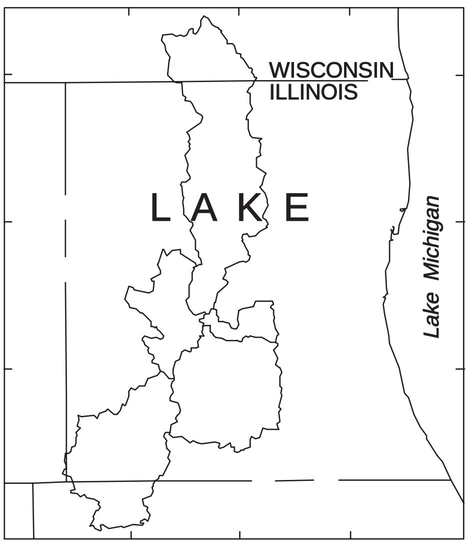
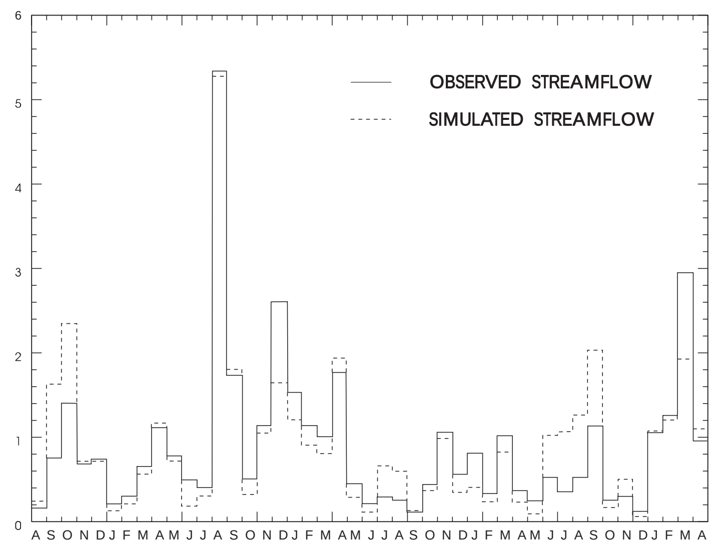
REGIONAL RAINFALL-RUNOFF RELATIONS FOR SIMULATION OF STREAMFLOW FOR WATERSHEDS IN LAKE COUNTY, ILLINOIS

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 95–4023





Prepared in cooperation with the

LAKE COUNTY STORMWATER MANAGEMENT COMMISSION

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

By James J. Duncker, Tracy J. Vail, and
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Urbana, Illinois
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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS OF MODEL PARAMETERS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
acre	4,047	square meter
acre	0.4047	hectare
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

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

$$°C=5/9 \times (°F-32)$$

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

Abbreviations of model parameters used in this report:

AGWETP – Ground-water evapotranspiration

AGWRC – Ground-water recession constant

BASETP – Baseflow evapotranspiration

CEPSC – Interception storage

DEEPFR – Inactive ground water

ET – Evapotranspiration

IMPLND – Impervious land cover

INFILT – Infiltration

INTFW – Interflow

IRC – Interflow recession constant

KVARY – Variable ground-water recession

LSUR – Length of overland flow path

LZETP – Lower zone evapotranspiration

LZSN – Lower zone nominal storage

NSUR – Roughness of overland flow path

PERLND – Pervious land cover

RETSC – Retention storage

SLSUR – Slope of overland flow path

UZSN – Upper zone nominal storage

Simulation of Regional Rainfall-Runoff Relations for Watersheds in Lake County, Illinois

By James J. Duncker, Tracy J. Vail, *and* Charles S. Melching

Abstract

Rainfall and streamflow data collected in Lake County, Ill., from March 1990 through September 1993 were used to (1) calibrate a rainfall-runoff model for an area encompassing three watersheds (individual areas of 17.2, 35.7, and 37.0 mi^2 (square miles)) and (2) verify the regional model parameter set obtained from the calibration by applying the parameter set to rainfall-runoff models for an additional small (6.3 mi^2) watershed and a large (59.6 mi^2) watershed. In addition, rainfall and streamflow data collected from April 1991 through September 1993 were used to calibrate the rainfall-runoff model for three single land-use watersheds (38.2–305 acres), called hydrologic response units (HRU's). Significant differences were found between the best parameters used in the HRU models and in the larger watershed models. The main channels in the HRU's are intermittent streams; thus, the parameters in the HRU models were selected such that a fluctuating water table could be simulated; runoff from the larger watersheds is not as sensitive to the effects of a fluctuating water table. Classification of land cover into two pervious subareas (forest and grass) and one impervious subarea (including parking lots, streets, and rooftops, among others) was sufficient to simulate the rainfall-runoff relations for all watersheds accurately. The model parameters presented in this report, which were refined through regional calibration and verified for watersheds not considered in the calibration, allow simulation of runoff in watersheds in Lake County, Ill., with approximately 93-percent accuracy in the total water balance, an average absolute error in the annual-flow estimates of 10.9 percent (and an error rarely exceeding 25 percent for annual flow), and monthly water balances with correlation coefficients of 93 percent and coefficients of model-fit efficiency of 86 percent. The models closely reproduced the partial-duration series of runoff and storm-runoff frequencies for the modeled watersheds.

INTRODUCTION

The spread of development into rural counties surrounding metropolitan areas has the potential to affect the hydrologic environment adversely. Modifications of the land cover within a watershed can drastically alter the watershed hydrology. Documented hydrologic effects of urbanization include an increase in peak discharges during periods of flooding as well as an increase in the frequency of floods. In an effort to control and mitigate these effects, planners and engineers need accurate hydrologic data to quantify the magnitude of hydrologic problems. Accurate hydrologic data form the foundation of effective stormwater management. Because engineers and planners must design for unknown future floods on ungaged watersheds and for future land-use scenarios, relations among rainfall, basin characteristics, and stormwater runoff provide an important tool for stormwater management.

Severe flooding in the Des Plaines and Fox River watersheds in northeastern Illinois during the late 1980's and the rapid spread of the Chicago metropolitan area into the surrounding counties prompted State officials to develop stormwater-management legislation for counties in northeastern Illinois. In response to this legislation, the Lake County Stormwater Management Planning Committee (LCSMPC) was created in 1987. The U.S. Geological Survey (USGS), in cooperation with the Lake County Stormwater Management Commission (LCSMC) and the Illinois Department of Transportation, Division of Water Resources (DWR), began a study of regional rainfall-runoff relations in Lake County in July 1989 (fig.1). The study began with the collection of runoff data in five watersheds within the county. The raingage network in Lake County was started in December 1989, and the full network for rainfall-runoff modeling was operational in March 1990. The five watersheds (6.3–59.6 mi^2 in area) were selected by the USGS and DWR on the basis of current flood problems and future development plans. The study was expanded in April 1991 to collect rainfall and runoff data in four watersheds (3.5–305 acres in area) with distinct land-cover conditions. These watersheds are termed hydrologic response units (HRU's); they represent key land-cover types as designated by the LCSMC. The LCSMPC developed a comprehensive stormwater-management plan (Lake County Department of Planning, Zoning, and Environmental Quality and others, 1990) that addresses stormwater issues on a watershed basis. Hydrologic data collected and the regional rainfall-runoff relations (models) developed in this study are key elements of the stormwater-management plan.

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 Lake 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 March 1990 through September 1993. Streamflow data were collected from five watersheds with drainage areas of 6.3 to 59.6 mi^2 and from four HRU's with drainage areas of 3.5 to 305 acres. Rainfall data were collected at 23 sites in and near Lake County. Land-cover data were compiled by use of aerial photographs taken in the spring of 1990, remotely sensed thematic mapping (TM), and side-looking-airborne-radar (SLAR) imagery. Rainfall-runoff relations were simulated with the Hydrological Simulation Program–Fortran (HSPF) model (Johanson and others, 1984) for each watershed.

Acknowledgments

The authors are grateful to Mr. Carroll Schaal, principal planner for the Lake County Stormwater Management Commission, for his assistance throughout this study. Twelve municipalities in and near Lake County allowed gage installations at facilities such as wastewater-treatment plants, fire stations, and airports. Their cooperation and assistance are appreciated. The authors also wish to express their appreciation to the number of private citizens throughout the county who allowed installation of gages on their property and who recorded data for the study.

DESCRIPTION OF STUDY AREA

The study area consists of five watersheds and four HRU's (two within the five watersheds) in and near Lake County, Ill. (fig. 2). Lake County lies entirely within the Wheaton Morainal Region (Leighton and others, 1948). This region is a physiographic division where the topography was formed by glaciers during the Wisconsinan period of glaciation. The glacial ice during this period was primarily confined to the deep Lake Michigan Basin and to closely spaced moraines along the edge of the basin that form the eastern edge of Lake County. The complex topography formed by the moraines is characterized by the broad morainic ridges and a variety of glacial land forms, such as elongated hills, mounds, basins, lakes, and wetlands. Altitude in Lake County ranges from 481 to 991 ft.

The glacial drift deposited during the Wisconsinan period is underlain primarily by Silurian dolomite. Two small areas along the western edge of the county are underlain by Ordovician shale. The glacial drift is approximately 100 to 300 ft thick in Lake County and averages about 200 ft thick. Approximately 1 to 3 in. of ground water flows from the glacial drift to bedrock aquifers annually in northeastern Illinois (Zeizel and others, 1962).

Watersheds within Lake County contain upland areas with gently sloping to steep topography and

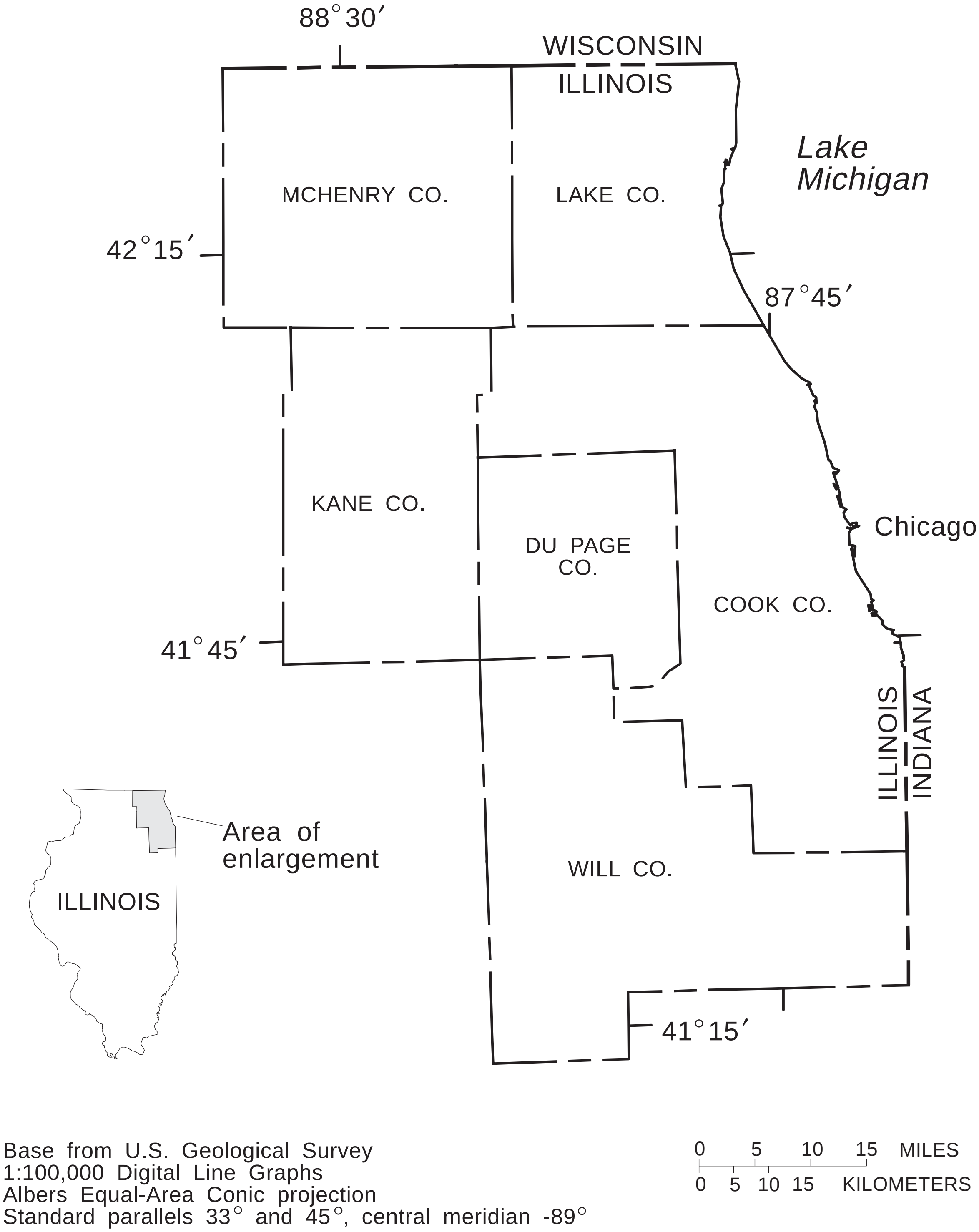


Figure 1. Location of Lake County, Ill., and surrounding counties.

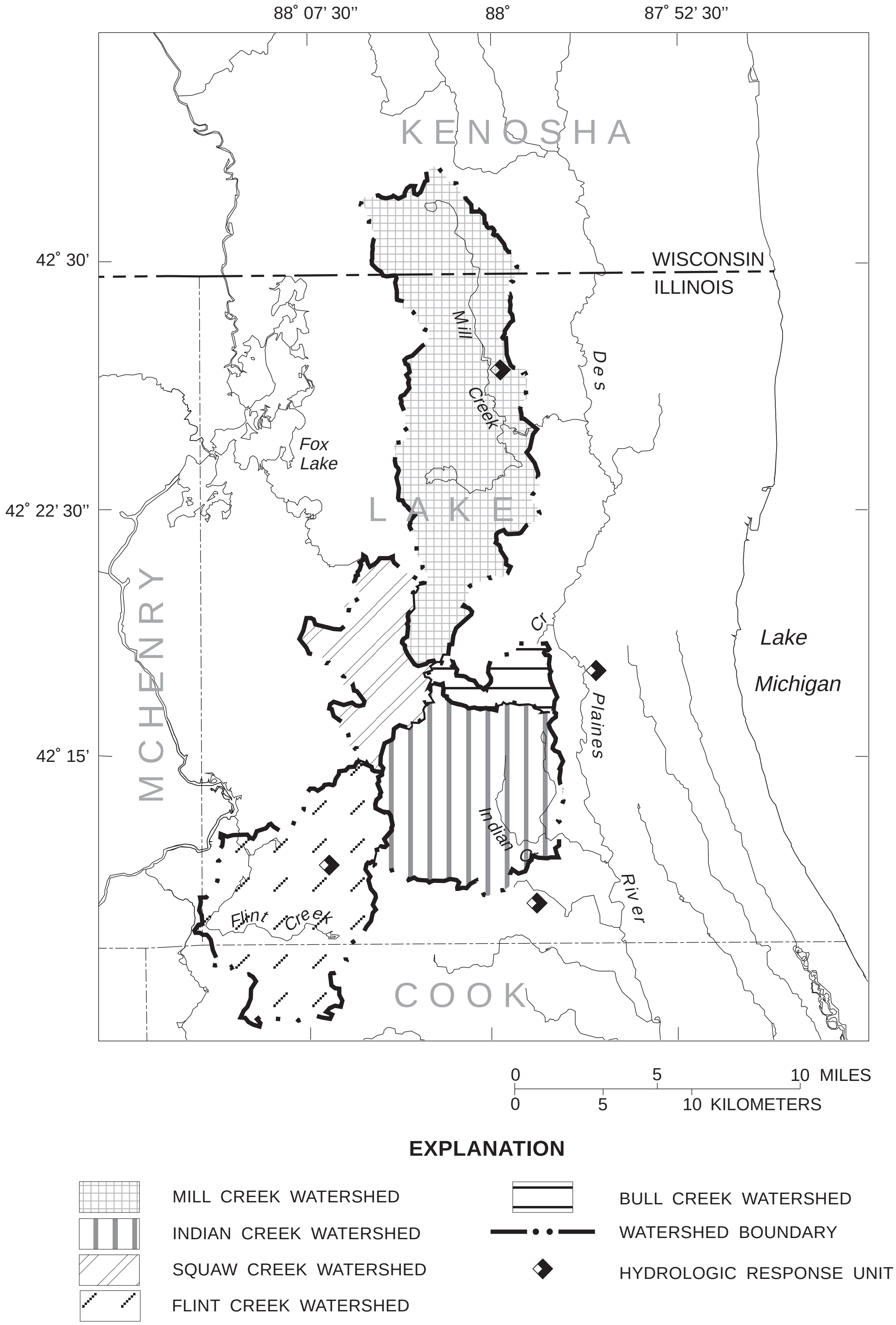


Figure 2. Location of the watersheds and hydrologic response units in the study area.

poorly drained to well-drained soils of moderate permeability (Soil Conservation Service, 1969). Lowland areas within these watersheds consist of generally level to depressional topography and very poorly drained, low-permeability soils (Soil Conservation Service, 1969). Eleven soil associations have been identified within Lake County, although only four of these soil associations are predominant within the county. The hydrologic characteristics of these four soil associations are similar in effects on rainfall-runoff relations. The soils in the study area are predominantly silt loams to clays and are categorized by the Soil Conservation Service (SCS) as hydrologic soil types B, C, and D.

Northeastern Illinois has a temperate, humid, continental climate that is slightly modified by Lake Michigan. Long-term climatic data have been recorded in and near the study area (fig. 3) by the National Oceanic and Atmospheric Administration (NOAA). Most of the precipitation in the Lake County area is rainfall. The long-term (1951–80) average annual precipitation for Lake County is approximately 39 in., and the long-term mean annual temperature for Lake County is approximately 49°F (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1989–93).

Rainfall in Lake County is generally associated with one of three types of weather systems: frontal systems (cold, warm, or stationary fronts), air-mass systems (cold or warm), or squall lines (Hiser, 1956). Cold-front systems commonly produce heavy summer rainfall throughout Illinois (Huff and Vogel, 1977). Isolated thunderstorms associated with unstable air masses can produce intense rainfall for brief periods over small areas during the summer months. Squall-line storms consist of a group of thunderstorms in a narrow band that are independent of a frontal system. Each of these weather systems can produce large amounts of rain (Changnon and Huff, 1980).

Watersheds

Five watersheds with drainage areas of 6.3 to 59.6 mi^2 were selected for instrumentation to determine rainfall-runoff relations. Drainage areas and land-cover characteristics, including impervious-, grass-, and forest-area percentages, for each of the five watersheds are presented in table 1. The watersheds provide a good representation of drainage features that are typical of most of Lake County. Three of the watersheds (Bull, Flint, and Indian Creeks) are also priority basins as defined by the

Table 1. Land-cover characteristics for selected watersheds in Lake County, Ill.
[mi^2, square miles]

Watershed	Streamflow-gaging station and number	Drainage area (mi^2)	Impervious area (percent)	Pervious area	
				Grass (percent)	Forest (percent)
Mill Creek	Mill Creek at Old Mill Creek, Ill. 05527950	59.6	7.33	87.17	5.50
Bull Creek	Bull Creek near Libertyville, Ill. 05528030	6.30	13.87	78.65	7.48
Indian Creek	Indian Creek near Prairie View, Ill. 05528230	35.7	15.75	80.76	3.49
Squaw Creek	Squaw Creek at Round Lake, Ill. 05547755	17.2	7.32	88.95	3.73
Flint Creek	Flint Creek near Fox River Grove, Ill. 05549850	37.0	8.83	82.33	8.84

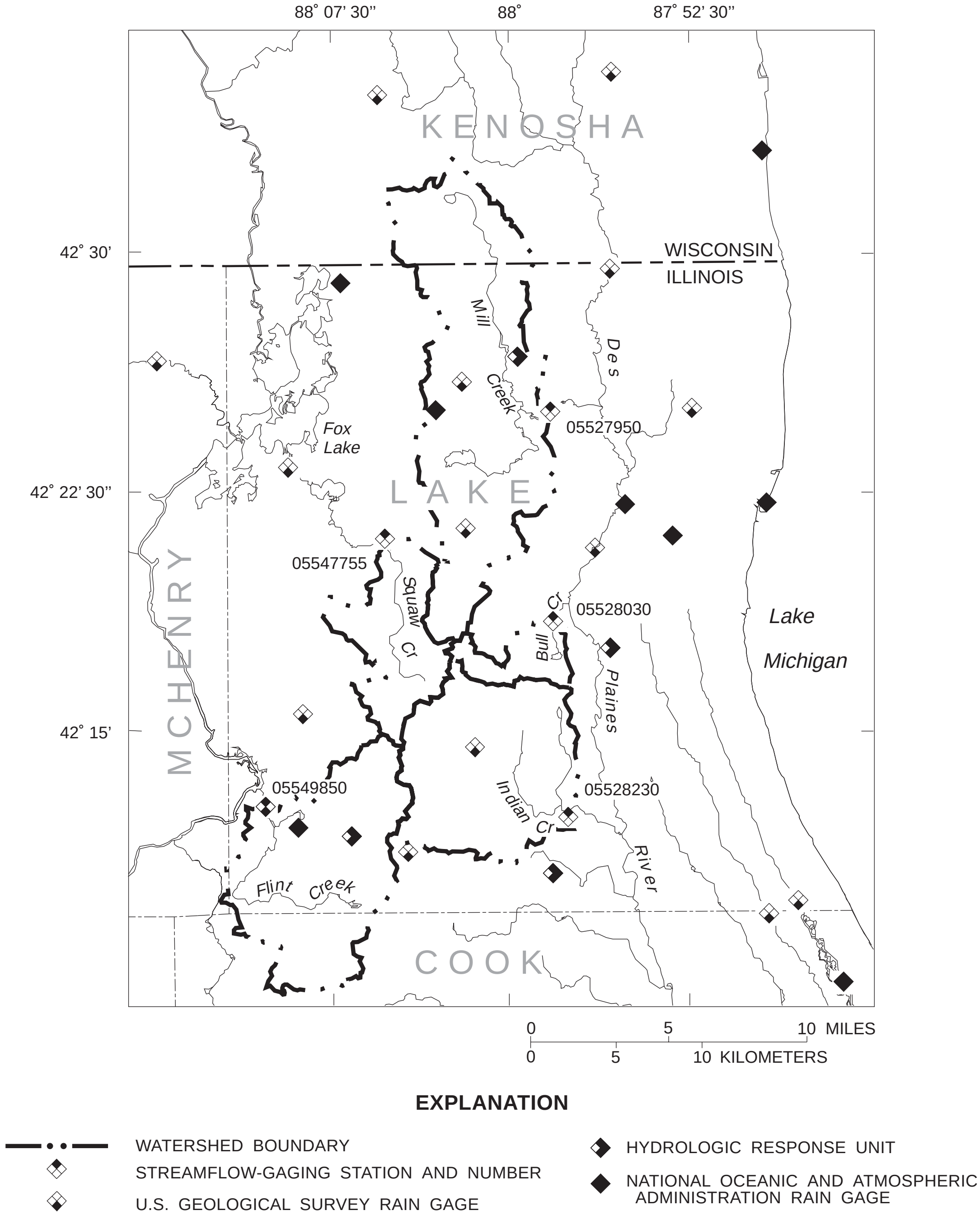


Figure 3. Location of study area, watershed boundaries, streamflow-gaging stations, and rain gages in and near Lake County, Ill.

LCSMC. Priority watersheds have present stormwater problems or may have future stormwater problems according to the LCSMC.

Mill Creek Watershed

The Mill Creek watershed (59.6 mi^2), shown in figure 4, is predominantly rural. About 92.7 percent of the land cover is pervious (table 1), consisting primarily of farm pastures and row crops mixed with tracts of hardwood forests. Runoff in Mill Creek is affected by large areas of pervious land, which facilitates infiltration of rainfall and delays the runoff response. Surface runoff generally occurs only during intense storms when the infiltration capacity of the soil has been exceeded or when precipitation falls on frozen ground. Stormflow hydrographs recorded by the Mill Creek streamflow gage have gradually rising and receding limbs, and the time lag between rainfall and streamflow peaks is relatively long. Semipermanent debris jams along the stream channel can form large backwater areas during high flows, which also contribute to the long time lag. The forested tracts within the watershed intercept a large part of the rainfall. The gradually receding limbs of stormflow hydrographs indicate a significant amount of interflow. Interflow may be more prevalent in the Mill Creek watershed than in other studied watersheds because of the large pervious areas and slightly greater topographical relief. Base flow within the Mill Creek watershed is sustained by the discharge of ground water from the glacial drift. The base flow also may be slightly affected by effluent discharged from a small wastewater-treatment plant approximately 5.3 mi upstream from the streamflow gage.

Bull Creek Watershed

The Bull Creek watershed (6.3 mi^2), shown in figure 5, is predominantly urban. About 13.9 percent of the land cover is impervious (table 1). Runoff in Bull Creek is strongly affected by impervious areas. Stormflow hydrographs recorded by the Bull Creek streamflow gage have relatively steep rising and receding limbs, which are common characteristics of urban watersheds with large impervious surfaces. A few remnant wetland areas and small lakes provide some storage of runoff within the watershed and tend to attenuate some of the rapid runoff from impervious areas within the watershed. Base flow within the Bull Creek watershed is sustained by the discharge of ground water from the glacial drift.

Indian Creek Watershed

The Indian Creek watershed (35.7 mi^2), shown in figure 6, is predominantly urban and is probably the most rapidly urbanizing watershed considered in this study. About 15.8 percent of the land cover is impervious (table 1). Three tributaries drain the watershed to form Indian Creek (fig. 6). Parts of the tributaries have been channelized, and impoundments of a wide range of designs and ages have been built along these channels. These impoundments provide variable degrees of storage for surface runoff. Stormflow hydrographs recorded by the Indian Creek streamflow gage are appreciably affected by the storage capabilities of these impoundments. For example, relatively long time lags between rainfall and peak discharge in such an urban watershed indicate that surface storage is occurring within the watershed. Base flow is relatively low compared with that in other streams in the study with similar contributing drainage areas.

Squaw Creek Watershed

The Squaw Creek watershed (17.2 mi^2), shown in figure 7, is predominantly rural. About 92.7 percent of the land cover is pervious and consists primarily of farmland (table 1). Surface runoff is affected by the relatively large amounts of pervious area, which facilitates infiltration of rainfall and delays runoff response to rainfall. Squaw Creek has been channelized in some parts of the watershed. Remnant wetlands and depressional areas can store some surface runoff. Stormflow hydrographs recorded by the Squaw Creek streamflow gage have a relatively steep rising limb, which is unusual for a rural watershed and may reflect stream channelization. Base flow within the Squaw Creek watershed is sustained by the discharge of ground water from the glacial drift.

Flint Creek Watershed

The Flint Creek watershed (37.0 mi^2), shown in figure 8, is a combination of urban and rural areas. About 8.8 percent of the land cover is impervious (table 1). The rural parts of the watershed consist of mixed farmland and forested tracts. Surface runoff is affected primarily by impervious surfaces in the urban

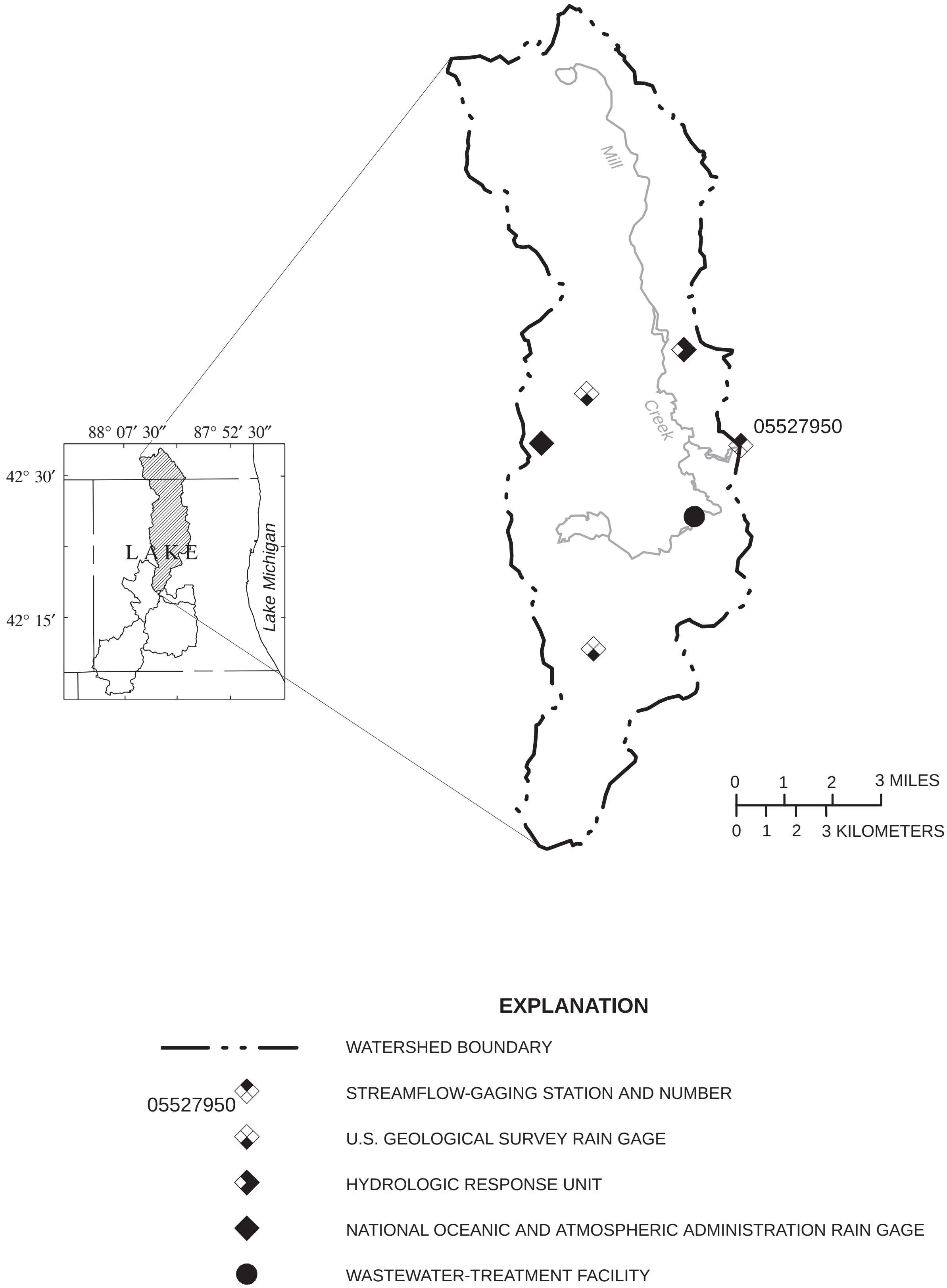
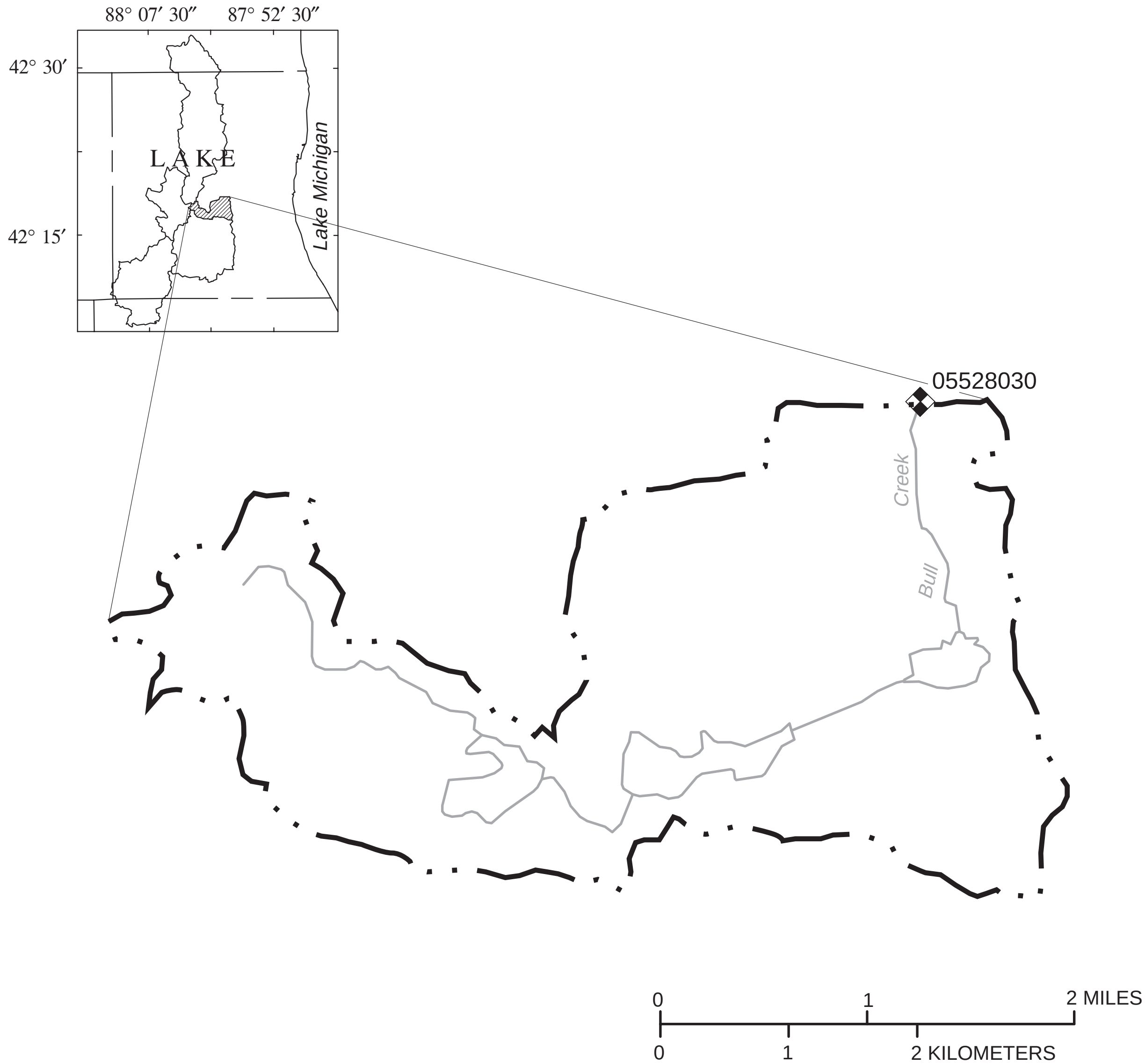


Figure 4. Mill Creek watershed, and the streamflow-gaging station and rain gages used for model simulation.



EXPLANATION

WATERSHED BOUNDARY

05528030 STREAMFLOW-GAGING STATION AND NUMBER

U.S. GEOLOGICAL SURVEY RAIN GAGE

Figure 5. Bull Creek watershed, and the streamflow-gaging station and rain gage used for the model simulation.

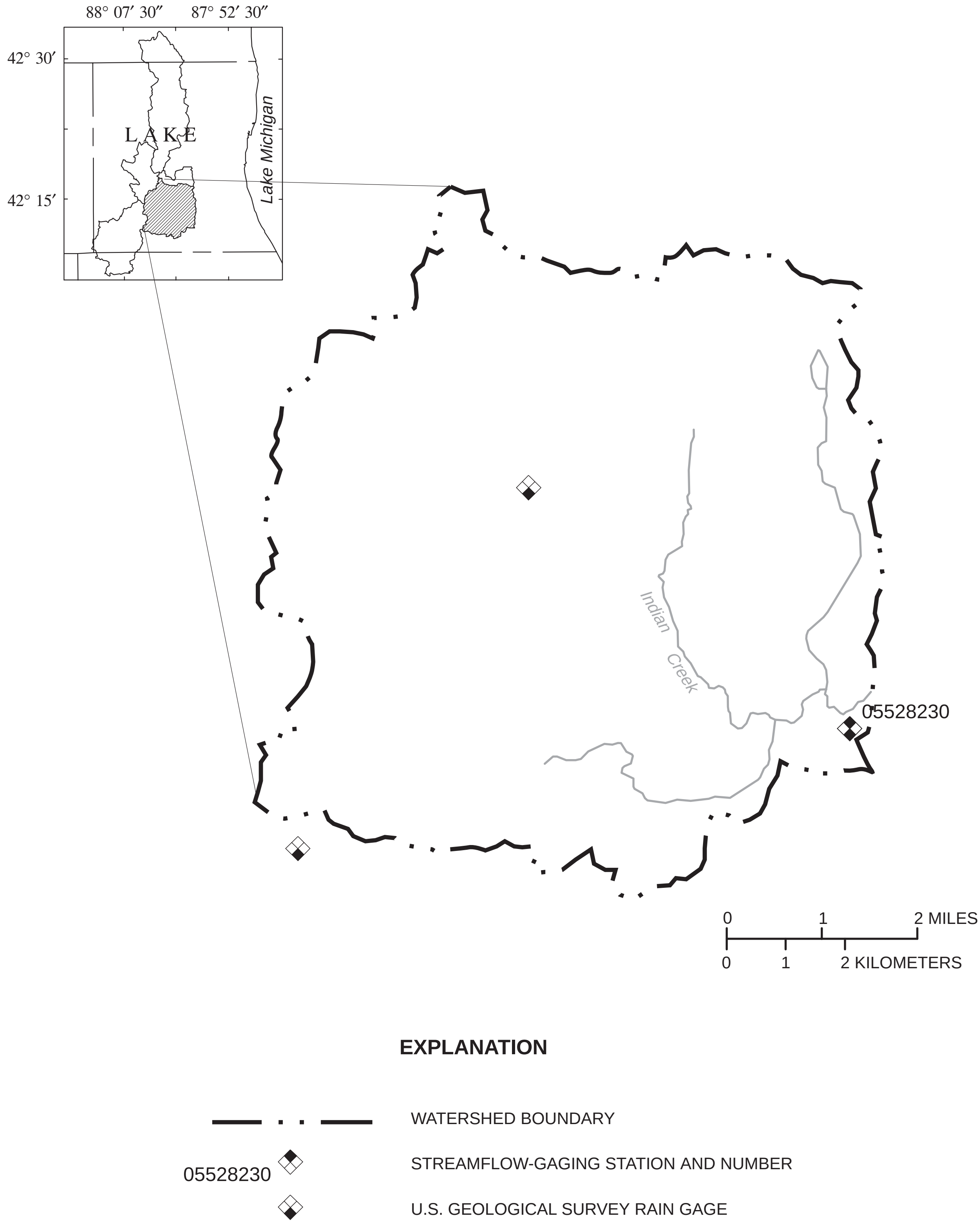


Figure 6. Indian Creek watershed, and the streamflow-gaging station and rain gages used for model simulation.

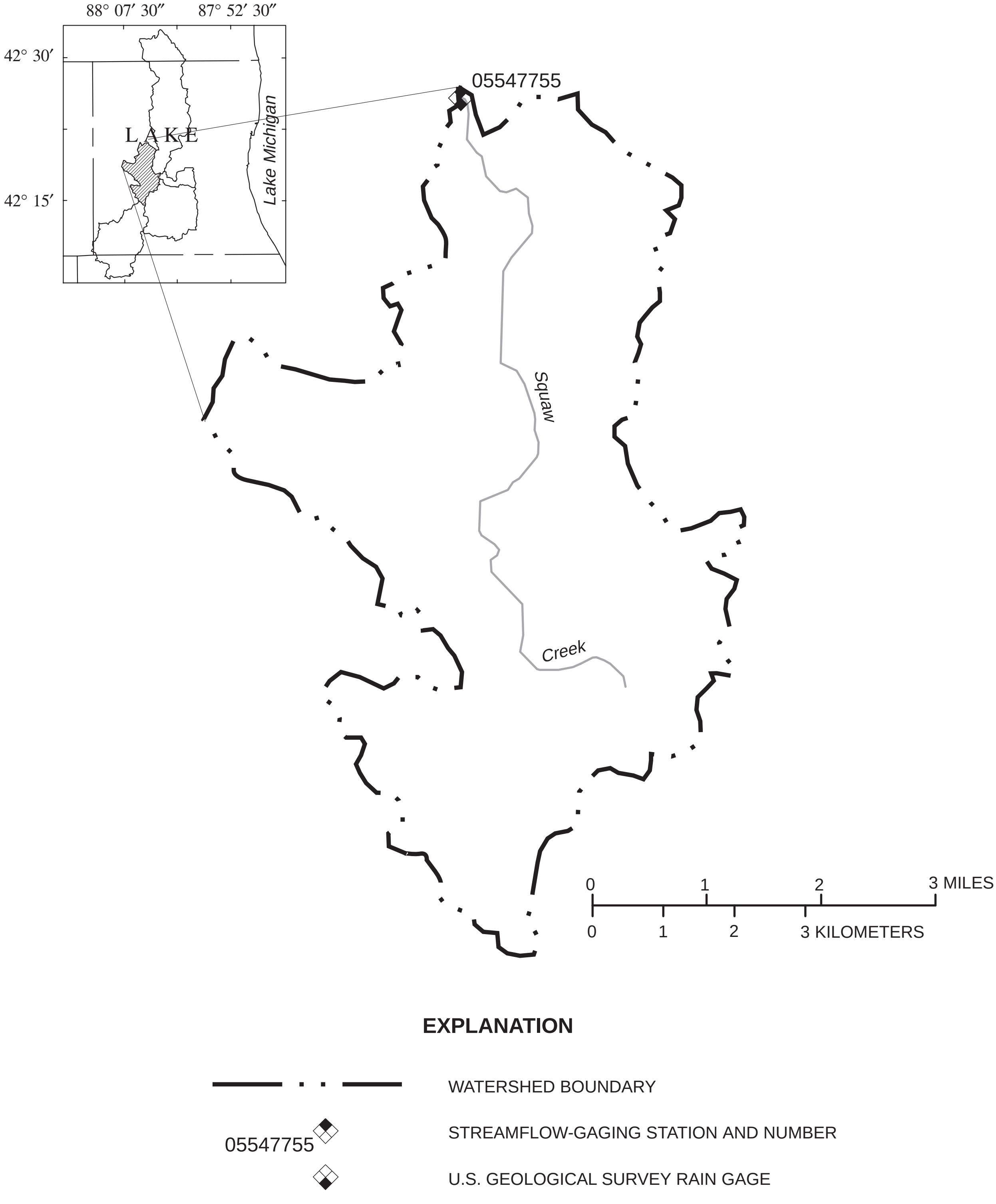


Figure 7. Squaw Creek watershed, and the streamflow-gaging station and rain gage used for model simulation.

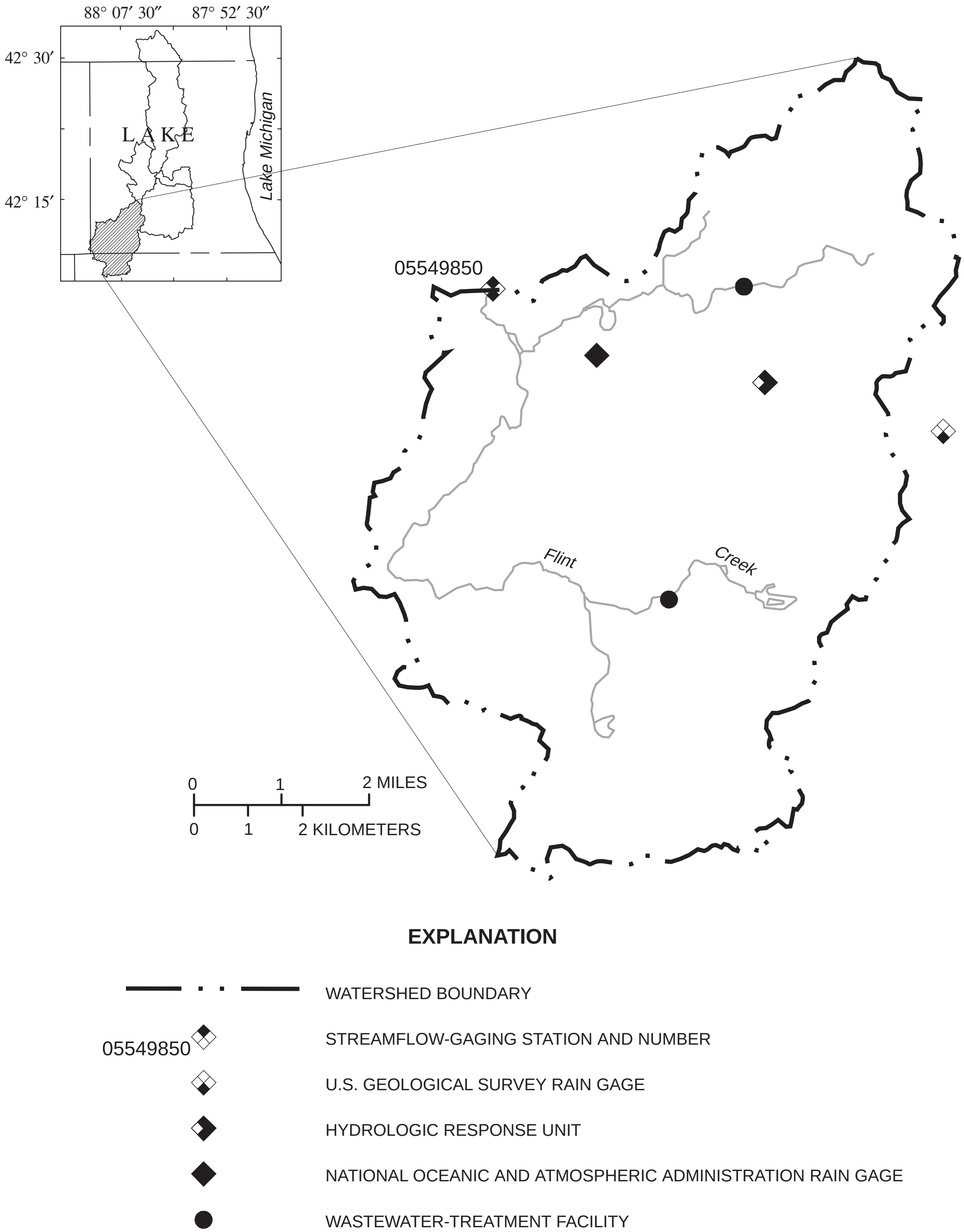


Figure 8. Flint Creek watershed, and the streamflow-gaging station and rain gages used for model simulation.

areas and secondarily by estates surrounding the urban areas. Many estates are larger than 1 acre, with mature forests on parts of the acreage and swales as the primary drainage features. The forested tracts throughout the watershed may intercept a significant amount of rainfall. Remnant wetlands and depressional storage along the channel can store some surface runoff. Base flow is relatively high and is slightly affected by effluent discharged by two wastewater-treatment facilities in the upper reaches of the watershed (fig. 8).

Hydrologic Response Units

The rainfall-runoff investigation was expanded in April 1991 in an effort to define regional rainfall-runoff relations at a small scale. Four HRU's (with drainage areas of 3.5–305 acres) were selected for instrumentation and use in model calibration (table 2). The HRU land-cover categories were selected on the basis of a range of impervious area and predominant land-cover categories within Lake County. The four land-cover categories are (1) open space, (2) estate-type residential, (3) low-density (single-family) residential, and (4) commercial strip.

Tempel Farms Ditch

Tempel Farms Ditch drains a 305-acre watershed consisting of 100 percent pervious land cover (table 2) in the form of agricultural pasture. A network of agricultural drainage tiles covers the entire watershed.

Table 2. Hydrologic response unit land-cover characteristics in Lake County, Ill.

Hydrologic response unit and station number	Drainage area (acres)	Impervious area (percent)	Pervious area (percent)
Tempel Farms Ditch near Old Mill Creek, Ill. 05527940	305	0.03	99.97
Terre Faire Ditch at Libertyville, Ill. 05528040	49.4	27.7	72.3
Green Lake Ditch at Buffalo Grove, Ill. 05528475	38.2	40.6	59.4
Lakeview Plaza Ditch at Lake Zurich, Ill. 05549835	3.52	99.95	.05

The watershed consists of soils of the Morley-Markham-Houghton soil association, which consists of well drained to moderately well drained, deep soils with moderately slow permeability (Soil Conservation Service, 1969).

Terre Faire Ditch

Terre Faire Ditch drains a 49.4-acre watershed consisting of 72.3 percent pervious land cover and 27.7 percent impervious land cover (table 2) in the form of estate-type residential housing. Grass swales are the primary drainage feature throughout the watershed. All of the residential housing in the watershed is serviced by a sanitary sewer system. The typical residential lot is approximately 0.5 acre. The watershed consists of soils from the Nappanee-Montgomery soil association, which consists of somewhat poorly drained soils with slow to moderate permeability (Soil Conservation Service, 1969).

Green Lake Ditch

Green Lake Ditch drains a 38.2-acre watershed consisting of 59.4 percent pervious land cover and 40.6 percent impervious land cover (table 2) in the form of low-density residential housing. Storm sewers are the primary drainage feature throughout the watershed. The typical lot is approximately 0.34 acre. The watershed consists of soils from the Elliot-Markham soil association, which consists of well drained to somewhat poorly drained soils with moderately slow permeability (Soil Conservation Service, 1969).

Lakeview Plaza Ditch

Lakeview Plaza Ditch drains a 3.52-acre watershed consisting of nearly 100 percent impervious land cover (table 2) in the form of a commercial shopping mall and adjacent parking lot. A very small section of pervious landscaped area borders parts of the parking lot. Storm sewers drain the entire watershed to a small detention basin.

METHODS OF STUDY

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 for a watershed define the complex interaction of the processes that compose the land-surface part of the hydrologic cycle. The amount of runoff produced by a storm is determined by physical characteristics of a watershed, such as geology, slope, soils, and land cover, as well as climatic conditions, such as rainfall, evaporation, and transpiration. This study sought to (1) develop regional rainfall-runoff relations suitable for stormwater planning and design on ungaged streams in watersheds undergoing land-use changes, and (2) study the effects of watershed size on model-simulation performance.

In order to develop regional rainfall-runoff relations, climatic conditions and physical characteristics of the watershed must be quantified. The climatic conditions of rainfall, evaporation, and potential evapotranspiration can be measured directly or derived from other climatic data. The physical characteristics of the watersheds within the study area are relatively uniform, except land cover, which varies widely within the study area. For stormwater-management purposes in Lake County, planners recognize eight distinct land-cover categories (Carroll Schaal, Lake County Stormwater Management Commission, oral commun., 1990), each of which provides a unique runoff response to rainfall. The eight land-cover categories are as follows:

1. Open space: agricultural land, public and private parks, and golf courses.
2. Forested land: areas that are predominantly covered by trees.
3. Water: inland lakes, ponds, rivers, streams, and reservoirs.
4. Estate residential: residential housing on 0.5- to 5-acre lots drained by grassed ditches and swales.
5. Low-density residential: residential housing of 1.1 to 4.0 units per acre drained by storm sewers.
6. Medium-density residential: residential housing of 4.1 to 8.0 units per acre drained by storm sewers.
7. High-density residential: multifamily residential housing greater than 8.1 units per acre drained by storm sewers.
8. Commercial or industrial: relatively large impervious areas such as businesses, shopping malls, offices, utilities, and institutional facilities.

These eight categories of land cover are distributed throughout the study area.

This study sought to develop rainfall-runoff relations for four HRU's (3.5–305 acres in area), each consisting entirely of one of the eight land-cover categories. In addition, rainfall-runoff relations for five watersheds (6.3–59.6 mi^2 in area) consisting of various amounts of each land-cover category also were simulated. The effects of watershed size on rainfall-runoff model simulations could then be determined by comparing the model performance on the HRU's with the model performance on the larger watersheds. Regional model parameters were developed that could be applied to a wide range of watersheds by studying watersheds varying both in size and land cover.

In order to assess rainfall-runoff relations on the watersheds studied, land-cover and hydrologic data were collected throughout the study area. These data provide a quantitative description of the physical conditions within the watersheds during the study. Rainfall-runoff relations were simulated by utilizing land-cover and hydrologic data to calibrate and verify a continuous-simulation model. Rainfall, land-cover data, and calculated potential evapotranspiration are used in the model to simulate a continuous time series of runoff. The model was calibrated such that the simulated runoff volume corresponded to the observed runoff volume within statistically defined limits. Model verification can be accomplished through model simulations of the same watersheds with different time periods, or through model simulations of different but hydrologically similar watersheds not utilized in the calibration phase of modeling. Verification with hydrologically similar watersheds is a more stringent test of the regional applicability of the rainfall-runoff relations than using the same watersheds for different time periods. If rainfall-runoff relations cannot be simulated within statistically defined limits during verification, new rainfall-runoff relations must be formulated and tested (that is, a new rainfall-runoff model must be examined).

In the original plan for this study, the rainfall-runoff relations, defined by a set of model parameters for each land-cover category, were to be calibrated on the HRU's and verified by testing the rainfall-runoff model on the large watersheds. The HRU's were selected and instrumented for four of the eight land-cover categories. The four categories selected were open space, low-density residential (with storm sewers), estate residential (with grass swales), and commercial or industrial. Rainfall-runoff relations for the four land-cover categories that were not instrumented were to be estimated by interpolation of rainfall-runoff relations determined for the HRU's. However, significant scale problems caused by the difference in drainage areas were found between the rainfall-runoff processes for the HRU's and the watersheds. The HRU streams are intermittent because the drainage channels do not intersect the water table throughout the year. Runoff from the HRU's is strongly affected by rising water tables. Water-table elevations in the study area vary seasonally, with high water tables generally occurring during winter and spring. As such, the base-flow contribution to runoff, which is derived from the water table, also tends to occur in the winter and spring. The stream channels in the large watersheds intersect the water table during most periods and have a permanent base flow.

The methods of study were altered because of the scale problems encountered in modeling the HRU's and watersheds. Model simulation of the HRU's and watersheds indicated that the variations in soil type and vegetative cover in the study area did not appreciably affect rainfall-runoff relations as modeled in HSPF. Therefore, only three land-cover categories, two pervious (forest and grass) and one impervious, were investigated. Similar results have been found by other researchers applying HSPF or the model from which it was developed (Singh, 1989, p. 251), the Stanford Watershed Model (Crawford and Linsley, 1963). For example, Lumb and James (1976) developed a system for stormwater management in Decatur County, Ga., based on the Stanford Watershed Model and parameter sets representing pervious and impervious areas. Lumb and James (1976) considered three types of pervious land (that is, three soil types) in Decatur County. However, the procedure was developed based on calibration for the dominant soil type, and they adjusted the model parameters to account for variable perviousness of soils in the county.

Data Collection

Development of rainfall-runoff relations for the watersheds requires the collection of hydrologic and land-cover data. Daily streamflow data for the five watersheds are published in USGS annual water-data reports for Illinois (Sullivan and others, 1990; Richards and others, 1991, 1992; LaTour and others, 1993; and Zuehls and others, 1994). Daily rainfall data collected during this study are given in Duncker and others (1994). Five-minute values of rainfall and streamflow are available from USGS files. Streamflow and rainfall data also were collected on the four HRU's. Five-minute values of streamflow and rainfall from the HRU gaging stations are also available from USGS files.

Hydrologic Data

All USGS streamflow-gaging stations and rain gages in and near Lake County, Ill., are given in table 3 with the streamflow-gaging stations used in this study identified. Stream gages were installed on each of the five watersheds and four HRU's. The streamflow-gaging stations on the five watersheds were installed at locations where historical streamflow data were available from previous studies. The four HRU's were selected on the basis of sites suitable for accurate rainfall and streamflow-gaging criteria. Continuous-stage data were collected at each of the streamflow-gaging stations. Stage-discharge ratings were developed using discharge measurements, with a special emphasis on high flows, following established methods (Rantz and others, 1982). Accurate stage-discharge relations were maintained by periodic confirmation of the stage-discharge ratings by discharge measurement on a monthly basis. Streamflow records for the gaging stations on the five watersheds are rated as good (plus or minus 5 percent error) for the full period of record except for estimated periods (such as periods of missing record or winter periods when the stream is ice covered), which are rated as poor (plus or minus 10 percent error). Low flows in Flint Creek are affected by effluent discharge from two wastewater-treatment facilities in the headwaters of the watershed (fig. 8). The combined mean daily discharge of the facilities averages approximately 2.5 ft^3/s. This average discharge from the two facilities was subtracted from the flow records at the Flint Creek gage prior to model simulation.

Twenty-three rain gages were installed in and near the study area to provide detailed information on the temporal and spatial distribution of rainfall (fig. 3). Five of the twenty-three rain gages were heated, which provided a water equivalent for snowfall. Potential evapotranspiration was calculated using the Penman-Monteith method (Monteith, 1965) and meteorological data collected at the O'Hare Airport NOAA station.

Table 3. U.S. Geological Survey streamflow-gaging stations and rain gages in and near Lake County, Ill.
[*, watersheds simulated in this study]

Station number	Station name	Type of gage
05527800	Des Plaines River at Russell, Ill.	Streamflow, Rain
*05527940	Tempel Farms Ditch near Old Mill Creek, Ill.	Streamflow, Rain
*05527950	Mill Creek at Old Mill Creek, Ill.	Streamflow
05528000	Des Plaines River near Gurnee, Ill.	Streamflow, Rain
*05528030	Bull Creek near Libertyville, Ill.	Streamflow, Rain
*05528040	Terre Faire Ditch at Libertyville, Ill.	Streamflow, Rain
*05528230	Indian Creek at Prairie View, Ill.	Streamflow
*05528475	Green Lake Ditch at Buffalo Grove, Ill.	Streamflow, Rain
*05528500	Buffalo Creek near Wheeling, Ill.	Streamflow, Rain
05534500	North Branch Chicago River at Deerfield, Ill.	Streamflow, Rain
05535000	Skokie River at Lake Forest, Ill.	Streamflow
05535070	Skokie River near Highland Park, Ill.	Streamflow, Rain
*05547755	Squaw Creek at Round Lake, Ill.	Streamflow, Rain
05548280	Nippersink Creek near Spring Grove, Ill.	Streamflow, Rain
05549835	Lakeview Plaza Ditch at Lake Zurich, Ill.	Streamflow, Rain
*05549850	Flint Creek near Fox River Grove, Ill.	Streamflow, Rain
421113088042200	Lake Zurich Wastewater Treatment Facility at Lake Zurich, Ill.	Rain
421215087573400	Vernon Hills Rain Gage at Prairie View, Ill.	Rain
421428088012900	Diamond Lake Wastewater Treatment Facility at Diamond Lake, Ill.	Rain
421533088084600	Wauconda Wastewater Treatment Facility at Wauconda, Ill.	Rain
422118088014700	Grayslake Wastewater Treatment Facility at Grayslake, Ill.	Rain
422315088091800	Fox Lake Rain Gage at Fox Lake, Ill.	Rain
422459087520700	Waukegan Airport at Waukegan, Ill.	Rain
422553088015300	Lindenhurst Wastewater Treatment Facility at Lindenhurst, Ill.	Rain
423451088052400	Paddock Lake Wastewater Treatment Facility at Paddock Lake, Wis.	Rain
423526087551800	Kenosha Airport Rain Gage at Kenosha, Wis.	Rain

Land-Cover Data

An accurate representation of the land cover within a watershed during the study is necessary for rainfall-runoff modeling. Changes in land cover over short periods of time can make this a difficult, if not impossible, task. Land-cover data from the spring of 1990 was utilized in simulating the watersheds because of the availability of aerial photographs, digital remote-sensing data, and other on-going, land-cover-related work within the county.

Initially, land-cover data were to be delineated by aerial-photo interpretation on transparent overlays of the spring 1990 aerial photographs. However, several drawbacks result with this method. Application of the method is very time consuming, watershed boundaries are difficult to transfer from topographic maps to aerial photographs, and linear features, such as roads, are difficult to distinguish from photographs. On the basis of these drawbacks, two additional methods for generating a digital land-cover data base were investigated. The first method involved delineating the land cover from scanned images of a watershed. The scanned images were generated from the aerial photographs at the USGS National Mapping Division (NMD) in Rolla, Mo. Manpower, time constraints, and the availability of the scanning equipment at NMD precluded the use of this method for determining the land-cover data for this study. The second method involved utilizing a readily available digital land-cover data base to generate the required land-cover data. This data base consisted of eight bands of TM and SLAR data sets that were collected in the spring of 1990. Previous studies have indicated that use of TM–SLAR data is an accurate means of delineating land cover (Lillesand and Kiefer, 1987, p. 498). Digital coverages of the watershed boundaries were incorporated with the TM–SLAR data to provide an accurate land-cover data base for each watershed.

One assumption of the simulation procedure applied in this study is that the primary land-cover characteristic differentiating runoff production among watersheds is the amount of impervious land cover. The TM–SLAR digital land-cover data base was used to delineate the impervious areas within each watershed, as well as the two categories of pervious land cover.

The land-cover data generated from the TM–SLAR data base were checked utilizing the following method. Land-cover data were delineated from the scanned images of the aerial photographs for the Bull Creek watershed at the NMD in Rolla, Mo. The land-cover data derived from the scanned images were then compared to the TM–SLAR data for the same watershed. Initial comparison of the raw TM–SLAR data with the NMD scanned-image derived data was poor. The TM–SLAR data overestimated the amount of impervious land cover. The overestimation is probably a result of the relatively strong SLAR signal strength of impervious surfaces compared to pervious surfaces. To rectify the overestimation, a simple digital signal-processing technique was applied that gave added weight to frequency bands representing pervious surfaces. To determine the appropriate weighting factor, direct field measurements of the amount of impervious and pervious land cover were made in the Green Lake Ditch catchment. The Green Lake Ditch catchment consists of 38.2 acres of uniform, low-density, single-family, residential housing. An appropriate weighting factor was selected such that the TM–SLAR data matched the field-measured values. A second land-cover delineation of the Bull Creek watershed was made applying the weighted TM–SLAR data. The land-cover delineations generated from the weighted TM–SLAR data were then compared to the scanned-image data from NMD. Impervious area from the scanned-image data was 13.2 percent of the drainage area and was 13.9 percent of the drainage area from the TM–SLAR data. These area calculations were considered satisfactory, thus verifying the weighting factor for the TM–SLAR method.

Model-Simulation Approach

Version 9.0 of the HSPF model (Johanson and others, 1984) was selected for modeling the five watersheds and the four HRU's. HSPF is a continuous-simulation model like the Stanford Watershed Model. The main premise for using continuous-simulation models for planning and design is that accounting for water stored in the watershed throughout time more realistically considers antecedent conditions and estimates flood sequences than do event-based models using assumed antecedent conditions. 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 (on average, once 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 rain gages. For example, Schilling and Fuchs (1986) demonstrated that the magnitude of error in urban-runoff calculations for small watersheds, from rainfall spatial variability, may be greater than 100 percent in peak discharge and runoff estimation. Therefore, matching observed and simulated storm runoff for all storms is difficult. At best, the individual storm runoff can be examined to eliminate bias (that is, tendencies to overestimate or underestimate) in the simulated runoff. Matching the observed and simulated runoff frequency relations is a good criterion for calibration of continuous-simulation models utilized for stormwater management. In addition, comparing observed and simulated runoff-duration time series 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 partial-duration series of storm runoff, 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 where 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 land-surface portion of the hydrologic cycle by a series of interconnected water storages: an upper zone, a lower zone, and a ground-water zone. The amounts of water in these storages and the flux of water between the storages 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 storages and to the stream or atmosphere are controlled by model parameters. The model parameters have physical meaning conceptually; some are physically measurable but most 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 9.

The flow paths through the upper, lower, and ground-water zones and the relations between the storage in the zones and streamflow and evapotranspiration are shown in figure 9. 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 contains water stored in the soil that does not discharge to the stream. The ground-water zone stores the water resulting in 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 by application of the Thiessen polygon method (fig. 10). A watershed is divided into several polygons that represent the portion of the watershed nearest to a given rain gage. Each polygon is assigned an amount of rainfall from the nearest rain gage. Land-cover data were aggregated into pervious and impervious categories for each of the Thiessen polygons, with the pervious category further subdivided into grass and forest land-cover categories. As the HRU rain gages were added to the data-collection network at a later date, the rainfall data from these gages were only used for HRU simulation and were not utilized in the simulation of the large watersheds; thus, the HRU rain gages are not shown in figure 10. Two broad categories of land cover are utilized in HSPF: pervious land cover (PERLND) and impervious land cover (IMPLND). A wide range of physical attributes can be assigned to a PERLND or IMPLND to represent various land-cover conditions.

Initial values for model parameters were selected from 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 several 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.

SIMULATION OF STREAMFLOW

A conceptualization of the land-based portion of the hydrologic cycle for each watershed in the study and the relative contributions that each flow path and storage area have in a particular watershed are important aspects of the streamflow simulation process. As the combination of model parameters that can produce a streamflow output in the HSPF model are not unique, the conceptualization of the watershed is necessary to develop a meaningful calibrated model parameter set.

Model Development

Initial model simulations were done in an attempt to develop a regional calibration parameter set that would provide a satisfactory simulation of all watersheds in Lake County, regardless of drainage area. The early model simulations, however, indicated that developing a regional parameter set applicable for both the watersheds and the HRU’s was not feasible. This is primarily because a continuous base flow occurs in the watersheds even during extended dry periods, whereas an intermittent base flow occurs in the HRU’s. Base flows in the HRU’s last for only short periods, typically during winter and spring when the ground-water levels are relatively high. For much of the year, ground-water levels are low enough that they do not intersect the shallow stream channels. Flow during the summer and fall typically lasts only for short periods after storms. For these reasons, two regional parameter sets were developed: one for the watersheds, and the other for the HRU’s.

In order to develop a regional parameter set for the HRU’s that would simulate the intermittent flows in a satisfactory manner, it was necessary to restrict the water routed to the stream as base flow. Several

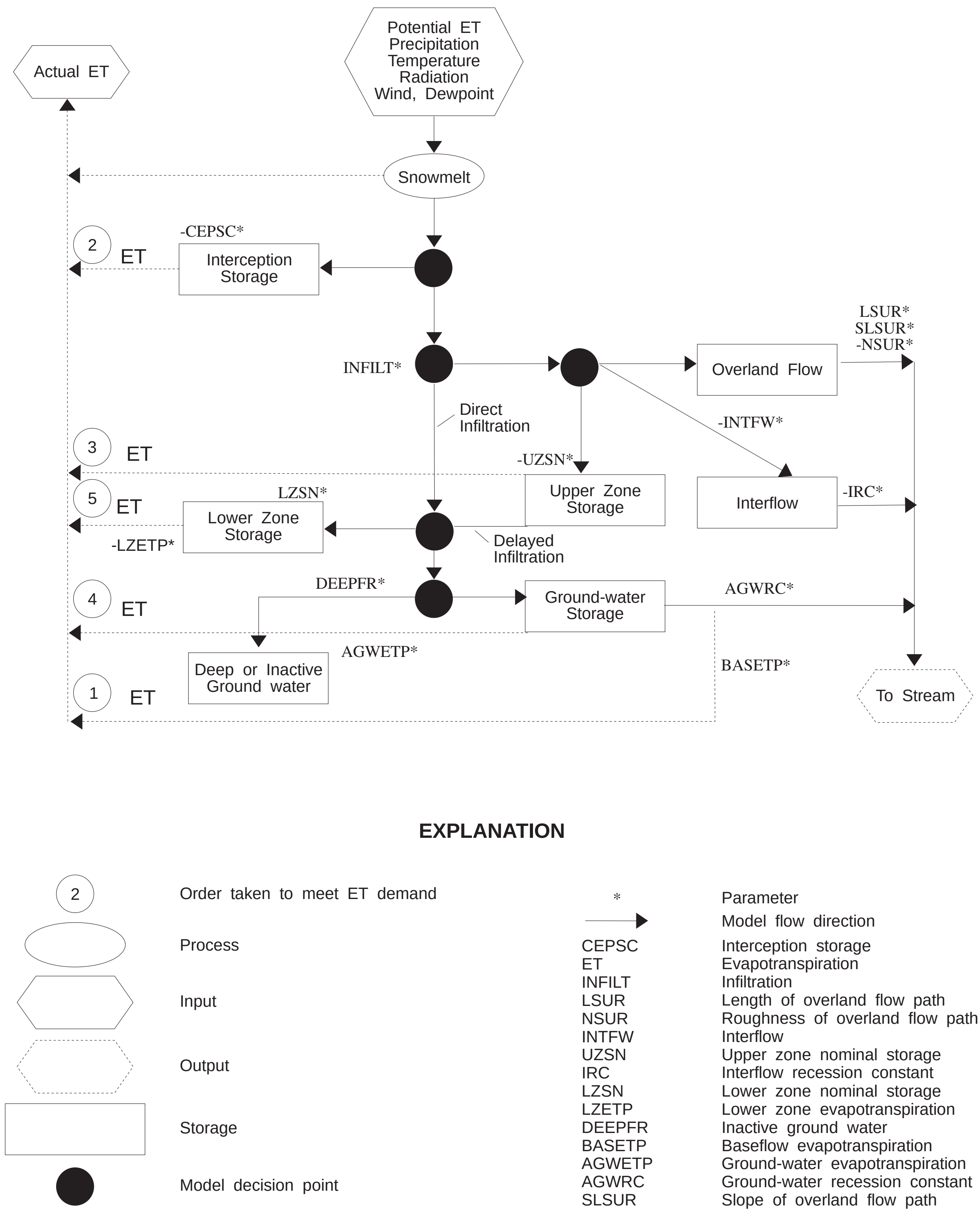


Figure 9. Schematic diagram of the Hydrological Simulation Program–Fortran model.

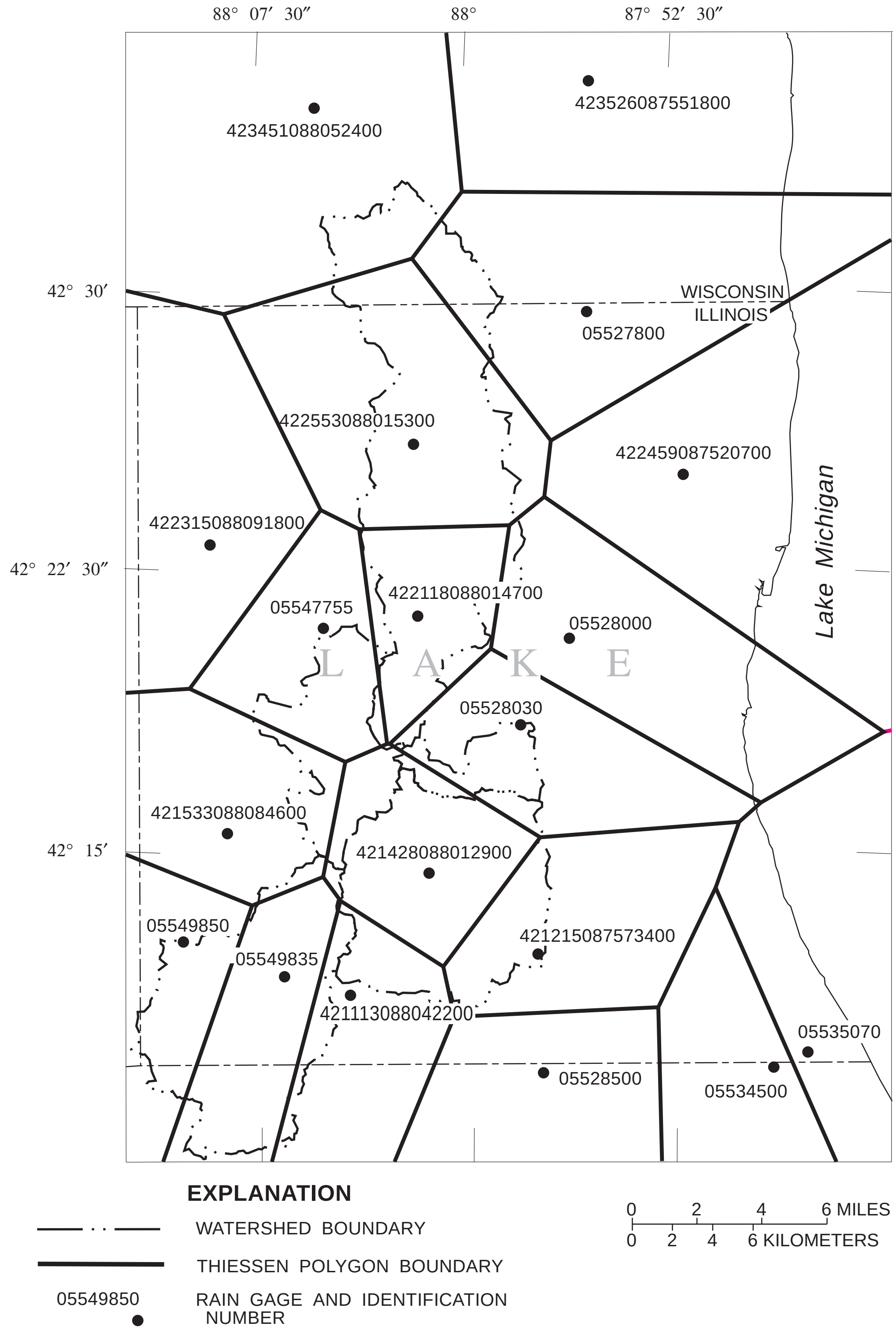


Figure 10. Study area, watershed boundaries, rain-gage locations, and the Thiessen polygons used to distribute the rainfall data in and near Lake County, Ill.

parameters in the HSPF model can be adjusted to reduce the base-flow contribution to the stream. HSPF model parameters, such as inactive ground water (DEEPFR), infiltration (INFILT), ground- water recession constant (AGWRC), ground-water evapotranspiration (AGWETP), and lower zone nominal storage (LZSN), each affect the simulated base-flow component of streamflow. The specific parameters used to reduce the base-flow contribution for a given HRU were determined by the physical characteristics of the HRU and a conceptual understanding of the relative proportions of ground-water flow, interflow, and surface runoff in the total streamflow. The delayed response associated with the interflow and ground-water flow that form the recession limbs of stormflow hydrographs was simulated with the parameter that determines the relative amounts of interflow (INTFW) and surface runoff, and the interflow recession constant (IRC), which regulates the rate at which water is released from interflow storage to the stream. The use of interflow as the primary process in shaping the stormflow hydrographs for the HRU's could be viewed as simulation of the effects of agricultural-drainage tiles and urban storm sewers.

The HSPF snowmelt-simulation process was not applied in this study. The HSPF snowmelt-simulation process incorporates a complex snowmelt routine that simulates snowfall based on precipitation and air-temperature data and adjusts for changes to a permanent snowpack. This portion of the model was not applied because permanent snowpacks typically are not found in the study area. The timing of the snowmelt runoff was determined by the amount of snow on the ground as recorded at the Gurnee NOAA station, which is centrally located in the study area and records both daily snowfall and the amount of snow on the ground. Snowmelt runoff was simulated by manually adding a 0.1-in. water equivalent for every 1-in. decrease in snow on the ground as recorded at the Gurnee NOAA station. The water equivalent was added to the rainfall data sets on the date corresponding to the decrease in the amount of snow on the ground. This method provided adequate snowmelt-runoff quantities for the overall mass balance.

Model-Calibration Procedures

Model calibration was achieved in a stepwise manner by first obtaining acceptable annual and monthly mass balances, and then adjusting parameters to obtain acceptable agreement between the observed and simulated partial-duration series of storm-runoff and runoff-duration curves of daily runoff. Calibration is facilitated by the hierarchical structure in HSPF in which the annual balance is most affected by one set of parameters, the monthly balances by another set, and storm runoff by a third set (Donigian and others, 1984). For example, the annual mass balance is affected primarily by the varying lower zone evapotranspiration (LZETP), DEEPFR, LZSN, and INFILT parameters, whereas seasonal mass balances are affected by varying upper zone nominal storage (UZSN), baseflow evapotranspiration (BASETP), variable ground-water recession (KVARY), and interception storage (CEPSC). Storm runoff is affected by varying INFILT, INTFW, and IRC.

Calibration Criteria

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, the sum of absolute differences, and the 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). However, calibration could only be performed for 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 because of the size of the model-output file and the complexity of the model. 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.

Because the HSPF calibration is performed in a stepwise manner—matching the overall water balance, the annual water balances, followed by the monthly water balances, and finally, considering storm-runoff 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 Burges (1982) recommend that graphical and statistical means be utilized 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 percentage of error was considered. Donigian and others (1984) state that in HSPF simulation, the annual or monthly fit is very good when the error is less than 10 percent, good when the error is 10 to 15 percent, and fair when the error is 15 to 25 percent.

Plots of observed and simulated runoff were prepared for the monthly water balance and checked for periods of consistent overestimation or underestimation. The quality of fit for monthly values was also 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 of error was less than a specified percentage (10 and 25 percent were used in this study). The average relative percentage of error in monthly flows over the calibration period was also used, but 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

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

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, and N is the number of months in the calibration period. The coefficient of model-fit efficiency, E, is calculated as

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

James and Burges (1982) suggest that an excellent calibration is obtained if the coefficient of model-fit efficiency exceeds 0.97. They present an example of an HSPF application where both the correlation coefficient and the coefficient of model-fit efficiency for daily flows exceed 0.98. For the Stanford Watershed Model, Crawford and Linsley (1966) reported correlation coefficients for daily flows of 0.94 to 0.98 for seven watersheds with areas of 18 to 1,342 mi^2 and with periods of record of 4 to 8 years. Other researchers studying monthly flows have determined best model fits with lower correlation coefficient 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. Chew and others (1991) applied HSPF to a 56.4 mi^2 agricultural watershed in western Tennessee and obtained a correlation coefficient for monthly flows of 0.8 for a 54-month calibration period.

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 indicate adequate calibration over the range of the flow conditions simulated. Significant or consistent departures between the observed and simulated runoff-duration curves indicate inadequate calibration. Certain characteristics of the model applied could contribute to departure of the runoff-duration curves. For example, hydraulically unconnected impervious areas are not simulated in the model. These are impervious areas that generate runoff that does not directly reach the stream channel. Runoff from these areas drains across adjacent pervious areas and may infiltrate before reaching a stream channel. Differences between the observed and simulated 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. Instead of routing, 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 analysis were avoided by applying 3-day storm volumes.

The quality of fit for the larger storms was checked graphically by the agreement between the simulated and observed partial-duration series of runoff. Runoff volumes were compared because the hydraulic routing in HSPF was not utilized in this study. Three-day runoff volumes were compared to ensure consistency in the definition of the runoff resulting from a storm. For example, Bradley and Potter (1992) compared 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 considered in the five watersheds in Lake County, the runoff had returned to near base-flow conditions in 3 days. The storms in the partial-duration-series analysis were selected such that no storms of less than 0.5 in. of observed runoff would be considered. The threshold value of 0.5 in. of runoff was selected to provide a suitable number of storms for analysis and yet exclude smaller storms. The annual probability of exceedance of each storm was determined according to Langbein (1949).

Regional Calibration

The initial phase of model calibration determined best-fit simulations for each of the five watersheds and the four HRU's. Each watershed was calibrated separately. This procedure provided a best-fit parameter set for each watershed. Results of simulations with the best-fit parameter sets were used to assess the quality of the regional calibrations. A trial-and-error approach of varying the model parameters beginning with the best-fit calibration parameters was used to develop the regional-calibration parameter sets. The goal of the regional calibrations was to develop two regional parameter sets: one that would adequately simulate runoff for the five watersheds and another that would adequately simulate runoff for the four HRU's. In the development of the regional parameter set for the five watersheds, three watersheds were used for joint model calibration, and two watersheds were used for model verification. The three watersheds chosen for model calibration (Squaw, Flint, and Indian Creeks) have drainage areas between 17.2 and 37.0 mi^2 and represent the midrange of drainage-area size for watersheds considered in this study. The largest (Mill Creek) and the smallest (Bull Creek) of the five watersheds were used for model verification.

In order to develop a regional parameter set for the HRU's, only the three HRU's with pervious area (Tempel Farms Ditch, Terre Faire Ditch, and Green Lake Ditch) were used. This was done because most of the HSPF parameters affect only the simulation of pervious areas. Because of the relatively short period of input data available for the HRU's (26 months), no model verification was done. Therefore, more confidence can be placed in the regional parameter set for the watersheds than in the regional parameter set for the HRU's.

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 of the calibrated parameter set would indicate that, within certain conditions identified in the calibration process, the parameter set is suitable for simulating runoff on small watersheds within Lake County.

The regional parameter set for the watersheds was verified with streamflow records from two of the watersheds (Bull and Mill Creeks) that were not used in the regional model calibration. The two watersheds used for verification have drainage areas of 6.3 and 59.6 mi^2, and represent the smallest and largest watersheds in this study, respectively. These two watersheds were selected to provide a more rigorous verification of the calibrated parameter set because they represent the extremes in drainage-area size. Because neither of the two watersheds used for verification was used in the regional calibration procedure, the entire period of streamflow record (43 months) at each watershed was available for the verification of the calibrated parameter set. Verification of the calibrated parameter set consisted of simulating the entire period of record for each of the verification watersheds using the calibrated parameter set. An acceptable verification was achieved if statistical results from the verification simulation were close to those for the best-fit model simulations.

Results of Model Calibration

Model-calibration results for the watersheds are presented in two formats: results of individual best-fit calibration for each watershed and the results of regional calibration. The statistical results of the best-fit model calibrations for the watersheds are summarized in table 4. Parameter values for both the best-fit and regional calibrations of individual watersheds are listed for each of the fixed parameters and monthly variable parameters in tables 5 and 6, respectively. The statistics obtained when the watersheds are simulated with the regional-calibration parameter set are summarized in table 7. The annual and grand total water balances for simulations with application of the best-fit and regional model parameters for the five watersheds are summarized in table 8. The statistical results of the best-fit model calibrations for the three HRU's that were simulated are summarized in table 9. Parameter values for both the best-fit and regional calibrations of individual watersheds are listed for each of the HRU fixed parameters and monthly variable parameters in tables 10 and 11,

Table 4. Model-calibration statistics for five watersheds in Lake County, Ill., simulated with application of the best-fit calibration parameter set for a 43-month calibration period

	Watershed				
	Indian Creek	Squaw Creek	Flint Creek	Mill Creek	Bull Creek
Coefficient of model-fit efficiency	0.9184	0.8796	0.9347	0.8687	0.8989
Correlation coefficient	.9586	.9391	.9672	.9328	.9503
Number of months when the difference between simulated and observed average monthly discharge was less than 10 percent	16	13	18	12	13
Number of months when the difference between simulated and observed average monthly discharge was less than 25 percent	26	24	29	24	22

Table 5. Fixed parameter values for the best-fit and regional calibrations of five watersheds in Lake County, Ill.

[HSPF, Hydrological Simulation Program–Fortran; --, variable depending on watershed drainage area]

HSPF parameters: INFILT, infiltration; INTFW, interflow; IRC, interflow recession constant; LZSN, lower zone nominal storage; AGWRC, ground-water recession constant; DEEPFR, inactive ground water; AGWETP, ground-water evapotranspiration

	Watershed					
HSPF parameters	Indian Creek	Squaw Creek	Flint Creek	Mill Creek	Bull Creek	Regional calibration
INFILT	0.040	0.040	0.042	0.040	0.040	0.040
INTFW	10.0	10.0	10.0	10.0	10.0	10.0
IRC	.83	.83	.84	.88	.65	--
LZSN	.020	.022	.020	.013	.020	.020
AGWRC	.99	.99	.99	.99	.99	.99
DEEPFR	.25	.25	.25	.25	.25	.25
AGWETP	.050	.085	.085	.045	.045	.068

Table 6. Monthly variable model parameter values for the best-fit and regional calibrations of five watersheds in Lake County, Ill.
[UZSN, upper zone nominal storage parameter; LZETP, lower zone evapotranspiration parameter; CEPSC, interception storage parameter; RETSC, retention storage parameter]

Parameter	Watershed or land cover[1]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
UZSN	Mill	3.4	1.8	1.0	0.7	0.4	0.3	2.4	3.5	4.5	6.5	4.0	2.3
	Bull	2.6	2.2	1.0	.9	.3	.2	1.5	1.5	3.9	6.0	3.0	2.6
	Indian	3.2	2.3	1.6	1.0	.4	.6	1.3	2.1	2.1	6.0	4.7	2.0
	Flint	3.3	1.8	1.5	1.3	.7	.7	1.5	2.1	2.1	6.0	3.8	2.8
	Squaw	3.7	2.5	1.3	1.0	.4	.5	2.0	3.0	4.0	5.2	3.8	2.3
	Regional	3.2	2.1	1.3	.9	.4	.5	1.7	2.4	3.3	5.9	3.9	2.4
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
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
RETSC	Impervious	.10	.10	.10	.10	.10	.10	.20	.20	.20	.20	.20	.10

[1]Mill, Bull, Indian, Flint, and Squaw refer to watersheds. Regional refers to the regional parameter set developed during the calibration phase of modeling. Grass and forest refer to land covers.

Table 7. Model-calibration and verification statistics for five watersheds in Lake County, Ill., simulated with application of the regional-calibration parameter set for a 43-month calibration period

	Calibration watershed			Verification watershed	
	Indian Creek	Squaw Creek	Flint Creek	Mill Creek	Bull Creek
Coefficient of model-fit efficiency	0.9089	0.8799	0.9106	0.8678	0.8838
Correlation coefficient	.9372	.9354	.9463	.9340	.9454
Number of months when the difference between simulated and observed average monthly discharge was less than 10 percent	14	14	16	11	12
Number of months when the difference between simulated and observed average monthly discharge was less than 25 percent	26	24	26	24	23

Table 8. Observed and simulated (with application of the best-fit and regional parameter sets) annual and total runoff from five watersheds in Lake County, Ill.

[Values are in inches of runoff. Observed refers to observed data; best-fit refers to simulated data with application of the best-fit parameter set; regional refers to simulated data with application of the regional parameter set]

Watershed	Water Year				Total
	[1]1990	1991	1992	1993	
Indian Creek:					
observed	9.96	12.71	8.62	21.72	53.01
best-fit	10.68	12.90	10.56	19.82	53.96
regional	10.39	13.48	10.72	19.60	54.19
Squaw Creek:					
observed	7.98	12.51	8.07	21.82	50.38
best-fit	9.10	10.84	9.68	20.20	49.82
regional	9.29	10.77	9.73	20.93	50.72
Flint Creek:					
observed	9.80	12.34	9.04	18.81	49.99
best-fit	9.13	10.21	9.81	17.53	46.68
regional	10.19	11.68	10.43	17.98	50.28
Mill Creek:					
observed	8.43	12.41	8.09	22.66	51.59
best-fit	8.34	11.88	10.18	20.03	50.43
regional	8.85	10.87	9.94	20.33	49.99
Bull Creek:					
observed	8.69	12.13	7.40	20.09	48.31
best-fit	8.34	11.45	9.02	18.19	47.00
regional	9.12	11.28	8.95	17.25	46.60

[1]1990 data for all watersheds represents a partial year, March through September 1990.

respectively. The statistical results of the regional model calibrations for each HRU are shown in table 12.

Best-Fit Calibration

Best-fit model calibration of the five watersheds produced good results. Best-fit model calibration statistics were similar to or better than reported results from similar studies with the Stanford Watershed Model or HSPF (Ligon and Law, 1973; Dinicola, 1989; Chew and others, 1991; Price and Dreher, 1991). For simulations using the best-fit model-parameter sets, correlation coefficients range from 93.3 to 96.7 percent and coefficients of model-fit efficiency range from 86.9 to 93.5 percent (table 4). The relatively narrow range in the best-fit model parameters (tables 5 and 6) is an indication that the model calibration of the best-fit parameter set for each watershed is acceptable. A wide range in parameter values would indicate a need for further calibration. Water balances for the five watersheds simulated with the best-fit parameter set were within 6.7 percent of the observed data during the study (table 8). Annual water balances for each of the five watersheds are more variable. Errors in annual water balances ranged from –17.3 to 25.8 percent. The average absolute relative difference between the observed and simulated annual water balances for the five watersheds was 10.4 percent, falling just outside the range for a “very good” calibration as defined by Donigian and others (1984). Simulated annual water balances for the watersheds are consistently within 2 in. of the observed annual water balances, but, for the drier years with low total runoff, the absolute relative differences are greater. In each watershed, the annual water balances show the most departure from the observed data in the 1992 water year, which was the driest year during the study, resulting in only 50 to 75 percent of the runoff observed in the other years.

Runoff-frequency plots indicate a good correlation between the observed and simulated 3-day storm totals for the five watersheds (figs. 11–15, at end of report). The simulation of storm-runoff was most sensitive to the IRC, because most of the storm runoff from the pervious segments was simulated as flowing through interflow storage (fig. 9).

Analysis of the runoff-duration curves for the observed and simulated (with application of the best-fit and regional parameter sets) data (figs. 16–20, at end of report) provides insight into model performance over the full range of hydrologic conditions. Runoff-duration curves of the observed and simulated data for the five watersheds indicate excellent simulations for all flow conditions, except for low-flow periods at Flint Creek. The higher sustained base-flow condition at Flint Creek may be the result of the wastewater-treatment effluent discharged into Flint Creek in the upper reaches of the watershed. Low-flow periods at Mill and Bull Creeks are somewhat oversimulated, although within reasonable limits. Simulated low-flow runoff is most sensitive to values of parameters that affect evapotranspiration, such as AGWETP, LZSN, and UZSN, as well as the AGWRC (fig. 9).

Best-fit model calibration of the HRU’s produced mixed results. The period of record available for HRU model calibration was relatively short (26 months). Model parameter values for the HRU’s are given in tables 10 and 11. The correlation coefficients and coefficients of model-fit efficiency obtained during model calibration were very good for Tempel Farms Ditch and Terre Faire Ditch, and good for Green Lake Ditch (table 9). However, the

Table 9. Model-calibration statistics for three hydrologic response units in Lake County, Ill., simulated with application of the best-fit calibration parameter set for a 26-month calibration period

	Hydrologic response unit		
	Tempel Farms Ditch	Terre Faire Ditch	Green Lake Ditch
Coefficient of model-fit efficiency	0.9551	0.9751	0.9073
Correlation coefficient	.9780	.9883	.9580
Number of months when the difference between simulated and observed average monthly discharge was less than 10 percent	5	8	2
Number of months when the difference between simulated and observed average monthly discharge was less than 25 percent	9	12	10

Table 10. Model parameter values for the best-fit and regional calibrations of three hydrologic response units in Lake County, Ill.

[HSPF, Hydrological Simulation Program–Fortran; --, not applicable because no impervious land cover was present]

HSPF parameters: INFILT, infiltration; INTFW, interflow; IRC, interflow recession constant; LZSN, lower zone nominal storage; AGWRC, ground-water recession constant; DEEPFR, inactive ground water; AGWETP, ground-water evapotranspiration; RETSC, retention storage

	Hydrologic response unit			
HSPF parameters	Tempel Farms Ditch	Terre Faire Ditch	Green Lake Ditch	Regional calibration
INFILT	0.042	0.045	0.018	0.034
INTFW	25	35	30	30
IRC	.68	.08	.10	.40
LZSN	.020	.065	.018	.028
AGWRC	.91	.94	.89	.91
DEEPFR	.03	.25	.00	.04
AGWETP	.16	.24	.13	.07
RETSC	--	.95	.34	.50

confidence in the model parameter sets is relatively low because of the short period of streamflow record. Most references on HSPF or the Stanford Watershed Model recommend 3 to 5 years or more of record for adequate model calibration (Donigian and others, 1984; Linsley and others, 1982, p. 347). Significant changes in certain model parameters, such as the monthly variable parameter UZSN, can be expected as more data are collected and the period of record available for calibration increases.

Analysis of the observed and simulated (with application of the best-fit parameter set) runoff-duration curves for the HRU's indicates an excellent fit for most flow conditions, except low-flow conditions at Tempel Farms Ditch and Green Lake Ditch, where simulated runoff was greater than observed runoff (figs. 21–23, at end of report). This oversimulation of low flow results from difficulties simulating an intermittent stream. The lowest point plotted on the runoff-duration curves represents the lower limit of measurable runoff at 0.01 ft^3/s. Simulation of intermittent flows characteristic of the HRU's was accomplished by adjusting ground-water parameters such as LZSN, AGWETP, DEEPFR, and

Table 11. Monthly variable model parameter values for the best-fit and regional calibrations of three hydrologic response units in Lake County, Ill.

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

Parameter	Watershed or land cover[1]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
UZSN	Tempel Farms	3.0	3.0	1.2	0.7	0.1	0.4	0.7	1.0	5.0	5.0	4.7	2.2
	Terre Faire	4.0	4.5	1.5	.9	.9	.4	.2	.2	3.9	6.0	6.0	3.2
	Green Lake	2.2	2.2	1.0	.4	.5	.5	.9	3.0	2.5	2.5	2.5	2.2
	Regional	3.0	3.2	1.2	.6	.4	.4	.3	1.4	3.7	4.0	4.0	2.5
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
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

[1] Tempel Farms, Terre Faire, and Green Lake refer to watersheds. Regional refers to the regional parameter set developed during the calibration phase of modeling. Grass and forest refer to land covers.

Table 12. Model-calibration statistics for three hydrologic response units in Lake County, Ill., simulated with application of the regional calibration parameter set for a 26-month calibration period

	Hydrologic response unit		
	Tempel Farms Ditch	Terre Faire Ditch	Green Lake Ditch
Coefficient of model-fit efficiency	0.8953	0.8752	0.8675
Correlation coefficient	.9473	.9460	.9371
Number of months when the difference between simulated and observed average monthly discharge was less than 10 percent	5	4	3
Number of months when the difference between simulated and observed average monthly discharge was less than 25 percent	7	10	12

AGWRC (fig. 9). The adjustment essentially shut down the ground-water reservoir in HSPF. The fluctuations of the water table were simulated through variations in the upper-zone storage and interflow. Low IRC values were utilized to simulate the quick runoff response that is characteristic of small developed watersheds such as Green Lake Ditch and Terre Faire Ditch. In each of the HRU's, depending on storm characteristics and ground-water levels, runoff may last for only a relatively short time following a storm.

Relation Between Interflow Recession Constant and Drainage Area

In the development of the regional-calibration parameter set for the five watersheds, a single value of IRC was determined. However, significant differences resulted between the observed and simulated runoff-frequency plots when this value for IRC was applied in model verification for Bull and Mill Creek watersheds. If IRC is too high, storm peaks and 3-day runoff are undersimulated because the interflow is released to the stream from interflow storage over a long period. If IRC is too low, oversimulation of peak flows and 3-day runoff results because all of the interflow is released to the stream in a short period. Analysis of the best-fit calibration of the five watersheds revealed that the value of IRC increased with increasing drainage area. This increase is reasonable because interflow should reach the stream sooner in smaller watersheds.

The preliminary verification indicated that accounting for the relation between IRC and drainage area in the regional approach to rainfall-runoff modeling in Lake County with HSPF simulation is necessary. A relation between IRC and drainage area was developed for use with the regional parameter set. Optimum values for IRC were determined for the five watersheds for simulations with all other model parameters set to the values determined by regional calibration on Indian, Squaw, and Flint Creeks. Utilizing these optimum IRC values and the drainage areas of the five watersheds, the following relation between the IRC value and drainage area was obtained by linear regression as

$$IRC = 0.09389 \ ln \ A + 0.5043, \qquad (3)$$

where A is drainage area, in square miles (fig. 24, at end of report). The coefficient of determination for equation 3 is 0.8965. The regional parameter set for the watersheds discussed in the following sections consists of the parameter values given in tables 5 and 6 and the IRC value calculated with equation 3.

Regional Calibration

The purpose of the regional calibration was to develop a single parameter set that would adequately simulate rainfall-runoff relations for watersheds within Lake County. Developing two regional parameter sets, however, was necessary because of important hydrologic differences between the watersheds and the HRU's. The regional parameter set developed for the watersheds is appropriate for watersheds of approximately 6 to 60 mi^2. The parameter set developed for the HRU's is appropriate for watersheds of approximately 40 to 300 acres.

The quality of model simulations with the regional parameter sets was assessed by comparing regional statistics for each watershed. Tables 5 and 6 summarize the regional calibration parameter set, and a comparison of the regional calibration parameter values and the best-fit parameter values. As expected, the regional calibration statistics (table 7) indicate a worse fit between observed data and simulated results than the best-fit statistics (table 4) for each watershed. However, the decrease in the coefficient of model-fit efficiency was smaller than 2.5 percent, and the correlation coefficient was smaller than 2.2 percent for all three watersheds. Thus, the regional-calibration statistics indicate that the regional-calibration parameter set provides an acceptable simulation of watersheds in Lake County.

For Indian Creek, the regional parameter set is very similar to the best-fit parameter set because the regional parameter set that was developed with Indian, Squaw, and Flint Creeks produced a better simulation of Indian Creek than the parameter set that had previously been considered to be the best-fit parameter set for Indian Creek. Thus, Indian Creek is the only watershed where there is no decrease in model performance when the regional parameter set is used instead of the best-fit parameter set. The observed and simulated (with the application of the regional parameter set) monthly runoffs are shown in figures 25–32 (at end of report) for the watersheds used for calibration.

For Squaw Creek, 3-day storm volumes were oversimulated with the regional parameter set (fig. 12) because the value of IRC is too low, as seen by comparing the regional value of IRC (0.75) with the best-fit value of IRC (0.83) for Squaw Creek. For medium and low flows, satisfactory simulation for Squaw Creek resulted with the regional parameter set (fig. 17). The observed and simulated (with the application of the regional parameter set) monthly runoffs are shown in figure 26.

The runoff-frequency plots and runoff-duration curves for Flint Creek (figs. 13 and 18, respectively) are satisfactorily simulated with application of the regional parameter set. Except for the largest storm, most 3-day storm volumes are slightly oversimulated with application of the regional parameter set. The observed runoff-duration curve departs from both simulated curves at low-flow conditions, which may be the result of variability in effluent discharge rates from the wastewater-treatment facility in the upper reaches of the watershed. The observed and simulated (with the application of the regional parameter set) monthly runoffs are shown in figure 27.

The graphical and statistical evaluations between the simulation with application of the regional parameter set and the simulation with application of the best-fit parameter set indicate that the degradation in overall fit quality needed to establish a regional parameter set for the watersheds is small. The model verification reported in the next section further tests the county-wide applicability of the regional parameter set.

Regional calibration of the HRU's produced mixed results. Regional parameters for the HRU's are given in tables 10 and 11. Again, the period of record available for calibration limits the confidence in the regional parameter set. As expected, the correlation coefficients and coefficients of model-fit efficiency for simulation with application of the regional parameter set were slightly lower than the statistics for simulation with application of the best-fit parameter sets. Correlation coefficients ranged from 0.94 to 0.95, and coefficients of model-fit efficiency ranged from 0.88 to 0.90 (table 12). The regional parameter-set statistics indicate a 1 to 5 percent decrease in correlation coefficient and a 2 to 8 percent decrease in the coefficient of model-fit efficiency between the best-fit parameter set and the regional parameter set. The degradation in the overall fit needed to establish a regional parameter set for the HRU's is relatively small and indicates that with further data collection and verification, a satisfactory regional parameter set can be developed.

Analysis of the observed and simulated (with application of the regional parameter set) runoff-duration curves for the HRU's (figs. 21–23) indicates an overall satisfactory fit for high- and medium-flow conditions, with some departure of the curves for low-flow conditions. As for the simulations with the application of the best-fit parameter set, the departure of the simulated runoff-duration curves at low-flow conditions reflects the difficulty in simulating the intermittent flows for each of the HRU's during certain periods. These difficulties in simulating intermittent flows are clearly illustrated in figures 30–32 in which the observed and simulated (with application of the regional parameter set) monthly runoffs are compared for each HRU. A special emphasis on simulation of high flows was utilized during the calibration procedure because the primary application of modeling was stormwater management. Runoff-frequency plots were not analyzed for the HRU's because of the short periods of record. Continued data collection in the HRU's through the 1995 water year may provide for a more thorough calibration and verification of the HRU parameter sets.

The entire period of record was used for calibration because of the short period of record available for the HRU's. Therefore, the regional parameter set for the HRU's should be considered preliminary because of the short period of record and the absence of model verification.

An example User Control Input (UCI) file illustrating the input of the regional parameter set for simulation of rainfall-runoff relations for Indian Creek with HSPF is shown in Appendix A. Similarly, an example UCI file for simulation of the Tempel Farms Ditch HRU is shown in Appendix B.

Results of Model Verification

The results of model verification for simulation with the regional parameter set that was developed for the watersheds are presented in table 7 and figures 14, 15, 19, 20, 31, and 32. The coefficient of model-fit efficiency and correlation coefficient are reduced 4.4 and 1.9 percent, respectively, for Mill Creek and 3.6 and 1.5 percent, respectively, for Bull Creek relative to the results obtained for simulations with application of the best-fit parameter set for these watersheds (tables 4 and 7). Variation in the annual water balances between the simulations with application of the best-fit parameter set and the regional parameter set (table 8) ranged from 0 to 8.1 percent for most years. Variation in the grand total water balance (table 8) ranged from 0 to 6.7 percent. The relatively small variation in water balances between simulations with application of the best-fit parameter set and the regional parameter set are an indication of the simulation quality possible with the regional parameter set for ungaged watersheds.

For Mill Creek, the verification (simulation with application of the regional parameter set) yields a slightly better estimate of the two highest flows than does simulation with application of the best-fit parameter set and also provides a reasonably good approximation to the overall runoff-frequency plot (fig. 14). The Mill Creek verification provides a slightly worse approximation of medium flows and a slightly better approximation of low flows than does the best-fit calibration (fig. 19). The simulated and observed monthly runoff for the Mill Creek verification are shown in figure 31.

For Bull Creek, the verification (simulation with application of the regional parameter set) yields estimates of runoff frequency only slightly lower than estimates from the best-fit calibration (fig. 15). For medium and low flows, simulation with application of the regional parameter set produced results similar to simulation with application of the best-fit parameter set, except during extremely low-flow periods, for which simulated values with application of the regional parameter set were significantly lower than the observed data (fig. 20). Overall, however, the regional parameter set provided a very satisfactory simulation of Bull Creek runoff. The simulated and observed monthly runoff for the Bull Creek verification are shown in figure 29.

The verification and regional calibration results indicate that the regional parameter set given in tables 5 and 6 and equation 3 can be used to simulate ungaged watersheds in Lake County in a satisfactory manner. Grand total water balances were simulated within 6.2 percent of the observed data. All 20 annual water balances (4 years of data at five stations) were simulated within 23 percent of the observed data; 18 annual water balances were within 20 percent and 10 annual water balances were within 10 percent. Monthly runoff was simulated with efficiencies ranging from 0.86 to 0.91 and correlation coefficients ranging from 0.93 to 0.96. Accurate reproduction of the runoff-duration curves and runoff-frequency plots indicates satisfactory simulation of a full range of hydrologic conditions and for large storms. Therefore, the regional parameter set is adequate for simulation of runoff time series for stormwater and flood management on ungaged watersheds (with drainage areas from 6 to 60 mi^2) in Lake County. Collection of additional rainfall and runoff data can improve the quality and reliability of the regional parameters, particularly the equation to estimate IRC, if new watersheds are studied. Collection of additional data on the HRU's is needed for refinement and verification of the regional parameter set.

RAINFALL-RUNOFF RELATIONS

The simulation of runoff in a watershed provides insight to the processes that affect runoff. Most parameters in HSPF cannot be physically measured; however, parameter values should define the general relations between the processes that control 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 more than one parameter set.

The initial approach to modeling applied in this study involved calibration of the four HRU's, followed by calibration of the five watersheds, incorporating the HRU parameters. Initial parameter values were obtained from values listed in a table of the *User's Manual for the Agricultural Runoff Management (ARM) Model* (Donigian and Davis, 1978, p. 58). The value for the DEEPFR parameter, which affects the amount of recharge to aquifers, was selected on the basis of Zeizel and others (1962). This value determined the average amount of recharge to the glacial aquifers underlying the study area.

The Tempel Farms Ditch HRU, which consists of 305 acres of pasture, was the first watershed to be calibrated. The entire watershed contains agricultural drainage tiles that are used extensively throughout Illinois. Utilizing the ARM parameters and a fixed value of DEEPFR, the initial simulations produced a good overall mass balance with only minor parameter adjustment (decreased INFILT and LZSN), but the seasonal and monthly distribution of runoff was poor. The conceptualization of the HRU's focused on the small drainage areas, the lack of a continuous base flow, and the effects of drainage tiles on the subsurface flow regime. The combination of these factors resulted in the particular sensitivity of the HRU's to the effects of frozen ground conditions and the fluctuations of the water table (high in the winter and low in the summer). Therefore, a method to account for the seasonal variation in the runoff process was needed for model simulation. The most logical approach would have been to use a monthly variable INFILT parameter to consider frozen ground and a monthly variable LZSN parameter to account for water-table fluctuations (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). An alternate means of obtaining monthly variability was needed because a single value can be utilized for these parameters throughout the year. The model was essentially simplified to have only one subsurface zone by constricting INFILT and reducing LZSN to a very small value. The simplified subsurface zone was not conceived as part of the conceptualization for the HRU's prior to modeling but was developed during the calibration process as simulation quality improved while LZSN was systematically reduced. The INTFW and IRC parameters were then calibrated to simulate the natural interflow process as well as the tile-drainage system. 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) (fig. 9). This type of simplification of the model is not unprecedented, as 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 a modification of HSPF in which the subsurface is modeled 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 found that the interacting parameters were difficult to calibrate properly and that the calibration problems could lead to significant errors when the model is used in forecasting. Therefore, Gupta and Sorooshian (1983) suggested merging the three lower zones into a single lower zone with some of the functions of the lower zone partially absorbed by the upper zone to improve parameter identification (that is, make calibrations more consistent) and the accuracy of the model in forecasting.

Initial HSPF simulations for the five watersheds in Lake County also yielded good overall and annual water balances when the ARM Model parameters were used. However, the monthly flow variations were again quite large. The water table in Lake County is typically quite shallow and water-table fluctuations cause the available moisture capacity in the root zone (the lower zone storage) to be low in the winter and high in the summer. Thus, because the LZSN parameter cannot be varied on a monthly basis, the lower zone and upper zone were again functionally combined (that is, LZSN was set to 0.02) to simulate the effects of monthly variations in lower zone storage. In contrast to the HRU's, the watersheds studied had a continuous base flow, and INFILT was assigned a reasonable value to allow the ground-water zone to be active.

As outlined earlier, hydraulic routing of the runoff was beyond the scope of this study. Peak flows associated with the runoff volumes can be derived by linking the runoff volumes generated in HSPF to a hydraulic model. The routing routine within HSPF, a modified kinematic-wave method, will determine peak flows given the appropriate data on the channel characteristics. Other hydraulic models have been linked to HSPF with satisfactory results. In particular, recent work in Du Page County, Ill., linked HSPF to an unsteady-flow model to generate peak flows (Price, 1994).

SUMMARY AND CONCLUSIONS

Hydrologic data were collected for five watersheds (from 6.3 to 59.6 mi^2 in area) and four watersheds (from 3.5 to 305 acres in area) with a single land-cover type (hydrologic response units, HRU's) within Lake County, Ill., to simulate rainfall-runoff relations. Rainfall-runoff relations were simulated through calibration of a rainfall-runoff model, Hydrological Simulation Program–Fortran, for the five watersheds and three of the four HRU's. The model-calibration approach consisted of two phases: obtaining best-fit parameter sets for each of the five watersheds and four HRU's, and developing two regional parameter sets through joint calibration (one for the watersheds and the other for the HRU's). The model calibration and verification errors for simulations with application of the regional parameter sets were sufficiently small for overall, annual, and monthly mass balances and event-based runoff-frequency plots to justify the use of the model for stormwater-management-planning purposes.

Correlation coefficients greater than 0.94 and coefficients of model-fit efficiency greater than 0.88 for monthly flows for the Indian, Squaw, and Flint Creek watersheds calibrated jointly indicate a satisfactory calibration of the model. Verification of the calibrated regional model parameter set for the watersheds was accomplished by applying the parameters to two watersheds with no parameter adjustment. This approach was selected because of the relatively short period of record (3 years) available for calibration at each site. Flow records from the Bull and Mill Creek watersheds were utilized for model verification. Verification demonstrated the transferability of the calibrated regional model parameters to other watersheds within Lake County, Ill. Direct application of the calibrated parameter set to the watersheds used in the verification resulted in correlation coefficients of greater than 0.93, a coefficient of model-fit efficiency of greater than 0.86, overall water balances within 7 percent, and an average absolute error in annual flow estimates of 12 percent, with all annual errors less than 23 percent. Graphical comparisons of the observed and simulated runoff-frequency plots and runoff-duration curves indicate good agreement between the observed data and simulation results. These graphical comparisons also indicate small decreases in fit quality between simulations with application of the best-fit and regional parameter sets for all five watersheds. The verification was acceptable indicating the regional parameter set may be used to simulate runoff on other watersheds of 6 to 60 mi^2 within Lake County with reasonably good results.

Although the calibration period for the HRU's was limited (26 months), the correlation coefficients of greater than 0.93 and coefficients of model-fit efficiency of greater than 0.88 indicate an acceptable regional calibration. Graphical comparison of the observed and simulated runoff-duration curves for the HRU's indicate good agreement for flows with lower exceedance probabilities (0–50 percent range). Departure of the observed and simulated runoff-duration curves for flows with higher exceedance probabilities can be related to the lack of a continuous base-flow component in the runoff from HRU's. Runoff-frequency plots were not analyzed for the HRU's, and no verification of the regional parameter set was done because of the short periods of available record. Data collection on the HRU's will continue at least through September 30, 1995. As the period of record is extended, a more thorough calibration and verification may be done.

Limits are present to the extent of the transferability of the regional parameter sets. Careful consideration should be taken if a parameter set is utilized for watersheds outside the range of drainage area studied (38.2 to 305 acres for the HRU's and 6.3 to 59.6 mi^2 for the watersheds). Similarly, the parameter set may not give satisfactory results if applied in watersheds where watershed characteristics, such as soils, are substantially different from those in the study area. The soils in the study area are predominantly silt loams to clays in texture and categorized by the Soil Conservation Service as types B, C, and D. A knowledge of wastewater-treatment facilities or other artificial flows that are not represented in the modeling process is important. Wastewater-treatment discharges need to be subtracted from streamflow records or added to simulation results. Likewise, any water withdrawals may need to be accounted for if water is removed from the watershed.

The HRU parameter set, while not formally verified, does provide useful information to a variety of stormwater-management applications, especially site design and applications dealing with watersheds with very small drainage areas. The HRU parameter set can be updated and verified as additional rainfall-runoff data become available for HRU's in Lake County.

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FIGURES 11–32

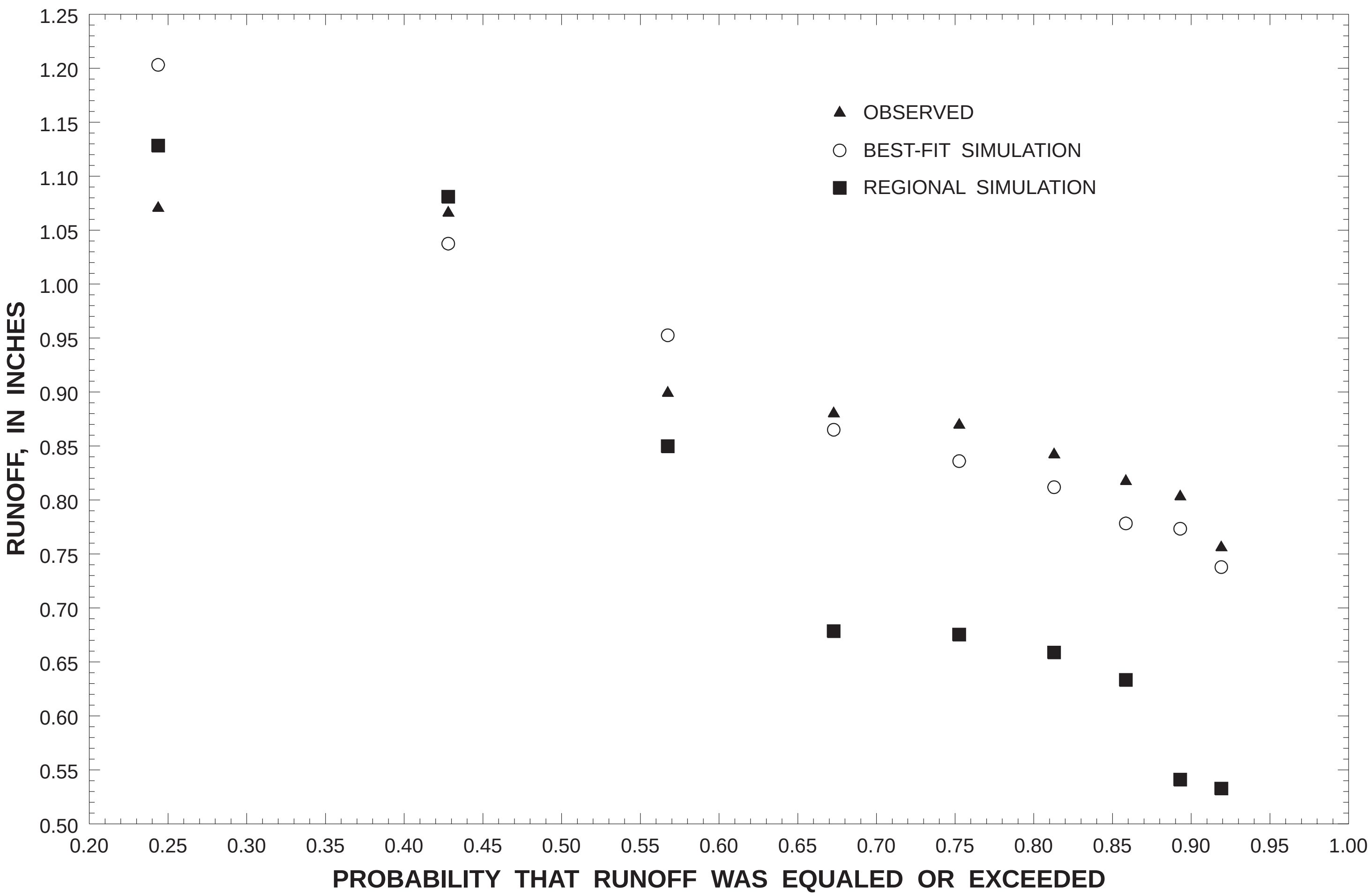

Figure 11. Runoff-frequency plots for observed data and simulations with application of the best-fit and regional parameter sets for storms producing greater than 0.5 inch of runoff in a 3-day period for Indian Creek near Prairie View, Ill.

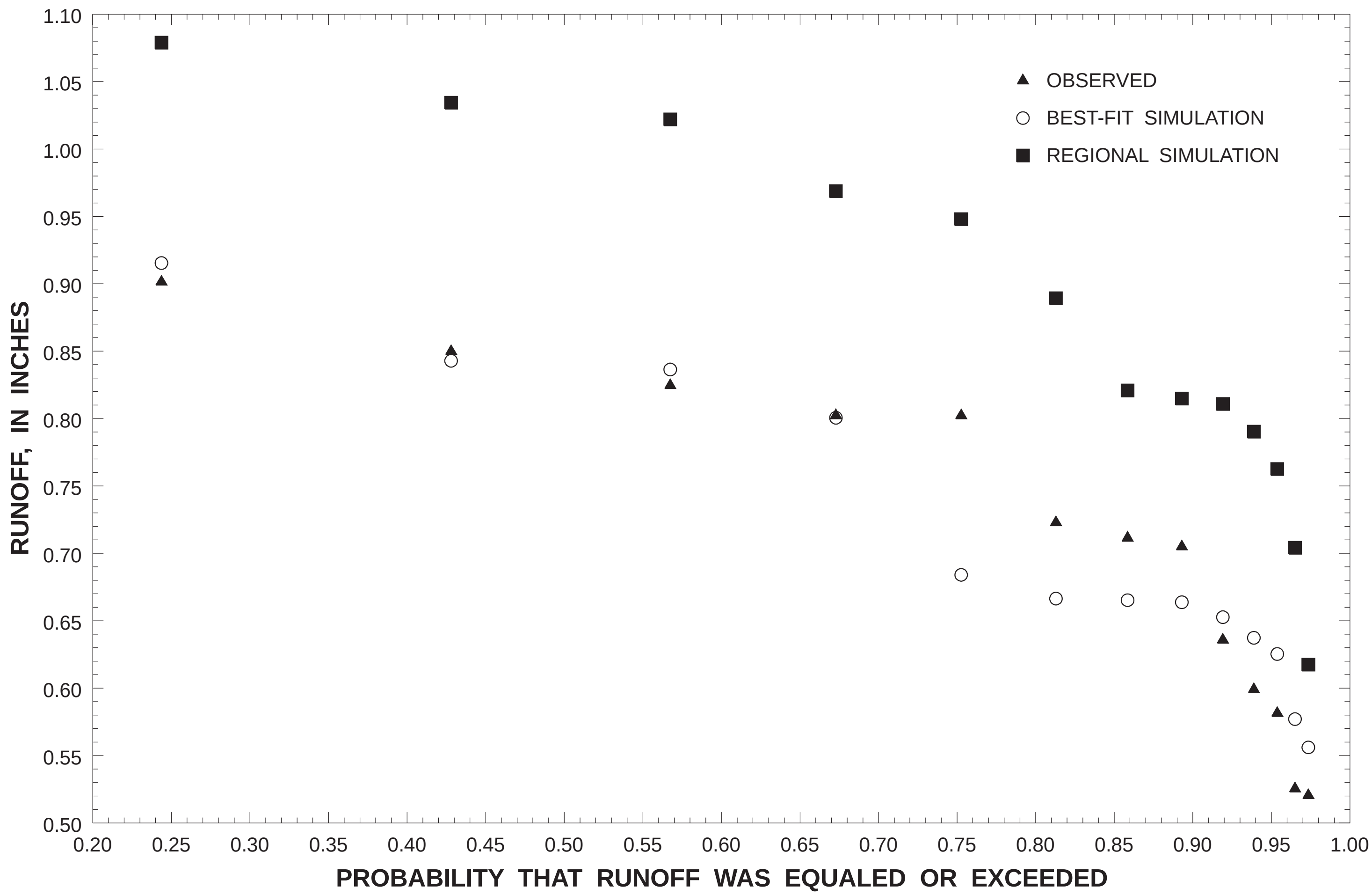

Figure 12. Runoff-frequency plots for observed data and simulations with application of the best-fit and regional parameter sets for storms producing greater than 0.5 inch of runoff in a 3-day period for Squaw Creek at Round Lake, Ill.

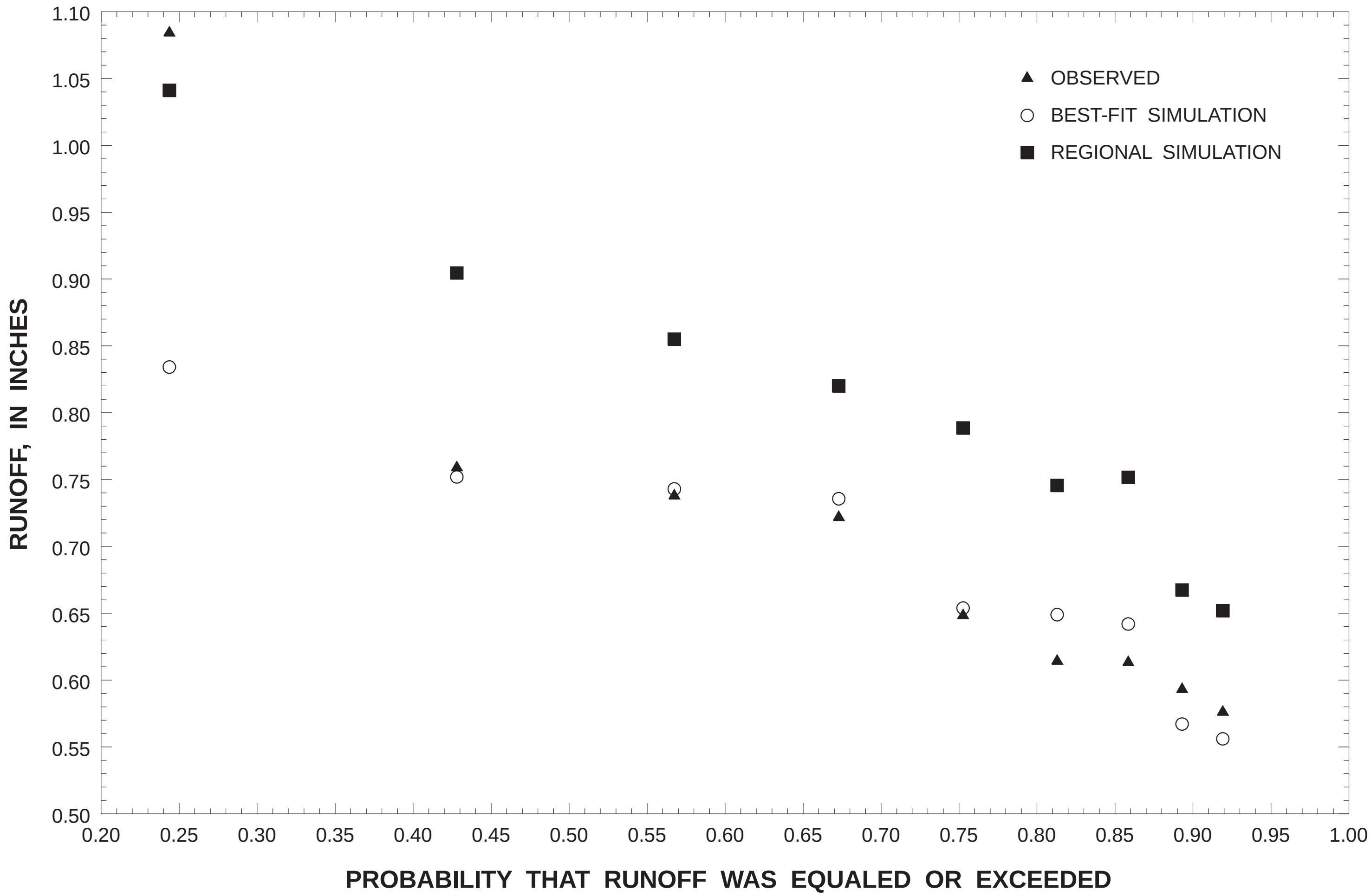

Figure 13. Runoff-frequency plots for observed data and simulations with application of the best-fit and regional parameter sets for storms producing greater than 0.5 inch of runoff in a 3-day period for Flint Creek near Fox River Grove, Ill.

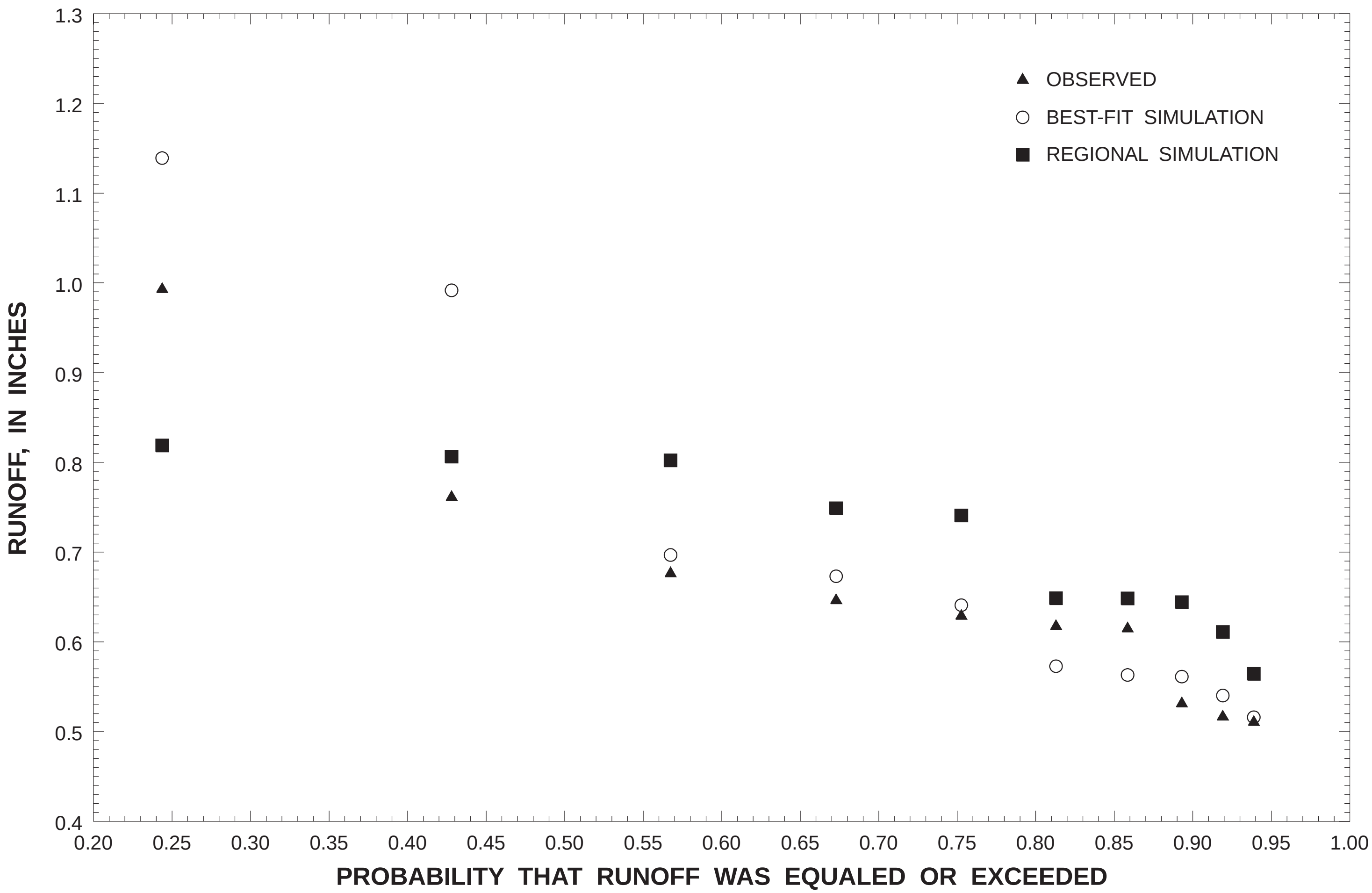

Figure 14. Runoff-frequency plots for observed data and simulations with application of the best-fit and regional parameter sets for storms producing greater than 0.5 inch of runoff in a 3-day period for Mill Creek at Old Mill Creek, Ill.

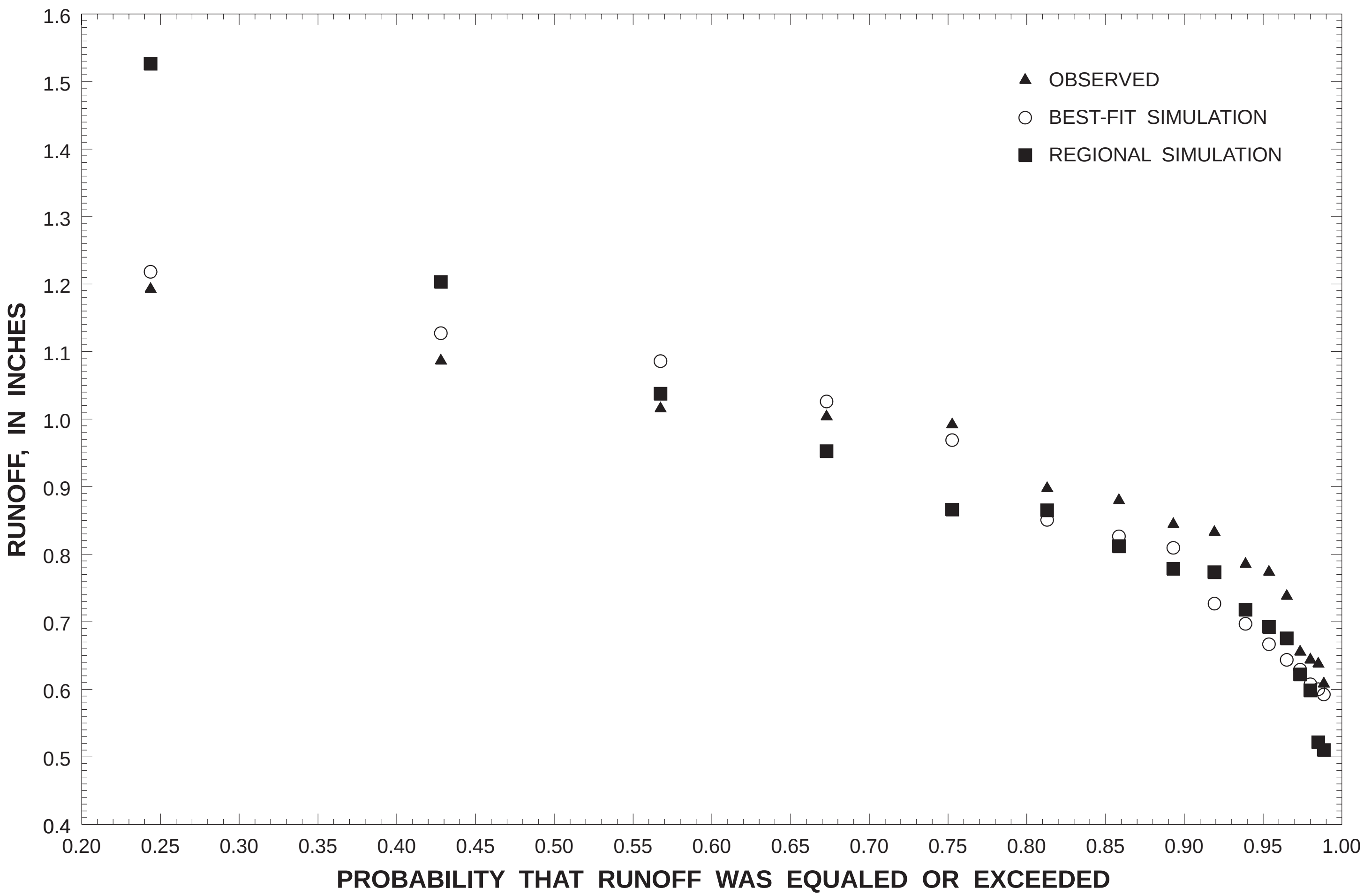

Figure 15. Runoff-frequency plots for observed data and simulations with application of the best-fit and regional parameter sets for storms producing greater than 0.5 inch of runoff in a 3-day period for Bull Creek near Libertyville, Ill.

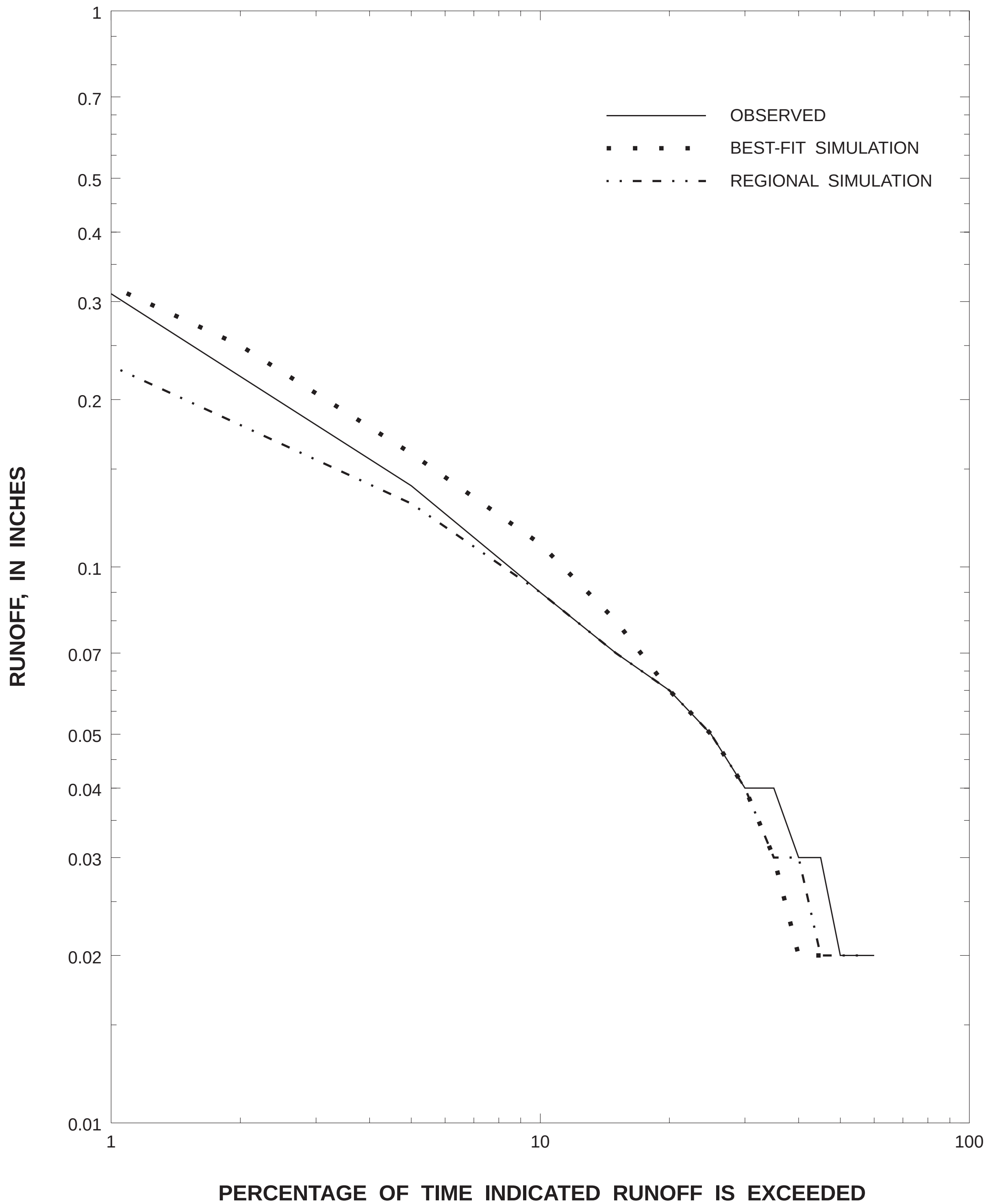

Figure 16. Runoff-duration curves with observed data and simulations with the application of the best-fit and regional parameter sets for Indian Creek near Prairie View, Ill.

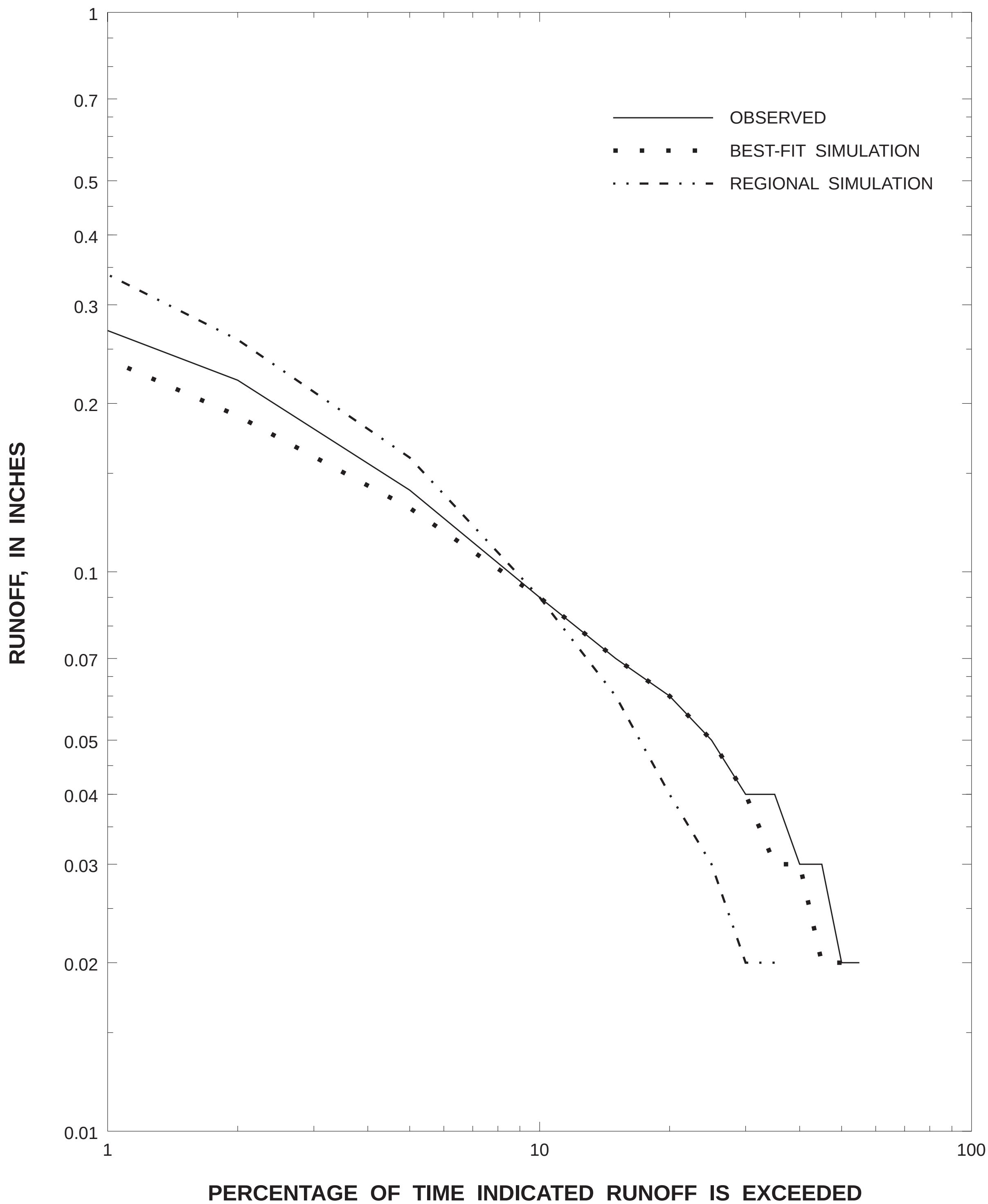

Figure 17. Runoff-duration curves with observed data and simulations with the application of the best-fit and regional parameter sets for Squaw Creek at Round Lake, Ill.

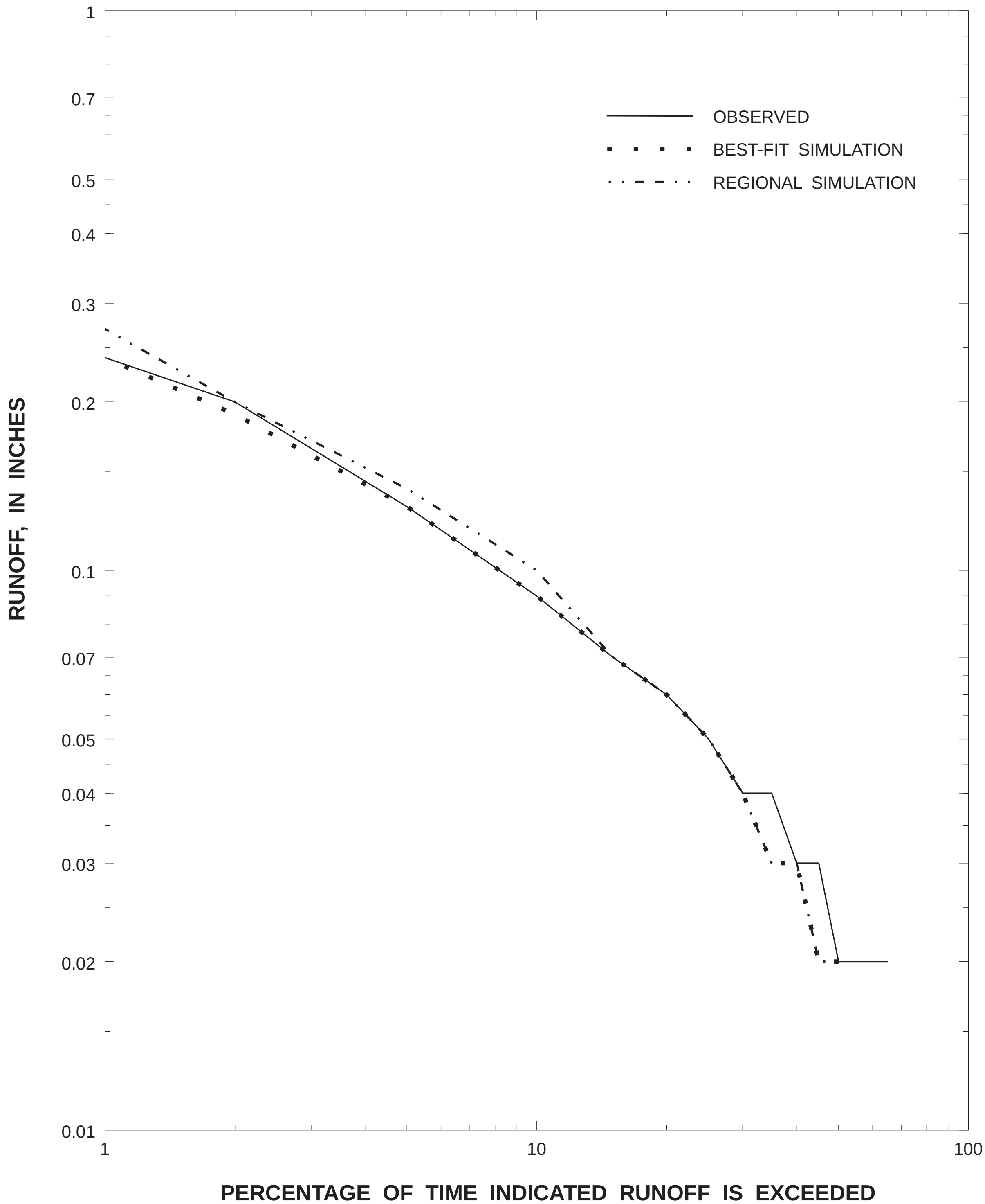

Figure 18. Runoff-duration curves with observed data and simulations with the application of the best-fit and regional parameter sets for Flint Creek near Fox River Grove, Ill.

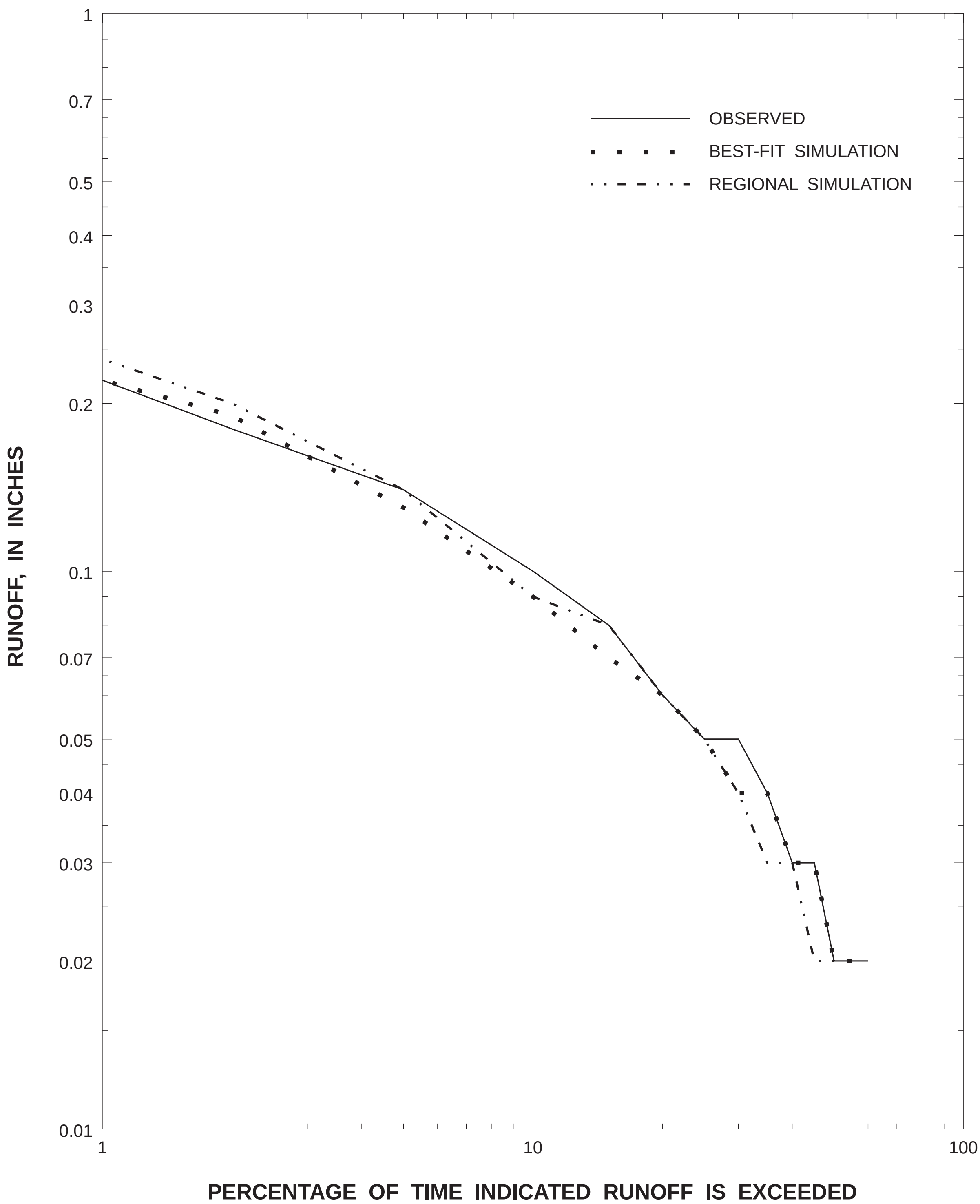

Figure 19. Runoff-duration curves with observed data and simulations with the application of the best-fit and regional parameter sets for Mill Creek at Old Mill Creek, Ill.

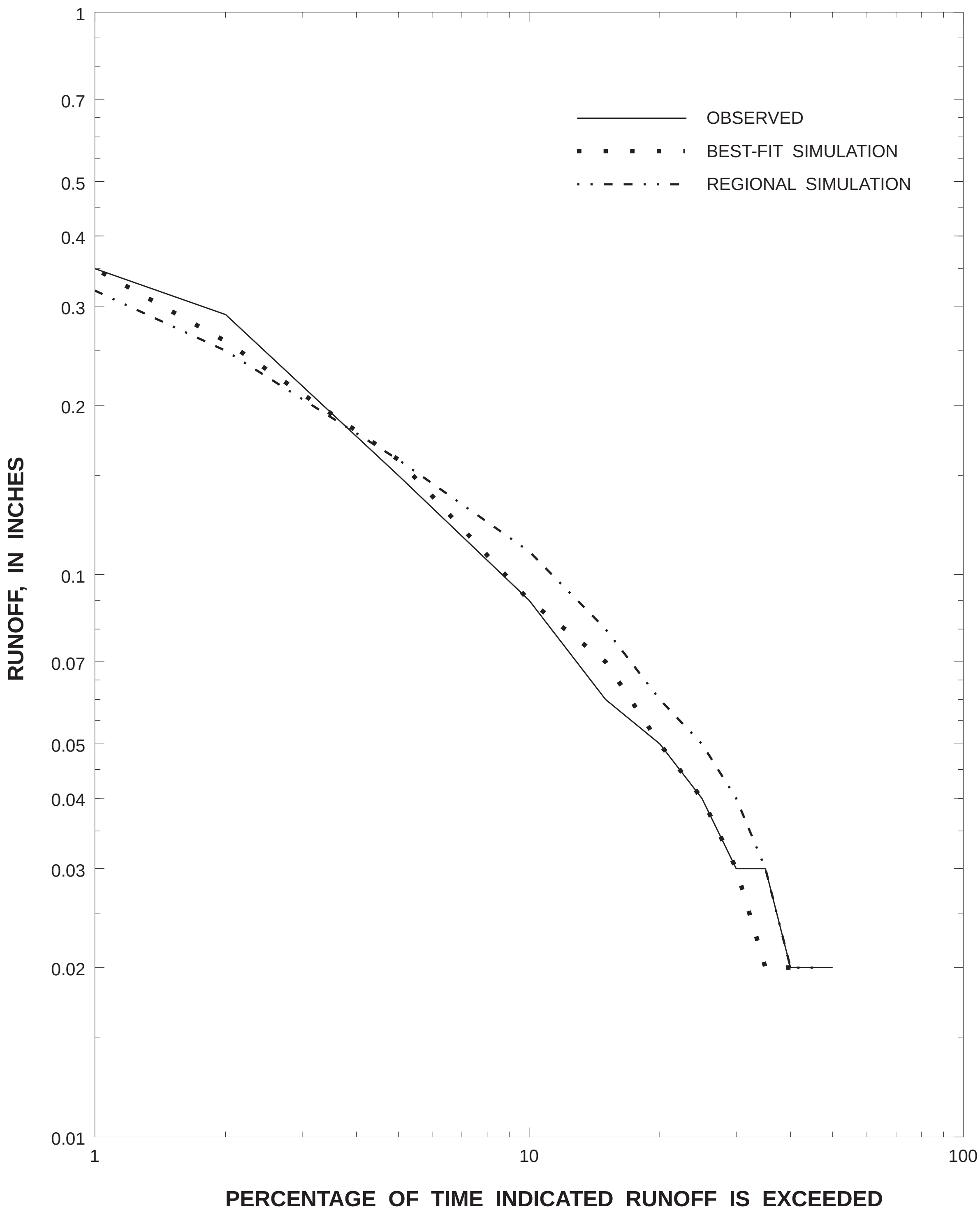

Figure 20. Runoff-duration curves with observed data and simulations with the application of the best-fit and regional parameter sets for Bull Creek at Libertyville, Ill.

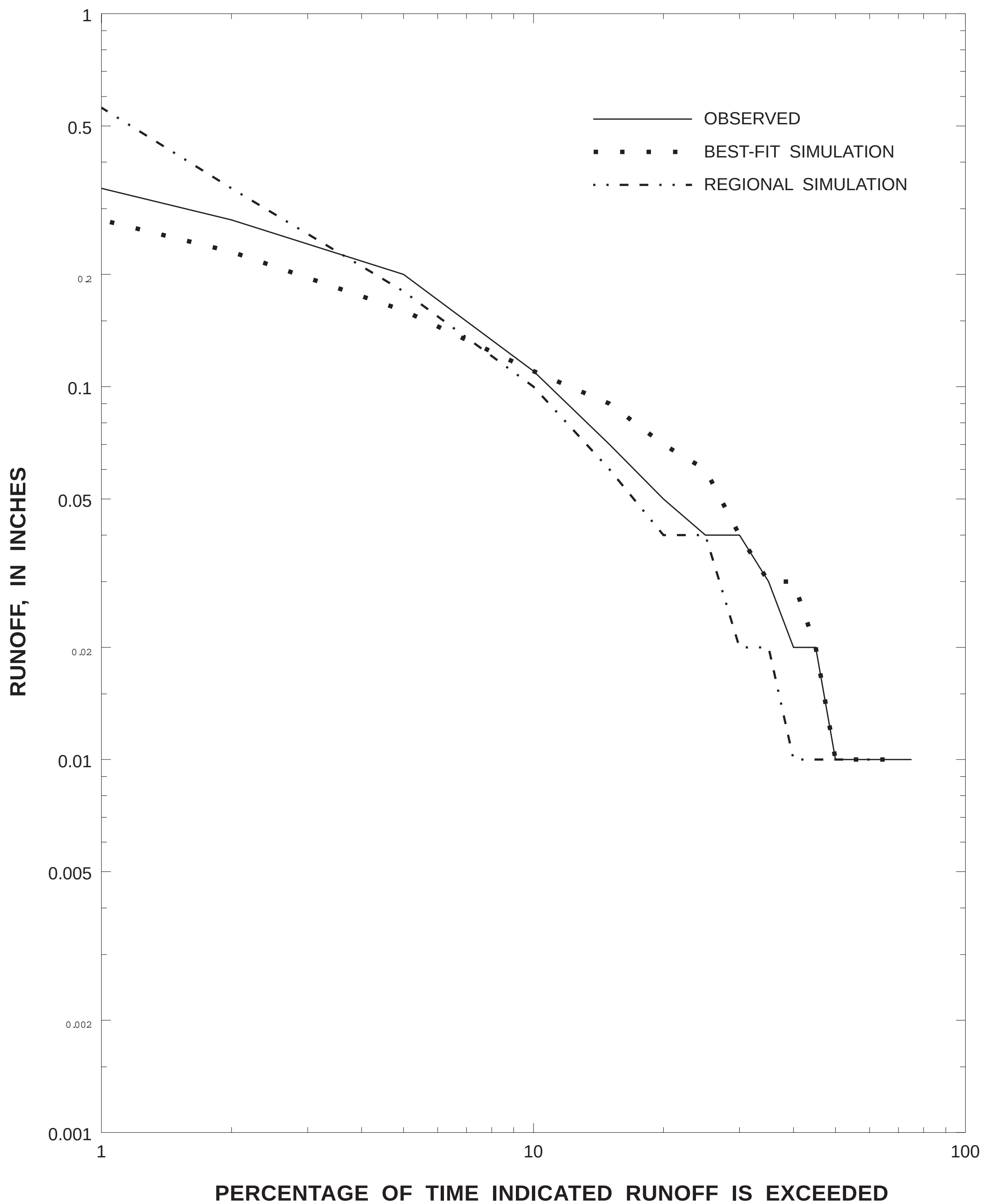

Figure 21. Runoff-duration curves with observed data and simulations with the application of the best-fit and regional parameter sets for Tempel Farms Ditch at Old Mill Creek, Ill.

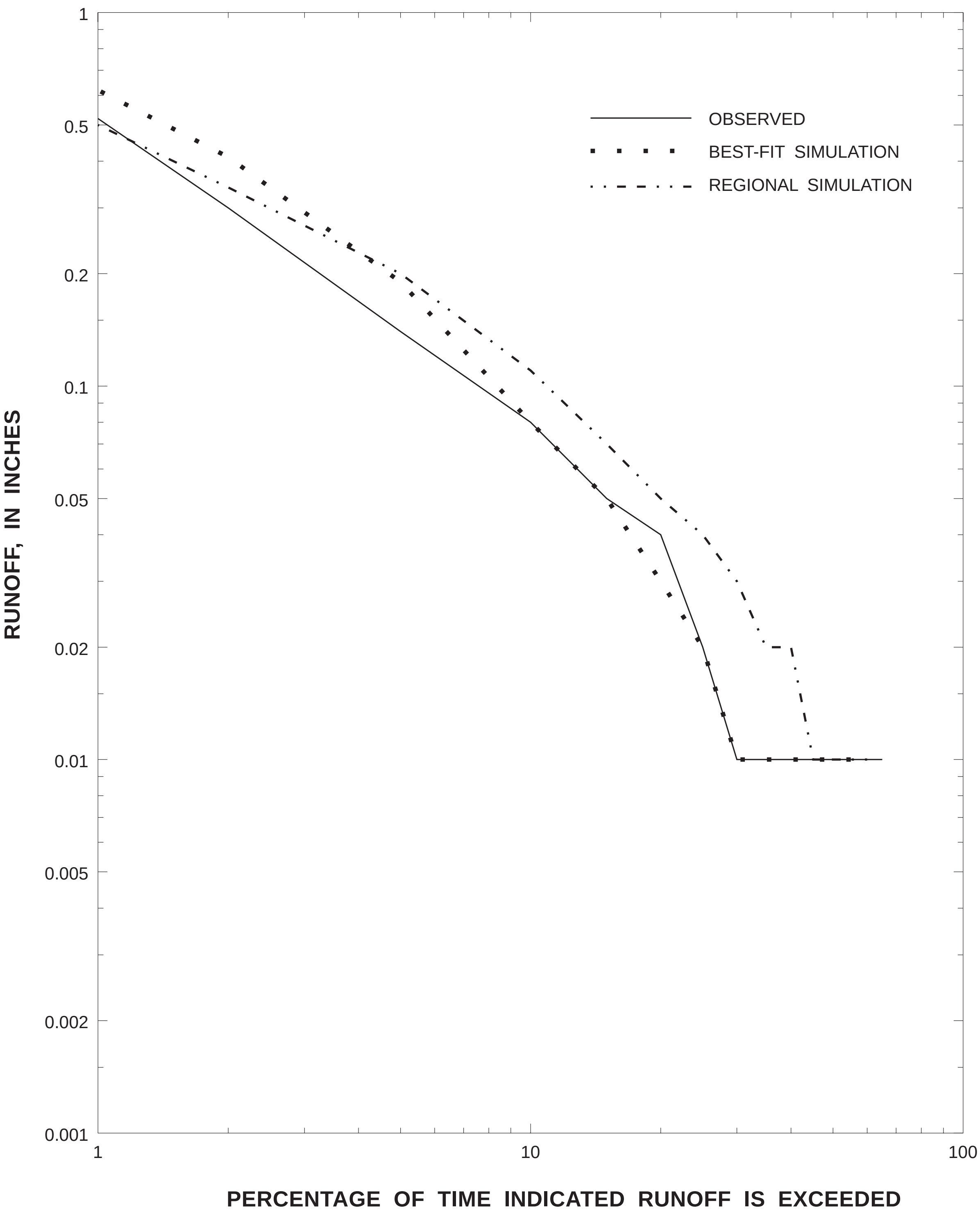

Figure 22. Runoff-duration curves with observed data and simulations with the application of the best-fit and regional parameter sets for Terre Faire Ditch at Libertyville, Ill.

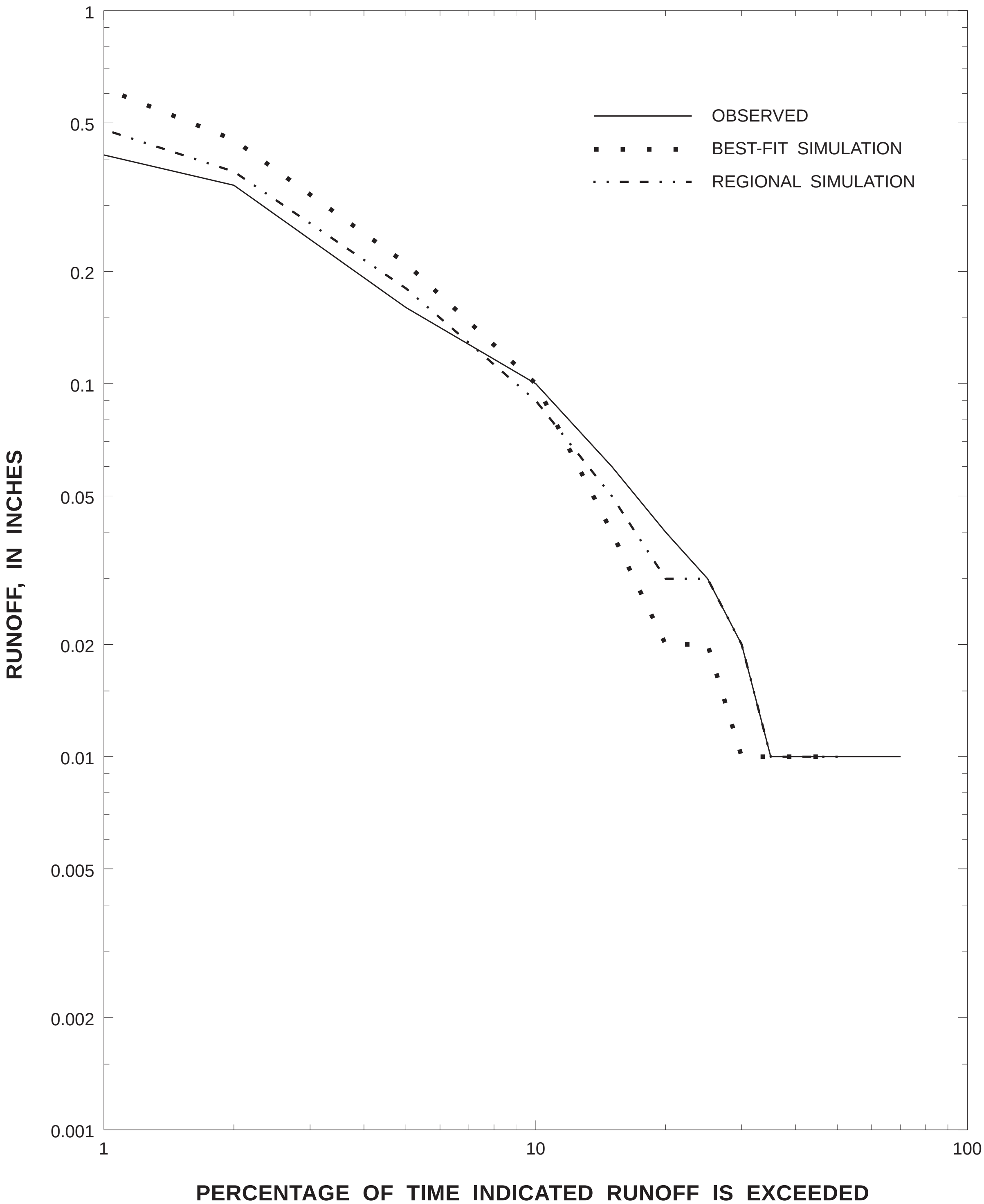

Figure 23. Runoff-duration curves with observed data and simulations with the application of the best-fit and regional parameter sets for Green Lake Ditch at Buffalo Grove, Ill.

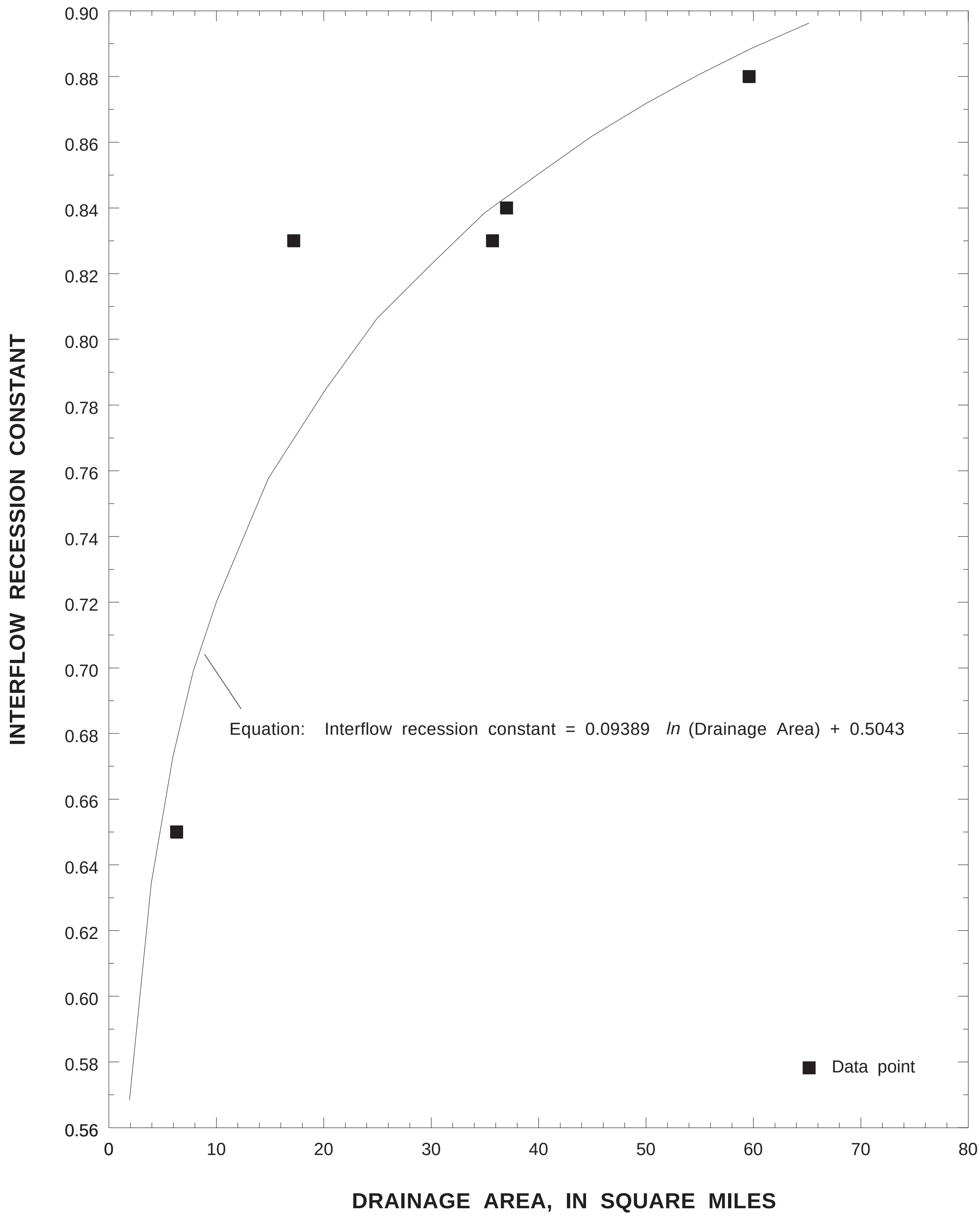

Figure 24. Relation between the calculated interflow recession constant and watershed area for five watersheds in Lake County, Ill.

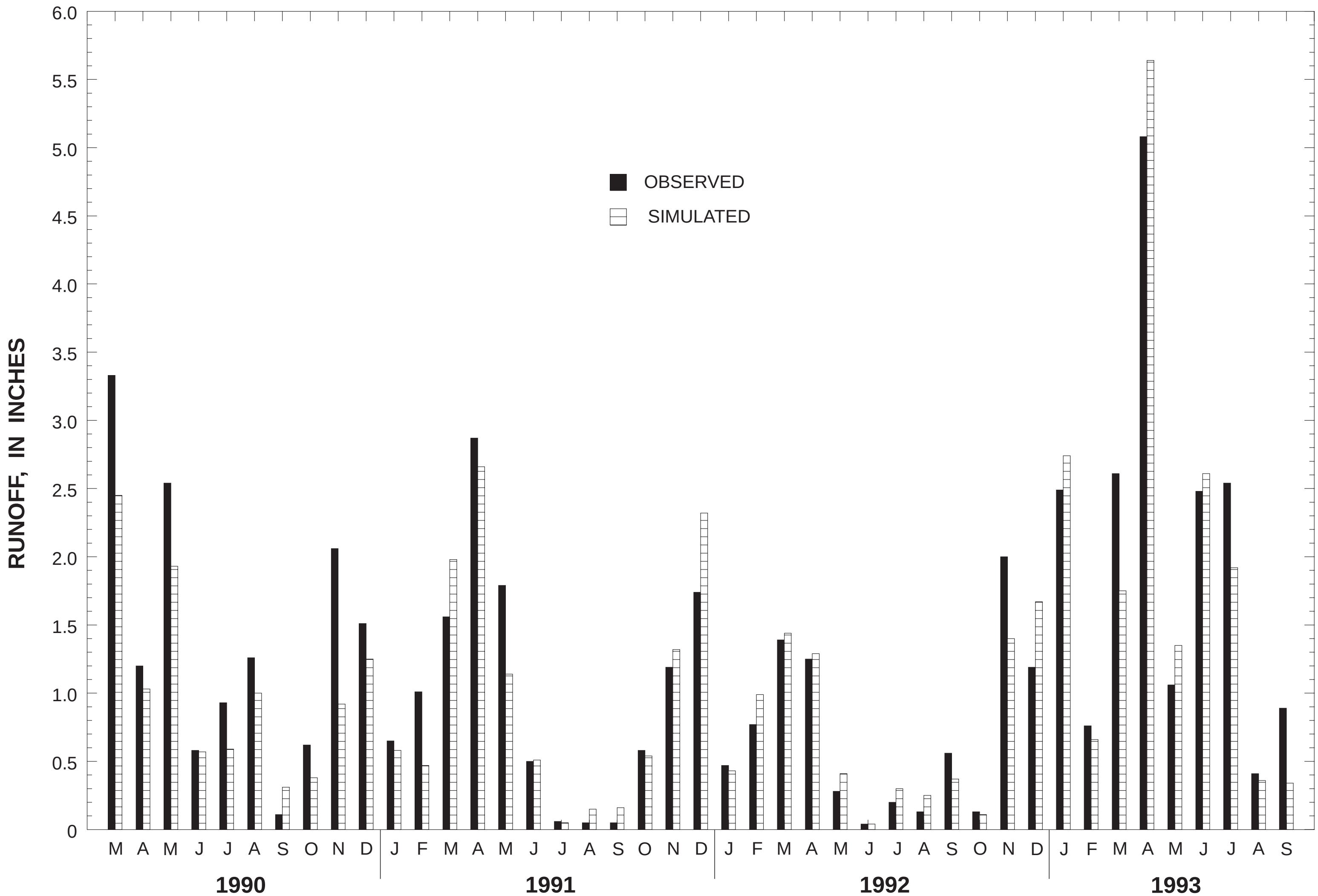

Figure 25. Observed and simulated (with application of the regional parameter set) monthly runoff for Indian Creek near Prairie View, Ill.

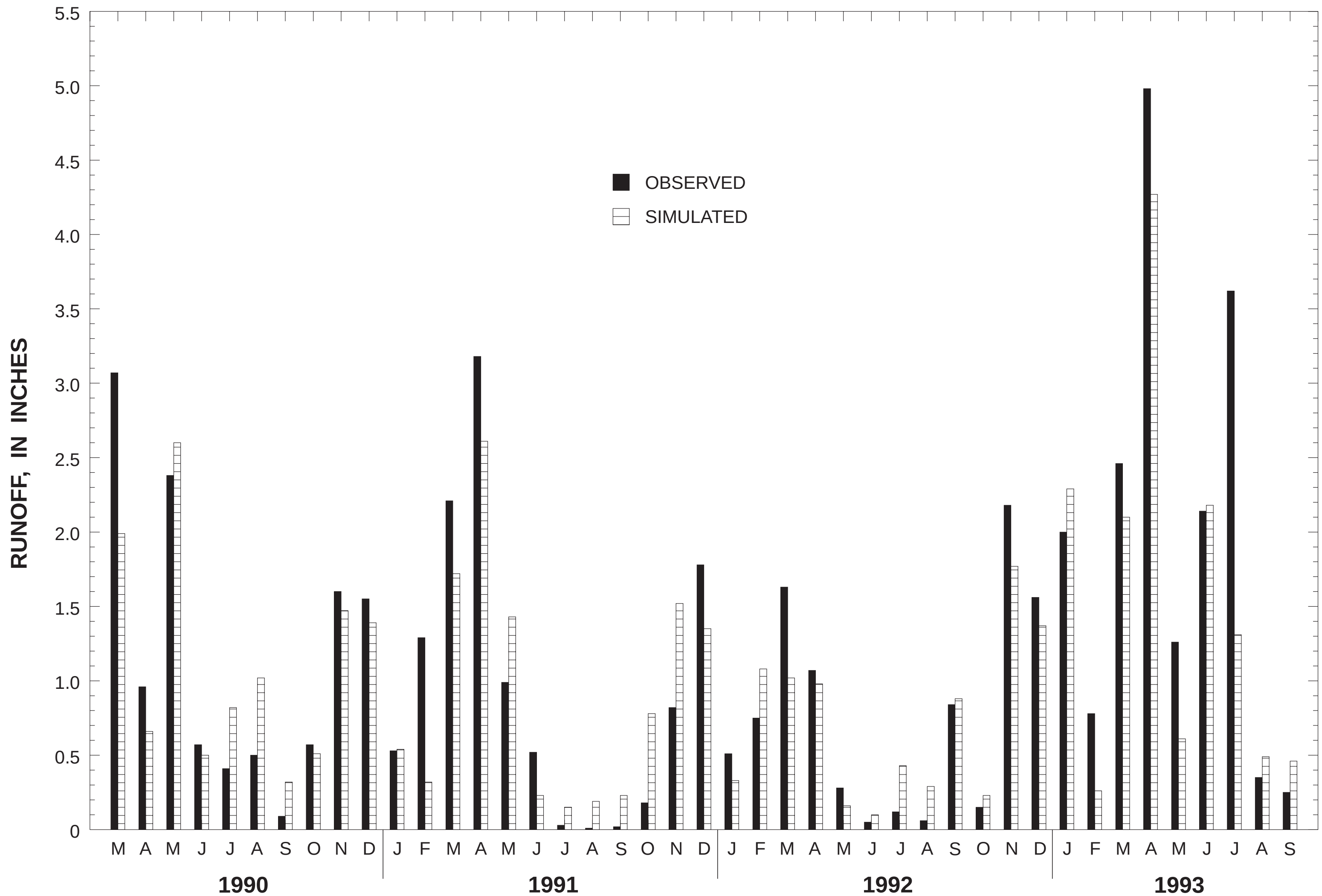

Figure 26. Observed and simulated (with application of the regional parameter set) monthly runoff for Squaw Creek at Round Lake, Ill.

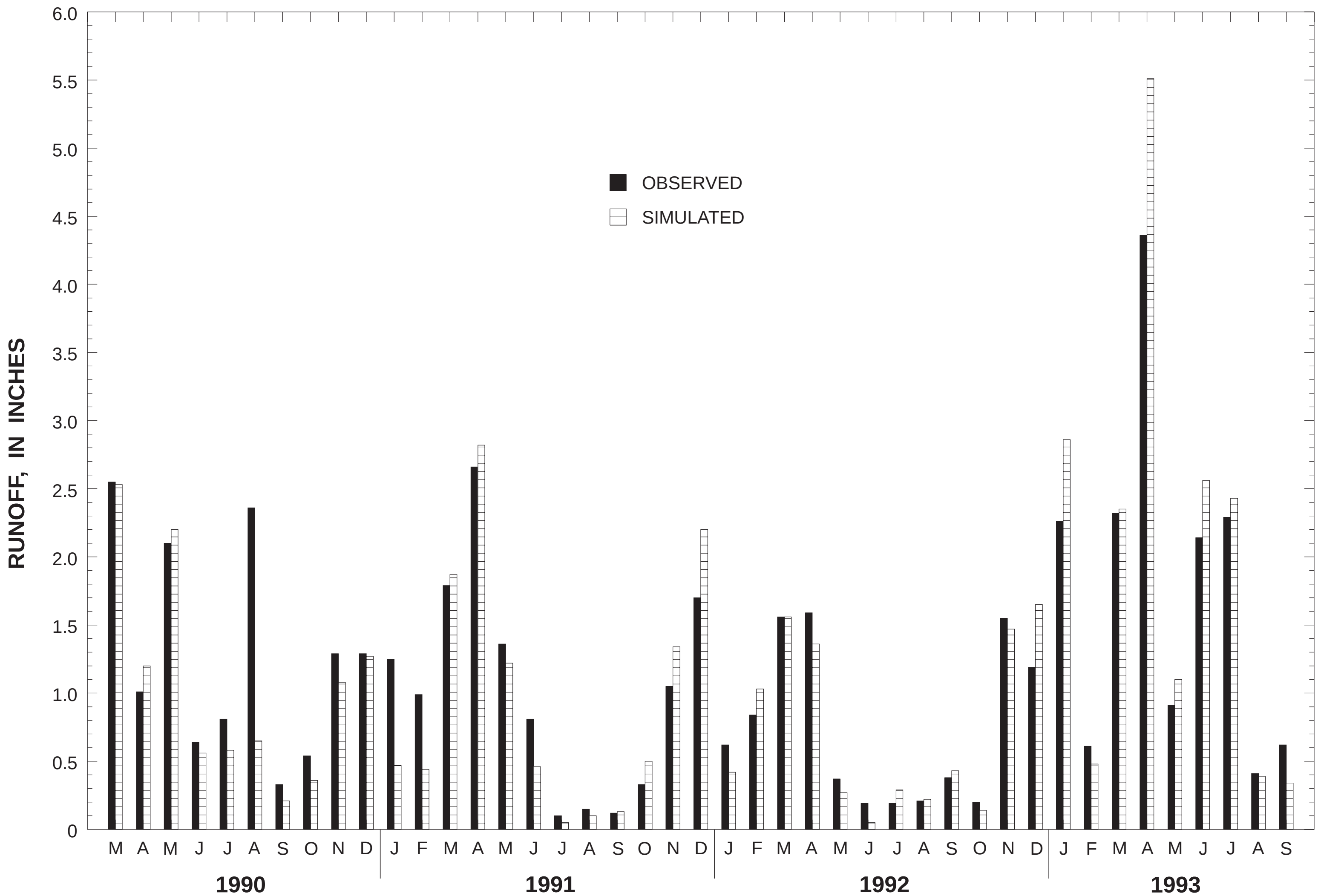

Figure 27. Observed and simulated (with application of the regional parameter set) monthly runoff for Flint Creek near Fox River Grove, Ill.

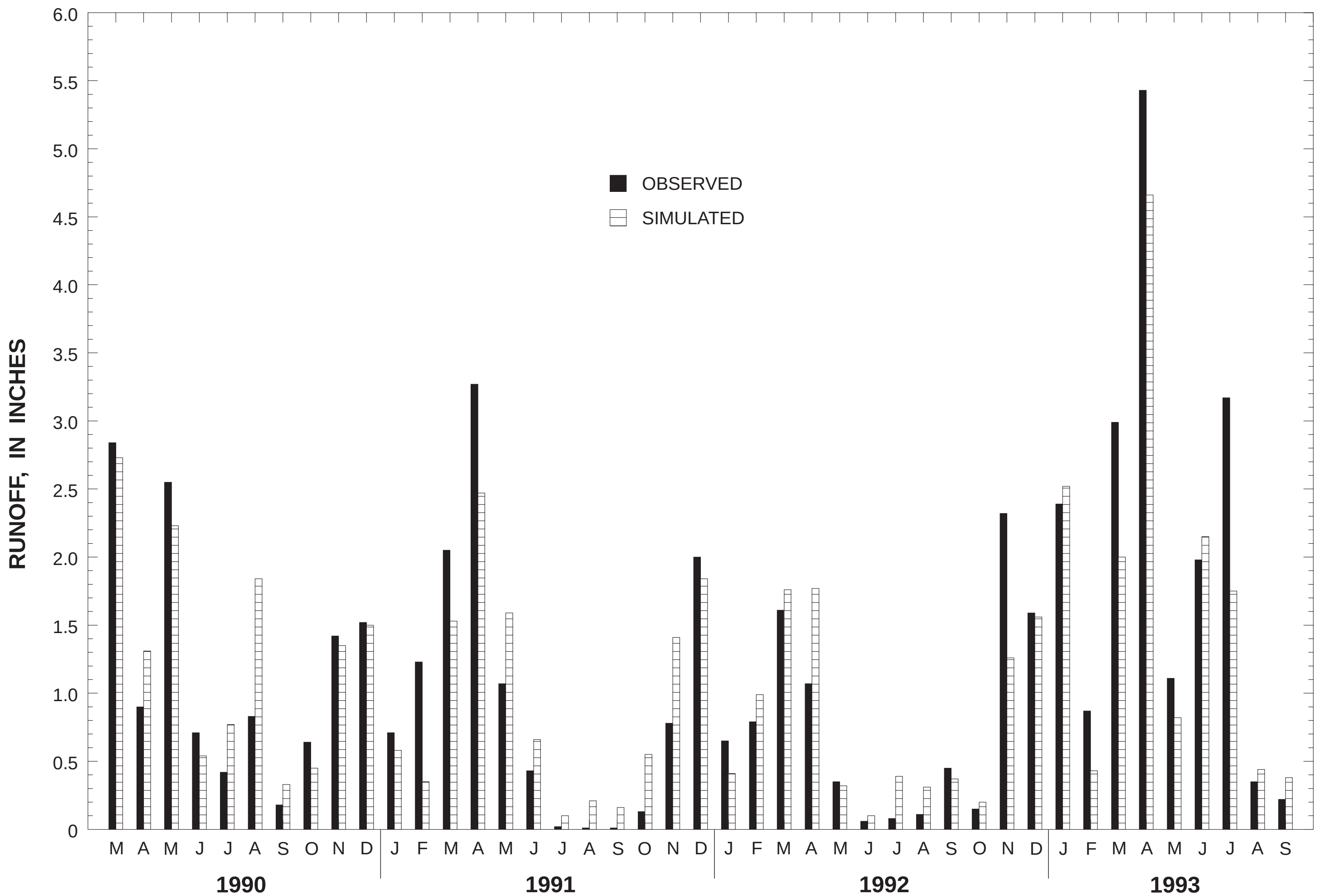

Figure 28. Observed and simulated (with application of the regional parameter set) monthly runoff for Mill Creek at Old Mill Creek, Ill.

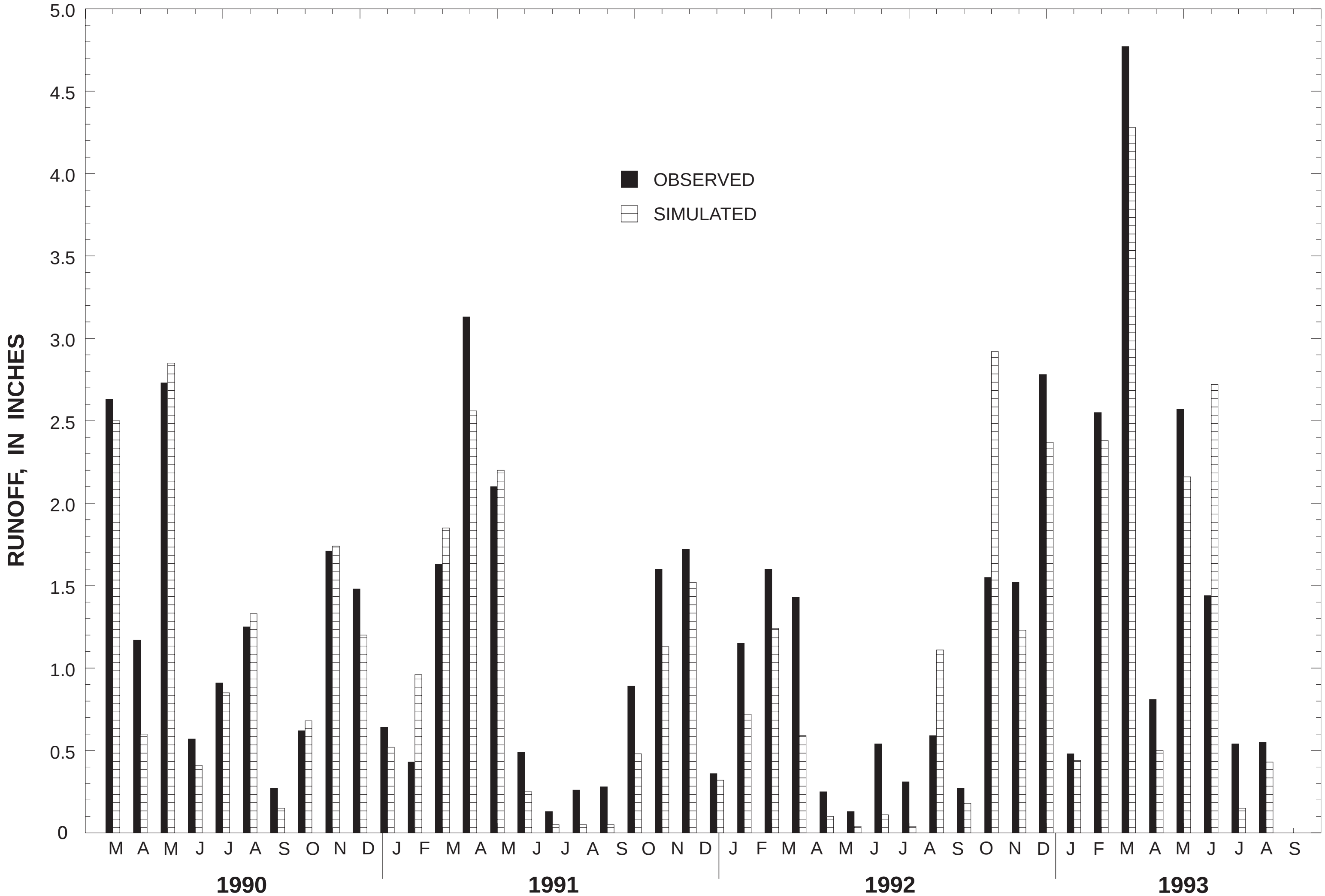

Figure 29. Observed and simulated (with application of the regional parameter set) monthly runoff for Bull Creek near Libertyville, Ill.

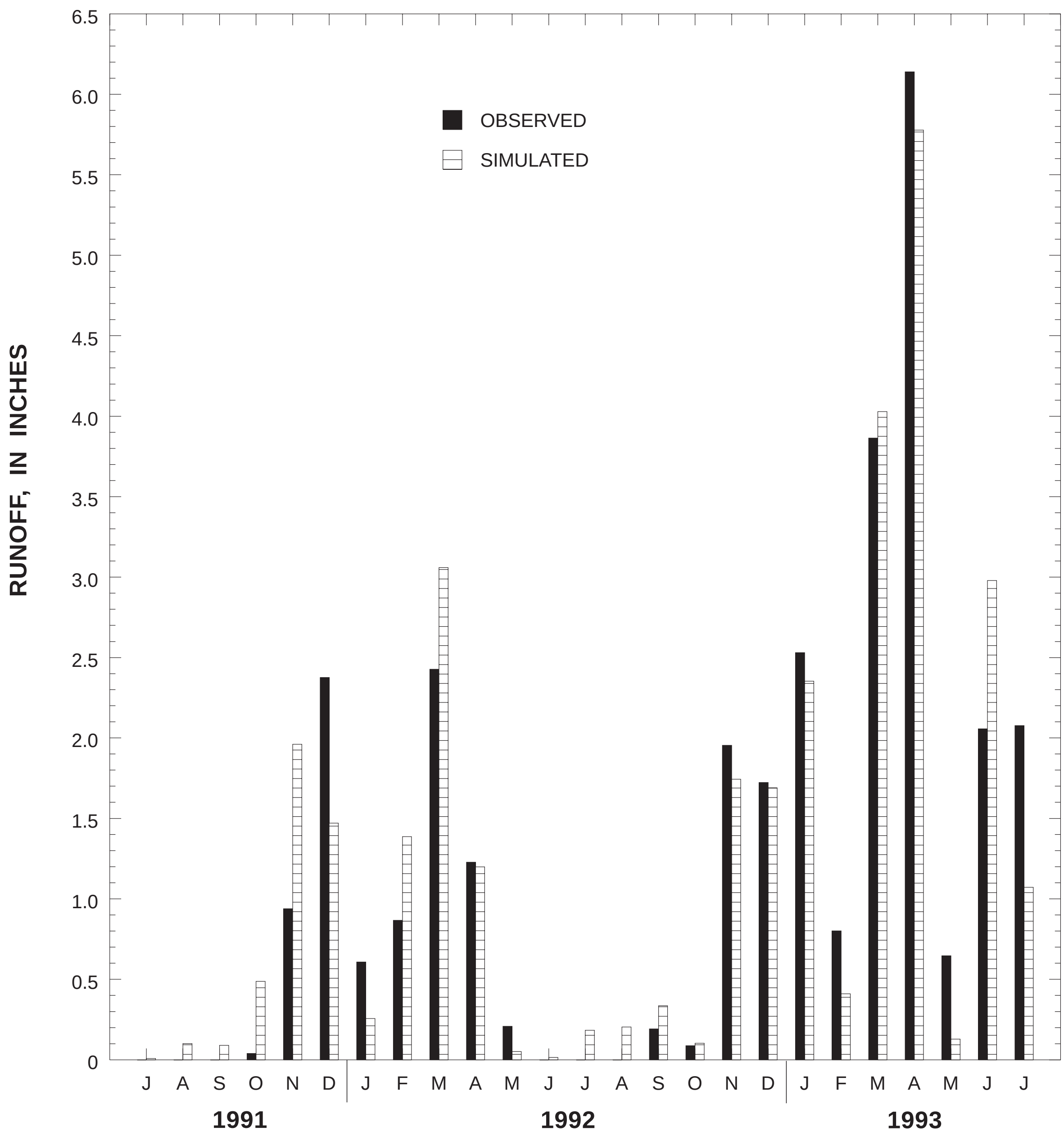

Figure 30. Observed and simulated (with application of the regional parameter set) monthly runoff for Tempel Farms Ditch at Old Mill Creek, Ill.

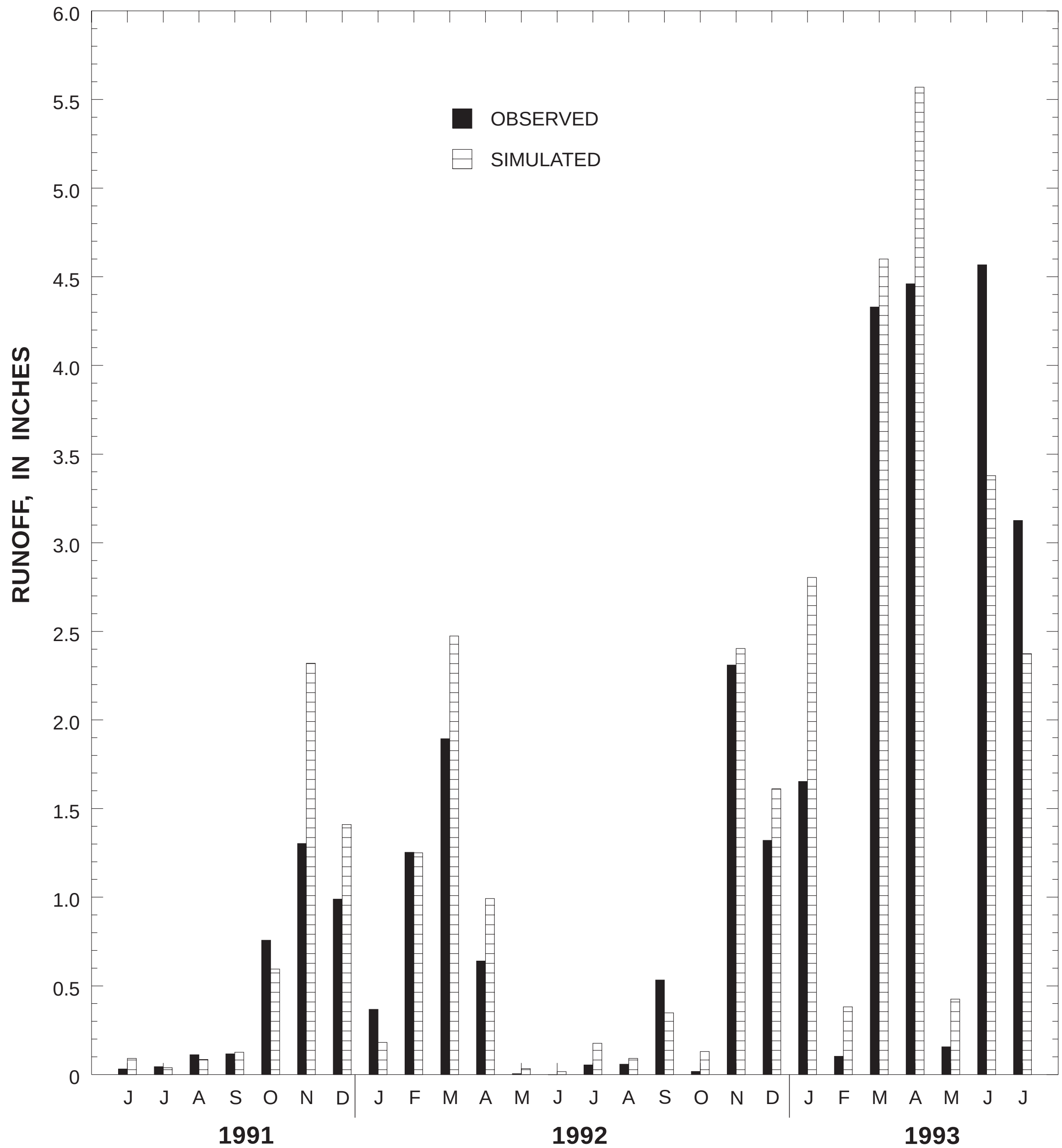

Figure 31. Observed and simulated (with application of the regional parameter set) monthly runoff for Terre Faire Ditch at Libertyville, Ill.

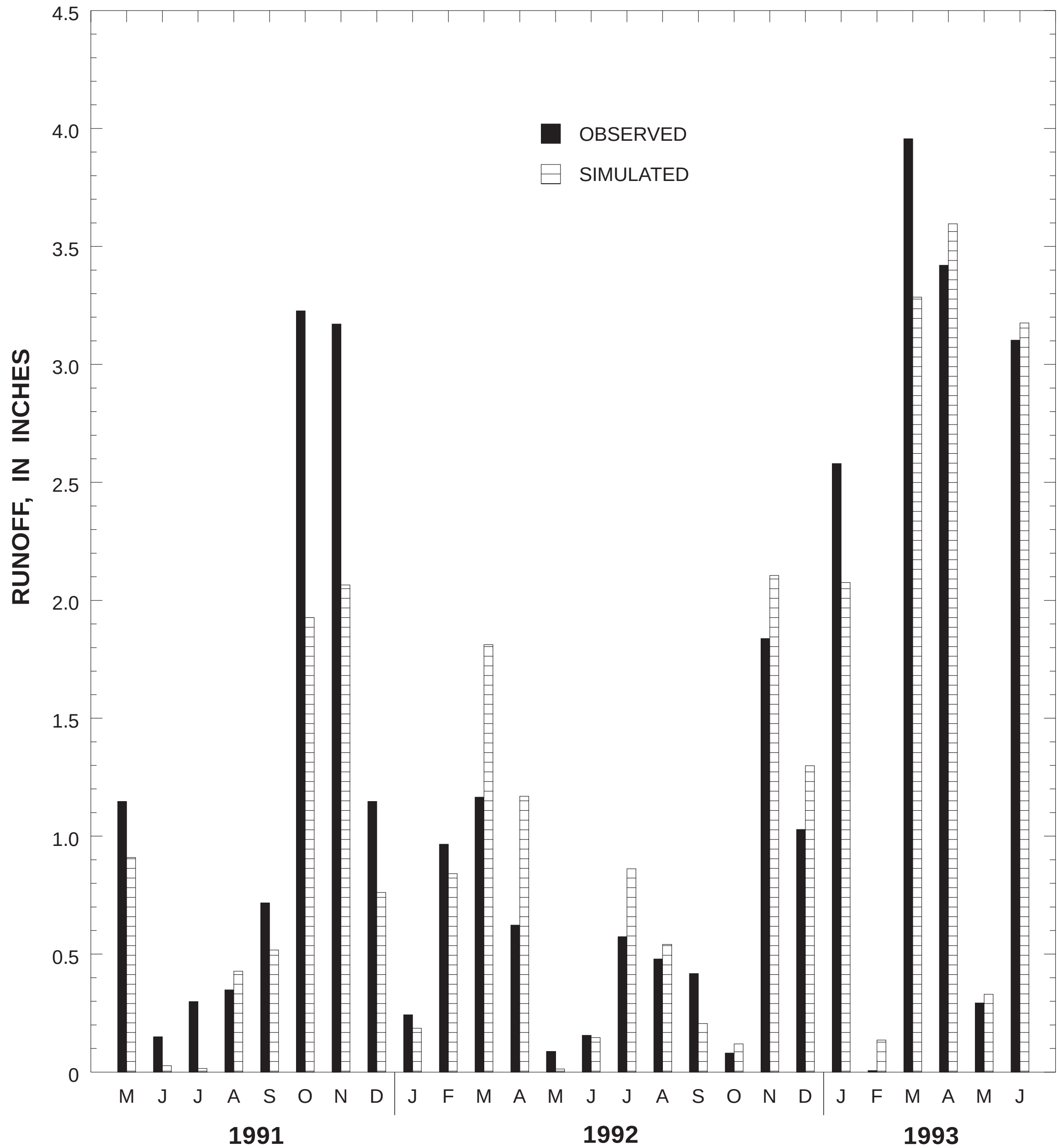

Figure 32. Observed and simulated (with application of the regional parameter set) monthly runoff for Green Lake Ditch at Buffalo Grove, Ill.

APPENDIXES

APPENDIX A—EXAMPLE USER CONTROL INPUT (UCI) FILE FOR SIMULATING WATERSHEDS WITH THE HYDROLOGICAL SIMULATION PROGRAM–FORTRAN (HSPF)

```
RUN

GLOBAL

  Calibration run #01:
      ***       yy mm dd hr:mn           yy mm dd hr:mn
  START       1990/02/15        END    1993/09/30
  RUN INTERP OUTPUT LEVEL    3
  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
      PERLND       6
      IMPLND       1
      IMPLND       2
      IMPLND       3
      COPY         1
      COPY         2
      COPY         3
      COPY         4
      COPY         5
      COPY         6
      COPY         7
      COPY         8
      COPY         9
      DISPLY       1***

    END INGRP
END OPN SEQUENCE


           *** 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
         ***
         ***Diamond Lake raingage
         ***      Pervious + water (PERLND 1).5094
         ***      Forest       (PERLND 2)     .0157
         ***      Impervious       (IMPLND 1)     .0898
         ***
```

```
         ***Lake Zurich raingage
         ***      Pervious + water (PERLND 3)      .1203
         ***      Forest           (PERLND 4)      .0044
         ***      Impervious       (IMPLND 2)      .0222
         ***
         ***Vernon Hills raingage
         ***      Pervious + water (PERLND 5)      .1779
         ***      Forest   (PERLND 6)      .0148
         ***      Impervious       (IMPLND 3)      .0455
         ***
         ***
         ***
         ***

EXT SOURCES
<-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    144 PREC     ENGL                   PERLND   1   2 EXTNL  PREC
WDM    148 PREC     ENGL                   PERLND   3   4 EXTNL  PREC
WDM   1240 PREC     ENGL                   PERLND   5   6 EXTNL  PREC
WDM     46 EVAP     ENGL                   IMPLND   1   3 EXTNL  PETINP
WDM    144 PREC     ENGL                   IMPLND   1     EXTNL  PREC
WDM    148 PREC     ENGL                   IMPLND   2     EXTNL  PREC
WDM   1240 PREC     ENGL                   IMPLND   3     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      0.5094         COPY     1     INPUT  MEAN
PERLND   2 PWATER PERO      0.0157         COPY     1     INPUT  MEAN
PERLND   3 PWATER PERO      0.1203         COPY     1     INPUT  MEAN
PERLND   4 PWATER PERO      0.0044         COPY     1     INPUT  MEAN
PERLND   5 PWATER PERO      0.1779         COPY     1     INPUT  MEAN
PERLND   6 PWATER PERO      0.0148         COPY     1     INPUT  MEAN
IMPLND   1 IWATER SURO      0.0898         COPY     1     INPUT  MEAN
IMPLND   2 IWATER SURO      0.0222         COPY     1     INPUT  MEAN
IMPLND   3 IWATER SURO      0.0455         COPY     1     INPUT  MEAN
PERLND   1 PWATER TAET      0.5094         COPY     2     INPUT  MEAN
PERLND   2 PWATER TAET      0.0157         COPY     2     INPUT  MEAN
PERLND   3 PWATER TAET      0.1203         COPY     2     INPUT  MEAN
PERLND   4 PWATER TAET      0.0044         COPY     2     INPUT  MEAN
PERLND   5 PWATER TAET      0.1779         COPY     2     INPUT  MEAN
PERLND   6 PWATER TAET      0.0148         COPY     2     INPUT  MEAN
IMPLND   1 IWATER IMPEV     0.0898         COPY     2     INPUT  MEAN
IMPLND   2 IWATER IMPEV     0.0222         COPY     2     INPUT  MEAN
IMPLND   3 IWATER IMPEV     0.0455         COPY     2     INPUT  MEAN
PERLND   1 PWATER PET       0.5094         COPY     3     INPUT  MEAN
PERLND   2 PWATER PET       0.0157         COPY     3     INPUT  MEAN
PERLND   3 PWATER PET       0.1203         COPY     3     INPUT  MEAN
PERLND   4 PWATER PET       0.0044         COPY     3     INPUT  MEAN
PERLND   5 PWATER PET       0.1779         COPY     3     INPUT  MEAN
PERLND   6 PWATER PET       0.0148         COPY     3     INPUT  MEAN
```

```
IMPLND   1 IWATER PET       0.0898          COPY     3      INPUT  MEAN
IMPLND   2 IWATER PET       0.0222          COPY     3      INPUT  MEAN
IMPLND   3 IWATER PET       0.0455          COPY     3      INPUT  MEAN
PERLND   1 PWATER UZS       0.6047          COPY     4      INPUT  POINT
PERLND   2 PWATER UZS       0.0186          COPY     4      INPUT  POINT
PERLND   3 PWATER UZS       0.1429          COPY     4      INPUT  POINT
PERLND   4 PWATER UZS       0.0052          COPY     4      INPUT  POINT
PERLND   5 PWATER UZS       0.2111          COPY     4      INPUT  POINT
PERLND   6 PWATER UZS       0.0175          COPY     4      INPUT  POINT
PERLND   1 PWATER LZS       0.6047          COPY     5      INPUT  POINT
PERLND   2 PWATER LZS       0.0186          COPY     5      INPUT  POINT
PERLND   3 PWATER LZS       0.1429          COPY     5      INPUT  POINT
PERLND   4 PWATER LZS       0.0052          COPY     5      INPUT  POINT
PERLND   5 PWATER LZS       0.2111          COPY     5      INPUT  POINT
PERLND   6 PWATER LZS       0.0175          COPY     5      INPUT  POINT
PERLND   1 PWATER AGWS      0.6047          COPY     6      INPUT  POINT
PERLND   2 PWATER AGWS      0.0186          COPY     6      INPUT  POINT
PERLND   3 PWATER AGWS      0.1429          COPY     6      INPUT  POINT
PERLND   4 PWATER AGWS      0.0052          COPY     6      INPUT  POINT
PERLND   5 PWATER AGWS      0.2111          COPY     6      INPUT  POINT
PERLND   6 PWATER AGWS      0.0175          COPY     6      INPUT  POINT
PERLND   1 PWATER AGWO      0.5094          COPY     7      INPUT  MEAN
PERLND   2 PWATER AGWO      0.0157          COPY     7      INPUT  MEAN
PERLND   3 PWATER AGWO      0.2203          COPY     7      INPUT  MEAN
PERLND   4 PWATER AGWO      0.0044          COPY     7      INPUT  MEAN
PERLND   5 PWATER AGWO      0.1779          COPY     7      INPUT  MEAN
PERLND   6 PWATER AGWO      0.0148          COPY     7      INPUT  MEAN
PERLND   1 PWATER IFWO      0.5094          COPY     8      INPUT  MEAN
PERLND   2 PWATER IFWO      0.0157          COPY     8      INPUT  MEAN
PERLND   3 PWATER IFWO      0.2203          COPY     8      INPUT  MEAN
PERLND   4 PWATER IFWO      0.0044          COPY     8      INPUT  MEAN
PERLND   5 PWATER IFWO      0.1779          COPY     8      INPUT  MEAN
PERLND   6 PWATER IFWO      0.0148          COPY     8      INPUT  MEAN
PERLND   1 PWATER SURO      0.5094          COPY     9      INPUT  MEAN
PERLND   2 PWATER SURO      0.0157          COPY     9      INPUT  MEAN
PERLND   3 PWATER SURO      0.1203          COPY     9      INPUT  MEAN
PERLND   4 PWATER SURO      0.0044          COPY     9      INPUT  MEAN
PERLND   5 PWATER SURO      0.1779          COPY     9      INPUT  MEAN
PERLND   6 PWATER SURO      0.0148          COPY     9      INPUT  MEAN
IMPLND   1 IWATER SURO      0.0898          COPY     9      INPUT  MEAN
IMPLND   2 IWATER SURO      0.0222          COPY     9      INPUT  MEAN
IMPLND   3 IWATER SURO      0.0455          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

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

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    6
  END PRINT-INFO

  GEN-INFO
      ***
      *** replace name with an identifier for the PERLND segments

                                     1=ENGL 2=METR PRINT FILES ***
    #THRU#<-----NAME--------->NBLKS<----UNITS----> ENGL METR  ***
    1      Diamond Lake Gage      1    1    1    1    2    0
    3      Lake Zurich Gage       1    1    1    1    2    0
    5      Vernon Hills Gage      1    1    1    1    2    0
    2      Diamond Lake Forest    1    1    1    1    2    0
    4      Lake Zurich Forest     1    1    1    1    2    0
    6      Vernon Hills Forest    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

  #THRU#FOREST      LZSN     INFILT     LSUR     SLSUR     KVARY     AGWR***
  1    6 0.0        .020      .040      400.     0.004      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    6       40.       35.       2.0       2.0      .25        .00     0.050

END PWAT-PARM3

PWAT-PARM4

  #THRU# CEPSC      UZSN      NSUR     INTFW       IRC     LZETP   ***
  1    6  0.01      10.0      0.1       10         .80      0.00

END PWAT-PARM4

PWAT-STATE1

  #THRU#  CEPS      SURS       UZS      IFWS       LZS      AGWS  *** GWVS
  1    6  0.00      0.00       5.5      0.00       0.0      0.80      0.00

END PWAT-STATE1

MON-INTERCEP

  #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
  1       .01  .01  .02  .02  .03  .04  .04  .04  .03  .02  .01  .01
  2       .02  .03  .04  .06  .08  .10  .10  .10  .09  .07  .03  .02
  3       .01  .01  .02  .02  .03  .04  .04  .04  .03  .02  .01  .01
  4       .02  .03  .04  .06  .08  .10  .10  .10  .09  .07  .03  .02
  5       .01  .01  .02  .02  .03  .04  .04  .04  .03  .02  .01  .01
  6       .02  .03  .04  .06  .08  .10  .10  .10  .09  .07  .03  .02

END MON-INTERCEP
MON-LZETPARM

  #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
  1       .02  .02  .07  .16  .21  .30  .32  .32  .27  .16  .07  .02
  2       .02  .02  .10  .25  .35  .45  .50  .50  .40  .25  .10  .02
  3       .02  .02  .07  .16  .21  .30  .32  .32  .27  .16  .07  .02
  4       .02  .02  .10  .25  .35  .45  .50  .50  .40  .25  .10  .02
  5       .02  .02  .07  .16  .21  .30  .32  .32  .27  .16  .07  .02
  6       .02  .02  .10  .25  .35  .45  .50  .50  .40  .25  .10  .02

END MON-LZETPARM

MON-UZSN
  #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
  1    6  3.0  2.3  1.6  1.0  0.4  0.6  1.3  2.1  2.1  6.0  4.7  2.0
END MON-UZSN
```

```
  MON-INTERFLW
    #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
    1    6  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
  END MON-INTERFLW
  MON-IRC
    #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
    1    6  .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5
  END MON-IRC

END PERLND

IMPLND
  ACTIVITY
    <ILS >     ACTIVE SECTIONS           ***
    # -  # ATMP SNOW IWAT  SLD  IWG IQAL ***
    1    3   0    0    1    0     0   0
  END ACTIVITY
  PRINT-INFO
    <ILS >   ***   PRINT  FLAGS   ***
    # -  # ATMP SNOW IWAT  SLD  IWG  IQAL ***
    1    3              4
  END PRINT-INFO

  GEN-INFO
    #THRU#<-----NAME---------><----UNITS----> ENGL METR  ***
    1      Diamond Impervious     1    1    1    2    0
    2      Lake Aurich Imper.     1    1    1    2    0
    3      Vernon Impervious      1    1    1    2    0

  END GEN-INFO

  IWAT-PARM1
    <ILS >         FLAGS              ***
    # -  # CSNO RTOP  VRS  VNN RTLI    ***
    1    3   0     1    1    0    0
  END IWAT-PARM1

  IWAT-PARM2
    <ILS >                                          ***
    # -  #      LSUR     SLSUR      NSUR      RETSC ***
    1    3      400       0.02      .013      0.10
  END IWAT-PARM2
  IWAT-PARM3
    <ILS >                           ***
    # -  #    PETMAX    PETMIN       ***
    1    3       40       35
  END IWAT-PARM3

  IWAT-STATE1
    <ILS >   IWATER STATE VARIABLES  ***
    # -  #      RETS      SURS       ***
    1    3     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    3  .10  .10  .10  .10  .10  .10  .20  .20  .20  .20  .20  .10
  END MON-RETN
END IMPLND


DISPLY***
                         ***
  DISPLY-INFO1***
    #thru#***<----------Title-------->        <-short-span->

          ***                                 <---disply--->  <annual summary ->
          ***                            TRAN PIVL DIG1 FIL1  PYR DIG2 FIL2 YRND
    1     ***Bull Creek (cfs)            AVER    0    2    6    1    2    6   9
  END DISPLY-INFO1***
END DISPLY***
END RUN
```

APPENDIX B—EXAMPLE USER CONTROL INPUT (UCI) FILE FOR SIMULATING HYDROLOGIC RESPONSE UNITS (HRU'S) WITH THE HYDROLOGICAL SIMULATION PROGRAM–FORTRAN (HSPF)

```
RUN

GLOBAL

  Calibration run #01:
      ***       yy mm dd hr:mn            yy mm dd hr:mn
  START       1991/07/01        END    1993/08/25
  RUN INTERP OUTPUT LEVEL    3
  RESUME     0 RUN     1 TSSFL     0 WDMSFL   16
END GLOBAL

OPN SEQUENCE
          ***                 hr mn
    INGRP              INDELT 01:00
      PERLND       1

                       *** 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


           *** 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

EXT SOURCES

<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name> dsn <Name> # tem strg<-factor->strg <Name>   #   #        <Name> # #  ***
WDM     46 EVAP     ENGL                   PERLND   1     EXTNL  PETINP
WDM   1134 PREC     ENGL                   PERLND   1     EXTNL  PREC

END EXT SOURCES


EXT TARGETS
        ***
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Tgap Amd ***
<Name>   #        <Name> # #<-factor->strg <Name> dsn <Name> #  tem strg strg***
PERLND   1 PWATER PERO                     WDM     11 FLOW     ENGL      REPL
PERLND   1 PWATER TAET                     WDM     12 TAET     ENGL      REPL
PERLND   1 PWATER PET                      WDM     13 PET      ENGL      REPL
PERLND   1 PWATER UZS                      WDM     14 UZS      ENGL      REPL
PERLND   1 PWATER LZS                      WDM     15 LZS      ENGL      REPL
PERLND   1 PWATER AGWS                     WDM     16 AGWS     ENGL      REPL
PERLND   1 PWATER AGWO                     WDM     17 AGWO     ENGL      REPL
```

```
PERLND   1 PWATER IFWO                         WDM     18 IFWO     ENGL      REPL
PERLND   1 PWATER SURO                         WDM     19 SURO     ENGL      REPL
END EXT TARGETS


PERLND
   ***
  ACTIVITY
    #THRU# ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC***
    1    1    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    1    0    0    4    0    0    0    0    0    0    0    0    0    0    7
  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    1 Agriculture            1    1    1    1    2    0
  END GEN-INFO

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

  PWAT-PARM2

    #THRU#FOREST      LZSN     INFILT     LSUR     SLSUR     KVARY     AGWR***
    1    1 0.0        .028      .034      400.      0.004     0.00     0.91

  END PWAT-PARM2

  PWAT-PARM3
      *** DEEPFR should be adjusted towards 1.0 for intermittent streams.
    #THRU# ***PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
    1    1       40.       35.       2.0       2.0     .04         0.0     .07

  END PWAT-PARM3

  PWAT-PARM4

    #THRU# CEPSC      UZSN      NSUR     INTFW       IRC     LZETP   ***
    1    1  0.00      0.35      0.1       30.        .40      0.00

  END PWAT-PARM4
```

```
  PWAT-STATE1

    #THRU#  CEPS      SURS       UZS      IFWS       LZS      AGWS  *** GWVS
    1    1  0.00      0.00      0.00      0.00       0.0      0.00      0.00

  END PWAT-STATE1

  MON-INTERCEP

    #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
    1    1  .01  .01  .02  .02  .03  .04  .04  .04  .03  .02  .01  .01


  END MON-INTERCEP
  MON-LZETPARM

    #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
    1    1  .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    1  3.0  3.2  1.2  0.6  0.3  0.4  0.5  1.4  3.7  4.3  4.0  2.5
  END MON-UZSN

  MON-INTERFLW
    #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
    1    1  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
  END MON-INTERFLW
  MON-IRC
    #THRU#  JAN  FEB  MAR  APR  MAY JUNE JULY  AUG SEPT  OCT  NOV  DEC ***
    1    1  .93  .93  .97  .97  .90  .10  .10  .10  .10  .90  .99  .93
  END MON-IRC

END PERLND


END RUN
```