) in an area that is physiographically different from Du Page County. The optimal IRC values determined for watersheds in Lake County and Du Page County are plotted on figure 26 along with a curve computed utilizing the Du Page and Lake County watersheds. Results from the calibration of the three watersheds in this study support the general relation that IRC increases with drainage area but also indicate that equation 3 is most applicable for Lake County. Utilizing the IRC parameters from the calibration of the Du Page County watersheds in addition to those IRC parameters from the Lake County watersheds, a new equation was defined between drainage area and the IRC parameter. The equation is

$$IRC = 0.130 \ln A + 0.368\,. \qquad (4)$$

A coefficient of determination of 0.793 was calculated for equation 4. In simulating runoff from ungaged watersheds in Du Page County, the value for the IRC parameter could be determined on the basis of drainage area and equation 4 (shown in fig. 26).

An analysis of the detailed simulation output files (HSPF.PRINT) for months that included large storms and large amounts of runoff indicated that the hydraulically connected impervious areas are the primary source of runoff to the stream during storms. For example, in the Kress Creek watershed during the series of storms in August 1987, the grassland parts of the watershed generated from 3.37 to 5.20 in. of runoff per area from a total rainfall of 12.37 to 13.83 in., respectively. During this same period, the impervious parts of the watershed generated from 10.98 to 12.18 in. of runoff per area. Runoff also is generated from other areas of the watershed, but in general, the impervious areas generated most of the runoff.

The medium- to low-flow parts of the runoff-duration curves were extremely sensitive to changes in the model parameters that affect the ground-water part of the HSPF model, such as AGWRC and DEEPFR. Because these parameters reflect the varied soil and subsurface geology within each watershed, a single regional value was not developed. The low-flow part of the runoff-duration curves also was sensitive to changes in the model parameters, which affect the evapotranspiration processes in the model, such as

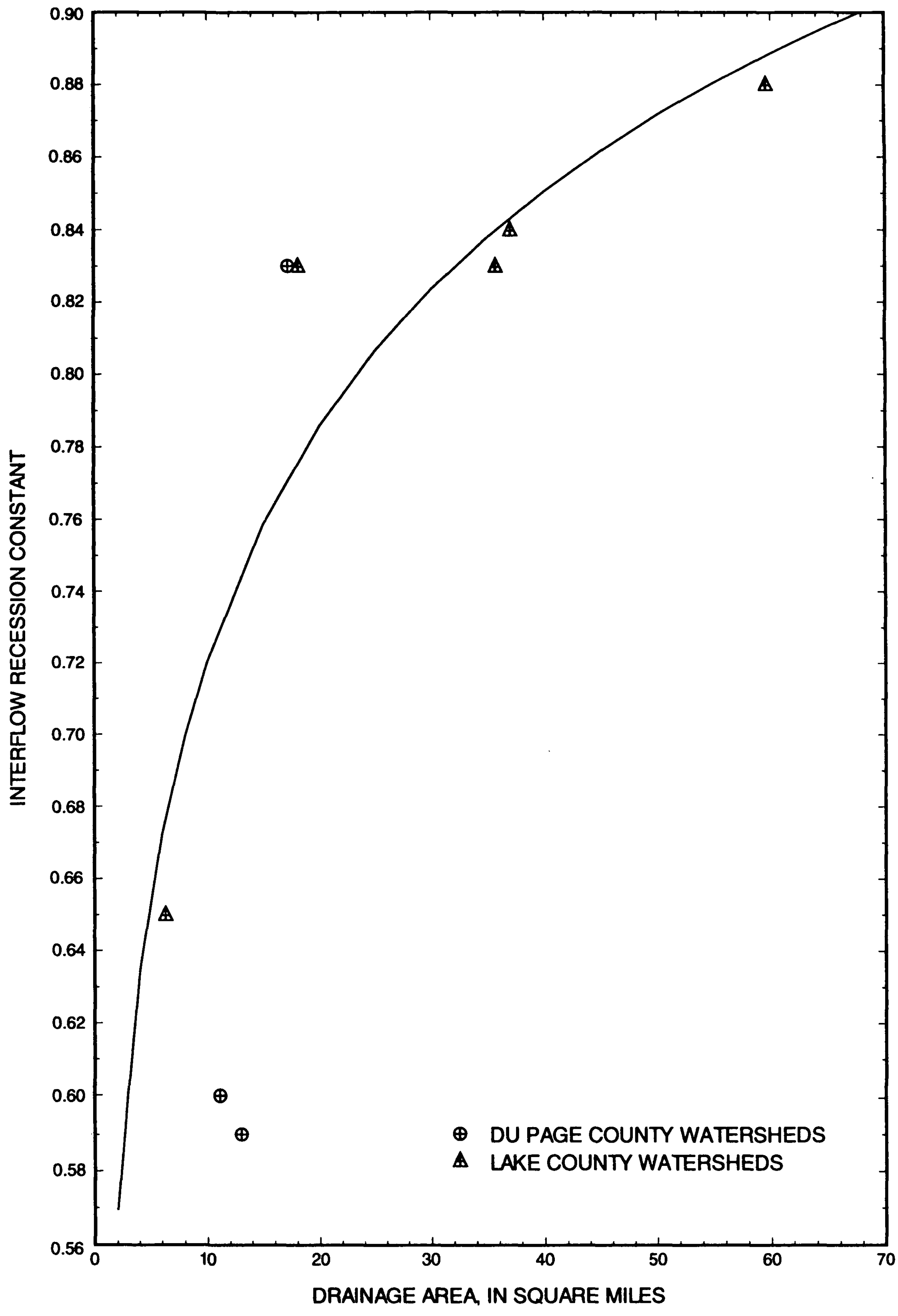


Figure 26. Relation between the interflow recession constant in the Hydrological Simulation Program—Fortran and watershed area for three watersheds in Du Page County, Ill., and five watersheds in Lake County, Ill.

BASETP. To achieve a satisfactory overall mass balance and to match the simulated runoff-duration curves, a single regional value for BASETP also was not developed but varied from 0.03 to 0.05 between watersheds.

The differences between the monthly UZSN values from the 45-month regional calibration and the 87-month regional recalibration are shown in table 14. Adjustments in monthly UZSN were needed to account for a wider range of hydrologic conditions encountered during the longer recalibration period. Although monthly values of UZSN differ slightly between the 45-month regional calibration and the 87-month regional recalibration, the overall seasonal trends in UZSN values were preserved. Slight adjustments in fixed parameters, such as DEEPFR, BASETP, and active ground-water evapotranspiration (AGWETP), were made to provide a better fit to the low-flow part of the runoff-duration curves.

Transferability of the regional parameter set includes inherent limitations relevant to stormwater management in Du Page County. Careful consideration should be given to determine if the soils or land cover within a watershed are substantially different from those soils or land cover in the watersheds considered in this study. Attempts to simulate short time series of runoff for periods that include extreme changes in climatic conditions may not produce acceptable results. A knowledge of wastewater-treatment facility discharges or other flows that are not represented in the modeling process also is important.

SUMMARY AND CONCLUSIONS

Hydrologic data were collected for three watersheds within Du Page County, Ill., from July 1986 to September 1993. The three watersheds, St. Joseph Creek, Sawmill Creek, and Kress Creek have drainage areas of 11.8, 13.3, and 18.0 square miles (mi^2), respectively. The hydrological data were used to simulate rainfall-runoff relations through calibration of a continuous-simulation rainfall-runoff model, Hydrological Simulation Program—Fortran. The model calibration approach consisted of three phases: obtaining best-fit parameter sets for each of the three watersheds and developing regional parameter sets reflecting two soil groups in Du Page County through joint calibration for a 45-month subset of the available data, verification of the regional parameter sets for a 39-month subset of the available data, and regional recalibration to the full period of record (July 1986–September 1993). The model-calibration errors with the regional parameter set were sufficiently small for overall, annual, and monthly mass balances and event-based runoff frequency curves to support the use of the model for stormwater-management planning purposes.

Correlation coefficients greater than 0.92 and coefficients of model-fit efficiency greater than 0.83 for monthly flows that were obtained for the three watersheds calibrated jointly to the 45-month period (January 1990–September 1993) indicate a satisfactory calibration of the model. The calibrated regional parameter set was verified by simulating runoff for each of the watersheds with observed rainfall and runoff data not utilized during the calibration process with no parameter adjustment. Verification errors for the Sawmill Creek watershed were exceptionally large. Direct application of the calibrated regional parameter set to the watersheds during verification resulted in correlation coefficients greater than 0.78 and coefficients of model-fit efficiency ranging from 0.34 to 0.82. The graphical comparisons between observed and simulated runoff duration curves also indicate acceptable decreases in fit quality between simulations applying the best-fit and regional parameter sets for all three watersheds. The verification was acceptable for the Kress Creek and St. Joseph Creek watersheds, whereas the acceptable results of the Sawmill Creek 87-month regional recalibration (coefficient of model-fit efficiency of 0.7612 and correlation coefficient of 0.8742) indicate that the regional parameter set may be used to simulate runoff on other watersheds within Du Page County with reasonably good results.

Graphical comparison of the observed and simulated runoff-frequency curves indicated that runoff from large storms tended to be substantially undersimulated. This undersimulation resulted primarily from difficulties in properly (1) measuring rainfall for intense thunderstorms and (2) determining the percentage of hydraulically connected impervious areas in the watershed. Errors related to inadequate rainfall data currently are being studied by the U.S. Geological Survey through dual-gage paired installations of tipping-bucket and weighing-bucket rain gages at two locations in Du Page County and detailed statistical analysis of rainfall data for rain gages in and near Du Page County.

Transferability of the regional parameter set includes inherent limitations relevant to stormwater management in Du Page County. Careful consideration should be given to determine if the soils or land cover within a watershed are substantially different from those soils or land cover in the watersheds considered in this study. Attempts to simulate short time series of runoff for periods that include extreme changes in climatic conditions may not produce acceptable results. A knowledge of wastewater-treatment facility discharges or other flows that are not represented in the modeling process also is important.

REFERENCES CITED

Allen, H.E., Jr., and Bejcek, R.M., 1979, Effects of urbanization on the magnitude and frequency of floods in northeastern Illinois: U.S. Geological Survey Water-Resources Investigations Report 79–36, 48 p.

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., Donigian, A.S., Jr., and Johanson, R.C., 1993, Hydrological simulation program—FORTRAN (HSPF): Users manual for release 10: Athens, Ga., U.S. Environmental Protection Agency Research Laboratory, 660 p.

Bradley, A.A., and Potter, K.W., 1992, Flood frequency analysis of simulated flows: Water Resources Research, v. 28, no. 9, p. 2375–2385.

Chiew, C.Y., Moore, L.W., and Smith, R.H., 1991, Hydrologic simulation of Tennessee's North Reelfoot Creek watershed: Research Journal of the Water Pollution Control Federation, v. 63, p. 10–16.

Coupe, R.H., Hayes, P.D., Richards, T.E., and Stahl, R.L., 1989, Water Resources Data-Illinois, Water Year 1988, Volume 2, Illinois River Basin: U.S. Geological Water-Data Report IL–88–2, 556 p.

Crawford, N.H., and Linsley, R.K., 1966, Digital simulation in hydrology—the Stanford Watershed Simulation Model IV: Stanford, Calif., Department of Civil Engineering, Stanford University, Technical Report no. 39, 210 p.

Dinicola, R.S., 1989, Characterization and simulation of rainfall-runoff relations for headwater basins in western King and Snohomish Counties, Washington: U.S. Geological Survey Water-Resources Investigations Report 89–4052, 52 p.

Donigian, A.S., Jr., and Davis, H.H., Jr., 1978, User's manual for the agricultural runoff management (ARM) model: Environmental Research Laboratory, EPA-600/3-78-080, 163 p.

Donigian, A.S., Jr., Imhoff, J.C., Bicknell, B.R., and Kittle, J.L., Jr., 1984, Application Guide for Hydrological Simulation Program-FORTRAN (HSPF): Environmental Research Laboratory, EPA-600/3-84-065, 177 p.

Duncker, J.J., Vail, T.J., and Earle, J.D., 1992, Rainfall in and near Du Page County, Illinois, February 1986–September 1991: U.S. Geological Survey Open-File Report 92–485, 142 p.

Duncker, J.J., Vail, T.J., and Melching, C.S., 1995, Regional rainfall-runoff relations for simulation of streamflow for watersheds in Lake County, Illinois: U.S. Geological Survey Water-Resources Investigations Report 95–4023, 71 p.

Fitzgerald, K.K., Coupe, R.H., Hayes, P.D., Richards, T.E., and Stahl, R.L., 1987, Water Resources Data-Illinois, Water Year 1986, Volume 2, Illinois River Basin: U.S. Geological Survey Water-Data Report IL–86–2, 415 p.

Fitzgerald, K.K., Coupe, R.H., Hayes, P.D., Richards, T.E., and Stahl, R.L., 1988, Water Resources Data-Illinois, Water Year 1987, Volume 2, Illinois River Basin: U.S. Geological Survey Water-Data Report IL–87–2, 492 p.

Gupta, V.K., and Sorooshian, S., 1983, Uniqueness and observability of conceptual rainfall-runoff parameters—The percolation process examined: Water Resources Research, v. 19, no. 1, p. 269–276.

Hamon, W.R., 1961, Estimating potential evapotranspiration: Journal of the Hydraulics Division, American Society of Civil Engineers, v. 87, no. HY3, p. 107–120.

Hydrocomp International, Incorporated, 1970, The LANDS Module of the Hydrocomp Program: Palo Alto, Calif.

James, L.D., 1972, Hydrologic modeling, parameter estimation, and watershed characteristics: Journal of Hydrology, v. 17, p. 283–307.

James, L.D., and Burgess, S.J., 1982, Selection, calibration and testing of hydrologic models in Hydrologic Modeling of Small Watersheds: American Society of Agricultural Engineers, p. 466.

Kohler, M.A., Nordenson, T.J., and Fox, W.E., 1955, Evaporation from pans and lakes: U.S. Weather Bureau Research Paper 38, 21 p.

Kunkel, K.E., Changnon, S.A., Lonnquist, C.G., and Angel, J.A., 1990, A real-time climate information system for the midwestern United States: Bulletin of the American Meteorological Society, v. 71, no. 11, p. 1601–1609.

Langbein, W.B., 1949, Annual floods and the partial-duration flood series: Transactions of the American Geophysical Union, v. 30, no. 6, p. 879–881.

La Tour, J.K., Richards, T.E., and Coupe, R.H., 1993, Water Resources Data-Illinois, Water Year 1992, Volume 2, Illinois River Basin: U.S. Geological Survey Water-Data Report IL–92–2, 315 p.

Leighton, M.M., Ekblaw, G.E., and Horberg, L., 1948, Physiographic divisions of Illinois: Illinois State Geological Survey, Report of Investigations 129, 33 p.

Ligon, J.T., and Law, A.G., 1973, Application of a version of the Stanford Watershed Model to a small Piedmont watershed: Transactions of the American Society of Agricultural Engineers, v. 16, no. 2, p. 261–265.

Lumb, A.M., and James, L.D., 1976, Runoff files for flood hydrograph simulation: Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, v. 102, no. HY10, p. 1515–1531.

Lumb, A.M., McCammon, R.B., and Kittle, J.L., Jr., 1994, Users manual for an expert systems (HSPEXP) for calibration of the Hydrological Simulation Program—Fortran: U.S. Geological Survey Water-Resources Investigations Report 94–4168, 102 p.

Mapes, D.R., 1979, Soil survey of Du Page and part of Cook Counties, Illinois: U.S. Department of Agriculture, Soil Conservation Service, 217 p.

Monteith, J.L., 1965, Evaporation and environment: Symposium of the Society for Experimental Biology, v. 19, p. 205–235.

Nash, J.E., and Sutcliffe, J.V., 1970, River flow forecasting through conceptual models—Part 1- A discussion of principles: Journal of Hydrology, v. 10, p. 282–290.

Price, T.H., 1993, Hydrologic model assistance for Du Page County, Illinois: Northeastern Illinois Planning Commission, 44 p.

———1994a, Hydrologic calibration of HSPF model for Du Page County—West Branch Du Page River at West Chicago, West Branch Du Page River at Warrenville, East Branch Du Page River at Maple Avenue, Salt Creek at Western Springs, including hydraulic evaluation at: Salt Creek at Western Springs, Salt Creek at Rolling Meadows: Northeastern Illinois Planning Commission, 92 p.

———1994b, Meteorologic data base extension and hydrologic verification of HSPF model for Du Page County, Illinois: Northeastern Illinois Planning Commission, 92 p.

———1996, Hydrologic and hydraulic evaluation of HSPF model for Sawmill Creek watershed: Northeastern Illinois Planning Commission, Draft Report, 41 p.

Price, T.H., and Dreher, D.W., 1991, Investigation of hydrologic design methods for urban development in northeastern Illinois: Northeastern Illinois Planning Commission, 98 p.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow, volumes 1 and 2: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Richards, T.E., Hayes, P.D., and Sullivan, D.J., 1991, Water Resources Data-Illinois, Water Year 1990, Volume 2, Illinois River Basin: U.S. Geological Survey Water-Data Report IL–90–2, 530 p.

———1992, Water Resources Data-Illinois, Water Year 1991, Volume 2, Illinois River Basin: U.S. Geological Survey Water-Data Report IL–91–2, 515 p.

Schilling, W., and Fuchs, L., 1986, Errors in stormwater modeling-a quantitative assessment: Journal of Hydraulic Engineering, American Society of Civil Engineers, v. 112, no. 2, p. 111–123.

Straub, T.D., Hornewer, N.J., and Duncker, J.J., 1998, Rainfall in and near Du Page County, Illinois, October 1991–September 1995: U.S. Geological Survey Open-File Report 97–582, 72 p.

Sullivan, D.J., Hayes, P.D., Richards, T.E., and Maurer, J.C., 1990, Water Resources Data-Illinois, Water Year 1989, Volume 2, Illinois River Basin: U.S. Geological Survey Water-Data Report IL–89–2, 467 p.

Troutman, B.M., 1985, Errors and parameter estimation in precipitation-runoff modeling theory: Water Resources Research, v. 21, no. 8, p. 1195–1213.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1972, National Weather Service River Forecast System Forecast Procedures: Silver Spring, Md., National Oceanic and Atmospheric Administration Technical Memorandum NWS HYDRO-14, variously paginated.

———1986–1993, Climatological data, Illinois: Asheville, N.C., Environmental Data and Information Service.

Zeizel, A.J., Walton, W.C., Sasman, R.T., and Prickett, T.A., 1962, Ground-water resources of Du Page County, Illinois: State of Illinois, Cooperative Ground-Water Report 2, 103 p.

Zuehls, E.E., La Tour, J.K., and Wicker, T.L., 1994, Water Resources Data-Illinois, Water Year 1993, Volume 2, Illinois River Basin: U.S. Geological Survey Water-Data Report IL–94–2, 352 p.

APPENDIX

APPENDIX 1: USER CONTROL INPUT FILES

User-Controlled Input (UCI) file for an 87-month simulation of the Kress Creek watershed

```
RUN

GLOBAL
  Calibration run #01: Kress Creek, IL
    ***        yy mm dd hr:mn          yy mm dd hr:mn
  START       1986 07 01       END     1993 09 30
  RUN INTERP OUTPUT LEVEL    0
  RESUME     0 RUN     1 TSSFL     0 WDMSFL   16
END GLOBAL

OPN SEQUENCE
    ***                         hr mn
    INGRP              INDELT 01:00
      PERLND       1
      PERLND       2
      PERLND       3
      IMPLND       1
      PERLND       4
      PERLND       5
      PERLND       6
      IMPLND       2
      PERLND       7
      PERLND       8
      PERLND       9
      IMPLND       3
      PERLND      10
      PERLND      11
      PERLND      12
      IMPLND       4
      COPY         1
      COPY         2
      COPY         3
      COPY         4
      COPY         5
      COPY         6
      COPY         7
      COPY         8
      COPY         9
                       *** place *** behind any of the operations that are
                       *** not needed for the simulation.  You __DO NOT__
                       *** need to delete other references to the operation
    END INGRP
END OPN SEQUENCE
```

```
*** Areas for Kress Creek:
***                                              sq miles        percent
***
***   ------------------------------------------------------------------
***   Du Page Airport rain gage                    10.14
***       Y Soil Group
***
***   PERLND1  grassland                                          16.31
***   PERLND5  forest                                              2.69
***   PERLND9  agriculture                                        14.82
***   IMPLND1  impervious                                          7.51
***
***       N Soil Group
***
***   PERLND2  grassland                                           2.70
***   PERLND6  forest                                              0.43
***   PERLND10 agriculture                                         9.85
***   IMPLND2  impervious                                          0.56
***
***   Kress Creek rain gage                                        7.86
***       Y Soil Group
***
***   PERLND3  grassland                                          12.18
***   PERLND7  forest                                              3.86
***   PERLND11 agriculture                                        15.65
***   IMPLND3  impervious                                          5.99
***
***       N Soil Group
***
***   PERLND4  grassland                                           0.88
***   PERLND8  forest                                              0.20
***   PERLND12 agriculture                                         6.05
***   IMPLND4  impervious                                          0.32
***
***   ------------------------------------------------------------------
***         totals                                               100.00

       *** Conversion factors
       *** inches-->cfs-days = 26.9 * area in sq miles
       ***                   = .042 * area in acres
       *** ratio is fraction of PERLND or IMPLND area to the
       *** total area of the watershed, should sum to 1.0
```

```
PERLND
  ACTIVITY
    #THRU# ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC***
    1   12    0    0    1    0    0    0    0    0    0    0    0    0
  END ACTIVITY

  PRINT-INFO
 ***#THRU# ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC PIVL  PYR
    1   12    0    0    4    0    0    0    0    0    0    0    0    0    0    9
  END PRINT-INFO

  GEN-INFO
      *** replace name with an identifier for the PERLND segments
      *** e.g., Piedmont forest, Surface mine, Reclaimed, Pasture
                                    1=ENGL 2=METR PRINT FILES ***
    #THRU#<-----NAME--------->NBLKS<----UNITS----> ENGL METR  ***
    1     4 Grass                 1    1    1    1    2    0
    5     8 Forest                1    1    1    1    2    0
    9    12 Agriculture           1    1    1    1    2    0
  END GEN-INFO

  PWAT-PARM1
    #thru# CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE             ***
    1   12    0    0    0    1    1    0    0    0    1
  END PWAT-PARM1

  PWAT-PARM2
      *** Calibration parameters:
      ***     LZSN should be calibrated, initially 2/3 of the available
      ***          water capacity in the rooting zone.
      ***   INFILT is major calibration parameter to shift surface runoff
      ***          and interflow to baseflow (by increasing INFILT).
      ***     AGWR is baseflow recession constant, used to match baseflows.
      ***     LSUR is length of overland flow. Do not change for natural
      ***          areas.  Should not exceed 1000 ft. For small disturbed
      ***          plots, use measured values.
      ***   FOREST is fraction of PERLND segment containing vegetation that
      ***          transpires during the winter.
    #THRU#FOREST      LZSN     INFILT     LSUR      SLSUR     KVARY     AGWR***
    1       0.0        .01       .20      400.       0.02      0.00      0.98
    2       0.0        .01       .02      400.       0.02      0.00      0.99
    3       0.0        .01       .20      400.       0.02      0.00      0.98
    4       0.0        .01       .02      400.       0.02      0.00      0.99
    5       0.0        .01       .20      400.       0.02      0.00      0.98
    6       0.0        .01       .02      400.       0.02      0.00      0.99
    7       0.0        .01       .20      400.       0.02      0.00      0.98
    8       0.0        .01       .02      400.       0.02      0.00      0.99
    9       0.0        .01       .20      400.       0.02      0.00      0.98
   10       0.0        .01       .02      400.       0.02      0.00      0.99
   11       0.0        .01       .20      400.       0.02      0.00      0.98
   12       0.0        .01       .02      400.       0.02      0.00      0.99
  END PWAT-PARM2
```

```
PWAT-PARM3
    *** DEEPFR should be adjusted towards 1.0 for intermittent streams.
  #THRU# ***PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
  1   12       40.       35.       2.0       2.0      0.09      0.06      0.02

END PWAT-PARM3

PWAT-PARM4
    *** Calibration parameters:
    ***     UZSN should be 1/10th of LZSN.
    ***    INTFW is calibration parameter for volume of interflow.
    ***      IRC is calibration parameter for interflow recession.
    ***     NSUR is Manning's 'n' for overland flow. Can be adjusted
    ***          for shaping storm hydrograph when 5- or 15-minute time
    ***          step is used.
  #THRU# CEPSC      UZSN      NSUR      INTFW       IRC      LZETP    ***
  1   12  0.01      0.75       0.1         7         .83       0.3

END PWAT-PARM4

PWAT-STATE1
    *** Initialization parameters:
    ***     LZS should be about 2/3 rds LZSN.
    ***    AGWS should be adjusted to match the initial baseflow or it
    ***         can be calculated using recession constant and observed
    ***         baseflow at the beginning of the simulation.
  #THRU#   CEPS      SURS       UZS      IFWS        LZS      AGWS  *** GWVS
  1   12   0.1        .02       1.1      0.02        0.1      0.4       0.00

END PWAT-STATE1

MON-INTERCEP
    *** Monthly inteception.
    ***    Used instead of CEPSC when VCSFG=1.
    ***    Examples for hardwood forest, bare soil, and grass land.
    ***    Evergreen forest should have all months at least 0.10.
  #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
  1    4  .01  .01  .02  .02  .03  .04  .04  .04  .03  .02  .01  .01
  5    8  .02  .03  .04  .06  .08  .10  .10  .10  .09  .07  .03  .02
  9   12  .00  .00  .00  .02  .03  .08  .08  .08  .08  .04  .01  .00
*** hardwood.02  .03  .04  .06  .08  .10  .10  .10  .09  .07  .03  .02
*** baresoil.01  .01  .01  .01  .01  .01  .01  .01  .01  .01  .01  .01
*** grasslnd.01  .01  .02  .02  .03  .04  .04  .04  .03  .02  .01  .01
END MON-INTERCEP
```

```
  MON-LZETPARM
      *** Monthly lower zone ET parameter
      ***    Used instead of LZETP when VLEFG=1
      ***    Examples for hardwood forest, bare soil, and grass land.
      ***    Evergreen forest should have all months at least 0.10.
    #THRU#   JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
    1    4  .02  .02  .07  .16  .21  .30  .32  .32  .27  .16  .07  .02
    5    8  .02  .02  .10  .25  .35  .45  .50  .50  .40  .25  .10  .02
    9   12  .02  .02  .10  .25  .35  .45  .45  .45  .45  .30  .10  .02
*** hardwood.02  .02  .10  .25  .35  .45  .50  .50  .40  .25  .10  .02
*** baresoil.02  .02  .03  .04  .04  .04  .04  .04  .04  .03  .02  .02
*** grasslnd.02  .02  .07  .16  .21  .30  .32  .32  .27  .16  .07  .02
  END MON-LZETPARM

  MON-UZSN
    #THRU#   JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC  ***
    1   12  3.2  1.9  2.3  1.7  1.5  0.9  1.0  1.2  3.6  5.0  4.6  5.0
  END MON-UZSN

END PERLND

IMPLND
  ACTIVITY
    <ILS >     ACTIVE SECTIONS          ***
    # -  # ATMP SNOW IWAT  SLD   IWG IQAL ***
    1    4   0    0    1    0      0   0
  END ACTIVITY
  PRINT-INFO
    <ILS >    ***   PRINT  FLAGS    ***
    # -  # ATMP SNOW IWAT  SLD   IWG   IQAL ***
    1    4              4
  END PRINT-INFO

  GEN-INFO
    #THRU#<-----NAME---------><----UNITS----> ENGL METR   ***
    1    4    Impervious           1    1    1    2    0

  END GEN-INFO

  IWAT-PARM1
    <ILS >          FLAGS                ***
    # -  # CSNO RTOP  VRS   VNN RTLI     ***
    1    4   0     1    1    0    0
  END IWAT-PARM1

  IWAT-PARM2
    <ILS >                                                    ***
    # -  #      LSUR      SLSUR       NSUR       RETSC ***
    1    4      400        0.02       .013        0.10
  END IWAT-PARM2
  IWAT-PARM3
    <ILS >                             ***
    # -  #     PETMAX    PETMIN        ***
    1    4       40        35
  END IWAT-PARM3
```

```
  MON-RETN
    <ILS >  Retention storage capacity at start of each month ***
    # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1    4  .10  .10  .10  .10  .10  .10  .20  .20  .20  .20  .20  .10
  END MON-RETN

  IWAT-STATE1
    <ILS >   IWATER STATE VARIABLES  ***
    # -  #      RETS      SURS       ***
    1    4     0.001     0.001
  END IWAT-STATE1
END IMPLND

COPY
  TIMESERIES
  Copy-opn                                                             ***
    # -  #  NPT  NMN                                                   ***
    1         0    1
    2         0    1
    3         0    1
    4         1    0
    5         1    0
    6         1    0
    7         0    1
    8         0    1
    9         0    1

  END TIMESERIES
END COPY


EXT SOURCES

      *** note: a multiplier is used on potential ET so the annual PET
      ***        will be equivalent to lake evaporation for the location
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name> dsn <Name> # tem strg<-factor->strg <Name>   #   #        <Name> # #   ***
WDM     46 EVAP     ENGL                   PERLND   1  12 EXTNL  PETINP
WDM     46 EVAP     ENGL                   IMPLND   1   4 EXTNL  PETINP
WDM    201 PREC     ENGL                   PERLND   1   2 EXTNL  PREC
WDM    201 PREC     ENGL                   PERLND   5   6 EXTNL  PREC
WDM    201 PREC     ENGL                   PERLND   9  10 EXTNL  PREC
WDM    201 PREC     ENGL                   IMPLND   1   2 EXTNL  PREC
WDM   1203 PREC     ENGL                   PERLND   3   4 EXTNL  PREC
WDM   1203 PREC     ENGL                   PERLND   7   8 EXTNL  PREC
WDM   1203 PREC     ENGL                   PERLND  11  12 EXTNL  PREC
WDM   1203 PREC     ENGL                   IMPLND   3   4 EXTNL  PREC
END EXT SOURCES
```

```
NETWORK
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   #        <Name> # #<-factor->strg <Name>   #   #        <Name> # #  ***
PERLND   1 PWATER PERO       .1631         COPY     1       INPUT  MEAN
PERLND   2 PWATER PERO       .0269         COPY     1       INPUT  MEAN
PERLND   3 PWATER PERO       .1482         COPY     1       INPUT  MEAN
IMPLND   1 IWATER SURO       .0751         COPY     1       INPUT  MEAN
PERLND   4 PWATER PERO       .0270         COPY     1       INPUT  MEAN
PERLND   5 PWATER PERO       .0043         COPY     1       INPUT  MEAN
PERLND   6 PWATER PERO       .0985         COPY     1       INPUT  MEAN
IMPLND   2 IWATER SURO       .0056         COPY     1       INPUT  MEAN
PERLND   7 PWATER PERO       .1218         COPY     1       INPUT  MEAN
PERLND   8 PWATER PERO       .0386         COPY     1       INPUT  MEAN
PERLND   9 PWATER PERO       .1565         COPY     1       INPUT  MEAN
IMPLND   3 IWATER SURO       .0599         COPY     1       INPUT  MEAN
PERLND  10 PWATER PERO       .0088         COPY     1       INPUT  MEAN
PERLND  11 PWATER PERO       .0020         COPY     1       INPUT  MEAN
PERLND  12 PWATER PERO       .0605         COPY     1       INPUT  MEAN
IMPLND   4 IWATER SURO       .0032         COPY     1       INPUT  MEAN

PERLND   1 PWATER TAET       .1631         COPY     2       INPUT  MEAN
PERLND   2 PWATER TAET       .0269         COPY     2       INPUT  MEAN
PERLND   3 PWATER TAET       .1482         COPY     2       INPUT  MEAN
IMPLND   1 IWATER IMPEV      .0751         COPY     2       INPUT  MEAN
PERLND   4 PWATER TAET       .0270         COPY     2       INPUT  MEAN
PERLND   5 PWATER TAET       .0043         COPY     2       INPUT  MEAN
PERLND   6 PWATER TAET       .0985         COPY     2       INPUT  MEAN
IMPLND   2 IWATER IMPEV      .0056         COPY     2       INPUT  MEAN
PERLND   7 PWATER TAET       .1218         COPY     2       INPUT  MEAN
PERLND   8 PWATER TAET       .0386         COPY     2       INPUT  MEAN
PERLND   9 PWATER TAET       .1565         COPY     2       INPUT  MEAN
IMPLND   3 IWATER IMPEV      .0599         COPY     2       INPUT  MEAN
PERLND  10 PWATER TAET       .0088         COPY     2       INPUT  MEAN
PERLND  11 PWATER TAET       .0020         COPY     2       INPUT  MEAN
PERLND  12 PWATER TAET       .0605         COPY     2       INPUT  MEAN
IMPLND   4 IWATER IMPEV      .0032         COPY     2       INPUT  MEAN

PERLND   1 PWATER PET        .1631         COPY     3       INPUT  MEAN
PERLND   2 PWATER PET        .0269         COPY     3       INPUT  MEAN
PERLND   3 PWATER PET        .1482         COPY     3       INPUT  MEAN
IMPLND   1 IWATER PET        .0751         COPY     3       INPUT  MEAN
PERLND   4 PWATER PET        .0270         COPY     3       INPUT  MEAN
PERLND   5 PWATER PET        .0043         COPY     3       INPUT  MEAN
PERLND   6 PWATER PET        .0985         COPY     3       INPUT  MEAN
IMPLND   2 IWATER PET        .0056         COPY     3       INPUT  MEAN
PERLND   7 PWATER PET        .1218         COPY     3       INPUT  MEAN
PERLND   8 PWATER PET        .0386         COPY     3       INPUT  MEAN
PERLND   9 PWATER PET        .1565         COPY     3       INPUT  MEAN
IMPLND   3 IWATER PET        .0599         COPY     3       INPUT  MEAN
PERLND  10 PWATER PET        .0088         COPY     3       INPUT  MEAN
PERLND  11 PWATER PET        .0020         COPY     3       INPUT  MEAN
PERLND  12 PWATER PET        .0605         COPY     3       INPUT  MEAN
IMPLND   4 IWATER PET        .0032         COPY     3       INPUT  MEAN
```

PERLND	1	PWATER	UZS	.1631	COPY	4	INPUT	POINT
PERLND	2	PWATER	UZS	.0269	COPY	4	INPUT	POINT
PERLND	3	PWATER	UZS	.1482	COPY	4	INPUT	POINT
IMPLND	1	IWATER	RETS	.0751	COPY	4	INPUT	POINT
PERLND	4	PWATER	UZS	.0270	COPY	4	INPUT	POINT
PERLND	5	PWATER	UZS	.0043	COPY	4	INPUT	POINT
PERLND	6	PWATER	UZS	.0985	COPY	4	INPUT	POINT
IMPLND	2	IWATER	RETS	.0056	COPY	4	INPUT	POINT
PERLND	7	PWATER	UZS	.1218	COPY	4	INPUT	POINT
PERLND	8	PWATER	UZS	.0386	COPY	4	INPUT	POINT
PERLND	9	PWATER	UZS	.1565	COPY	4	INPUT	POINT
IMPLND	3	IWATER	RETS	.0599	COPY	4	INPUT	POINT
PERLND	10	PWATER	UZS	.0088	COPY	4	INPUT	POINT
PERLND	11	PWATER	UZS	.0020	COPY	4	INPUT	POINT
PERLND	12	PWATER	UZS	.0605	COPY	4	INPUT	POINT
IMPLND	4	IWATER	RETS	.0032	COPY	4	INPUT	POINT
PERLND	1	PWATER	LZS	.1631	COPY	5	INPUT	POINT
PERLND	2	PWATER	LZS	.0269	COPY	5	INPUT	POINT
PERLND	3	PWATER	LZS	.1482	COPY	5	INPUT	POINT
PERLND	4	PWATER	LZS	.0270	COPY	5	INPUT	POINT
PERLND	5	PWATER	LZS	.0043	COPY	5	INPUT	POINT
PERLND	6	PWATER	LZS	.0985	COPY	5	INPUT	POINT
PERLND	7	PWATER	LZS	.1218	COPY	5	INPUT	POINT
PERLND	8	PWATER	LZS	.0386	COPY	5	INPUT	POINT
PERLND	9	PWATER	LZS	.1565	COPY	5	INPUT	POINT
PERLND	10	PWATER	LZS	.0088	COPY	5	INPUT	POINT
PERLND	11	PWATER	LZS	.0020	COPY	5	INPUT	POINT
PERLND	12	PWATER	LZS	.0605	COPY	5	INPUT	POINT
PERLND	1	PWATER	AGWS	.1631	COPY	6	INPUT	POINT
PERLND	2	PWATER	AGWS	.0269	COPY	6	INPUT	POINT
PERLND	3	PWATER	AGWS	.1482	COPY	6	INPUT	POINT
PERLND	4	PWATER	AGWS	.0270	COPY	6	INPUT	POINT
PERLND	5	PWATER	AGWS	.0043	COPY	6	INPUT	POINT
PERLND	6	PWATER	AGWS	.0985	COPY	6	INPUT	POINT
PERLND	7	PWATER	AGWS	.1218	COPY	6	INPUT	POINT
PERLND	8	PWATER	AGWS	.0386	COPY	6	INPUT	POINT
PERLND	9	PWATER	AGWS	.1565	COPY	6	INPUT	POINT
PERLND	10	PWATER	AGWS	.0088	COPY	6	INPUT	POINT
PERLND	11	PWATER	AGWS	.0020	COPY	6	INPUT	POINT
PERLND	12	PWATER	AGWS	.0605	COPY	6	INPUT	POINT
PERLND	1	PWATER	AGWO	.1631	COPY	7	INPUT	MEAN
PERLND	2	PWATER	AGWO	.0269	COPY	7	INPUT	MEAN
PERLND	3	PWATER	AGWO	.1482	COPY	7	INPUT	MEAN
PERLND	4	PWATER	AGWO	.0270	COPY	7	INPUT	MEAN
PERLND	5	PWATER	AGWO	.0043	COPY	7	INPUT	MEAN
PERLND	6	PWATER	AGWO	.0985	COPY	7	INPUT	MEAN
PERLND	7	PWATER	AGWO	.1218	COPY	7	INPUT	MEAN
PERLND	8	PWATER	AGWO	.0386	COPY	7	INPUT	MEAN
PERLND	9	PWATER	AGWO	.1565	COPY	7	INPUT	MEAN
PERLND	10	PWATER	AGWO	.0088	COPY	7	INPUT	MEAN
PERLND	11	PWATER	AGWO	.0020	COPY	7	INPUT	MEAN
PERLND	12	PWATER	AGWO	.0605	COPY	7	INPUT	MEAN

```
PERLND   1 PWATER IFWO       .1631         COPY    8      INPUT  MEAN
PERLND   2 PWATER IFWO       .0269         COPY    8      INPUT  MEAN
PERLND   3 PWATER IFWO       .1482         COPY    8      INPUT  MEAN
PERLND   4 PWATER IFWO       .0270         COPY    8      INPUT  MEAN
PERLND   5 PWATER IFWO       .0043         COPY    8      INPUT  MEAN
PERLND   6 PWATER IFWO       .0985         COPY    8      INPUT  MEAN
PERLND   7 PWATER IFWO       .1218         COPY    8      INPUT  MEAN
PERLND   8 PWATER IFWO       .0386         COPY    8      INPUT  MEAN
PERLND   9 PWATER IFWO       .1565         COPY    8      INPUT  MEAN
PERLND  10 PWATER IFWO       .0088         COPY    8      INPUT  MEAN
PERLND  11 PWATER IFWO       .0020         COPY    8      INPUT  MEAN
PERLND  12 PWATER IFWO       .0605         COPY    8      INPUT  MEAN

PERLND   1 PWATER SURO       .1631         COPY    9      INPUT  MEAN
PERLND   2 PWATER SURO       .0269         COPY    9      INPUT  MEAN
PERLND   3 PWATER SURO       .1482         COPY    9      INPUT  MEAN
IMPLND   1 IWATER SURO       .0751         COPY    9      INPUT  MEAN
PERLND   4 PWATER SURO       .0270         COPY    9      INPUT  MEAN
PERLND   5 PWATER SURO       .0043         COPY    9      INPUT  MEAN
PERLND   6 PWATER SURO       .0985         COPY    9      INPUT  MEAN
IMPLND   2 IWATER SURO       .0056         COPY    9      INPUT  MEAN
PERLND   7 PWATER SURO       .1218         COPY    9      INPUT  MEAN
PERLND   8 PWATER SURO       .0386         COPY    9      INPUT  MEAN
PERLND   9 PWATER SURO       .1565         COPY    9      INPUT  MEAN
IMPLND   3 IWATER SURO       .0599         COPY    9      INPUT  MEAN
PERLND  10 PWATER SURO       .0088         COPY    9      INPUT  MEAN
PERLND  11 PWATER SURO       .0020         COPY    9      INPUT  MEAN
PERLND  12 PWATER SURO       .0605         COPY    9      INPUT  MEAN
IMPLND   4 IWATER SURO       .0032         COPY    9      INPUT  MEAN

COPY     1 OUTPUT MEAN       11853.2       DISPLY  1      INPUT  TIMSER 1
END NETWORK

EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Tgap Amd ***
<Name>   #        <Name> # #<-factor->strg <Name> dsn <Name> #  tem strg strg***
COPY     1 OUTPUT MEAN                     WDM     11 FLOW     ENGL      REPL
COPY     2 OUTPUT MEAN                     WDM     12 TAET     ENGL      REPL
COPY     3 OUTPUT MEAN                     WDM     13 PET      ENGL      REPL
COPY     4 OUTPUT POINT                    WDM     14 UZS      ENGL      REPL
COPY     5 OUTPUT POINT                    WDM     15 LZS      ENGL      REPL
COPY     6 OUTPUT POINT                    WDM     16 AGWS     ENGL      REPL
COPY     7 OUTPUT MEAN                     WDM     17 AGWO     ENGL      REPL
COPY     8 OUTPUT MEAN                     WDM     18 IFWO     ENGL      REPL
COPY     9 OUTPUT MEAN                     WDM     19 SURO     ENGL      REPL
END EXT TARGETS

END RUN
```

User-Controlled Input (UCI) file for an 87-month simulation of the St. Joseph Creek watershed

```
RUN

GLOBAL

  Calibration run #01: St Joseph Creek, IL
      ***       yy mm dd hr:mn          yy mm dd hr:mn
  START       1986 07 01        END    1993 09 30
  RUN INTERP OUTPUT LEVEL    0
  RESUME      0 RUN      1 TSSFL      0 WDMSFL   16
END GLOBAL

OPN SEQUENCE
     ***                        hr:mn
    INGRP                INDELT 01:00
      PERLND       1
      PERLND       2
      PERLND       3
      PERLND       4
      PERLND       5
      IMPLND       1
      PERLND       6
      IMPLND       2
      COPY         1
      COPY         2
      COPY         3
      COPY         4
      COPY         5
      COPY         6
      COPY         7
      COPY         8
      COPY         9
                        *** place *** behind any of the operations that are
                        *** not needed for the simulation.  You __DO NOT__
                        *** need to delete other references to the operation
    END INGRP
END OPN SEQUENCE
```

```
*** Areas for St Joseph Creek:
***                                                    percent
***   ------------------------------------------------------------------
***   St. Joseph Creek at Rt. 34 rain gage
***
***   PERLND1  grassland                              27.72
***   PERLND3  forest                                  2.93
***   PERLND5  agriculture                             0.07
***   IMPLND1  impervious                              8.50
***
***   Clarendon Hills rain gage
***
***   PERLND2  grassland                              42.91
***   PERLND4  forest                                  3.86
***   PERLND6  agriculture                             0.18
***   IMPLND2  impervious                             13.83
***   ------------------------------------------------------------------
***         totals

       *** Conversion factors
       *** inches-->cfs-days = 26.9 * area in sq miles
       ***                   = .042 * area in acres
       *** ratio is fraction of PERLND or IMPLND area to the
       *** total area of the watershed, should sum to 1.0


PERLND
  ACTIVITY
    #THRU# ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC***
    1   10    0    0    1    0    0    0    0    0    0    0    0    0
  END ACTIVITY

  PRINT-INFO
***#THRU# ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC PIVL  PYR
    1   10    0    0    4    0    0    0    0    0    0    0    0    0    0    9
  END PRINT-INFO

  GEN-INFO
      *** replace name with an identifier for the PERLND segments
      *** e.g., Piedmont forest, Surface mine, Reclaimed, Pasture
                                  1=ENGL 2=METR PRINT FILES ***
    #THRU#<-----NAME--------->NBLKS<----UNITS----> ENGL METR  ***
    1    2 Grass                  1    1    1    1    2    0
    3    4 Forest                 1    1    1    1    2    0
    5    6 Agriculture            1    1    1    1    2    0
  END GEN-INFO

  PWAT-PARM1
    #thru# CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE               ***
    1    6    0    0    0    1    1    0    0    0    1
  END PWAT-PARM1
```

```
PWAT-PARM2
    *** Calibration parameters:
    ***      LZSN should be calibrated, initially 2/3 of the available
    ***           water capacity in the rooting zone.
    ***    INFILT is major calibration parameter to shift surface runoff
    ***           and interflow to baseflow (by increasing INFILT).
    ***      AGWR is baseflow recession constant, used to match baseflows.
    ***      LSUR is length of overland flow. Do not change for natural
    ***           areas.  Should not exceed 1000 ft. For small disturbed
    ***           plots, use measured values.
    ***    FOREST is fraction of PERLND segment containing vegetation that
    ***           transpires during the winter.
  #THRU#FOREST      LZSN     INFILT      LSUR      SLSUR      KVARY     AGWR***
  1    6 0.0         0.1       .02       400.       0.02       0.00      0.98
END PWAT-PARM2

PWAT-PARM3
  #THRU# ***PETMAX     PETMIN     INFEXP     INFILD     DEEPFR     BASETP     AGWETP
  1    6        40.        35.        2.0        2.0      0.32        0.05        .04

END PWAT-PARM3

PWAT-PARM4
    *** Calibration parameters:
    ***      UZSN should be 1/10th of LZSN.
    ***     INTFW is calibration parameter for volume of interflow.
    ***       IRC is calibration parameter for interflow recession.
    ***      NSUR is Manning's 'n' for overland flow. Can be adjusted
    ***           for shaping storm hydrograph when 5- or 15-minute time
    ***           step is used.
  #THRU# CEPSC      UZSN       NSUR       INTFW       IRC      LZETP    ***
  1    6  0.01      0.75       0.1          7         .60       0.3

END PWAT-PARM4

PWAT-STATE1
    *** Initialization parameters:
    ***       LZS should be about 2/3 rds LZSN.
    ***      AGWS should be adjusted to match the initial baseflow or it
    ***          can be calculated using recession constant and observed
    ***          baseflow at the beginning of the simulation.
  #THRU#  CEPS      SURS       UZS       IFWS       LZS       AGWS   *** GWVS
  1    6  0.00      0.00       1.9       0.2        0.1       0.0        0.00


END PWAT-STATE1
```

```
  MON-INTERCEP
      *** Monthly inteception.
      ***    Used instead of CEPSC when VCSFG=1.
      ***    Examples for hardwood forest, bare soil, and grass land.
      ***    Evergreen forest should have all months at least 0.10.
    #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
    1    2  .01  .01  .02  .02  .03  .04  .04  .04  .03  .02  .01  .01
    5    6  .01  .01  .01  .02  .03  .05  .06  .07  .07  .04  .01  .01
    3    4  .01  .01  .02  .04  .06  .08  .10  .10  .09  .07  .03  .02
*** hardwood.02  .03  .04  .06  .08  .10  .10  .10  .09  .07  .03  .02
*** baresoil.01  .01  .01  .01  .01  .01  .01  .01  .01  .01  .01  .01
*** grasslnd.01  .01  .02  .02  .03  .04  .04  .04  .03  .02  .01  .01
  END MON-INTERCEP
  MON-LZETPARM
      *** Monthly lower zone ET parameter
      ***    Used instead of LZETP when VLEFG=1
      ***    Examples for hardwood forest, bare soil, and grass land.
      ***    Evergreen forest should have all months at least 0.10.
    #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
    1    2  .02  .02  .07  .16  .21  .30  .32  .32  .27  .16  .07  .02
    5    6  .02  .02  .05  .16  .26  .38  .42  .42  .36  .18  .03  .02
    3    4  .02  .02  .10  .25  .35  .45  .50  .50  .40  .25  .10  .02
*** hardwood.02  .02  .10  .25  .35  .45  .50  .50  .40  .25  .10  .02
*** baresoil.02  .02  .03  .04  .04  .04  .04  .04  .04  .03  .02  .02
*** grasslnd.02  .02  .07  .16  .21  .30  .32  .32  .27  .16  .07  .02
  END MON-LZETPARM

  MON-UZSN
    #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC   ***
    1    6  3.2  1.7  2.3  1.7  1.5  0.9  1.0  1.2  3.6  5.0  4.6  5.0
  END MON-UZSN

  MON-INTERFLW
    #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
    1    6 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00
  END MON-INTERFLW

  MON-IRC
    #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
    1    6  .98  .98  .97  .97  .90  .90  .90  .90  .90  .90  .90  .93
  END MON-IRC
END PERLND

IMPLND
  ACTIVITY
    <ILS >     ACTIVE SECTIONS          ***
    # -  # ATMP SNOW IWAT  SLD  IWG IQAL ***
    1    2    0    0    1    0    0    0
  END ACTIVITY
  PRINT-INFO
    <ILS >  ***   PRINT  FLAGS    ***
    # -  # ATMP SNOW IWAT  SLD  IWG  IQAL ***
    1    2              4
  END PRINT-INFO
```

```
  GEN-INFO
    #THRU#<-----NAME---------><----UNITS----> ENGL METR    ***
    1    2  Impervious            1    1    1    2    0


  END GEN-INFO

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

  IWAT-PARM2
    <ILS >                                           ***
    # -  #       LSUR      SLSUR       NSUR      RETSC ***
    1    2       400        0.02       .013       0.10
  END IWAT-PARM2
  IWAT-PARM3
    <ILS >                             ***
    # -  #     PETMAX    PETMIN        ***
    1    2       40        35
  END IWAT-PARM3

  IWAT-STATE1
    <ILS >    IWATER STATE VARIABLES  ***
    # -  #       RETS       SURS      ***
    1    2      0.001      0.001
  END IWAT-STATE1

  MON-RETN
    <ILS >  Retention storage capacity at start of each month ***
    # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
    1    2  .10  .10  .10  .10  .10  .10  .20  .20  .20  .20  .20  .10
  END MON-RETN

END IMPLND

COPY
  TIMESERIES
  Copy-opn                                                   ***
    # -  #  NPT  NMN                                         ***
    1        0    1
    2        0    1
    3        0    1
    4        1    0
    5        1    0
    6        1    0
    7        0    1
    8        0    1
    9        0    1

  END TIMESERIES
END COPY
```

```
EXT SOURCES
                                                                    ***
      *** note: a multiplier is used on potential ET so the annual PET
      ***       will be equivalent to lake evaporation for the location
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name> dsn <Name> # tem strg<-factor->strg <Name>    #   #        <Name> # #  ***
WDM     46 EVAP      ENGL                  PERLND    1   6 EXTNL  PETINP
WDM     46 EVAP      ENGL                  IMPLND    1   2 EXTNL  PETINP
WDM    213 PREC      ENGL                  PERLND    1     EXTNL  PREC
WDM    213 PREC      ENGL                  PERLND    3     EXTNL  PREC
WDM    213 PREC      ENGL                  PERLND    5     EXTNL  PREC
WDM    213 PREC      ENGL                  IMPLND    1     EXTNL  PREC
WDM    205 PREC      ENGL                  PERLND    2     EXTNL  PREC
WDM    205 PREC      ENGL                  PERLND    4     EXTNL  PREC
WDM    205 PREC      ENGL                  PERLND    6     EXTNL  PREC
WDM    205 PREC      ENGL                  IMPLND    2     EXTNL  PREC
END EXT SOURCES

NETWORK
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   #        <Name> # #<-factor->strg <Name>    #   #        <Name> # #  ***
PERLND   1 PWATER PERO        .2772        COPY      1     INPUT  MEAN
PERLND   2 PWATER PERO        .4291        COPY      1     INPUT  MEAN
PERLND   3 PWATER PERO        .0293        COPY      1     INPUT  MEAN
PERLND   4 PWATER PERO        .0386        COPY      1     INPUT  MEAN
PERLND   5 PWATER PERO        .0007        COPY      1     INPUT  MEAN
IMPLND   1 IWATER SURO        .0850        COPY      1     INPUT  MEAN
PERLND   6 PWATER PERO        .0018        COPY      1     INPUT  MEAN
IMPLND   2 IWATER SURO        .1383        COPY      1     INPUT  MEAN

PERLND   1 PWATER TAET        .2772        COPY      2     INPUT  MEAN
PERLND   2 PWATER TAET        .4291        COPY      2     INPUT  MEAN
PERLND   3 PWATER TAET        .0293        COPY      2     INPUT  MEAN
PERLND   4 PWATER TAET        .0386        COPY      2     INPUT  MEAN
PERLND   5 PWATER TAET        .0007        COPY      2     INPUT  MEAN
IMPLND   1 IWATER IMPEV       .0850        COPY      2     INPUT  MEAN
PERLND   6 PWATER TAET        .0018        COPY      2     INPUT  MEAN
IMPLND   2 IWATER IMPEV       .1383        COPY      2     INPUT  MEAN

PERLND   1 PWATER PET         .2772        COPY      3     INPUT  MEAN
PERLND   2 PWATER PET         .4291        COPY      3     INPUT  MEAN
PERLND   3 PWATER PET         .0293        COPY      3     INPUT  MEAN
PERLND   4 PWATER PET         .0386        COPY      3     INPUT  MEAN
PERLND   5 PWATER PET         .0007        COPY      3     INPUT  MEAN
IMPLND   1 IWATER PET         .0850        COPY      3     INPUT  MEAN
PERLND   6 PWATER PET         .0018        COPY      3     INPUT  MEAN
IMPLND   2 IWATER PET         .1383        COPY      3     INPUT  MEAN

PERLND   1 PWATER UZS         .2772        COPY      4     INPUT  POINT
PERLND   2 PWATER UZS         .4291        COPY      4     INPUT  POINT
PERLND   3 PWATER UZS         .0293        COPY      4     INPUT  POINT
PERLND   4 PWATER UZS         .0386        COPY      4     INPUT  POINT
PERLND   5 PWATER UZS         .0007        COPY      4     INPUT  POINT
PERLND   6 PWATER UZS         .0018        COPY      4     INPUT  POINT
```

```
PERLND    1 PWATER LZS          .2772           COPY       5      INPUT   POINT
PERLND    2 PWATER LZS          .4291           COPY       5      INPUT   POINT
PERLND    3 PWATER LZS          .0293           COPY       5      INPUT   POINT
PERLND    4 PWATER LZS          .0386           COPY       5      INPUT   POINT
PERLND    5 PWATER LZS          .0007           COPY       5      INPUT   POINT
PERLND    6 PWATER LZS          .0018           COPY       5      INPUT   POINT

PERLND    1 PWATER AGWS         .2772           COPY       6      INPUT   POINT
PERLND    2 PWATER AGWS         .4291           COPY       6      INPUT   POINT
PERLND    3 PWATER AGWS         .0293           COPY       6      INPUT   POINT
PERLND    4 PWATER AGWS         .0386           COPY       6      INPUT   POINT
PERLND    5 PWATER AGWS         .0007           COPY       6      INPUT   POINT
PERLND    6 PWATER AGWS         .0018           COPY       6      INPUT   POINT

PERLND    1 PWATER AGWO         .2772           COPY       7      INPUT   MEAN
PERLND    2 PWATER AGWO         .4291           COPY       7      INPUT   MEAN
PERLND    3 PWATER AGWO         .0293           COPY       7      INPUT   MEAN
PERLND    4 PWATER AGWO         .0386           COPY       7      INPUT   MEAN
PERLND    5 PWATER AGWO         .0007           COPY       7      INPUT   MEAN
PERLND    6 PWATER AGWO         .0018           COPY       7      INPUT   MEAN

PERLND    1 PWATER IFWO         .2772           COPY       8      INPUT   MEAN
PERLND    2 PWATER IFWO         .4291           COPY       8      INPUT   MEAN
PERLND    3 PWATER IFWO         .0293           COPY       8      INPUT   MEAN
PERLND    4 PWATER IFWO         .0386           COPY       8      INPUT   MEAN
PERLND    5 PWATER IFWO         .0007           COPY       8      INPUT   MEAN
PERLND    6 PWATER IFWO         .0018           COPY       8      INPUT   MEAN

PERLND    1 PWATER SURO         .2772           COPY       9      INPUT   MEAN ***
PERLND    2 PWATER SURO         .4291           COPY       9      INPUT   MEAN ***
PERLND    3 PWATER SURO         .0293           COPY       9      INPUT   MEAN ***
PERLND    4 PWATER SURO         .0386           COPY       9      INPUT   MEAN ***
PERLND    5 PWATER SURO         .0007           COPY       9      INPUT   MEAN ***
IMPLND    1 IWATER SURO         .0850           COPY       9      INPUT   MEAN
PERLND    6 PWATER SURO         .0018           COPY       9      INPUT   MEAN ***
IMPLND    2 IWATER SURO         .1383           COPY       9      INPUT   MEAN

END NETWORK

EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Tgap Amd ***
<Name>    #        <Name> # #<-factor->strg <Name> dsn <Name> #  tem strg strg***
COPY      1 OUTPUT MEAN                     WDM      11 FLOW     ENGL      REPL
COPY      2 OUTPUT MEAN                     WDM      12 TAET     ENGL      REPL
COPY      3 OUTPUT MEAN                     WDM      13 PET      ENGL      REPL
COPY      4 OUTPUT POINT                    WDM      14 UZS      ENGL      REPL
COPY      5 OUTPUT POINT                    WDM      15 LZS      ENGL      REPL
COPY      6 OUTPUT POINT                    WDM      16 AGWS     ENGL      REPL
COPY      7 OUTPUT MEAN                     WDM      17 AGWO     ENGL      REPL
COPY      8 OUTPUT MEAN                     WDM      18 IFWO     ENGL      REPL
COPY      9 OUTPUT MEAN                     WDM      19 SURO     ENGL      REPL
END EXT TARGETS

END RUN
```

User-Controlled Input (UCI) for an 87-month simulation of the Sawmill Creek watershed

```
RUN

GLOBAL
  Calibration run #01: Sawmill Creek, IL
      ***        yy mm dd hr:mn           yy mm dd hr:mn
  START       1986 07 01         END    1993 09 30
  RUN INTERP OUTPUT LEVEL    0
  RESUME     0 RUN     1 TSSFL     0 WDMSFL   16
END GLOBAL

OPN SEQUENCE
     ***                         hr mn
    INGRP                  INDELT 01:00
      PERLND       1
      PERLND       2
      PERLND       3
      PERLND       4
      PERLND       5
      IMPLND       1
      PERLND       6
      IMPLND       2
      COPY         1
      COPY         2
      COPY         3
      COPY         4
      COPY         5
      COPY         6
      COPY         7
      COPY         8
      COPY         9
                          *** place *** behind any of the operations that are
                          *** not needed for the simulation.  You __DO NOT__
                          *** need to delete other references to the operation
    END INGRP
END OPN SEQUENCE
```

```
*** Areas for Sawmill Creek:
***                                                    sq miles       percent
***   ____________________________________________________________________
***   Clarendon Hills raingage
***
***   PERLND1  grassland                                              38.12
***   PERLND3  forest                                                  3.60
***   PERLND5  agriculture                                             1.76
***   IMPLND1  impervious                                             11.89
***
***   Sawmill Creek rain gage
***
***   PERLND2  grassland                                              24.56
***   PERLND4  forest                                                 13.82
***   PERLND6  agriculture                                             0.98
***   IMPLND2  impervious                                              5.27
***   ____________________________________________________________________
***         totals

      *** Conversion factors
      *** inches-->cfs-days = 26.9 * area in sq miles
      ***                   = .042 * area in acres
      *** ratio is fraction of PERLND or IMPLND area to the
      *** total area of the watershed, should sum to 1.0


PERLND
  ACTIVITY
    #THRU# ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC***
    1    6    0    0    1    0    0    0    0    0    0    0    0    0
  END ACTIVITY

  PRINT-INFO
 ***#THRU# ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC PIVL  PYR
    1    6    0    0    4    0    0    0    0    0    0    0    0    0    0    9
  END PRINT-INFO

  GEN-INFO
      *** replace name with an identifier for the PERLND segments
      *** e.g., Piedmont forest, Surface mine, Reclaimed, Pasture
                                  1=ENGL 2=METR PRINT FILES ***
    #THRU#<-----NAME--------->NBLKS<----UNITS----> ENGL METR  ***
    1    2 Grass                  1    1    1    1    2    0
    3    4 Forest                 1    1    1    1    2    0
    5    6 Agriculture            1    1    1    1    2    0
  END GEN-INFO

  PWAT-PARM1
    #thru# CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE             ***
    1    6    0    0    0    1    1    0    0    0    1
  END PWAT-PARM1
```

```
PWAT-PARM2
    *** Calibration parameters:
    ***     LZSN should be calibrated, initially 2/3 of the available
    ***          water capacity in the rooting zone.
    ***   INFILT is major calibration parameter to shift surface runoff
    ***          and interflow to baseflow (by increasing INFILT).
    ***     AGWR is baseflow recession constant, used to match baseflows.
    ***     LSUR is length of overland flow. Do not change for natural
    ***          areas.  Should not exceed 1000 ft. For small disturbed
    ***          plots, use measured values.
    ***   FOREST is fraction of PERLND segment containing vegetation that
    ***          transpires during the winter.
  #THRU#FOREST      LZSN      INFILT      LSUR      SLSUR      KVARY      AGWR***
  1    6 0.0        0.1        .02        400.       0.02       0.00       0.99

END PWAT-PARM2

PWAT-PARM3
  #THRU# ***PETMAX     PETMIN     INFEXP     INFILD     DEEPFR     BASETP     AGWETP
  1    6       40.        35.        2.0        2.0       0.33       0.05      0.02
END PWAT-PARM3

PWAT-PARM4
    *** Calibration parameters:
    ***     UZSN should be 1/10th of LZSN.
    ***    INTFW is calibration parameter for volume of interflow.
    ***      IRC is calibration parameter for interflow recession.
    ***     NSUR is Manning's 'n' for overland flow. Can be adjusted
    ***          for shaping storm hydrograph when 5- or 15-minute time
    ***          step is used.
  #THRU# CEPSC      UZSN       NSUR       INTFW        IRC       LZETP    ***
  1    6  0.01      0.75       0.1          7          .59        0.3
END PWAT-PARM4

PWAT-STATE1
    *** Initialization parameters:
    ***     LZS should be about 2/3 rds LZSN.
    ***    AGWS should be adjusted to match the initial baseflow or it
    ***         can be calculated using recession constant and observed
    ***         baseflow at the beginning of the simulation.
  #THRU#  CEPS       SURS        UZS       IFWS        LZS       AGWS   *** GWVS
  1    6  0.00       0.00        0.9        1.0        0.1        1.9        0.00
END PWAT-STATE1
```

```
  MON-INTERCEP
      *** Monthly inteception.
      ***    Used instead of CEPSC when VCSFG=1.
      ***    Examples for hardwood forest, bare soil, and grass land.
      ***    Evergreen forest should have all months at least 0.10.
    #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
    1    2  .01  .01  .02  .02  .03  .04  .04  .04  .03  .02  .01  .01
    3    4  .02  .03  .04  .06  .08  .10  .10  .10  .09  .07  .03  .02
    5    6  .00  .00  .00  .02  .03  .08  .08  .08  .08  .04  .01  .00
*** hardwood.02  .03  .04  .06  .08  .10  .10  .10  .09  .07  .03  .02
*** baresoil.01  .01  .01  .01  .01  .01  .01  .01  .01  .01  .01  .01
*** grasslnd.01  .01  .02  .02  .03  .04  .04  .04  .03  .02  .01  .01
  END MON-INTERCEP
  MON-LZETPARM
      *** Monthly lower zone ET parameter
      ***    Used instead of LZETP when VLEFG=1
      ***    Examples for hardwood forest, bare soil, and grass land.
      ***    Evergreen forest should have all months at least 0.10.
    #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
    1    2  .02  .02  .07  .16  .21  .30  .32  .32  .27  .16  .07  .02
    3    4  .02  .02  .10  .25  .35  .45  .50  .50  .40  .25  .10  .02
    5    6  .02  .02  .10  .25  .35  .45  .45  .45  .45  .30  .10  .02
*** hardwood.02  .02  .10  .25  .35  .45  .50  .50  .40  .25  .10  .02
*** baresoil.02  .02  .03  .04  .04  .04  .04  .04  .04  .03  .02  .02
*** grasslnd.02  .02  .07  .16  .21  .30  .32  .32  .27  .16  .07  .02
  END MON-LZETPARM

  MON-UZSN
    #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC  ***
    1    6  3.2  1.7  2.3  1.7  1.5  0.9  0.9  1.2  3.2  4.6  4.5  4.0

  END MON-UZSN

END PERLND

IMPLND
  ACTIVITY
    <ILS >     ACTIVE SECTIONS          ***
    # -  # ATMP SNOW IWAT  SLD  IWG IQAL ***
    1    2    0    0    1    0    0    0
  END ACTIVITY
  PRINT-INFO
    <ILS >   ***   PRINT  FLAGS   ***
    # -  # ATMP SNOW IWAT  SLD  IWG  IQAL ***
    1    2              4
  END PRINT-INFO

  GEN-INFO
    #THRU#<-----NAME---------><----UNITS----> ENGL METR   ***
    1    2    Impervious          1    1    1    2    0

  END GEN-INFO
```

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

IWAT-PARM2
  <ILS >                                                   ***
  # -  #       LSUR     SLSUR      NSUR       RETSC ***
  1    2       400       0.02       .013       0.10
END IWAT-PARM2
IWAT-PARM3
  <ILS >                              ***
  # -  #     PETMAX    PETMIN         ***
  1    2        40         35
END IWAT-PARM3

MON-RETN
  <ILS >  Retention storage capacity at start of each month ***
  # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
  1    2  .10  .10  .10  .10  .10  .10  .20  .20  .20  .20  .20  .10
END MON-RETN

IWAT-STATE1
  <ILS >   IWATER STATE VARIABLES  ***
  # -  #      RETS       SURS        ***
  1    2     0.001      0.001
END IWAT-STATE1
END IMPLND

COPY
 TIMESERIES
 Copy-opn                                                          ***
  # -  #  NPT  NMN                                                 ***
  1         0     1
  2         0     1
  3         0     1
  4         1     0
  5         1     0
  6         1     0
  7         0     1
  8         0     1
  9         0     1

 END TIMESERIES
END COPY
```

```
EXT SOURCES
      *** note: a multiplier is used on potential ET so the annual PET
      ***       will be equivalent to lake evaporation for the location
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name> dsn <Name> # tem strg<-factor->strg <Name>   #   #        <Name> # #  ***
WDM     46 EVAP     ENGL                   PERLND   1  10 EXTNL  PETINP
WDM     46 EVAP     ENGL                   IMPLND   1   2 EXTNL  PETINP
WDM    205 PREC     ENGL                   PERLND   1     EXTNL  PREC
WDM    205 PREC     ENGL                   PERLND   3     EXTNL  PREC
WDM    205 PREC     ENGL                   PERLND   5     EXTNL  PREC
WDM    205 PREC     ENGL                   PERLND   7     EXTNL  PREC
WDM    205 PREC     ENGL                   PERLND   9     EXTNL  PREC
WDM    205 PREC     ENGL                   IMPLND   1     EXTNL  PREC
WDM    204 PREC     ENGL                   PERLND   2     EXTNL  PREC
WDM    204 PREC     ENGL                   PERLND   4     EXTNL  PREC
WDM    204 PREC     ENGL                   PERLND   6     EXTNL  PREC
WDM    204 PREC     ENGL                   PERLND   8     EXTNL  PREC
WDM    204 PREC     ENGL                   PERLND  10     EXTNL  PREC
WDM    204 PREC     ENGL                   IMPLND   2     EXTNL  PREC
END EXT SOURCES

NETWORK
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   #        <Name> # #<-factor->strg <Name>   #   #        <Name> # #  ***
PERLND   1 PWATER PERO       .3812         COPY     1     INPUT  MEAN
PERLND   2 PWATER PERO       .2456         COPY     1     INPUT  MEAN
IMPLND   1 IWATER SURO       .1189         COPY     1     INPUT  MEAN
PERLND   3 PWATER PERO       .0360         COPY     1     INPUT  MEAN
PERLND   4 PWATER PERO       .1382         COPY     1     INPUT  MEAN
PERLND   5 PWATER PERO       .0176         COPY     1     INPUT  MEAN
PERLND   6 PWATER PERO       .0098         COPY     1     INPUT  MEAN
IMPLND   2 IWATER SURO       .0527         COPY     1     INPUT  MEAN

PERLND   1 PWATER TAET       .3812         COPY     2     INPUT  MEAN
PERLND   2 PWATER TAET       .2456         COPY     2     INPUT  MEAN
IMPLND   1 IWATER IMPEV      .1189         COPY     2     INPUT  MEAN
PERLND   3 PWATER TAET       .0360         COPY     2     INPUT  MEAN
PERLND   4 PWATER TAET       .1382         COPY     2     INPUT  MEAN
PERLND   5 PWATER TAET       .0176         COPY     2     INPUT  MEAN
PERLND   6 PWATER TAET       .0098         COPY     2     INPUT  MEAN
IMPLND   2 IWATER IMPEV      .0527         COPY     2     INPUT  MEAN

PERLND   1 PWATER PET        .3812         COPY     3     INPUT  MEAN
PERLND   2 PWATER PET        .2456         COPY     3     INPUT  MEAN
IMPLND   1 IWATER PET        .1189         COPY     3     INPUT  MEAN
PERLND   3 PWATER PET        .0360         COPY     3     INPUT  MEAN
PERLND   4 PWATER PET        .1382         COPY     3     INPUT  MEAN
PERLND   5 PWATER PET        .0176         COPY     3     INPUT  MEAN
PERLND   6 PWATER PET        .0098         COPY     3     INPUT  MEAN
IMPLND   2 IWATER PET        .0527         COPY     3     INPUT  MEAN

PERLND   1 PWATER UZS        .3812         COPY     4     INPUT  POINT
PERLND   2 PWATER UZS        .2456         COPY     4     INPUT  POINT
IMPLND   1 IWATER RETS       .1189         COPY     4     INPUT  POINT
PERLND   3 PWATER UZS        .0360         COPY     4     INPUT  POINT
```

```
PERLND    4 PWATER UZS        .1382         COPY     4      INPUT   POINT
PERLND    5 PWATER UZS        .0176         COPY     4      INPUT   POINT
PERLND    6 PWATER UZS        .0098         COPY     4      INPUT   POINT
IMPLND    2 IWATER RETS       .0527         COPY     4      INPUT   POINT

PERLND    1 PWATER LZS        .3812         COPY     5      INPUT   POINT
PERLND    2 PWATER LZS        .2456         COPY     5      INPUT   POINT
PERLND    3 PWATER LZS        .0360         COPY     5      INPUT   POINT
PERLND    4 PWATER LZS        .1382         COPY     5      INPUT   POINT
PERLND    5 PWATER LZS        .0176         COPY     5      INPUT   POINT
PERLND    6 PWATER LZS        .0098         COPY     5      INPUT   POINT

PERLND    1 PWATER AGWS       .3812         COPY     6      INPUT   POINT
PERLND    2 PWATER AGWS       .2456         COPY     6      INPUT   POINT
PERLND    3 PWATER AGWS       .0360         COPY     6      INPUT   POINT
PERLND    4 PWATER AGWS       .1382         COPY     6      INPUT   POINT
PERLND    5 PWATER AGWS       .0176         COPY     6      INPUT   POINT
PERLND    6 PWATER AGWS       .0098         COPY     6      INPUT   POINT

PERLND    1 PWATER AGWO       .3812         COPY     7      INPUT   MEAN
PERLND    2 PWATER AGWO       .2456         COPY     7      INPUT   MEAN
PERLND    3 PWATER AGWO       .0360         COPY     7      INPUT   MEAN
PERLND    4 PWATER AGWO       .1382         COPY     7      INPUT   MEAN
PERLND    5 PWATER AGWO       .0176         COPY     7      INPUT   MEAN
PERLND    6 PWATER AGWO       .0098         COPY     7      INPUT   MEAN

PERLND    1 PWATER IFWO       .3812         COPY     8      INPUT   MEAN
PERLND    2 PWATER IFWO       .2456         COPY     8      INPUT   MEAN
PERLND    3 PWATER IFWO       .0360         COPY     8      INPUT   MEAN
PERLND    4 PWATER IFWO       .1382         COPY     8      INPUT   MEAN
PERLND    5 PWATER IFWO       .0176         COPY     8      INPUT   MEAN
PERLND    6 PWATER IFWO       .0098         COPY     8      INPUT   MEAN

PERLND    1 PWATER SURO       .3812         COPY     9      INPUT   MEAN
PERLND    2 PWATER SURO       .2456         COPY     9      INPUT   MEAN
IMPLND    1 IWATER SURO       .1189         COPY     9      INPUT   MEAN
PERLND    3 PWATER SURO       .0360         COPY     9      INPUT   MEAN
PERLND    4 PWATER SURO       .1382         COPY     9      INPUT   MEAN
PERLND    5 PWATER SURO       .0176         COPY     9      INPUT   MEAN
PERLND    6 PWATER SURO       .0098         COPY     9      INPUT   MEAN
IMPLND    2 IWATER SURO       .0527         COPY     9      INPUT   MEAN

COPY      1 OUTPUT MEAN       11853.2       DISPLY   1      INPUT   TIMSER 1
END NETWORK
```

```
EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Tgap Amd ***
<Name>    #        <Name> # #<-factor->strg <Name> dsn <Name> #  tem strg strg***
COPY      1 OUTPUT MEAN                      WDM     11 FLOW     ENGL      REPL
COPY      2 OUTPUT MEAN                      WDM     12 TAET     ENGL      REPL
COPY      3 OUTPUT MEAN                      WDM     13 PET      ENGL      REPL
COPY      4 OUTPUT POINT                     WDM     14 UZS      ENGL      REPL
COPY      5 OUTPUT POINT                     WDM     15 LZS      ENGL      REPL
COPY      6 OUTPUT POINT                     WDM     16 AGWS     ENGL      REPL
COPY      7 OUTPUT MEAN                      WDM     17 AGWO     ENGL      REPL
COPY      8 OUTPUT MEAN                      WDM     18 IFWO     ENGL      REPL
COPY      9 OUTPUT MEAN                      WDM     19 SURO     ENGL      REPL
END EXT TARGETS

END RUN
```

U.S. Geological Survey, WRD
221 Broadway Ave.
Urbana, Illinois 61801

Duncker and Melching—REGIONAL RAINFALL-RUNOFF RELATIONS FOR SIMULATION OF STREAMFLOW FOR WATERSHEDS IN DU PAGE COUNTY, ILLINOIS—U.S. Geological Survey Water-Resources Investigations Report 98-4035

USGS