In cooperation with the Kane County Department of Environmental Management,
Illinois Department of Natural Resources–Office of Water Resources, and
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Continuous Hydrologic Simulation and Flood-Frequency, Hydraulic, and Flood-Hazard Analysis of the Blackberry Creek Watershed, Kane County, Illinois

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By David T. Soong, Timothy D. Straub, and Elizabeth A. Murphy

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Cover Photographs:

Background photograph was taken at the Lake Run tributary of Blackberry Creek west of Route 56 and south of Interstate Highway 88 in Kane County, Ill. Farm photograph was taken at the intersection of Main Street and Bliss Road, Bald Mound, Ill. Urban photograph was taken at Fox Hill Lane, at the upper portion of the East Run tributary, in Aurora, Ill. All photographs were taken in 2001 by U.S. Geological Survey personnel.

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CONVERSION FACTORS, DATUMS, AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	square hectometer (hm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch per hour (in/h)	0.0254	meter per hour (m/h)

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

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). Historical data collected and stored as National Geodetic Vertical Datum of 1929 (NGVD 29) have been converted to NAVD 88 for use in this publication.

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83). Historical data collected and stored as North American Datum of 1927 (NAD 27) have been converted to NAD 83 for use in this publication.

Acronyms and Abbreviations:

AML—ARC Macro Language

AMS—Annual Maximum Series

AES—Annual Exceedance Series

DOQ—Digital Orthophoto Quadrangle

FESWMS—Finite Element Surface Water Modeling System

FEMA—Federal Emergency Management Agency

FIS—Flood Insurance Study

FIRM—Flood Insurance Rate Map

GIS—Geographic Information System

HEC-RAS—Hydrologic Engineering Center, River Analysis System

HSPF—Hydrological Simulation Program-FORTRAN

HWM—High Water Mark

IDNR-OWR—Illinois Department of Natural Resources, Office of Water Resources

IDOT-DWR—Illinois Department of Transportation, Division of Water Resources

KCDEM—Kane County Department of Environmental Management

NATSGO—National Soil Geographic database

NEXRAD—Next Generation Radar

NFIP—National Flood Insurance Program

NRCS—Natural Resources Conservation Service

NWS—National Weather Service

SCS—Soil Conservation Service

TIN—Triangulated irregular network

UCI—User control input file for the HSPF model

USACOE—U.S. Army Corps of Engineers

USEPA—U.S. Environmental Protection Agency

USGS—U.S. Geological Survey

Continuous Hydrologic Simulation and Flood-Frequency, Hydraulic, and Flood-Hazard Analysis of the Blackberry Creek Watershed, Kane County, Illinois

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ABSTRACT

Results of hydrologic model, flood-frequency, hydraulic model, and flood-hazard analysis of the Blackberry Creek watershed in Kane County, Illinois, indicate that the 100-year and 500-year flood plains range from approximately 25 acres in the tributary F watershed (a headwater subbasin at the northeastern corner of the watershed) to almost 1,800 acres in Blackberry Creek main stem. Based on 1996 land-cover data, most of the land in the 100-year and 500-year flood plains was cropland, forested and wooded land, and grassland. A relatively small percentage of urban land was in the flood plains.

The Blackberry Creek watershed has undergone rapid urbanization in recent decades. The population and urbanized lands in the watershed are projected to double from the 1990 condition by 2020. Recently, flood-induced damage has occurred more frequently in urbanized areas of the watershed. There are concerns about the effect of urbanization on flood peaks and volumes, future flood-mitigation plans, and potential effects on the water quality and stream habitats. This report describes the procedures used in developing the hydrologic models, estimating the flood-peak discharge magnitudes and recurrence intervals for flood-hazard analysis, developing the hydraulic model, and the results of the analysis in graphical and tabular form.

The hydrologic model, Hydrological Simulation Program–FORTRAN (HSPF), was used to perform the simulation of continuous water movements through various patterns of land uses in the watershed. Flood-frequency analysis was applied to an annual maximum series to determine flood quantiles in subbasins for flood-hazard analysis. The Hydrologic Engineering Center-River Analysis System (HEC-RAS) hydraulic model was used to determine the 100-year and 500-year flood elevations, and to determine the 100-year floodway. The hydraulic model was calibrated and verified using high water marks and observed inundation maps for the July 17-18, 1996, flood event. Digital maps of the 100-year and 500-year flood plains and the 100-year floodway for each tributary and the main stem of Blackberry Creek were compiled.

INTRODUCTION

The Blackberry Creek watershed is a 71.16 mi^2 primarily agricultural watershed approximately 40 mi west of metropolitan Chicago in Kane and Kendall Counties, Illinois (fig. 1). In the past few decades, urban development has increased in the eastern portion of the watershed within the city of Aurora and some headwater sections of the creek. Population and urbanized land are both expected to double by 2020 (Blackberry Creek Watershed Resources Planning Committee, 1999).

Flooding and associated damages have increased in the Blackberry Creek watershed during the last two decades. Major flood damage has resulted during the storms of July 1983, July 1996, and February 1997. The storm of July 17-18, 1996, in particular, caused disastrous flood damage to many watershed locations, with more than 1,000 houses affected and more than $13 million in damage (Blackberry Creek Watershed Resource Planning Committee, 1999). The Blackberry Creek Watershed Resource Planning Committee was formed in 1996 to address effects of urban development on: flooding, in-stream biota, and pollutant loadings; and the need for information and scientific tools for resource protection in watershed planning and management. This committee drafted the Blackberry Creek Watershed Management Plan (Blackberry Creek Watershed Resources Planning Committee, 1999). One of the key recommendations in the plan was to update the available hydrologic and hydraulic models and the flood-hazard maps for the Blackberry Creek watershed.

Because of the need for hydrologic, hydraulic, and flood-hazard analysis in the watershed, a study by the

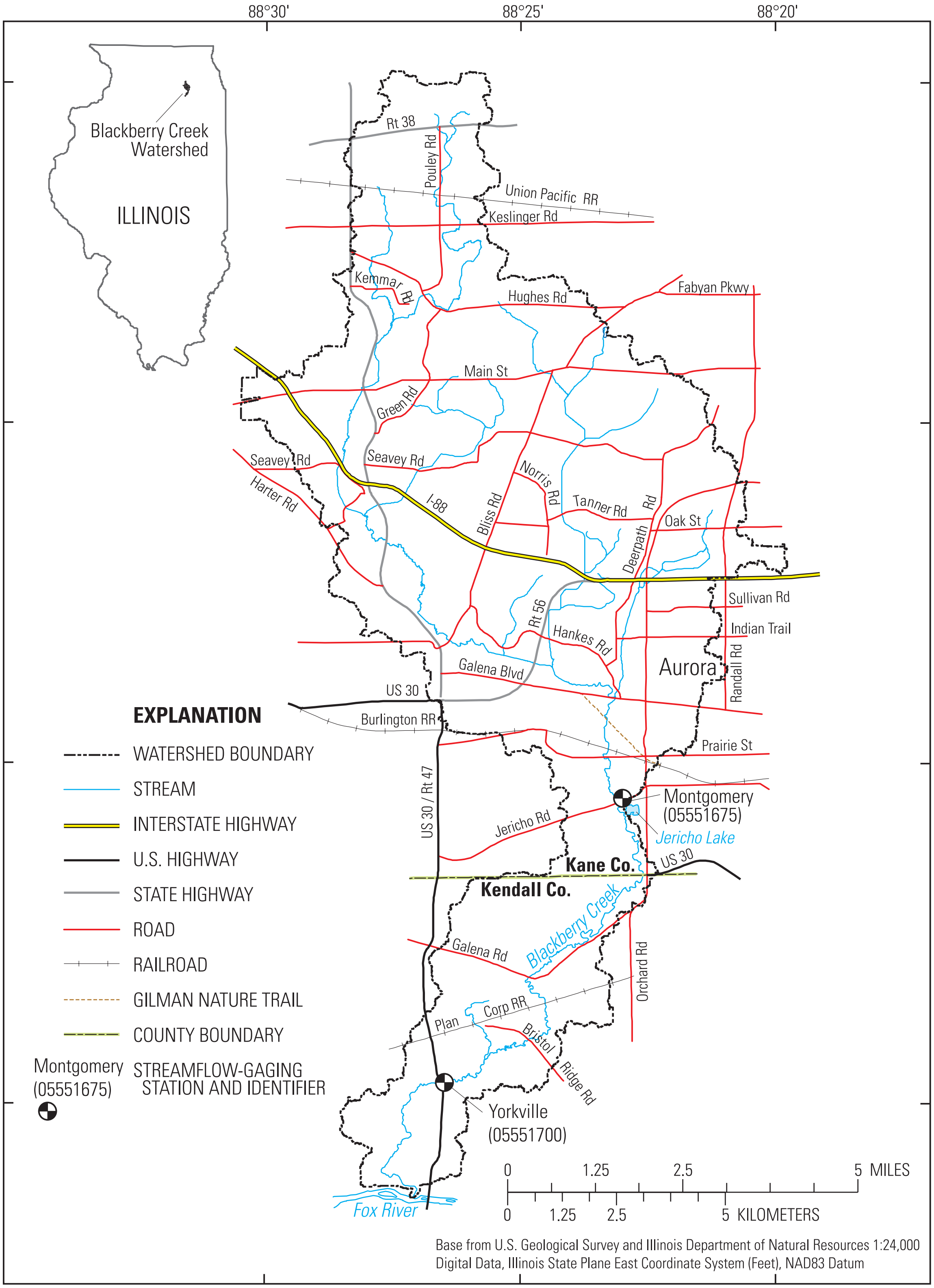


Figure 1. Location of the Blackberry Creek watershed in Kane and Kendall Counties, Ill. The study area only includes the portion of the watershed in Kane County.

U.S. Geological Survey (USGS), in cooperation with the Kane County Department of Environmental Management (KCDEM), Illinois Department of Natural Resource-Office of Water Resources (IDNR-OWR), and Federal Emergency Management Agency (FEMA), began in 2000. The USGS is using a continuous hydrologic simulation/flood-frequency approach to generate the flood quantiles used in the hydraulic model. This study demonstrates the successful application of this approach with the goal of promoting use of this advanced technique for flood-hazard studies in other watersheds.

Purpose and Scope

The purpose of this report is to describe the procedures used in developing hydrologic and hydraulic models, and estimating flood-peak discharge magnitudes and recurrence intervals used for flood-hazard analysis. The report includes detailed flood-hazard maps on digital orthophoto quadrangles (DOQs) of the watershed, as well as flood-frequency estimates for the watershed and subbasins and an analysis of flow diversion at Jericho Lake near Montgomery, Ill.

To address the flood-hazard analysis on the watershed scale, the entire watershed (main stem as well as seven major tributaries of the Blackberry Creek in both Kane and Kendall Counties) has been included in the hydrologic and hydraulic analyses. However, a refined 2-ft *digital elevation model* (DEM) was not available for the Kendall County portion of the watershed during the study period (from 2000 to 2004). (All terms in italics are defined in the Glossary.) Without detailed elevation data, refined watershed boundaries and flood-hazard mapping could not be completed. Also, some cross-section intervals were too large in Kendall County for accurate flood-hazard analysis. Therefore, flood-hazard analyses only were performed for the Kane County portion of the Blackberry Creek watershed in this study.

Flood-hazard maps for the Aurora Chain-of-Lakes tributary, the farthest-downstream major tributary of Blackberry Creek in Kane County (this tributary is discussed in the Continous-Simulation Hydrologic Model Analysis section), were completed in 1999 (Consoer Townsend Envirodyne Engineering, 1998). Because of the recent flood-hazard study of the Aurora Chain-of-Lakes tributary, it was decided not to include the tributary in the flood-hazard mapping done in this study (Karen Kosky, Kane County Department of Environmental Management and Liana Winsauer, Illinois Department of Natural Resources-Office of Water Resources northern office, written commun., 2001). However, the Aurora Chain-of-Lakes tributary hydraulic model was provided (Steve K. Andras, City of Aurora, written commun., 2001) and used in the present study for flood routing in the hydrologic model.

Approach

The overall approach of this study is depicted in a flowchart shown in figure 2. The steps followed are listed below:

1. Observed precipitation and other meteorological time series were input to a hydrologic model to supply a continuous streamflow time series at various locations in the watershed. The Hydrological Simulation Program–FORTRAN (HSPF) (Bicknell and others, 2000) was used to perform the hydrologic modeling.
2. Utilizing the flood-peak data—specifically, the *annual maximum series* (AMS), determined from the streamflow time series—flood quantiles for the 2-, 5-, 10-, 25-, 50-, *100-*, and *500-year floods* were then estimated at selected locations using flood-frequency analysis procedures. Procedures for the flood-frequency analysis followed the recommendations described in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). The frequency analysis was done with the PEAKFQ program (Version 4.1, Thomas and others, 1998).
3. a) The HEC-RAS (Hydrological Engineering Center–River Analysis System) hydraulic model (U.S. Army Corps of Engineers, 2001) was used in this study to route the flood-peak discharge and determine the flood elevations throughout Blackberry Creek watershed. The 100- and 500-year flood elevations were subsequently used to delineate *flood plains* for the creek and tributaries. Encroachment analysis was also performed in HEC-RAS to determine the floodway.
   b) The two-dimensional, finite-element surface-water modeling system (FESWMS, Froehlich, 1989) was used for modeling the flow diversion at Jericho Lake near Montgomery, Illinois. The FESWMS used in this study is an interface in the Surface-water Modeling System (SMS) (Environmental Modeling Systems, Inc., 1994). Results from the FESWMS model have been applied to determine the amount of flood discharges being diverted out of Blackberry Creek watershed. These results are used in the routing functions of the hydrologic model.
4. Using geographic information system (GIS) techniques and digital datasets, the resulting flood elevations from the hydraulic model were mapped for the 100- and 500-year flood plains and for the *floodway*. (See appendix C for a more detailed description of flood-plain and floodway delineation procedures.) These maps were overlaid on DOQs to determine flood-hazard areas. The FEMA designation for the areas within the 100-year flood-plain boundary,

areas between the 100-year and 500-year flood-plain boundaries, and areas within the 500-year flood-plain boundaries are *Special Flood Hazard Areas*, *Areas of Moderate Flood Hazard*, and *Areas of Minimal Flood Hazard*, respectively. These maps are not FEMA-approved FIRMs and are subject to revision.

The approach used in this flood-hazard study was unique because flood quantiles were estimated using flood-frequency analysis on simulated flood data and not from design storms. This flood-hazard study details the steps of the continuous-simulation/flood-frequency approach to explain how the approach is applied in the Blackberry Creek watershed. The success of the continuous-simulation/flood-frequency approach in this study suggests that this approach could be applied in flood-hazard studies in other watersheds in similar hydrogeologic settings.

In general, when observed data are used in flood-frequency analysis, the analysis relates observed events in the watershed to the estimated flood magnitudes. The recurrence intervals of flood peaks also are estimated from those observed events. This result means, however, that the confidence in the accuracy of estimated flood quantiles depends on the quality of the flood series and techniques used for estimating statistical parameters used in the underlying statistical distributions of the floods. Record length, coverage of high and low flood events, and non-homogeneity of the streamflow record (for example, flows affected by urbanization or channel regulation) are factors affecting the quality of flood series. Benson (1960) showed that 48 years of record were needed to define the 100-year flood within 25 percent and 115 years of record were needed to define the same flood within 10 percent with a 95-percent probability of certainty in both cases. If the rainfall-runoff transformation and flow routing are simulated properly, the synthesized streamflow records can be used to enhance observed flow records for determining the flood series to be used in flood-frequency analysis. The synthetic flood records can be specified at any location in the watershed. An advantage for the Blackberry Creek watershed in using the continuous hydrologic simulation/flood-frequency approach is that the available meteorologic records (from 1949 to present) are longer than the observed streamflow records (from 1961 to present). Therefore, the synthetic streamflow record is longer than the observed streamflow record.

Description of Study Area

Blackberry Creek watershed extends approximately 33 river mi from northeast of the intersection of Illinois Route 47 and 38 (fig. 1) to the confluence with the Fox River in Kendall County. The climate, topography, physiography, and streamflow are important characteris-

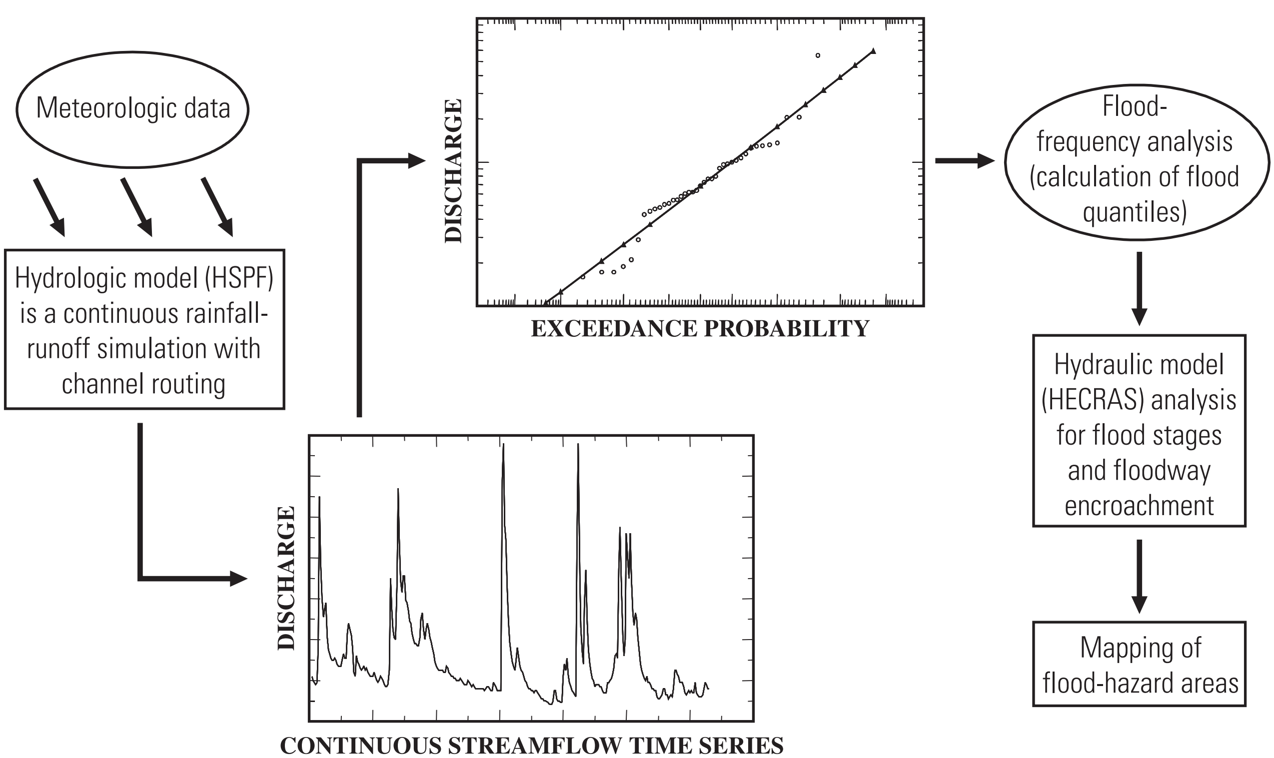


Figure 2. General approach used for the Blackberry Creek watershed study, Kane County, Ill.

tics in understanding the hydrology and hydraulics of the watershed.

Climate

The climate of northeastern Illinois is humid continental with warm to hot summers and moderate to fairly cold winters. The proximity of the watershed to Lake Michigan (approximately 45 mi) has a moderating effect on climate at the watershed (Federal Emergency Management Agency, 1996). The long-term average annual precipitation is 37 in. and the long-term mean temperature is approximately 49^{o}F at Aurora (U.S. Department of Commerce, 2001) for 132 and 122 years of data, respectively.

Cyclonic and convective storms have caused excessive surface runoff in northern Illinois. High streamflows often are observed from mid-winter to late spring when ground conditions (soil moisture and vegetation growth) are conducive to low infiltration rates and high runoff. High-intensity, short-duration storms during the summer season have produced major floods in the Blackberry Creek watershed.

Topography and Physiography

The Blackberry Creek watershed is within the Bloomington Ridged Plain (Leighton and others, 1948). The area is characterized by low, broad morainic ridges with intervening wide stretches of flat or gently undulating ground moraine. The physiographic contrasts between various parts of Illinois result because of the topography of the bedrock surface, extent of the various glaciations, differences in glacial morphology, the age of uppermost drift, and other factors (Leighton and others, 1948, p. 18). Parent soil materials in the Blackberry Creek watershed are loess, glacial till, lacustrine, outwash alluvium, and organic deposits. Illinois Episode and older drift are below the Wisconsin Episode in most places. The glacial deposits vary in thickness from thin (less than 1 ft) near the Fox River to thick (exceeding 100 ft) in the uplands (Leighton and others, 1948, fig. 3). Older drift sheets fill and cover irregularities of the bedrock surface. Watershed topography developed from the succession of two or three drift sheets resulting from subsequent glaciations. The topography varies from level and nearly level to rolling with numerous small depressions and steeper slopes at headwater sections of the main stem and tributaries. The change in relief from the headwaters to the mouth of Blackberry Creek is about 300 ft.

Streamflow Characteristics

The average and range of surface-water flows from the watershed are discussed in terms of the daily mean discharges at the USGS streamflow-gaging station Blackberry Creek near Yorkville (station 05551700, see fig. 1). Annual mean of the daily mean discharge is a characteristic of yearly flow budget from the watershed. Overall, the annual mean of daily mean discharge of Blackberry Creek watershed varied from 16.7 ft^3/s to 97.8 ft^3/s, with an average of 53.5 ft^3/s (based on streamflow records from *water year* (WY) 1961 to WY 2004). During the same period, the daily mean flow at this station varied between 1.3 ft^3/s recorded on September 20, 2003, and 3,460 ft^3/s, recorded on July 18, 1996 (in which the maximum peak discharge was 5,510 ft^3/s). A flow-duration curve for the same time period showed that the daily mean flow would equal or exceed 110 ft^3/s 10 percent of the time, 31 ft^3/s 50 percent of the time, and 9.9 ft^3/s 90 percent of the time.

Magnitudes of instantaneous flood peaks are used in the flood-hazard analysis. Instantaneous flood-peak series are organized according to the time interval specified (for example, the annual maximum flood series) or according to the base flood-peak magnitude specified (in other words, the exceedance series). Both annual maximum series (AMS) and *annual exceedance series* (AES) for the period from WY 1961 to WY 1999 were examined for their occurrences in the months of a year. Statistically speaking, the more occurrences of observed flood peaks in a month, the more likely future peak flows are to occur in that particular month, providing the flow characteristics are not altered by regulations or channel modifications. Counting the recurrences for both flood series on a monthly basis (table 1), high flows in Blackberry Creek recurred more often in the months

Table 1. Annual flood events organized according to the month of their occurrences based on observed streamflow data at the Yorkville streamflow-gaging station, Blackberry Creek, Ill., water years 1961-99.

[AMS, annual maximum series; AES, annual exceedance series]

	Number of occurrences by month											
Series	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
AMS	2	5	6	5	6	3	4	2	3	0	2	1
AES	3	8	6	5	4	4	2	1	2	1	1	2

from February to May than during the other months of the year. Although peak flows occur more frequently in the months from February to May, the magnitudes of these peaks generally are smaller than the peaks occurring during the other months. It is important to note that higher peak flows also have been produced by intense, short-duration storms in summer months. Major historical floods include July 1983 (peak discharge of 2,060 ft^3/s); July 1996 (peak discharge of 5,510 ft^3/s); and February 1997 (peak discharge of 2,040 ft^3/s).

Previous Studies

Many engineering studies involving hydrologic and hydraulic analyses have been performed in the Blackberry Creek watershed. However, most of the studies were focused on the design of hydraulic structures and were conducted in subbasins of the Blackberry Creek watershed.

Christopher B. Burke Engineering West Ltd. (2000) conducted a hydrologic analysis from the headwaters of tributary D watershed to Keslinger Road (fig. 1) (see table 4 for the tributary naming system) to determine the hydrologic characteristics of the subbasin based on HEC-1 model analysis. Consoer Townsend Envirodyne Engineering (1998) studied flood-reduction plans for the Aurora Chain-of-Lakes tributary, where the analyses were based on a TR-20 hydrologic model (U.S. Department of Agriculture, Soil Conservation Service, 1975; U.S. Department of Agriculture, Soil Conservation Service, 1993) and a WSP2 hydraulic model (U.S. Department of Agriculture, Soil Conservation Service, 1976; U.S. Department of Agriculture, Soil Conservation Service, 1993). The flood plain on the East Run tributary was studied by Environmental S/E (1990) based on HEC-1 and HEC-2 model analyses. Environmental S/E also studied flood plains and the floodway upstream of Hughes Road to Keslinger Road (fig. 1) for a culvert replacement (Environmental S/E, 1992).

Regional regression equations for Illinois were developed by Soong and others (2004). These equations can be applied to the rural streams in the watershed but could not be applied to the streams running through urban areas. The regional regression equations are further discussed in the Flood-Frequency Analysis section.

A watershed-wide, flood-hazard analysis was conducted by the U.S. Department of Agriculture, Soil Conservation Service (now known as the Natural Resources Conservation Service)(1989), where flood quantiles and flood stages along the main stem of Blackberry Creek and five major tributaries were estimated. Those results were used to produce a flood insurance rate map (FIRM) for the unincorporated areas of Kane County (Federal Emergency Management Agency, 1996). The U.S. Department of Agriculture, Soil Conservation Service (1989) study used the TR-20 hydrologic model with TP-40 rainstorms (Hershfield, 1961) for estimating peak discharges, and the WSP2 hydraulic model for estimating peak stages. Besides identifying the 100- and 500-year flood plains and the floodway, the study also identified developed areas prone to flooding, evaluated the importance of natural storage in the watershed, and suggested alternatives for flood-plain management.

The watershed-wide analysis by the U.S. Department of Agriculture, Soil Conservation Service (1989) study provided systematic information that could be used in other studies. For example, a study of the replacement of Hughes Road Bridge over Blackberry Creek conducted by MTA, Inc. (1998) used flood quantiles determined in the U.S. Department of Agriculture, Soil Conservation Service (1989) study in hydraulic analysis using a WSP2 program. The U.S. Department of Agriculture, Soil Conservation Service (1989) study also provided appreciably more information for flood-protection management than previous flood insurance studies (FIS) (U.S. Department of Housing and Urban Development, 1978, 1981, and 1982) that focused on portions of the watershed. However, continuous land-use changes and development in the watershed during the last decade have created a need to update the flood-hazard analysis and maps.

CONTINUOUS-SIMULATION HYDROLOGIC MODEL ANALYSIS

Observed precipitation and other meteorological time series were input to a hydrologic model, Hydrological Simulation Program–FORTRAN (HSPF), to provide a continuous-streamflow time series at various locations in the Blackberry Creek watershed. From each streamflow time series, a flood-peak series was determined and used to calculate flood quantiles at that location with the flood-frequency analysis.

HSPF (Bicknell and others, 2000) is a public-domain software supported by the USGS and U.S Environmental Protection Agency (USEPA). It is among the most comprehensive continuous simulation hydrologic models (Singh, 1995) that can be used for evaluating the effects of various land uses on runoff and stormwater-management practices. HSPF contains sediment and water-quality modules that could be used in later studies to perform water-quality analyses. HSPF also is an accepted hydrologic model by the Federal Emergency Management Agency (FEMA) for national flood insurance program (NFIP) usage (Federal Emergency Management Agency, 2003a). HSPF was used in this study to perform the simulation of continuous water movement through various patterns of land uses in the watershed. In model simulation, various water movements in the hydrologic cycle, including interception, depression and storage, infiltration, interflow, ground water, soil moisture, surface runoff, and evapotranspiration (fig. 3) were described. Snow accumulation and melt were also simulated in the model.

Input Data

Input data requirements for HSPF include meteorologic, topographic, land cover, and soils data.

Meteorologic Data

Meteorological data, including potential evapotranspiration, precipitation, air temperature, net solar radiation, wind movement, and dewpoint temperature, are input to HSPF (fig. 3). A meteorological database consisting of data collected at the Argonne National Laboratory, including measured air temperature, dewpoint temperature, wind movement, and net solar radiation, has been developed (Robl and others, 2003). The Argonne National Laboratory is located approximately 25 mi east of the watershed. The potential evapotranspiration and snowmelt are computed using meteorological data. The potential evapotranspiration was computed externally using the Lamoreux Potential Evapotranspiration (LXPET) program (Lamoreux, 1962; Murphy, 2005) and snowmelt accumulation and melt were computed with the energy balance approach specified in the HSPF program (Bicknell and others, 2000).

Precipitation stations in the vicinity of the watershed used in this study are shown in table 2 and figure 4. All these stations have a reading accuracy of 0.01 in. and record at 5-minute, hourly, or daily intervals. Because flow computations are performed at 1-hour intervals (treated as instantaneous flows), stations with time steps greater than 1 hour were disaggregated to a 1-hour time step by referring to information from nearby stations. Unless otherwise noted, periods of missing daily data at these stations were estimated by applying a distance-weighted average method and data from three surrounding stations (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1972).

Precipitation records from Aurora and St. Charles were used in the calibration and verification of the HSPF model because of their proximity to the Blackberry Creek watershed. The Thiessen method (Chow and others, 1988) was used to assign station values to portions of the watershed (fig. 4). For storm events during the calibration period, if the data at Aurora or St. Charles were not representative of the spatial rainfall distribution over the watershed (by comparing with nearby precipitation stations at Argonne, Kress Creek, Du Page County Airport, or Aurora), the data for that station were replaced by data from the other station. Periods of missing data for St. Charles were filled with data from the nearest station (National Accelerator Laboratory, Kress Creek, Du Page County Airport, or Aurora) that were available for the time period of missing data. Aurora data were used to fill periods of missing snowfall data at St. Charles.

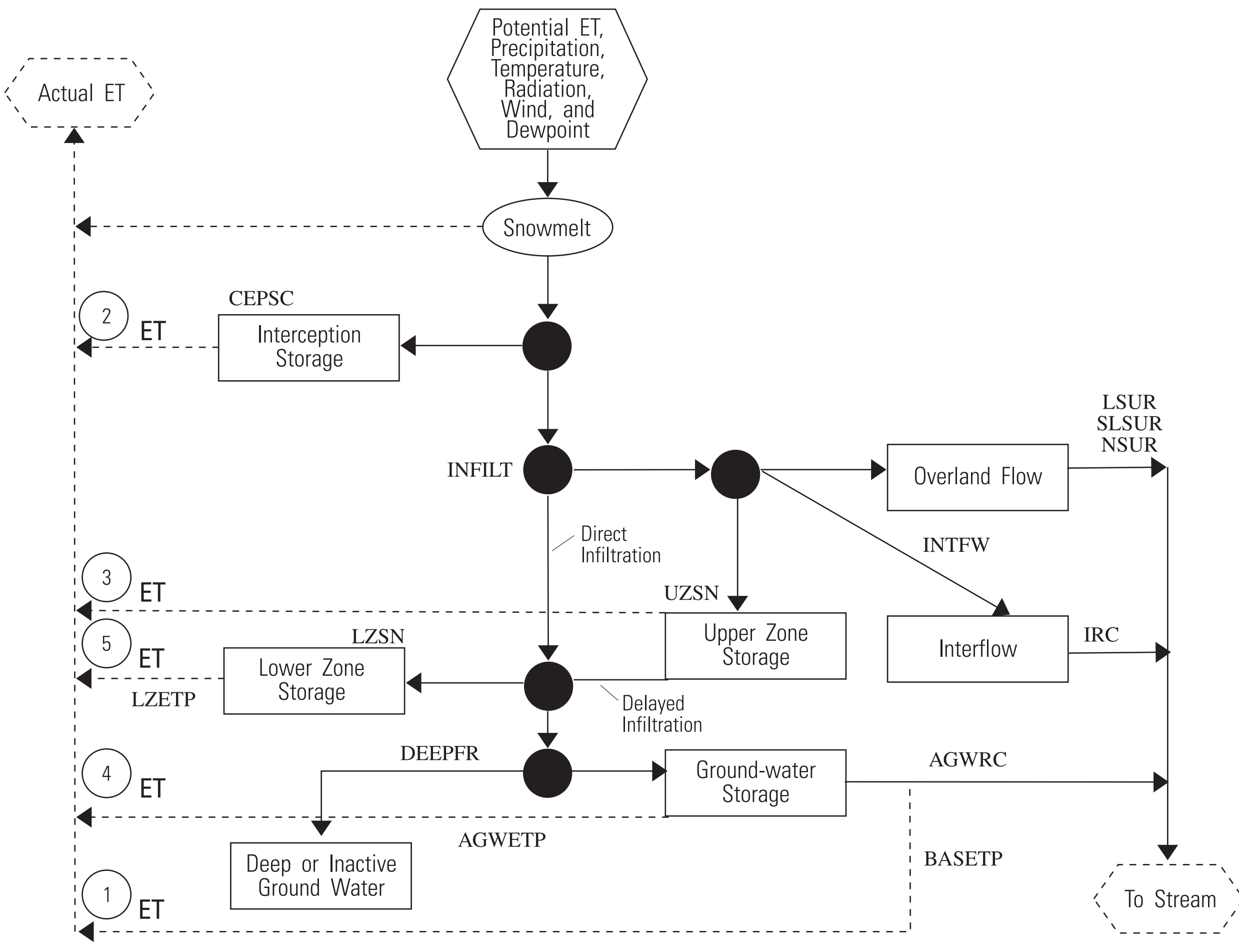
Topographic Data

Topographic features of the watershed and the stream were determined with a digital elevation model (DEM). The DEM also was used to analyze subbasin delineation and surface slopes and in flood-hazard map-

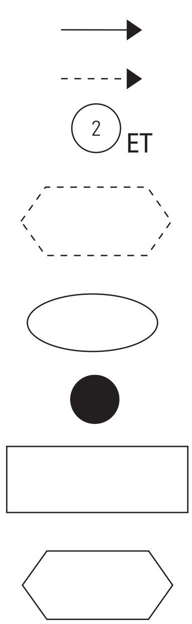
Table 2. Selected precipitation stations in the vicinity of the Blackberry Creek watershed, Kane County, Ill.

Station Name	Station Type	Time Step	Installed [1]
National Weather Service			
Aurora	Standard nonrecording	Daily	1948
O'Hare	Universal weighing	Hourly	1948
Elgin	Standard nonrecording	Daily	1948
Wheaton	Standard nonrecording	Daily	1948
Illinois State Water Survey			
St. Charles	Universal weighing	Hourly	1989
Argonne National Laboratory			
Argonne National Lab	Universal weighing	Daily	1948
U.S. Geological Survey			
DuPage County Airport	Tipping	5-minute	1986
Kress Creek	Tipping	5-minute	1986
National Accelerator Lab	Tipping	5-minute	1989

[1] All stations currently (2005) are in operation.



EXPLANATION



SYMBOLS

- Flow direction
- Water lost to evapotranspiration (ET)
- Number denotes the order water is taken to meet evapotranspiration (ET) demand
- Input
- Process
- Model decision point
- Storage
- Output

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

Figure 3. Hydrological Simulation Program–FORTRAN process model (modified from Duncker and Melching, 1998).

ping. The Kane County GIS Department developed a 10-ft by 10-ft grid-size DEM in 2001, and the DEM was revised in 2002 and 2004 by The Sidwell Company, St. Charles, Illinois (Gary Lobdell, The Sidwell Company, written commun., 2004). The National Elevation Dataset (NED; U.S. Geological Survey, 2001) contains a 30-m by 30-m grid-size DEM for the State of Illinois. This DEM was used for the Kendall County portion of the watershed.

The 2004 DEM, with a 10-ft by 10-ft grid size covering the Kane County portion of the Blackberry Creek watershed, was checked for elevation accuracy using a set of GPS benchmarks installed by Smith Engineering (Smith Engineering, 2001; also see appendix A). The check resulted in a vertical root-mean-square error ($RMSE_z$) of 0.52 ft, with a mean of -0.2 ft and standard deviation of 0.49 ft of the error (error is defined as benchmark elevation minus triangulated irregular network (TIN) elevation) for 18 points that were selected by The Sidwell Company from 45 benchmark points available in the Kane County portion of the watershed. According to the Guidelines and Specifications for Flood Hazard Mapping Partners (Federal Emergency Management Agency, 2003b), a DEM used for a 2-ft contour interval map should have an $RMSE_z$ of 0.6 ft, which is equivalent to a vertical accuracy of 1.2 ft at the 95-percent confidence level when errors follow a normal distribution. Vertical accuracy is defined as "the linear uncertainty value, such that the true or theoretical location of the point falls within ± of that linear uncertainty value 95-percent of the time." (Federal Emergency Management Agency, 2003b). The $RMSE_z$ of the 2004 DEM met these criteria but the errors did not follow a normal distribution. Guidelines for adjusting non-normally distributed errors were not provided in the Guidelines and Specifications for Flood Hazard Mapping Partners (Federal Emergency Management Agency, 2003b), so the 2004 DEM was used for model analysis because it meets the vertical accuracy standard.

The Blackberry Creek watershed boundary generated with the 2004 DEM was different from the hand-delineated boundary but the total watershed areas were similar. Most of the boundary differences were caused by hydraulic structures, such as culverts, not represented in the DEM. Field reconnaissance was used to identify hydraulic structures and other features not accounted for

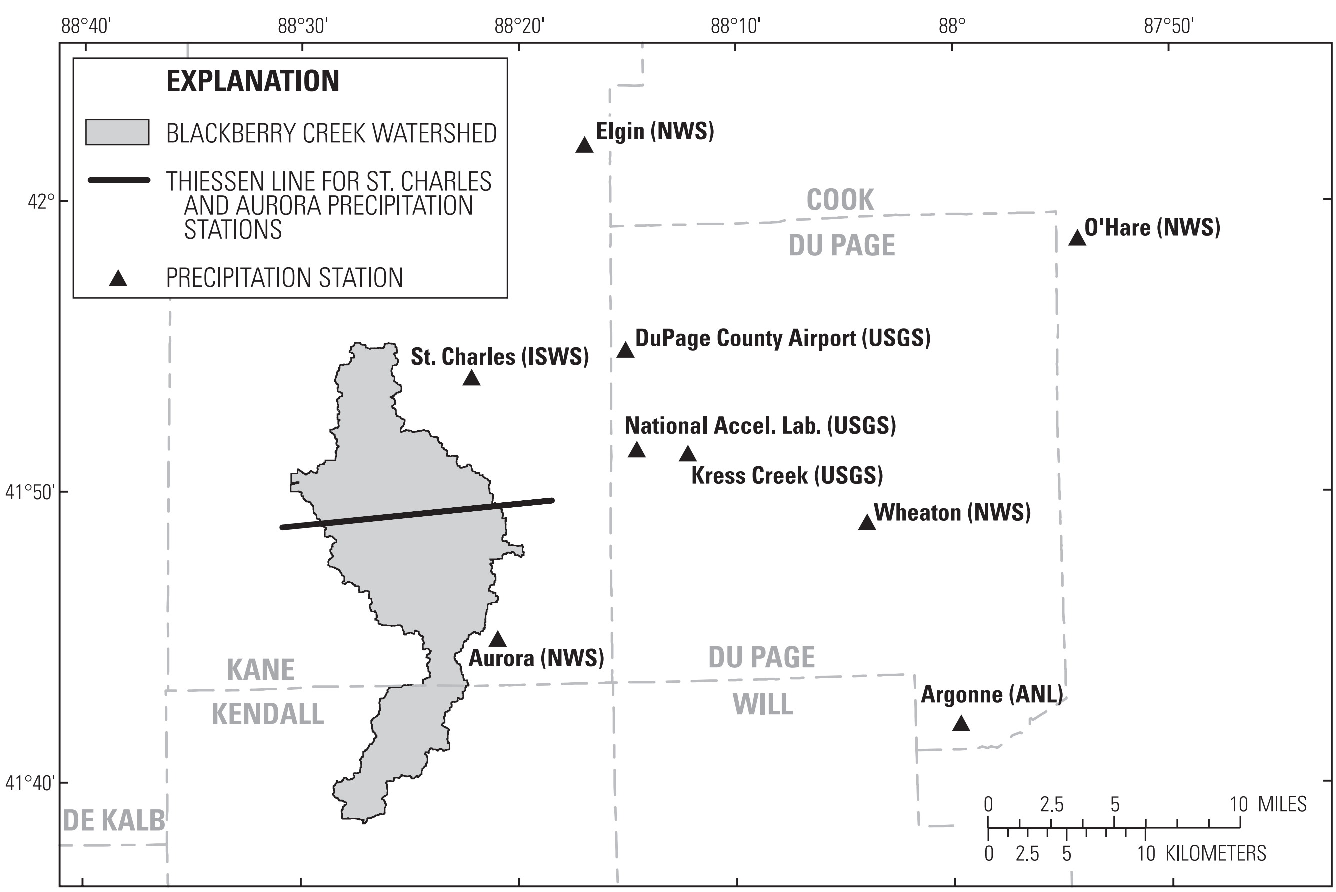


Figure 4. Location of precipitation stations in the vicinity of the Blackberry Creek watershed, Ill. [NWS, National Weather Service; ISWS, Illinois State Water Survey; USGS, U.S. Geological Survey; ANL, Argonne National Laboratory].

in the DEM. The refined DEM was used with ArcHydro (Maidment, 2002) to delineate subbasins of the Blackberry Creek watershed and in mapping the flood-hazard areas.

The DEM for the Kendall County portion of the watershed was resampled from a 30-m by 30-m grid-size DEM to a 10-ft by 10-ft grid-size DEM. The resample was completed for operational purposes and did not improve the accuracy of the original 30-m by 30-m grid-size DEM.

Land-Cover and Land-Use Data

The land-use categories used in the hydrologic model were interpreted from the Illinois land-cover database (Luman and others, 1996). The categories in the land-cover database were condensed to broader land-use categories used in the hydrologic model. For example, there are three categories of crop-land land covers but only one crop-land land-use category. The land-cover database was developed on the basis of the Thematic Mapper (TM) satellite imagery from Landsat 4, taken between April 1991 and May 1995 when the Illinois Department of Energy and Natural Resources established the Critical Trends Assessment Project. The ground resolution of the database is 93.5 ft by 93.5 ft (28.5 m by 28.5 m). Major land-cover categories (Luman and others, 1996) are described below and shown in figure 5.

- High Density Urban—all or most of the surface cover is impervious material
- Medium Density Urban—an appreciable portion of the surface cover is impervious material
- Low Density Urban—small amount of surface area is impervious material mixed with other pervious land cover
- Transportation
  - Abandoned Railroads (1991)
  - Major Roadways (Major Highways updated 1992)
  - Active Railroads (1991)
- Cropland
  - Row Crop—corn, soybeans, and other tilled crops
  - Small Grains—wheat, oats, and other grains
  - Orchards/Nurseries
- Grassland
  - Urban Grassland—parks, residential lawns, golf courses, cemeteries, and other open space
  - Rural Grassland—pastureland, grassland, waterways, buffer strips, Conservation Reserve Program (CRP) land, and others
- Wooded and Forested Land
  - Deciduous—undifferentiated broadleaf deciduous, closed canopy
  - Deciduous—undifferentiated broadleaf deciduous, open canopy
  - Coniferous—undifferentiated
- Wetland
  - Shallow Marsh/Wet Meadow
  - Deep Marsh
  - Forested Wetlands
  - Swamp
  - Shallow Water Wetlands
- Open Water
- Barren and Exposed Land—quarries, sandy beaches, exposed soil surfaces, and others

Soils Data

The NRCS maintains three soil geographic databases: the *SSURGO*, *STATSGO*, and National Soil Geographic (NATSGO) databases. Among the databases, the SSURGO database provides the most detailed soil information, whereas the NATSGO database provides the least detailed soil information. The SSURGO database for Illinois (U.S. Department of Agriculture, Natural Resources Conservation Service, 1995) was used for assessing soil information for the Kane County portion of the Blackberry Creek watershed, whereas the STATSGO database for Illinois (U.S. Department of Agriculture, Natural Resources Conservation Service, 1994) was used for the Kendall County portion of the watershed because the SSURGO database was not available for Kendall County at the time of this study.

The hydrologic soil groups A, B, C, and D (Donigian and Davis, 1978, p. 61) were used to classify soils in the watershed. Soil group A has the highest infiltration capacity (0.4-1.0 in/h). Soil group B has the second highest infiltration capacity (0.1-0.4 in/h) with soil group C and D having smaller infiltration capacities of 0.05-0.1 and 0.01-0.05 in/h, respectively (U.S. Environmental Protection Agency, 2000). Therefore, soil group A has the lowest runoff potential because of high infiltration capacity and good drainage with the amount of runoff increasing for B, C, and D. Soil group B is the dominant soil type for the Blackberry Creek watershed (fig. 6). In the hydrologic model, soil groups A and B were simulated as one soil type and soil groups C and D as another soil type.

Streamflow Data

Streamflow data are available at two locations in the watershed (table 3; fig. 1): the USGS streamflow-gaging station at Blackberry Creek near Yorkville (station 05551700), located close to the downstream end of the watershed; and the USGS streamflow-gaging station at Blackberry Creek near Montgomery (station 05551675), located at the Jericho Road Bridge crossing. The

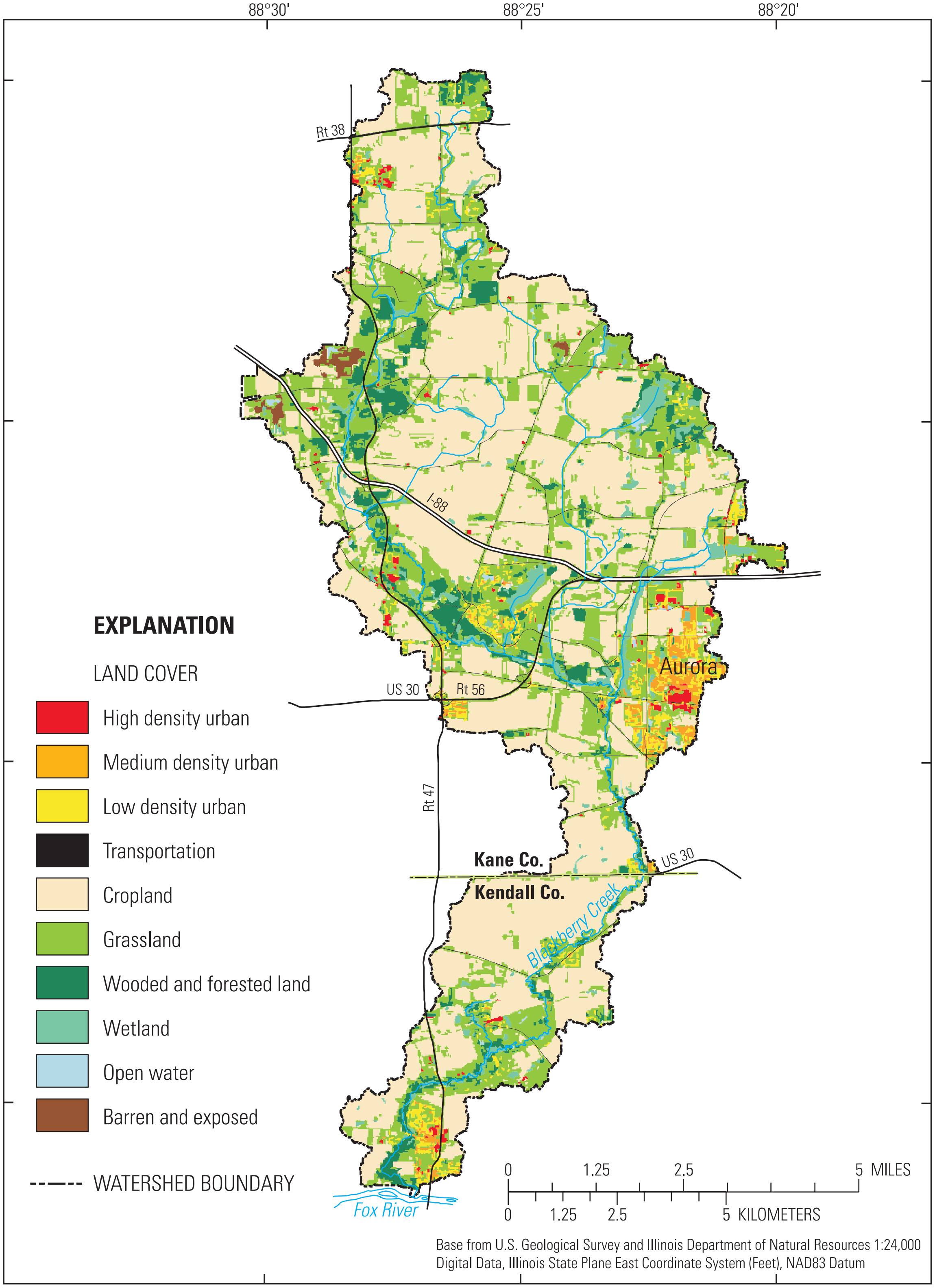


Figure 5. Land cover in the Blackberry Creek watershed, Ill. (from Luman and others, 1996).

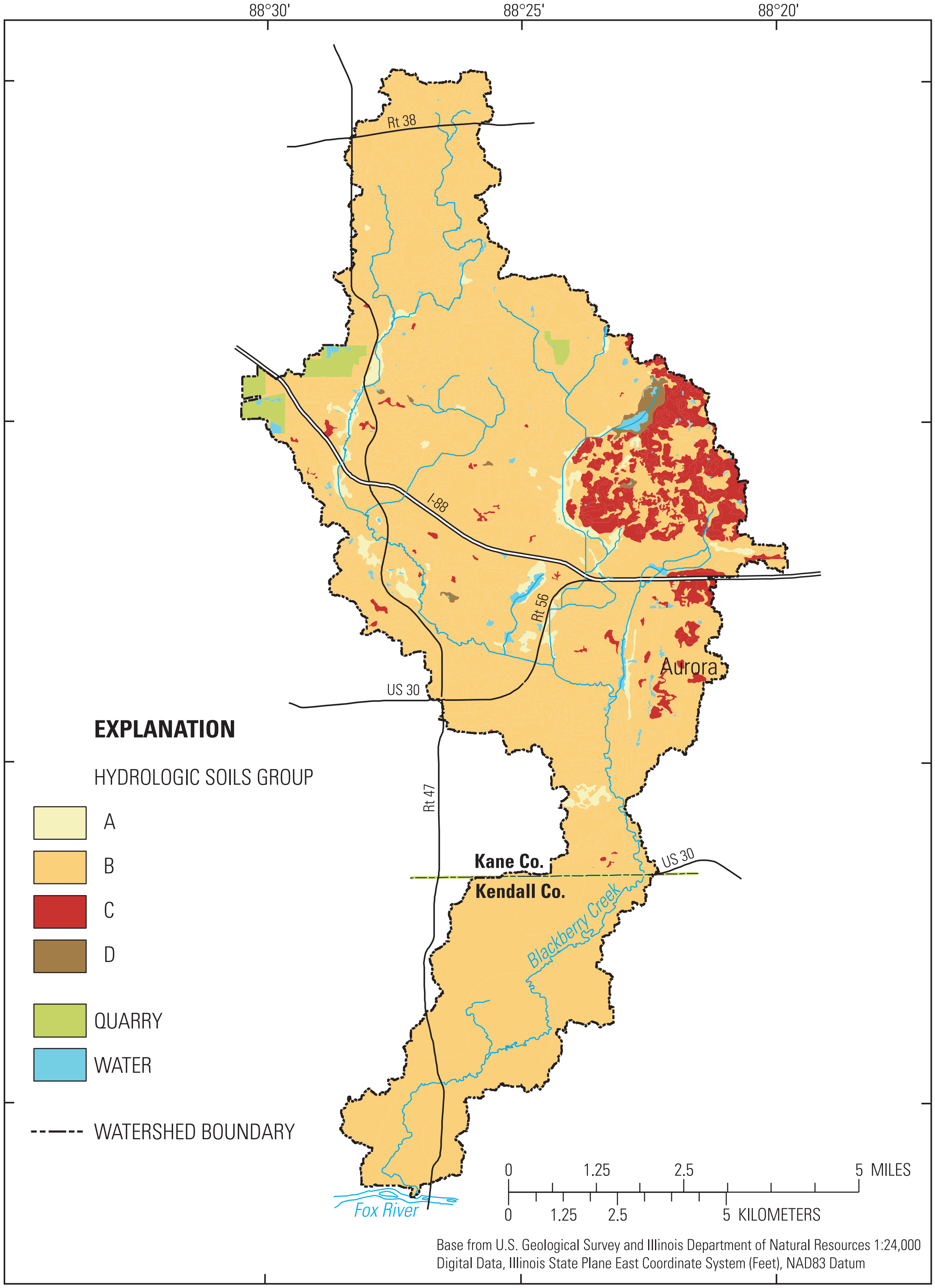


Figure 6. Hydrologic soil groups in the Blackberry Creek watershed, Ill. The Kane County portion of the watershed is from the SSURGO database (U.S. Department of Agriculture, Natural Resources Conservation Service, 1995), and the Kendall County portion is from the STATSGO database (U.S. Department of Agriculture, Natural Resources Conservation Service, 1994).

Table 3. U.S. Geological Survey (USGS) streamflow-gaging stations in the Blackberry Creek watershed, Ill.

USGS Station Number (fig. 1)	Station Name	Period of Record	Drainage Area (square miles)
05551700	Blackberry Creek near Yorkville	WY[1] 1961-present [2]	67.97
05551675	Blackberry Creek near Montgomery	WY 1998-present	56.54

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

[2] Present is defined as WY 2005.

streamflow at the Blackberry Creek near Montgomery station represents the outflow from the Kane County portion of the watershed. Records of AMS and unit-value discharges (streamflows reported at 15-minute intervals) at the two streamflow-gaging stations were used in this study. Because 10 years of record usually is the minimum length used for a reasonable frequency estimate, only the AMS at the Yorkville station was used for the flood-frequency analysis. The unit-value discharges have been developed for the Yorkville station after September 1989 and for the Montgomery station for the entire period of record (from WY 1998 to present (present is defined as WY 2005)). The unit-value discharges were aggregated to form the hourly streamflow time-series data so they could be compared to simulated hourly streamflow with the HSPF model simulation. The peak, daily mean, and unit-value discharge data for the two stations are published in the USGS annual water data report for Illinois (Robl and others, 2003).

Model Development

For the purpose of analyzing flood hazards in the Blackberry Creek watershed, the 71.16 mi^2 drainage area was divided between major tributaries and the main stem. The tributary and main-stem watersheds were further divided into subbasins so that drainage pattern in each subbasin could be identified and the subbasin acreage at the headwaters was approximately 1 mi^2. As a general rule, FEMA is concerned with flooding sources that have a drainage area of 1 mi^2 or more (Section 1.2.3.3 Mapping Needs Assessment for Unmapped Community [February 2002], Federal Emergency Management Agency, 2003b). In this study, subbasins were delineated with ArcHydro (Maidment, 2002) by selecting outlet points along the channel. In all, 49 subbasins were defined in the Blackberry Creek hydrologic model. These subbasins were numbered using a two-digit series to track the drainage sequence with the first digit identifying the tributary and second digit identifying the subbasin in the tributary. A higher second digit indicates a subbasin at the upstream end of the tributary. Subbasins along the main stem are designated in the 200 series ascending in the downstream direction. When a tributary enters the main stem, the first digit changes to reflect the combination with that tributary (see table 4 and fig. 7).

Tributaries F, D, C in Kane County are identified following the naming convention used in the U.S. Department of Agriculture, Soil Conservation Service (1989) study. The unnamed tributary in Kendall County (Series 80) was not analyzed in this study.

Simulating the physical processes of the hydrologic cycle in the Blackberry Creek watershed with HSPF involves preparing a user control input (UCI) file. The UCI file describes the conceptualized physical process of water (or other constituents) movement over the land and through the soil (fig. 3) and in the channels of the actual watershed so HSPF can simulate the movement.

In an HSPF simulation, computations are performed on land surfaces with spatially averaged land use and/or on channel reach segments. Land with a pervious surface is called a pervious-land segment (symbol PERLND) and land with impervious surface is called an impervious-land segment (symbol IMPLND). Further division of PERLND or IMPLND to more descriptive land-use

Table 4. Delineated subbasin numbering system used in this study of the Blackberry Creek watershed, Ill.

Tributary	Subbasins (upstream to downstream) (fig. 7)
Tributary F	10
Tributary D	22, 21, 20
Tributary C	33, 32, 31, 30
Prestbury Tributary	41, 40
Lake Run Tributary	57, 56, 55, 54, 53, 52, 51, 50
East Run Tributary	64, 63, 62, 61, 60
Chain-of-Lakes Tributary	73, 72, 71, 70
Unnamed Tributary in Kendall County	81, 80
Main stem of Blackberry Creek	208, 210, 213, 216, 218, 223, 226, 230, 233, 236, 240, 250, 260, 265, 270, 276, 278, 280, 290

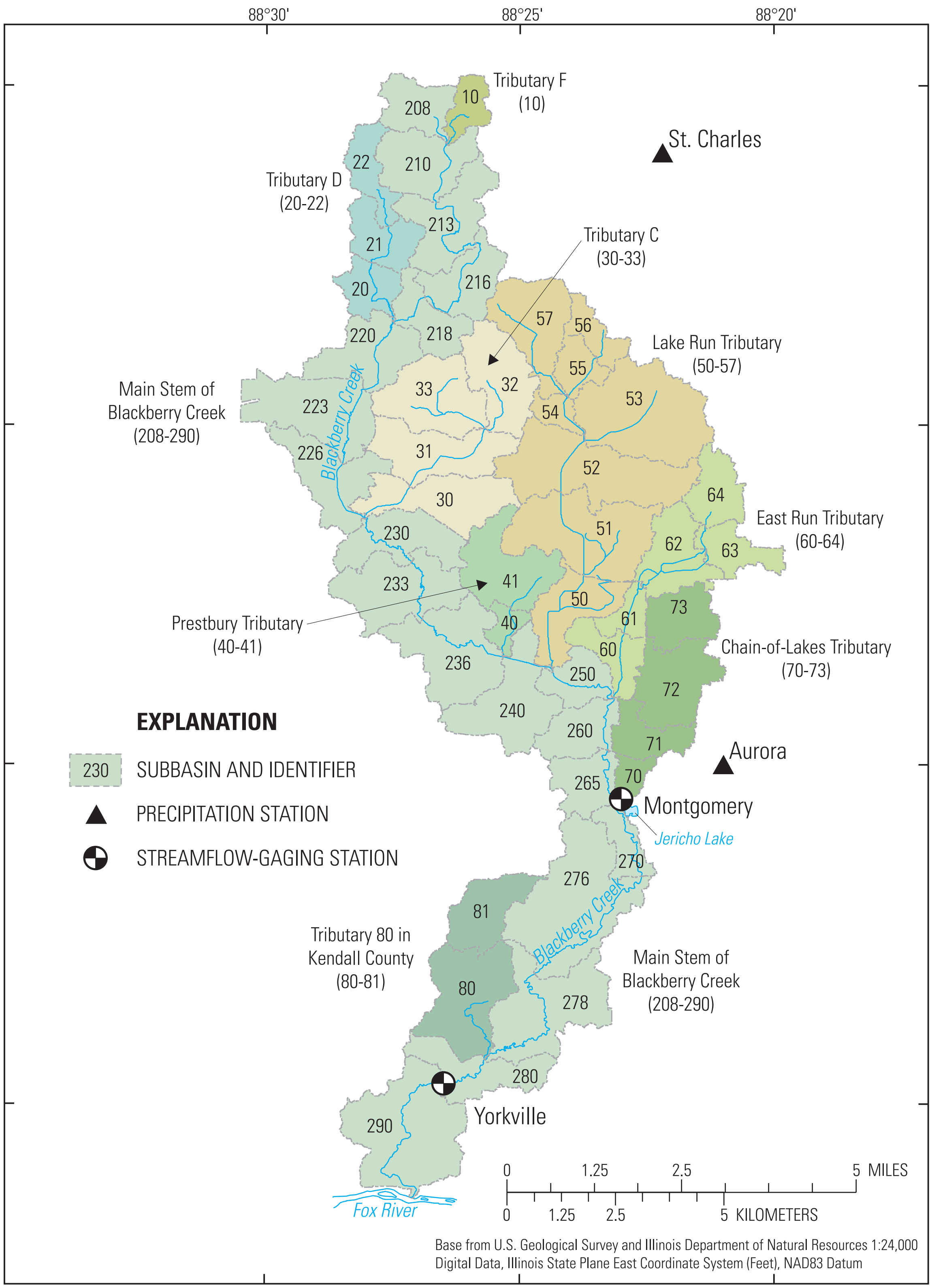


Figure 7. Subbasins and their associated numbering system used in the Blackberry Creek watershed, Ill., study.

segments can be done based on the objectives of model simulation.

The following PERLNDs and IMPLNDs are used in describing the land uses of the Blackberry Creek watershed. As described previously, the land-use categories generally follow the land-cover database categories, (Luman and others, 1996). A summary of the percentages of PERLNDs and IMPLNDs in the Blackberry Creek watershed is presented in table 5.

- PERLNDs
  - Cropland—row crops, small grains, orchards/nurseries
  - Grassland—urban grassland, rural grassland
  - Forested and Wooded Land—deciduous woods, open woods, coniferous woods
  - Pervious Residential—90 percent of low density urban; 50 percent of medium density urban
  - Wetland—shallow marsh/wet meadow, deep marsh, bottomland forest, swamp, shallow water wetland
  - Barren and Exposed Land—quarries, bare soil surfaces, beaches

- IMPLNDs
  - High Density Urban—all or nearly all of the land surface covered with manmade structures, open water (Open water is a separate category in the land-cover database but is simulated in the hydrologic model as impervious land.)
  - Impervious Residential—10 percent of low density urban; 50 percent of medium density urban
  - Transportation—interstates, highways, primary roads

Besides simulating surface runoff from the designated land-use segments, the simulated surface-runoff volumes were routed through each subbasin in this study.

Table 5. Percentages of PERLNDs (pervious lands) and IMPLNDs (impervious lands) in the Blackberry Creek watershed, Ill.

PERLND or IMPLND	Percentage in Watershed [1]
Cropland	54.1
Grassland	28.7
Forested and Wooded Land	6.1
Wetland	3.7
Pervious Residential	3.4
High Density Urban	1.2
Impervious Residential	1.2
Transportation	1.1
Barren and Exposed Land	.5

[1] Percentage values are rounded to the tenth.

Routing the flow allowed the storage and friction effects of the channels in each subbasin to be simulated. The flow routing characteristics are established in routing tables that describe the depth-surface, area-volume relations for each study reach (a subbasin in this study) and the depth-surface area-volume relations were obtained from hydraulic model analysis (described later). Different procedures were used to develop the routing tables at locations where diversion was observed, for example, from Jericho Lake (east of subbasin 270, see fig. 7) and from East Run Lake (subbasin 6, see fig. 7). Flows diverted out of the Blackberry Creek watershed from Jericho Lake near Montgomery, Illinois are discussed in detail in appendix B. Diverted flows from East Run Lake were estimated by using a weir-flow computation, and the outflow was added to subbasin 71 (see fig. 7). The simulated streamflow time series at each subbasin were used to calibrate and verify the hydrologic model and to generate the flood-frequency estimates.

Model Calibration

The storage and flux among various zones (fig. 3) are governed by a set of process parameters. These process parameters have physical meanings but their values for a specific watershed have to be determined through model calibration. Through calibration, a set of parameter values for a land-use segment is defined and the set of parameters are applied to all identical land-use segments in the watershed. These parameter values vary among the different land-use segments in a watershed.

Calibration of the process parameters for PERLND and IMPLND segments in the Blackberry Creek watershed hydrologic model was done with the HSPEXP (Version 2.3, Lumb and others, 1994), a manual-calibration expert system. Although automated calibration programs, such as PEST (parameter estimation program, Doherty 2002) were available for use in this study, using the HSPEXP system gives the opportunity to judge the values of the process parameters for the hydrologic model.

The objective of the calibration is to minimize the difference between the observed and simulated flows described in the hydrographs. Observed data were from the hourly flow records at the Yorkville station described previously. HSPEXP has a pre-determined set of criteria to guide the modeler to the convergence of parameter values. In the calibration process, BASINS Technical Note 6 (U.S. Environmental Protection Agency, 2000) was referenced for the maximum and minimum value of each parameter and these values were specified as the upper and lower limit, respectively, of the parameter being calibrated. Other references used included studies conducted in northeastern Illinois, such as Duncker and Melching (1998), Price (1996), and Duncker and others

(1995). The national database HSPFParm also was referenced (U.S. Environmental Protection Agency, 1999).

In HSPEXP (Version 2.3, Lumb and others, 1994), error terms for seven streamflow hydrograph characteristics and two other factors are computed as the criteria for accepting a set of model parameters or for adjusting certain specific parameter(s). These seven characteristics were:

1. error in total runoff volume for the calibration period,
2. error in the mean of the low-flow-recession rates,
3. error in the mean of the lowest 50 percent of the daily mean discharges,
4. error in the mean of the lowest 10 percent of daily mean discharges,
5. error in flow volumes for selected storms,
6. seasonal volume error, June-August runoff volume error minus December-February runoff volume error, and
7. error in runoff volume for selected summer storms.

The two factors were:

1. ratio of simulated surface runoff and interflow volumes, and
2. the difference between the simulated evapotranspiration and the potential evapotranspiration.

After optimal parameter values were determined with HSPEXP, three statistics were used to examine the goodness of fit between observed and simulated monthly runoff volume. These statistics were: (1) the correlation coefficient between simulated and observed flows, (2) the coefficient of model-fit efficiency (Nash and Sutcliffe, 1970), and (3) the number of months where the percentage error was less than a specific value. Duncker and Melching (1998) used these statistics in studying the regional parameters for watersheds in Du Page County, Ill. The correlation coefficient, r, is defined as

$$r = \frac{\sum_{i=1}^{N}(Q_{O_i} - Q_O)(Q_{S_i} - Q_S)}{\left[\sum_{i=1}^{N}(Q_{O_i} - X\,Q_O)^2 \times \sum_{i=1}^{N}(Q_{S_i} - Q_S)^2\right]^{1/2}} , \quad (1)$$

where

Q_{O_i} is observed total discharge for month i,

Q_{S_i} is the simulated total discharge for month i,

Q_O is the average observed total monthly discharge,

Q_S is the average simulated total monthly discharge, and

N is the number of months in the calibration period.

The r is a measure of how well the trends in simulated data follow trends in the observed data in the streamflow records. The coefficient of model-fit efficiency, E, is calculated as

$$E = 1 - \frac{\sum_{i=1}^{N}(Q_{O_i} - Q_{S_i})^2}{\sum_{i=1}^{N}(Q_{O_i} - Q_O)^2} . \quad (2)$$

The E is a direct measure of the fraction of the variance of the observed data series simulated with the model. If the data and model residuals are normally distributed, the E should nearly equal the square of the correlation coefficient (r^2). The E and r complement each other in the evaluation but the E can provide a more rigorous evaluation of the quality-of-fit than the r when the observed and simulated data have similar patterns. Helsel and Hirsch (1992), for example, showed that high correlation coefficients could be obtained between the observed and simulated values when the patterns of magnitudes are similar, although the differences in magnitude are large (that is, poor agreement). When the correlation coefficient is used, visual examination of the comparison between observed and simulated is necessary.

Calibration and Verification Results

Calibration and verification of the hydrologic model were done with observed discharges collected at Yorkville streamflow-gaging station for the periods from October 1, 1989, to September 30, 1995, and from October 1, 1995, to September 30, 1999, respectively. The use of 10 years of record (1989-99) was an attempt to include a wide range of variations in streamflows for calibrating and verifying the parameter values.

Meteorological data from Argonne and precipitation data from St. Charles and Aurora were used for simulating streamflow time series at the Yorkville site. The 1996 land-use conditions were considered representative during this 10-year period. Various streamflow characteristics were used in the calibration and verification procedures. Results of the calibration and verification are presented using five formats listed as follows.

1. Criteria specified for HSPEXP (table 6),
2. Correlation coefficient, model-fit efficiency, and percentage of months for which the percentage of error was less than 10- and 25- percent in monthly averaged discharges (table 7),
3. Comparison of simulated and observed monthly peak discharges (figs. 8-11). Monthly peak discharge is the highest instantaneous peak discharge in a month,

4. Comparison of simulated and observed storm hydrographs (figs. 12-13), and

5. Comparison of flow-duration curves generated from simulated and observed streamflow records (fig. 14).

The results of the HSPEXP calibration, used to minimize the difference between the various observed and simulated streamflow characteristics, are presented in table 6. It can be seen that the simulated and observed streamflow data are similar for the various specified criteria.

The correlation and model-fit efficiency coefficients for the averaged monthly streamflows were 0.92 and 0.81, respectively, for both the calibration and verification periods (table 7). During 20 percent of the study period (1989-99), the difference between observed and simulated average monthly streamflow was less than 10 percent; during 49 percent of the study period, the difference between observed and simulated average monthly streamflow was less than 25 percent (table 7). The model-simulation results based on these criteria compared well with three other studies in northeastern Illinois that were completed by the USGS and the Northeastern Illinois Planning Commission (table 7).

Observed and simulated monthly peak discharges were evaluated with linear-regression analysis. The value of the square of the correlation coefficient (r^2) and the plots of the regression and perfect agreement

Table 6. Calibration results from the Blackberry Creek watershed, Ill. hydrologic model analysis using criteria specified in the expert system for calibration of the Hydrological Simulation Program–FORTRAN (HSPEXP). The observed flow variables were obtained from streamflow records at the Yorkville streamflow-gaging station, Ill. (U.S. Geological Survey station number 05551700).

HSPEXP Criteria	Observed	Simulated
Error in total volume, in inches	71.13	81.85
Total of highest 10 percent flows, in inches	28.39	29.15
Total of lowest 50 percent flows, in inches	12.22	14.27
Total storm volume, in inches	16.89	22.24
Average of storm peaks, in cubic feet per second	283.6	309.6
Summer flow volume, in inches	12.82	14.77
Winter flow volume, in inches	19.88	25.42
Summer storm volume, in inches	5.17	6.80

Table 7. Model-fit statistics for the Blackberry Creek watershed study and other studies in northeastern Illinois.

[mi², square miles; - -, not determined]

Study	Correlation coefficient (*r*)	Coefficient of model-fit efficiency (*E*)	Percentage of months when the difference between observed and simulated average monthly discharge was less than 10 percent	Percentage of months when the difference between observed and simulated average monthly discharge was less than 25 percent	Watershed area (mi^2)	Number of months used for model simulation
Blackberry Creek watershed Study (this study)	0.92	0.81	20	49	68.0	120
DuPage County (U.S. Geological Survey, 1998)	0.93 - 0.96	0.86 – 0.92	22 – 33	47 – 60	11.1 - 13.3	45
DuPage County (Northern Illinois Planning Commission, 1994)	0.88 - 0.95	- -	- -	- -	28.2 - 115.6	108
Lake County (U.S. Geological Survey, 1995)	0.93 - 0.97	0.86 – 0.92	28 – 42	51 – 67	6.3 - 59.9	43

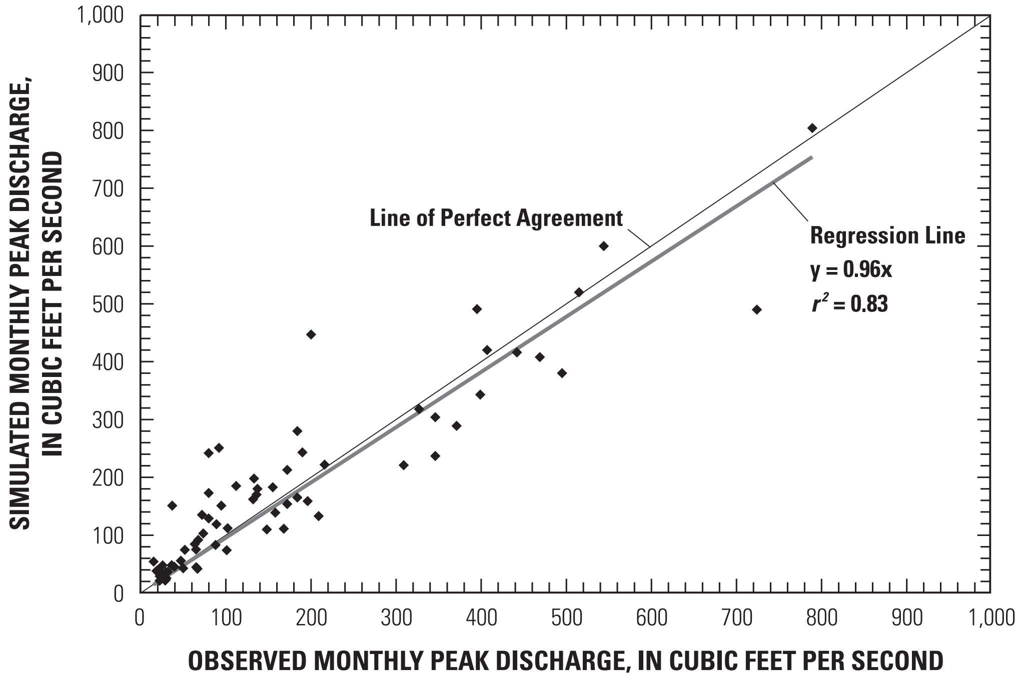


Figure 8. Observed and simulated monthly peak discharges for the calibration period (water years 1990-95) at the Yorkville streamflow-gaging station, Blackberry Creek watershed, Ill. Four of the 72 monthly peaks were considered outliers and are not included. r^2 is the square of the correlation coefficient.

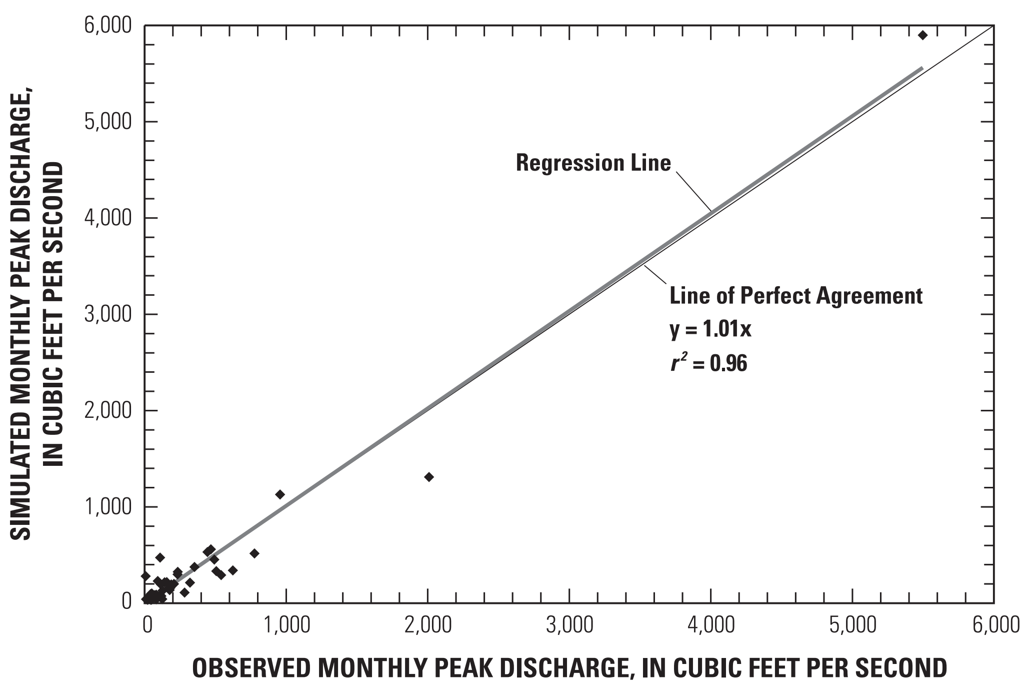


Figure 9. Observed and simulated monthly peak discharges for the verification period (water years 1996-99) at the Yorkville streamflow-gaging station, Blackberry Creek watershed, Ill. All verification monthly peak discharges are included. r^2 is the square of the correlation coefficient.

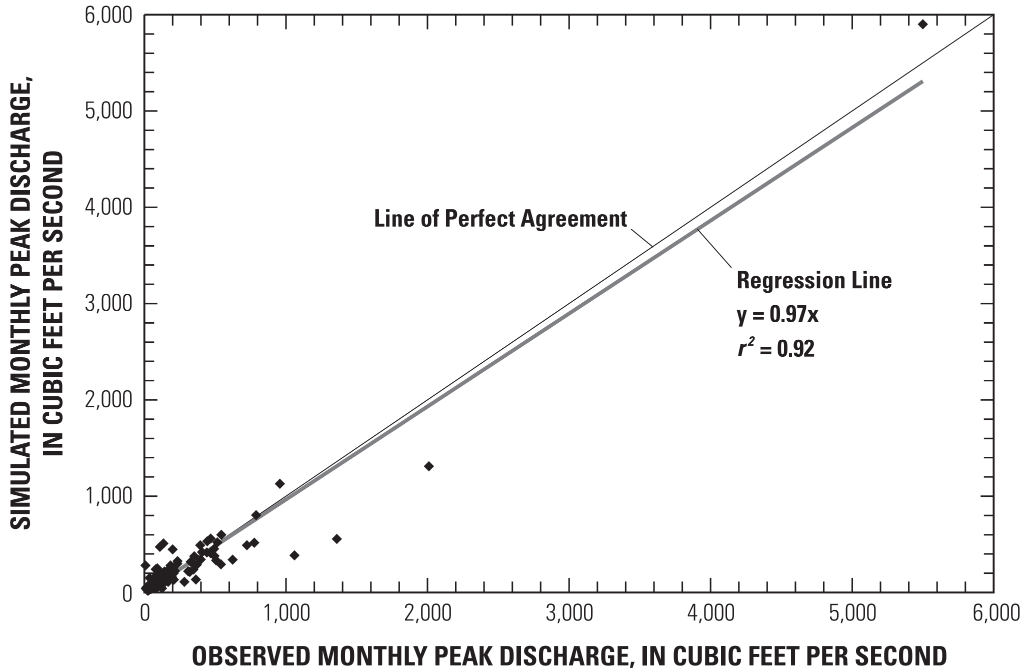


Figure 10. Observed and simulated monthly peak discharges for the calibration and verification periods (water years 1990-99) at the Yorkville streamflow-gaging station, Blackberry Creek watershed, Ill. All study period monthly peak discharges are included. r^2 is the square of the correlation coefficient.

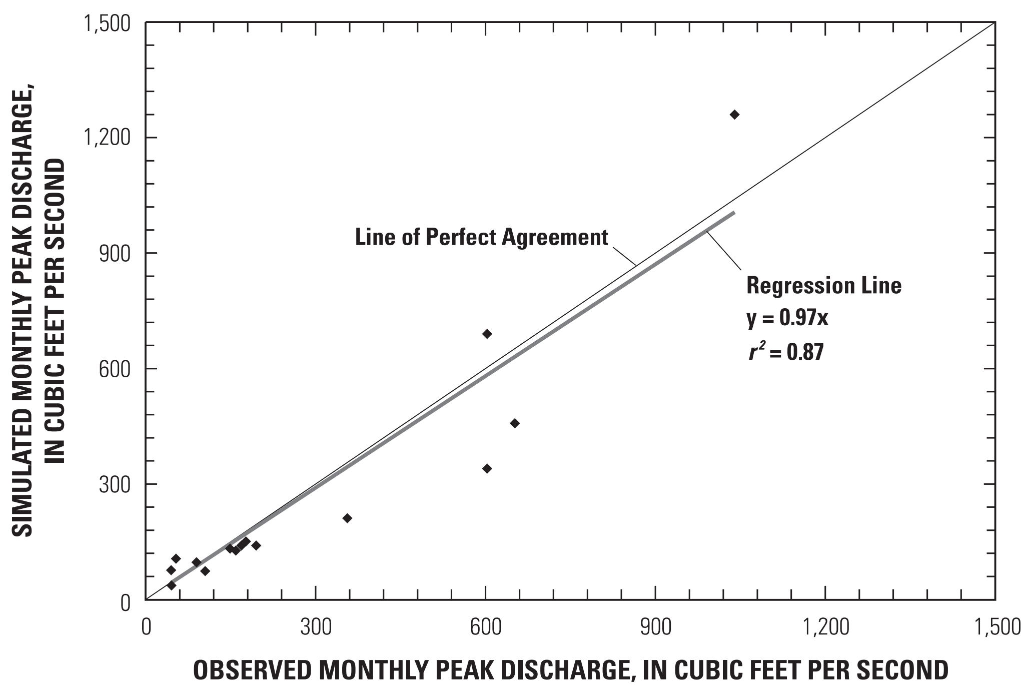


Figure 11. Observed and simulated monthly peak discharges for water year 1999 at the Montgomery streamflow-gaging station, Blackberry Creek watershed, Ill. r^2 is the square of the correlation coefficient.

lines showed good agreement between the observed and simulated data (figs. 8-10). Some differences between observed and simulated values (data pairs) could not be explained. Four out of the 72 data pairs used for model calibration were considered to be outliers and were removed from the analysis. Note that the July 1996 flood was in the verification period (fig. 9). This storm was an extreme event with a flood-peak magnitude (instantaneous value) of 5,510 ft^3/s. As an illustration of the overall fit for the entire calibration and verification periods, all the monthly peak discharges (including the calibration outliers) were included in regression analysis as shown in figure 10.

The observed monthly peak discharges at the Montgomery streamflow-gaging station, from October 1, 1998, to September 30, 1999, were used to evaluate how well the observed and simulated streamflows matched at a streamflow-gaging station other than the Yorkville streamflow-gaging station used in model calibration. The results at Montgomery station were similar to those obtained at the Yorkville streamflow-gaging station (fig. 11).

In addition to monthly peak discharges, storm hydrographs were compared to evaluate the magnitude, timing, and duration of flows throughout different storm events. Flows produced by three selected storms were compared at the Yorkville streamflow-gaging station (fig. 12), and one storm was compared at both the Yorkville and Montgomery stations (fig. 13).

The overall simulation quality was examined further using the flow-duration curve that includes flow magnitudes in all ranges. Daily mean discharge flow-duration curves were developed for the entire calibration and verification period, as shown in figure 14.

Results, as shown in the tables and figures presented in this section, indicated that simulated flow volumes, peak discharges, and the magnitude, timing and duration of flow hydrographs were, in general, in good agreement with the observed data at Yorkville and Montgomery streamflow-gaging stations. Therefore, a reasonable set of parameter values for Blackberry Creek watershed was developed. The final, calibrated model parameter values are presented in tables 8 and 9.

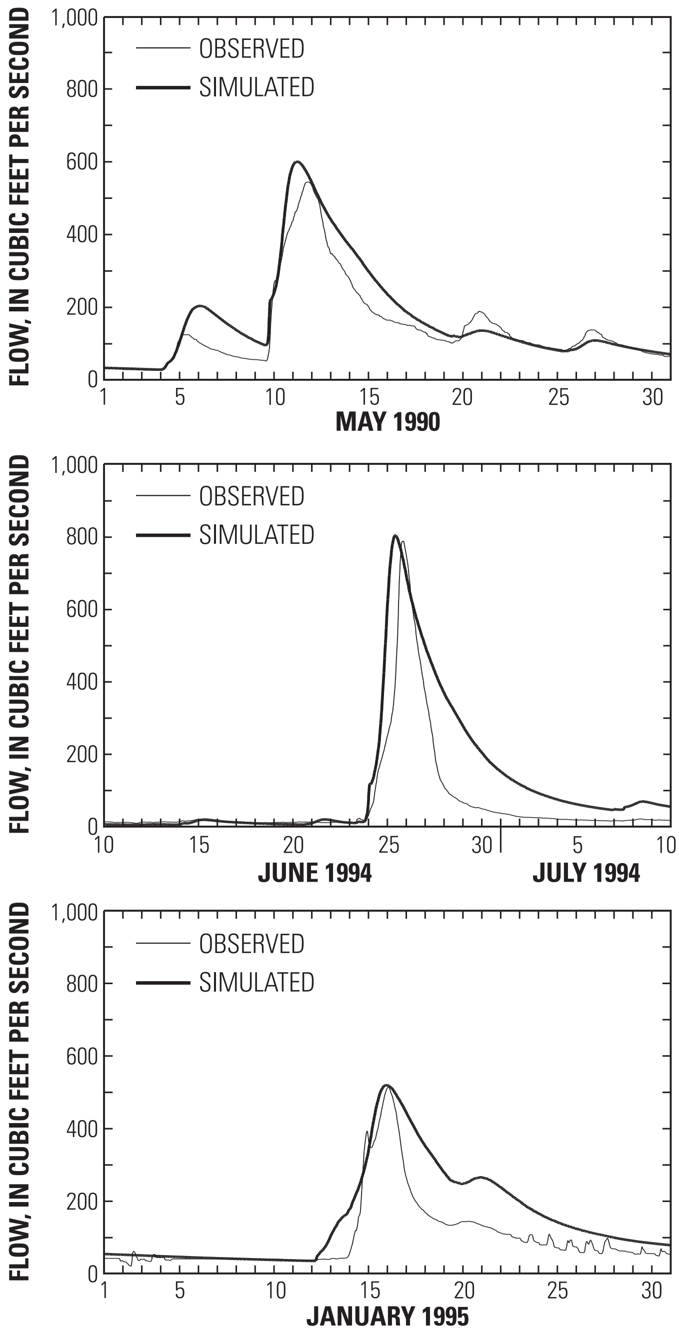


Figure 12. Observed and simulated hourly streamflow at the Yorkville streamflow-gaging station, Blackberry Creek watershed, Ill., for selected storm events during the 72-month calibration period (water years 1990-95).

Verification with the July 1996 Flood

Although the model simulation results were verified at one site (Montgomery) an appreciable distance away from the model calibration point, further verification of the simulation results at other locations inside the watershed was needed for this watershed-scale study. This additional verification was achieved using streamflows from the July 1996 flood event. The July 1996 flood was used to further verify the capability of the hydrologic model to simulate 1) reasonable discharge magnitudes at locations inside the watershed, and 2) extreme floods with low exceedance probabilities (such as rare floods with recurrence interval higher than 100 years). If the simulated July 1996 flood hydrograph at the Yorkville station was similar to the observed hydrograph, then flow hydrographs simulated for other locations in the watershed, together with high water marks (HWMs) and

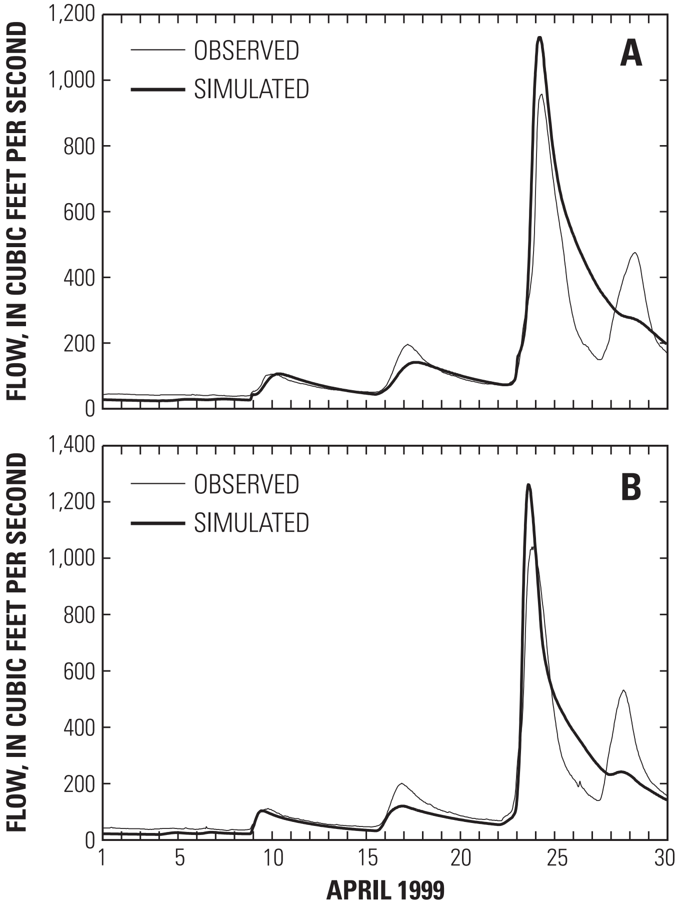


Figure 13. Observed and simulated streamflow at the (A) Yorkville and (B) Montgomery streamflow-gaging stations, Blackberry Creek watershed, Ill., for a selected storm during the 48-month verification period (water years 1996-99).

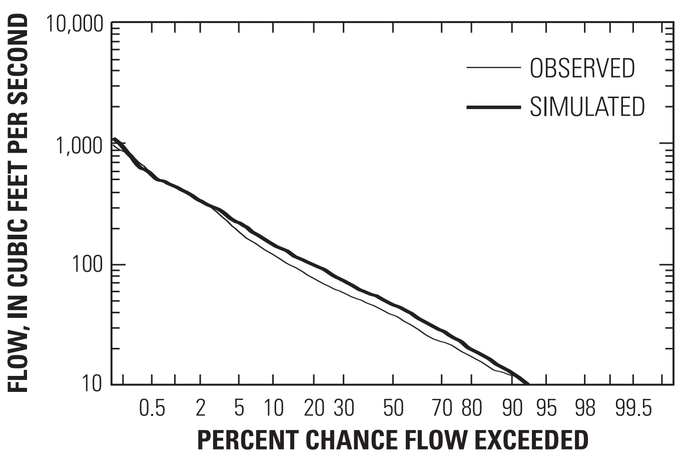


Figure 14. Observed and simulated flow-duration curves using daily values for water years 1990-99 at the Yorkville streamflow-gaging station, Blackberry Creek watershed, Ill.

inundation information collected for the July 1996 flood, could be used to examine the performance of the hydrologic model and routing functions developed from the hydraulic model.

Recorded rainfall totals for July 17-18, 1996, were 16.91 in. at Aurora and 6.59 in. at St. Charles precipitation stations (data from the National Weather Service; summarized in Holmes and Kupka, 1997). These 24-hour rainfall totals have exceedance probabilities less than 1 percent (higher than the 100-year event) according to Bulletin 70 (Huff and Angel, 1989). The measured instantaneous peak discharge at the Yorkville station (5,510 ft^3/s) exceeded the estimated 500-year flood quantile of 3,800 ft^3/s (Soong and others, 2004). Because the measured rainfall totals varied appreciably between the two precipitation stations, the ability to simulate the flood runoff also depends heavily on the accuracy of the rainfall input. To simulate the July 1996 storm event, the spatial distribution of the hourly rainfall data over the watershed were described by the Next Generation Radar (NEXRAD) rainfall information in addition to the Aurora and St. Charles rainfall data that were distributed with the Thiessen method as described below.

Flood Simulated with Rainfall Determined with the Thiessen Method

The July 17-18, 1996, flood hydrograph simulated with rainfall distributed with the Thiessen method (Chow and others, 1988) was compared to the observed hydrograph as shown in figure 15. Although the two hydrographs are similar, the simulated peak is higher and comes before the observed peak—similar to the comparisons presented in figures 12 and 13. This situation results because uniform rainfall amounts represented by the St. Charles and Aurora stations were assigned to the portions of the watershed divided with the Thiessen method (see fig. 4). In reality, the rainstorms traveled through the watershed with variable intensities. Yen and Chow (1968) found that the reduction and delay of peak discharge increases with the increase of the velocity magnitude in rainstorm movement.

Flood Simulated with Next Generation Radar (NEXRAD) Stage III Precipitation Data

The NEXRAD analysis was done with Stage III NEXRAD data (National Weather Service, 2002), radar data adjusted using hourly point rainfall data. The NEXRAD precipitation data are equivalent to having 16 precipitation stations (represented by the cells) over the watershed (fig. 16). The gridded 48-hour (July 17-18, 1996) radar rainfall totals were areally averaged over each of the 49 subbasins. For model-simulation pur-

Table 8. Hydrological Simulation Program–FORTRAN (HSPF) model parameters for the Blackberry Creek watershed, Ill.

[ft/ft, foot per foot]

Surface slopes: Flat to Moderate is defined by a slope of less than or equal to 0.03 ft/ft; Steep is defined by a slope greater than 0.03 ft/ft.
Soil groups: Soil 1 includes hydrologic soil groups A and B; Soil 2 includes hydrologic soil groups C and D (see Soils Data section for further explanation of soil groups).
Parameters: FOREST, fraction of pervious land covered by forest; LZSN, lower zone nominal storage; INFILT, infiltration; NSUR, Manning's n for overland flow plane; AGWRC, active ground-water recession constant; DEEPFR, fraction of ground-water inflow; AGWETP, active ground-water evapotranspiration; INTFW, interflow; IRC, interflow recession constant.

Pervious Land Segment (PERLND)/ Surface slope/Soil group	Parameters								
	FOREST	LZSN	INFILT	NSUR	AGWRC	DEEPFR	AGWETP	INTFW	IRC
Cropland/Flat to Moderate/Soil 1	0.00	4.0	0.080	0.10	0.980	0.05	0.05	4.5	0.70
Cropland/Flat to Moderate/Soil 2	.00	3.5	.030	.10	.980	.05	.05	4.5	.70
Cropland/Steep/Soil 1	.00	3.5	.075	.10	.980	.05	.05	4.0	.65
Cropland/Steep/Soil 2	.00	3.0	.025	.10	.980	.05	.05	4.0	.65
Grassland/Flat to Moderate/Soil 1	.05	4.5	.085	.40	.980	.05	.05	5.0	.70
Grassland/Flat to Moderate/Soil 2	.05	4.0	.035	.40	.980	.05	.05	5.0	.70
Grassland/Steep/Soil 1	.05	4.0	.080	.40	.980	.05	.05	4.5	.65
Grassland/Steep/Soil 2	.05	3.5	.030	.40	.980	.05	.05	4.5	.65
Forested and Wooded Land/ Flat to Moderate/Soil 1	.40	5.0	.105	.45	.980	.05	.10	4.7	.70
Forested and Wooded Land/ Flat to Moderate/Soil 2	.40	4.5	.055	.45	.980	.05	.10	4.7	.70
Forested and Wooded Land/ Steep/Soil 1	.40	4.5	.100	.45	.980	.05	.10	4.2	.65
Forested and Wooded Land/ Steep/Soil 2	.40	4.0	.050	.45	.980	.05	.10	4.2	.65
Pervious Residential/ Flat to Moderate/Soil 1	.20	4.7	.090	.25	.980	.05	.05	4.6	.70
Pervious Residential/ Flat to Moderate/Soil 2	.20	4.2	.040	.25	.980	.05	.05	4.6	.70
Pervious Residential/Steep/Soil 1	.20	4.2	.085	.25	.980	.05	.05	4.1	.65
Pervious Residential/Steep/Soil 2	.20	3.7	.035	.25	.980	.05	.05	4.1	.65
Wetland/Flat to Moderate/Soil 1	.10	4.5	.150	.20	.985	.05	.60	3.5	.70
Wetland/Flat to Moderate/Soil 2	.10	4.0	.100	.20	.985	.05	.60	3.5	.70
Barren and Exposed/ Flat to Moderate/Soil 1	.00	7.5	.250	.05	.980	.05	.15	3.5	.70
Barren and Exposed/Steep/Soil 2	.00	7.5	.200	.05	.980	.05	.15	3.5	.70

Table 9. Monthly variations of Hydrological Simulation Program–FORTRAN model parameters for the Blackberry Creek watershed, Ill.

[ft/ft, foot per foot]

Parameters: CEPSC, interception storage; UZSN, upper zone nominal storage; LZETP, lower zone evapotranspiration; RETSC, retention storage
Surface slopes: Flat to Moderate is defined by a slope of less than or equal to 0.03 ft/ft; Steep is defined by a slope greater than 0.03 ft/ft

Parameter and Land Segment	January	February	March	April	May	June	July	August	September	October	November	December
CEPSC												
Cropland	0.05	0.02	0.02	0.05	0.06	0.13	0.20	0.25	0.20	0.20	0.15	0.10
Grassland	.07	.04	.04	.07	.08	.13	.20	.25	.20	.20	.17	.12
Forested and Wooded Land	.08	.08	.08	.08	.09	.14	.22	.27	.22	.15	.10	.10
Pervious Residential	.07	.06	.06	.07	.09	.14	.21	.26	.21	.17	.16	.11
Wetland	.05	.05	.05	.05	.06	.13	.15	.15	.15	.15	.15	.10
Barren and Exposed	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05
UZSN												
Cropland/Flat to Moderate	.90	.60	.40	.40	.40	.90	1.10	1.10	1.10	1.05	1.05	1.00
Cropland/Steep/	.85	.55	.35	.35	.35	.85	1.05	1.05	1.05	1.00	1.00	.95
Grassland/Flat to Moderate	.70	.55	.45	.45	.45	.75	.90	.90	.90	.85	.85	.80
Grassland/Steep/	.65	.50	.40	.40	.40	.70	.85	.85	.85	.80	.80	.75
Forested and Wooded Land (Flat to Moderate	1.00	.60	.50	.50	.50	1.00	1.20	1.20	1.20	1.15	1.15	1.10
Forested and Wooded Land/Steep/	.95	.55	.45	.45	.45	.95	1.15	1.15	1.15	1.10	1.10	1.05
Pervious Residential/Flat to Moderate	.95	.65	.45	.45	.45	.95	1.15	1.15	1.15	1.10	1.10	1.05
Pervious Residential/Steep/	.90	.60	.40	.40	.40	.90	1.10	1.10	1.10	1.05	1.05	1.00
Wetland	.80	.80	.80	.80	.80	.80	.80	.80	.80	.80	.80	.80
Barren and Exposed	.80	.80	.80	.80	.80	.80	.80	.80	.80	.80	.80	.80
LZETP												
Cropland and Grassland	.00	.00	.00	.00	.00	.25	.35	.50	.40	.20	.10	.10
Forested and Wooded Land and Pervious Residential	.03	.00	.00	.04	.06	.35	.55	.70	.60	.40	.30	.20
Wetland	.02	.00	.00	.03	.05	.30	.45	.60	.50	.30	.20	.15
RETSC												
Impervious Land Segments	.09	.08	.05	.05	.06	.10	.10	.10	.10	.10	.10	.10

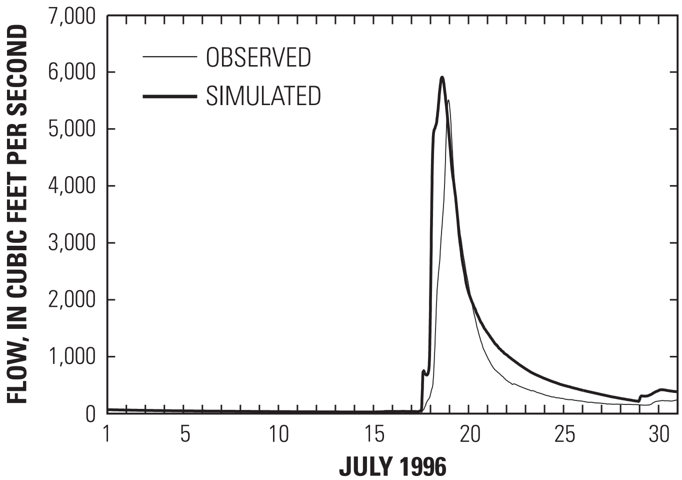


Figure 15. Observed and simulated flow hydrographs for July 1996 at the Yorkville streamflow-gaging station, Blackberry Creek watershed, Ill., based on the Thiessen method.

poses, the average rainfall value for each subbasin has been rounded to the nearest half inch.

During the analysis, it was found that eight cells (numbers 98308, 98438, 98631, 98755, 98883, 99009, 99202, and 99332; see figure 16) near the Aurora precipitation station contained missing data. Cells 98438 and 98883 were replaced with 48-hour totals from the Aurora precipitation station. For the remaining six cells containing missing data, values were interpolated from nearby cells. With this rainfall assignment, the resulting hydrograph for the July 1996 event is presented in figure 17.

By using the more spatially representative rain distribution, the resulting simulated hydrograph better matched the observed hydrograph. The peak discharge and timing of the peak were estimated better by utilizing the gridded radar rainfall data (table 10). However, the volume of the simulated hydrograph still was larger than the observed hydrograph. This difference in volume resulted probably either because the estimated rainfall was larger than the actual amount or inaccuracies remain in model parameters or routing characteristics. Comparisons with the observed HWMs and inundation map will be discussed in the Hydraulic Model Analysis section.

Based on the analysis of the July 1996 flood, the calibrated hydrologic model can accurately simulate infrequent floods. Satisfactory results also were obtained for the calibration and verification periods. Considering the successful simulation of the flood and calibration and verification periods, along with the limitations of the available data and the approximate nature of hydrologic modeling, the hydrologic model was considered successfully calibrated and further modification of parameter values was not pursued.

FLOOD-FREQUENCY ANALYSIS

Utilizing the annual maximum series (AMS) determined from simulated streamflow records at various locations in the watershed from the hydrologic model, flood-frequency analysis was used to estimate flood quantiles. The 100- and 500-year floods determined in this analysis were then used in the hydraulic model analysis. Throughout this section, recurrence interval and exceedance probability will be discussed and compared. To convert from recurrence interval to exceedance probability, the percent exceedance probability percentage is divided by 100 to obtain a fraction, then the inverse of that fraction is calculated. For example, an exceedance probability of 50 percent corresponds to a recurrence interval of 2 years (50/100 = 0.5; 1/0.5 = 2).

Simulation of Long-Term Flood Series and Frequency Quantiles

Because the precipitation data at St. Charles started in 1989, the combination of St. Charles and Aurora precipitation records could not be used for long-term simulation even though the record at Aurora started in 1948. Aurora, Argonne, Wheaton, O'Hare, and Elgin (fig. 4) are other long-term precipitation stations near the Blackberry Creek watershed. Using precipitation data recorded outside the watershed increased the uncertainty (because of climatic variability) in the simulated streamflow and estimated flood quantiles. However, uncertainties in estimated flood quantiles also can be reduced with

Table 10. Observed and simulated peak discharge for the July 17-18, 1996, storm event at the Yorkville streamflow-gaging station, Blackberry Creek watershed, Ill., using different rainfall inputs for the storm.

[ft^3/s, cubic feet per second; NEXRAD, Next Generation Radar]

Method	Observed peak discharge (ft^3/s)	Simulated peak discharge (ft^3/s)	Percent error in peak discharge	Observed time of peak on July 18, 1996	Simulated time of peak on July 18, 1996
Thiessen	5,510	5,900	7.3	22:00	14:00
NEXRAD	5,510	5,710	3.8	22:00	19:00

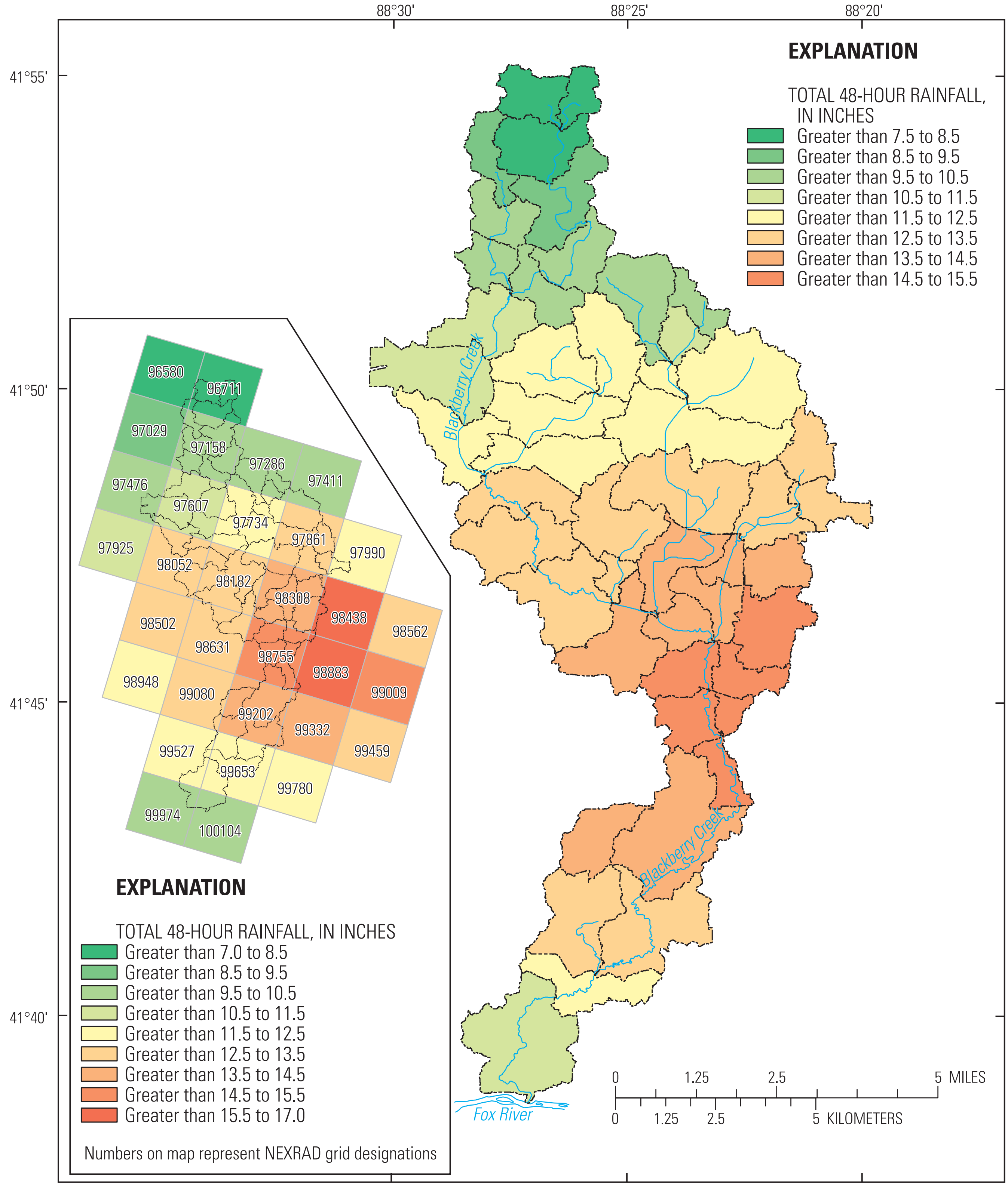


Figure 16. Next Generation Radar (NEXRAD)-generated rainfall totals for each grid cell and areally averaged to each subbasin for the July 17-18, 1996, storm event, Blackberry Creek watershed, Ill. NEXRAD data are from National Weather Service (2002).

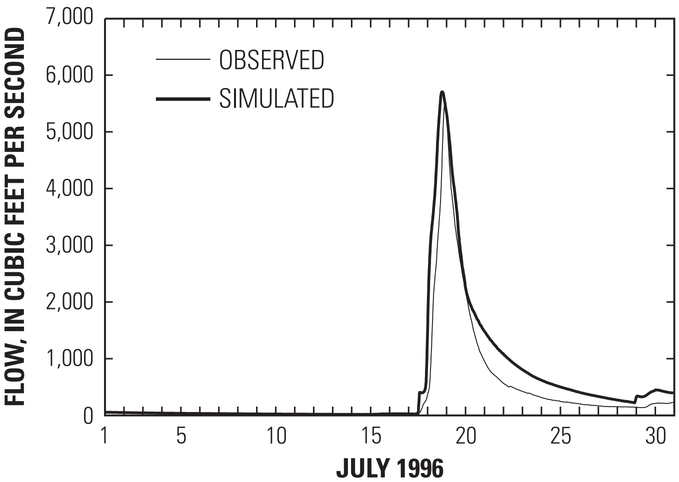


Figure 17. Observed and simulated flow hydrographs for July 1996 at the Yorkville streamflow-gaging station, Blackberry Creek watershed, Ill., based on Next Generation Radar (NEXRAD) Stage III data.

the use of the longest possible synthetic records, even if the stations where precipitation data are collected are in the vicinity but not in the watershed (Potter and Bradley, 1991). Hourly precipitation data from WY 1950-99 at the five long-term precipitation stations were separately applied to the HSPF Blackberry Creek hydrologic model. Flood quantiles were estimated based on the AMS from WY 1950-99.

The simulated flood-frequency curves from the five precipitation stations at subbasin 280 (where the Yorkville streamflow-gaging station is located) are presented in figure 18. Also included in figure 18 are the weighted regional flood-frequency curves and corresponding upper and lower 95-percent confidence intervals from the recent flood-frequency analysis (Soong and others, 2004). Frequency curves estimated with Argonne and O'Hare precipitation records were closest to the weighted regional frequency curve than with other precipitation records (fig. 18). However, comparing the timing of annual peaks at the Yorkville streamflow-gaging station showed that synthesized floods using Argonne records were closer to the observed data than using the O'Hare records.

The Argonne rainfall data were further evaluated with the Aurora and St. Charles rainfall data (Thiessen method used in the calibration and verification period) as shown in table 11. Because the yearly and cumulative yearly precipitation amounts were similar, it was assumed the Argonne precipitation data would be representative for the long-term simulation with the HSPF Blackberry Creek hydrologic model. The following section describes the evaluation of the flood quantiles at the Yorkville streamflow-gaging station.

Evaluation of Flood Quantiles at the Yorkville Streamflow-Gaging Station

The synthetic-flow flood quantile estimation was evaluated by comparing the quantiles to those estimated with observed data at the Yorkville streamflow-gaging station. Because the simulated AMS with Argonne precipitation data (WY 1950-99) is longer than the observed AMS at the Yorkville station (WY 1961-99), an additional set of flood quantiles was generated from an AMS with the same duration as the observed records.

The observed and simulated AMS data are plotted in figure 19. It can be seen that the flood peak discharge magnitudes compared reasonably well especially at higher annual peak discharges. The regression results were consistent with those obtained during model calibration and verification.

Flood quantiles resulting from the simulated WY 1950-99 (long-term) and the WY 1961-99 AMS are presented in table 12. The simulated WY 1961-99 flood quantile magnitudes were in agreement with the observed flood quantile magnitude, whereas the WY 1950-99 flood quantile magnitudes were generally higher than those estimated from observed AMS (WY

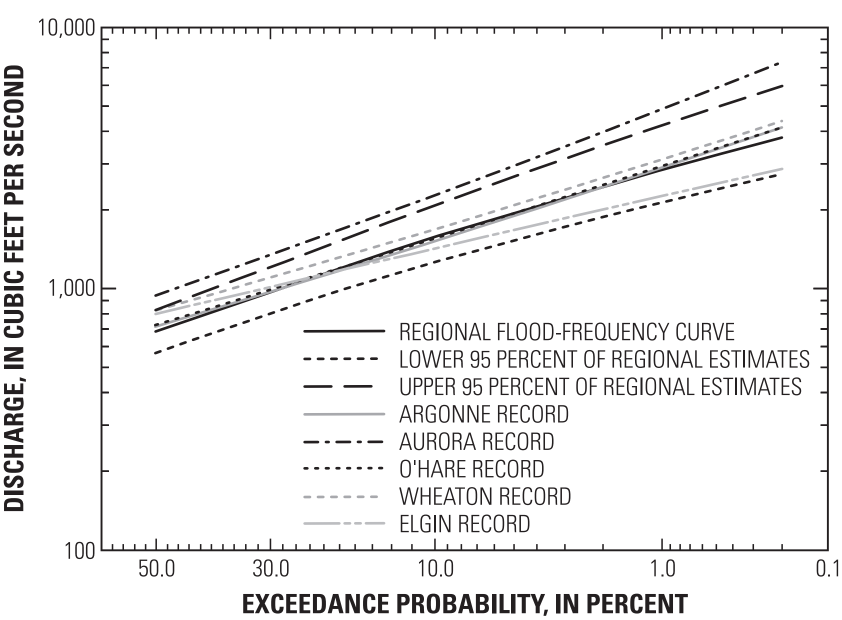


Figure 18. Comparison of flood-frequency curves simulated using precipitation records from five long-term precipitation stations in northern Illinois.

1961-99). This difference is because of two large floods in the 1950s, and other factors discussed below.

The simulated flood quantiles were slightly higher than those based on observed data at the 2- and 500-year recurrence interval of the flood-frequency curve (table 12). The HSPF model simulated the entire streamflow period using only the 1996 land-use conditions; whereas the observed streamflows (hence, the flood series) reflect the changes in land use in the watershed over the simulation period. When the impervious area increases in a watershed, the flood peaks and volumes, especially those with lower recurrence intervals (such as the 2-year recurrence interval), also increase (Rhoads, 1995). This increase is likely part of the reason for the larger difference between the observed and simulated flood peaks below 700 ft^3/s (approximately the 2-year recurrence interval) shown in figure 19, and the slightly higher flood quantiles at the lower end of the flood-frequency curve (table 12 and fig. 18). The difference between the observed and simulated low recurrence interval floods and the inclusion of the 500-year recurrence interval flood that occurred in July 1996 might have affected the curvature of flood-frequency curves calculated from the simulated AMS.

Another possible reason for the differences between the observed and simulated flood quantiles are the differences in the statistical parameters of the AMS. The statistical parameters (mean, standard deviation, and skew coefficient) calculated from the simulated AMS, were different from those calculated from the observed AMS. Because the statistical parameters are used for flood quantile calculation, the flood quantiles were different for the simulated and observed AMS. At the Yorkville streamflow-gaging station, the mean, standard, deviation, and skew of the simulated AMS (WY 1961-99) were 873 ft^3/s, 767 ft^3/s, and 4.44, respectively; whereas, for the observed AMS, the statistics were 901 ft^3/s, 883 ft^3/s, and 3.96, respectively. The slight differences in the mean and standard deviation of the simulated and observed AMS could have caused the differences between the resulting flood quantiles. In general, the differences in estimated flood quantiles were considered insignificant.

Table 11. Comparison of yearly and cumulative yearly precipitation for the calibration and verification periods at Argonne National Laboratory, Ill., and combined precipitation amount at Aurora and St. Charles, Ill. The combined yearly totals for Aurora/St. Charles are calculated by multiplying the weighted area ratio (Aurora rainfall amount by 52.1 percent and the St. Charles rainfall amount by 47.9 percent) as determined with the Thiessen method.

[NA, not applicable]

	Calibration Period (WY 1990-95)			
	Argonne Precipitation		Aurora/St.Charles Precipitation	
Water Year	Yearly total (inches)	Cumulative total (inches)	Yearly total (inches)	Cumulative total (inches)
1990	41.6	41.6	33.8	33.8
1991	34.9	76.5	32.7	66.5
1992	35.9	112.4	30.4	96.9
1993	47.0	159.4	42.6	139.5
1994	26.3	185.7	27.6	167.1
1995	32.3	218.0	37.3	204.4
Average	**36.3**	**NA**	**34.1**	**NA**
Standard Deviation	**7.2**	**NA**	**5.3**	**NA**

	Verification Period (WY 1996-99)			
	Argonne Precipitation		Aurora/St.Charles Precipitation	
Water Year	Yearly total (inches)	Cumulative total (inches)	Yearly total (inches)	Cumulative total (inches)
1996	41.0	41.0	44.3	44.3
1997	31.3	72.3	29.6	73.9
1998	41.4	113.7	39.8	113.7
1999	37.4	151.1	37.7	151.4
Average	**37.8**	**NA**	**37.9**	**NA**
Standard Deviation	**4.7**	**NA**	**6.2**	**NA**

Table 12. Comparison of flood quantiles resulting from observed and simulated annual maximum series at the Yorkville streamflow-gaging station, Kendall County, Ill.

[Q_T, flood quantile at T-year recurrence interval, in cubic feet per second; WY, water year]

	Flood Quantiles, Q_T							
	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{200}	Q_{500}
Station data WY 1961-99	686	1,197	1,570	2,071	2,457	2,850	3,252	3,795
Simulated WY 1961-99	720	1,154	1,484	1,948	2,327	2,735	3,173	3,806
Simulated WY 1950-99	716	1,168	1,521	2,027	2,450	2,911	3,416	4,157

Based on the evaluation described above, the Argonne precipitation data were used for performing the long-term streamflow simulation with the HSPF model. Flood quantiles for each subbasin estimated based on the AMS from WY 1950-99 using Argonne precipitation data as input into the HSPF Blackberry Creek hydrologic model are presented in table 13.

Comparison of Flood Quantiles to the U.S. Department of Agriculture, Soil Conservation Service (1989) Study

Flood quantiles estimated by U.S. Department of Agriculture, Soil Conservation Service (1989) study were based on the design storm approach and were given at specific cross sections in the watershed. A comparison between the flood quantiles calculated in the USDA study and this study was performed. However, it should be noted that land uses before 1989 were different from those in 1996. The subbasin delineations, channel and structural modifications, and other watershed characteristics were also different at the time of the two studies.

The comparison of estimated flood quantiles between the two studies is shown in table 14. Some of the differences could be clearly attributed to changes in land uses such as changes in East Run tributary. Minimal differences resulted in subbasins, for example, Prestbury tributary, where no appreciable changes in land use have occurred.

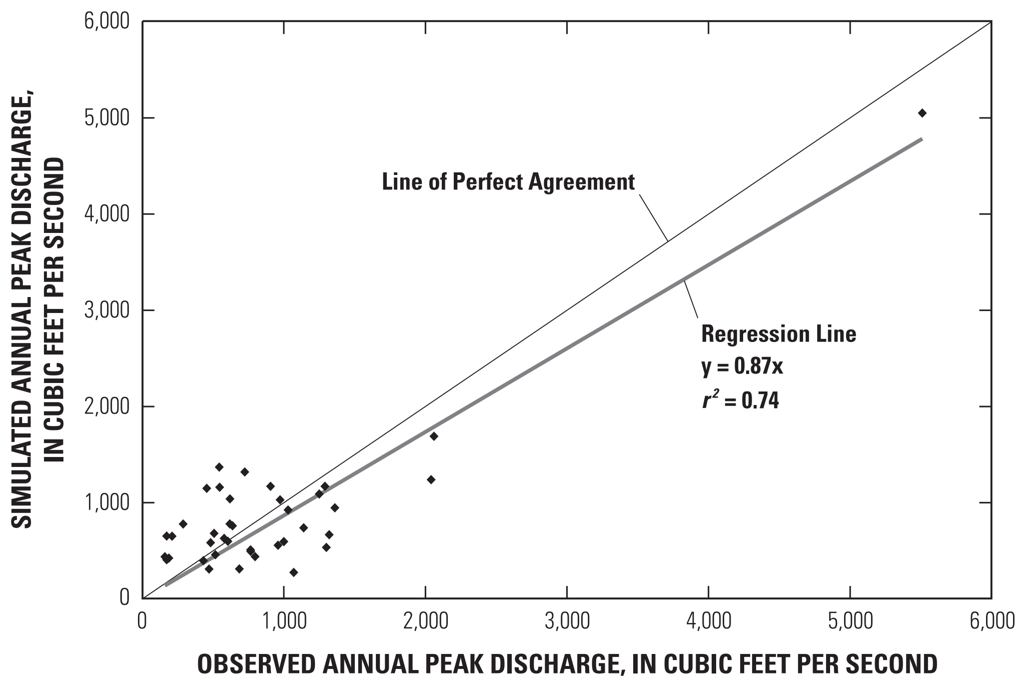


Figure 19. Comparison of observed and simulated annual flood-peak discharge magnitudes for water years 1961-99 at the Yorkville streamflow-gaging station, Blackberry Creek watershed, Ill. r^2 is the square of the correlation coefficient.

Table 13. Estimated flood quantiles at 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year recurrence intervals for subbasins (upstream to downstream) of the Blackberry Creek watershed, Ill.

[Q_T, flood quantile at T-year recurrence interval, in cubic feet per second]

Subbasin Number (Fig. 7)	Flood Quantiles, Q_T							
	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{200}	Q_{500}
				Tributary F				
10	25	45	59	78	93	108	123	144
				Tributary D				
[1]22	53	84	105	130	149	167	184	206
21	106	202	281	397	494	599	713	879
20	150	296	418	599	753	922	1,108	1,379
				Tributary C				
33	59	114	160	230	292	360	438	554
32	76	153	221	326	419	526	646	829
31	145	258	348	477	584	700	826	1,007
30	152	269	364	503	621	751	893	1,104
				Prestbury Tributary				
41	12	25	37	55	73	93	117	156
40	14	24	33	45	56	68	82	102
				Lake Run Tributary				
57	73	145	207	301	384	476	580	735
[1]56	11	26	41	69	97	133	177	252
55	24	51	77	121	162	212	272	368
54	100	199	286	419	536	668	817	1,043
53	18	30	38	47	54	60	65	72
52	284	513	688	933	1,130	1,337	1,555	1,861
51	301	516	672	879	1,039	1,202	1,368	1,593
50	235	400	529	710	859	1,020	1,192	1,440
				East Run Tributary				
[1]64	93	162	214	285	341	400	461	546
63	114	212	291	405	499	601	711	869
62	65	117	160	225	281	345	416	523
61	62	109	147	205	255	311	374	468
60	44	76	100	137	168	202	239	295
				Blackberry Creek main stem				
208	66	127	177	250	311	377	448	551
210	129	239	327	455	562	678	804	986
213	135	252	351	499	626	769	928	1,167
216	127	224	303	420	521	634	760	949
218	137	236	316	434	535	648	773	959
220	256	462	634	894	1,120	1,374	1,660	2,093
223	293	526	719	1,011	1,264	1,548	1,867	2,349
226	312	539	722	993	1,224	1,480	1,765	2,190
230	440	748	996	1,360	1,669	2,012	2,392	2,957
233	450	759	1,006	1,368	1,675	2,013	2,388	2,944
236	458	760	999	1,345	1,637	1,957	2,309	2,830
240	483	793	1,036	1,387	1,680	2,001	2,354	2,872
250	639	1,064	1,402	1,893	2,307	2,763	3,265	4,008
260	678	1,131	1,490	2,013	2,454	2,940	3,476	4,268
265	679	1,119	1,466	1,967	2,387	2,848	3,355	4,101
270	704	1,154	1,508	2,017	2,442	2,909	3,419	4,170
276	684	1,123	1,467	1,963	2,378	2,832	3,330	4,063
278	692	1,131	1,475	1,970	2,383	2,835	3,330	4,058
280	716	1,168	1,521	2,027	2,450	2,911	3,416	4,157
290	739	1,204	1,565	2,085	2,517	2,988	3,503	4,258

[1] Subbasins with insufficient description of channel

Table 14. Comparison of flood quantiles estimated in the U.S. Department of Agriculture, Soil Conservation Service (USDA) (1989) study and in the present study at subbasins of the Blackberry Creek watershed, Ill.

[Tributaries shown on figure 7; HSPF, Hydrological Simulation Program–FORTRAN; USDA (1989) study presented Q_T for 2, 10, 100, and 500 years; Q_T, flood quantile at T-year recurrence interval, in cubic feet per second; --, no estimate at this location]

Subbasin Number (Fig. 7)	Present Study (HSPF)				USDA (1989) STUDY			
	Flood Quantiles, Q_T							
	Q_2	Q_{10}	Q_{100}	Q_{500}	Q_2	Q_{10}	Q_{100}	Q_{500}
Tributary F								
10	25	59	108	144	--	--	--	--
Tributary D								
22	53	105	167	206	170	330	480	620
21	106	281	599	879	170	330	480	620
20	150	418	922	1,379	190	390	690	930
Tributary C								
33	59	160	360	554	--	--	--	--
32	76	221	526	829	--	--	--	--
31	145	348	700	1,007	280	560	1,000	1,350
30	152	364	751	1,104	280	560	1,000	1,350
Prestbury Tributary								
41	12	37	93	156	40	80	140	190
40	14	33	68	102	30	60	100	130
Lake Run Tributary								
57	73	207	476	735	260	510	850	1,140
56	11	41	133	252	--	--	--	--
55	24	77	212	368	30	50	90	110
54	100	286	668	1,043	420	840	1,400	1,880
53	18	38	60	72	30	50	90	110
52	284	688	1,337	1,861	560	1,110	1,860	2,490
51	301	672	1,202	1,593	390	730	1,080	1,410
50	235	529	1,020	1,440	360	680	1,000	1,300
East Run Tributary								
64	93	214	400	546	--	--	--	--
63	114	291	601	869	--	--	--	--
62	65	160	345	523	150	270	400	550
61	62	147	311	468	170	300	450	620
60	44	100	202	295	170	300	450	620
Blackberry Creek main stem								
208	66	177	377	551	120	280	520	690
210	129	327	678	986	270	570	900	1,110
213	135	351	769	1,167	260	550	870	1,070
216	127	303	634	949	280	600	1,170	1,540
218	137	316	648	959	290	610	1,200	1,580
220	256	634	1,374	2,093	430	920	1,800	2,380
223	293	719	1,548	2,349	460	930	1,850	2,550
226	312	722	1,480	2,190	730	1,450	2,900	4,000
230	440	996	2,012	2,957	730	1,450	2,900	4,000
233	450	1,006	2,013	2,944	750	1,500	3,000	4,140
236	458	999	1,957	2,830	780	1,550	3,100	4,280
240	483	1,036	2,001	2,872	1,110	2,100	3,970	5,480
250	639	1,402	2,763	4,008	1,220	2,310	4,350	6,010
260	678	1,490	2,940	4,268	1,180	2,320	3,370	4,080
265	679	1,466	2,848	4,101	1,230	2,460	3,970	5,280
270	704	1,508	2,909	4,170	1,100	2,140	3,340	3,940
276	684	1,467	2,832	4,063	1,100	2,140	3,340	3,940
278	692	1,475	2,835	4,058	1,120	2,180	3,400	4,010
280	716	1,521	2,911	4,157	1,120	2,180	3,400	4,010
290	739	1,565	2,988	4,258	1,130	2,190	3,420	4,030

Comparison of Flood Quantiles to the Regional Flood-Frequency Estimates

Regional regression equations for rural unregulated streams in the Blackberry Creek watershed have a general form of

$$Q_T = a(TDA)^b\ (MCS)^c\ [\%(Water + 5)]^d\ RF\ (N), \quad (3)$$

where *TDA* is the drainage area, in mi^2, *MCS* is the main-channel slope, in ft/mi, %(*Water+5*) is the percentage of open water and herbaceous wetlands in the watershed plus a constant 5, and *RF* is a regional factor (Soong and others, 2004). Given coefficient *a*, and exponents *b*, *c*, and *d*, flood quantiles for *T* from 2 to 500 years can be estimated.

The regional equation estimates the mean (logarithmic) value of flood quantiles obtained at different watersheds in a region with the same set of explanatory variables. Therefore, local features that can affect flow magnitudes, such as channel storage and flow diversions, are not accounted for in the regional equation.

Comparisons of flood quantiles estimated in the present study of Blackberry Creek and with the regional flood-frequency equation are presented in table 15. When applying the regional flood-frequency equations, subbasins 40, 41, 53, 60, 61, 62, and 63 were excluded from the analysis because they either contain reservoirs or are in urban areas. However, these subbasins were still included in the drainage area as rural areas in the regional equation at downstream locations, so the regional flood-frequency equations should estimate higher flood quantiles. The regional estimates are higher at most recurrence intervals (table 15). As a result of these comparisons, the 100-year and 500-year flood quantiles could be used confidently in the flood-hazard analysis.

HYDRAULIC MODEL ANALYSIS

The HEC-RAS (Hydrological Engineering Center-River Analysis System) hydraulic model (U.S. Army Corps of Engineers, 2001) was used in this study for the following three purposes.

1. Computing corresponding 100- and 500-year flood elevations with respect to flood quantiles estimated from hydrologic analysis. The flood elevations are used for delineating flood plains on maps.

2. Computing the reach-wise, depth-surface, area-volume relations for channel and reservoir routing in HSPF model simulation.

3. Performing encroachment analysis to determine proper floodway boundaries.

HEC-RAS is the successor for the widely used HEC-2 hydraulic model (U.S. Army Corps of Engineers, 1991) in flood-plain analysis. In addition to the HEC-2 functions, HEC-RAS has enhanced graphical user interface for organizing and presenting input data and results; capabilities for computing mixed flow regimes (sub-, super-critical, and mixed flows); simulating flow through a wide range of hydraulic structures, such as inline weirs and gates, multiple culvert openings, and bridge piers; and tabulated presentation of results. HEC-RAS is an accepted computer hydraulic model by FEMA for NFIP usage (Federal Emergency Management Agency, 2003b).

The two-dimensional, finite-element, surface-water-modeling system (FESWMS, Froehlich, 1989) was used for analyzing the flow diversion at Jericho Lake near Montgomery, Illinois. Results from the FESWMS model have been applied to determine the amount of discharge being diverted out of Blackberry Creek watershed through the lake. These results are used in the routing functions of the hydrologic model. A summary of the diversion analysis from Garcia (2001) is included in appendix B.

Input Data

Input data required for HEC-RAS model simulation include discharge, and reach and channel characteristics. Discharge data are the flow magnitudes (for this study, the flood frequencies obtained from HSPF model simulation are used), flow regime, and boundary conditions. The discharge data are explained in more detail in the Model Development section. Channel characteristics include cross-sectional data, descriptions of hydraulic structures, distances between cross sections, contraction and expansion coefficients, and Manning's coefficients. High-water marks and an inundation map were used in the calibration and verification of the hydraulic model.

Cross Sections

The WSP2 hydraulic routing model developed in the U.S. Department of Agriculture, Soil Conservation Service study (1989) included natural and structural cross sections surveyed by IDOT-DWR in 1985 and by Illinois State Water Survey in 1975. The WSP2 program (U.S. Department of Agriculture, Soil Conservation Service, 1976; U.S. Department of Agriculture, Soil Conservation Service, 1993) simulates hydraulic structures using fewer cross sections (no approach or departure cross sections) than the HEC-RAS program. Review and field verification of the 1985 data also indicated that approximately 9 bridges had been modified since 1985 and an additional 10 bridges, as well as many culverts, needed to be added in model simulation. Also, the approach and departure

Table 15. Comparison of flood quantiles resulting from the present study for the Blackberry Creek watershed, Ill. and the regional flood-frequency equations (Soong and others, 2004).

[Tributaries are shown on figure 7; all flows are in cubic feet per second; HSPF, Hydrological Simulation Program – FORTRAN; Q_T, flood quantile at T-year recurrence interval, in cubic feet per second; --, not applicable]

Subbasin Number (Fig. 7)	Present Study (HSPF model)					Regional flood-frequency equations				
	Flood Quantiles, Q_T									
	Q_2	Q_{10}	Q_{50}	Q_{100}	Q_{500}	Q_2	Q_{10}	Q_{50}	Q_{100}	Q_{500}
Tributary F										
10	25	59	93	108	144	23	48	76	90	128
Tributary D										
22	53	105	149	167	206	33	70	107	124	166
21	106	281	494	599	879	131	370	673	827	1,244
20	150	418	753	922	1,379	193	518	909	1,101	1,610
Tributary C										
33	59	160	292	360	554	114	317	586	728	1,125
32	76	221	419	526	829	72	207	383	473	721
31	145	348	584	700	1,007	229	521	814	945	1,260
30	152	364	621	751	1,104	235	525	840	988	1,368
Prestbury Tributary										
41	12	37	73	93	156	--	--	--	--	--
40	14	33	56	68	102	--	--	--	--	--
Lake Run Tributary										
57	73	207	384	476	735	129	346	627	773	1,181
56	11	41	97	133	252	11	43	95	126	222
55	24	77	162	212	368	32	67	98	110	136
54	100	286	536	668	1,043	171	453	795	966	1,424
53	18	38	54	60	72	--	--	--	--	--
52	284	688	1,130	1,337	1,861	407	979	1,598	1,888	2,618
51	301	672	1,039	1,202	1,593	408	703	925	1,010	1,191
50	235	529	859	1,020	1,440	318	613	886	1,004	1,282
East Run Tributary										
64	93	214	341	400	546	118	281	464	551	778
63	114	291	499	601	869	--	--	--	--	--
62	65	160	281	345	523	--	--	--	--	--
61	62	147	255	311	468	--	--	--	--	--
60	44	100	168	202	295	--	--	--	--	--
Blackberry Creek main stem										
208	66	177	311	377	551	74	192	328	393	563
210	129	327	562	678	986	168	384	622	734	1,024
213	135	351	626	769	1,167	178	418	699	839	1,213
216	127	303	521	634	949	159	349	572	683	984
218	137	316	535	648	959	178	380	612	727	1,035
220	256	634	1,120	1,374	2,093	403	945	1,567	1,871	2,671
223	293	719	1,264	1,548	2,349	436	998	1,644	1,961	2,803
226	312	722	1,224	1,480	2,190	449	986	1,588	1,881	2,650
230	440	996	1,669	2,012	2,957	639	1,428	2,334	2,780	3,968
233	450	1,006	1,675	2,013	2,944	626	1,404	2,304	2,749	3,940
236	458	999	1,637	1,957	2,830	597	1,303	2,117	2,520	3,598
240	483	1,036	1,680	2,001	2,872	619	1,355	2,211	2,637	3,785
250	639	1,402	2,307	2,763	4,008	869	1,890	3,050	3,618	5,130
260	678	1,490	2,454	2,940	4,268	896	1,967	3,203	3,813	5,450
265	679	1,466	2,387	2,848	4,101	797	1,798	2,977	3,567	5,163
270	704	1,508	2,442	2,909	4,170	844	1,843	2,981	3,539	5,023
276	684	1,467	2,378	2,832	4,063	807	1,740	2,809	3,336	4,748
278	692	1,475	2,383	2,835	4,058	812	1,744	2,812	3,338	4,747
280	716	1,521	2,450	2,911	4,157	849	1,805	2,891	3,426	4,852
290	739	1,565	2,517	2,988	4,258	869	1,833	2,922	3,455	4,876

cross sections of hydraulic structures were needed in the HEC-RAS models.

Limited surveys were conducted by the IDNR-OWR, Smith Engineering Consultants, Inc., and the USGS to acquire data for new bridges and culverts, to survey approach and departure cross sections for the hydraulic structures, and to obtain a limited number of natural cross sections in the watershed. New natural cross-sectional surveys were conducted to fill in the gaps between available surveyed data in the main stem of Blackberry Creek or in upstream reaches where data were sparse. The cross sections surveyed in 1985 were kept in the model with the coordinates converted from NAD27/NGVD29 to NAD83/NAVD88 (using the CORPSCON program, U.S. Army Corps of Engineers, 1997); the cross sections surveyed in 1975 were discarded because of uncertainties in georeferencing and because the cross sections were completed using a simplified approach (8-point surveys). The rest of the survey coordinates are referred to the Illinois State Plane Coordinate System - East Zone, NAD83, and NAVD88 altitude. For the Kendall County portion of Blackberry Creek, all hydraulic structures were updated in the 2000-01 resurvey by IDNR-OWR but no natural cross sections were included. During model development, additional cross-sectional survey data were obtained from other studies or by using the detailed DEM in the Kane County portion of the watershed.

The Aurora Chain-of-Lakes tributary model, developed by Consoer Townsend Envirodyne Engineering, Inc. (Consoer Townsend Envirodyne Engineering, Inc., 1998), was provided by the City of Aurora Engineering Department. Descriptions of a storage pond north of Interstate Highway 88 (I-88) in East Run and of culverts under Orchard Road overpass (10 total cross sections) were provided by Hey and Associates (David Olson, Hey and Associates, written commun., 2002).

Manning's Roughness Coefficients

Manning's roughness coefficients (*n*-values) were determined based on observations made during field reconnaissance in summer months when vegetation was fully grown and high flows typically occur (table 1). These Manning's roughness coefficients were assigned to other reaches with similar reach conditions with reference to the 1998 aerial DOQ. The resulting Manning's roughness coefficients vary approximately from 0.045 to 0.075 in the main-stem channel (higher values at headwater sections and downstream reaches), and from 0.045 to 0.15 in the flood plains. In the flood plains, the Manning's roughness coefficients for vegetated flood plain varied from 0.10 to 0.15.

An assumption made in the hydraulic model simulation is that vegetation and bank/bed materials of the channel were not appreciably different at the time of field observations than from the 1996 conditions used for calibration and verification. Note that the Manning's roughness coefficients also were used in a special case for determining routing characteristics for HSPF model simulation. In that case, an $n = 100$ was assigned to all *ineffective flow areas* in the hydraulic model to account for storage but to not exclude ineffective flow areas from the routing tables (U.S. Army Corps of Engineers, 1990).

The determined Manning's roughness coefficients were compared to reference values (Chow, 1959) and values used in the U.S. Department of Agriculture, Soil Conservation Service (1989) study. In the U.S. Department of Agriculture, Soil Conservation Service (1989) study, the Manning's roughness coefficients used in the WSP2 Blackberry Creek model, varied from 0.012 to 0.09 in the main channel and from 0.1 to 0.3 on the flood plains

High Water Marks and Inundation Map

Information, such as high-water mark (HWM) elevations, collected after major flood events is useful in calibration and verification of hydraulic models. The most recent flooding event in the Blackberry Creek watershed occurred on July 17-18, 1996, with the observed peak discharge at the Yorkville streamflow-gaging station exceeding the estimated 500-year flood. Information on the HWM elevations collected for this event is discussed below.

Immediately after the July 1996 flood, KDOT engineers marked debris lines and/or HWMs at bridge structures for six bridges along the main stem of Blackberry Creek during a field reconnaissance. The debris lines and HWMs were surveyed by the county in 1998 (Paul Schuch, Kane County Water Resources Department, written commun., 2001). These HWMs provide point information about the flood in the watershed. HWMs in tributaries also were obtained in this study by contacting local residents during field surveys. Information from local residents was used qualitatively in hydraulic model analysis.

The IDNR-OWR and Kane County conducted a fly-over in the afternoon of July 18, 1996, to inspect flood damages in the watershed. Images captured with videos and still photographs taken during the fly-over were used to develop an inundation map that essentially shows continuous HWMs over a portion of Blackberry Creek watershed. On a georeferenced DOQ (1998 version) overlaid with roads and watershed boundary images, the water's edge was traced from those videos and photographs by both Kane County (Paul Schuch, Kane County Water Resources Department, written commun., 2001) and USGS staff. Assumptions were made when trees, houses, clouds, or other obstacles shadowed the water's edge. The traced water's edge could only reflect the conditions when the images were taken (the afternoon of July 18), and this information was limited by the extent of the fly-over and level of detail captured in the video.

Model Development

Procedures for developing a HEC-RAS model can be found in the HEC-RAS users' manual (U.S. Army Corps of Engineers, 2001). In model development, surveyed cross sections first were mapped in a GIS layer, and overlaid with a DOQ, stream centerline, contours/DEM, and road layers for checking errors and orientations. Distances between cross sections, adequacy of cross-section widths in relation to the 500-year flood water-surface elevations, consistency of assigned Manning's coefficient, location of natural levees, blocked obstructions, and ineffective flow areas also were determined.

The initial hydraulic model then was tested for the correctness of hydraulic structure modeling and possible need for additional cross sections. If additional cross sections were deemed necessary, the elevation data were obtained from the Kane County 10-ft by 10-ft grid-size DEM for points in the flood plain and from nearby surveyed cross sections for the points in the channel. In describing Blackberry Creek in the HEC-RAS model, the centerline of the channel followed the stream orientation. The HEC-RAS Blackberry Creek model covered the length from the uppermost headwater subbasins to the junction with the Fox River, including the main-stem channel and major tributaries as defined in the Continuous-Simulation Hydrologic Model Analysis section (fig. 7). Steady-state analysis was used in the present study to determine the water-surface elevations for flood-hazard analysis. Data needed for a steady-state flow simulation with HEC-RAS included boundary conditions, peak discharges, and flow regimes.

Boundary conditions, as known stages or flood discharges, are needed for starting a water-surface computation in a river reach. Stage boundary conditions were specified at both the upstream and downstream ends of the Blackberry Creek HEC-RAS model for mixed flow analysis. Normal depth boundary conditions were specified at all uppermost stream cross sections of the hydraulic model except for Lake Run, where critical depths were used because of the steep bed slope. A normal depth boundary condition also was specified at the most downstream cross section with the junction of the Fox River. Stage corresponding to 10-, 50-, 100-, and 500-year events on the Fox River including the confluence with Blackberry Creek were obtained from the U.S. Army Corps of Engineers (written commun., 2003). After conversion to NAD83/NAVD88, the computed normal stage at the mouth of Blackberry Creek for the 100-year event in the creek was approximately at an elevation between 10- and 50-year stages on the Fox River. Without further information for determining the relation between flood stages on Blackberry Creek and the Fox River, the normal depth was specified at the downstream end of Blackberry Creek at the junction with the Fox River.

In HEC-RAS simulation, discharges are specified at selected cross sections. The generated flood quantiles are specified at the outlet of each subbasin or the downstream end of a routed reach. Therefore, it is necessary to develop a method to distribute the discharges within cross sections in a routed reach. The area above each cross section was determined so that a weighted-area method could be used to distribute the estimated flood quantiles at the downstream end of a routed reach to other cross sections in the reach. The point at which to change discharges between cross sections in a routed reach was determined based on how much the drainage area increased between the two cross sections. For example, discharge magnitudes would change at a downstream cross section if there was an incoming secondary tributary, or an appreciable increase in drainage area. The amounts of increase in flood quantiles within a subbasin have to be consistent with the estimated flood quantiles at upstream and downstream locations on the subbasin.

Model Calibration and Verification

Observed stages, discharges, and/or velocities are generally used for calibrating and verifying a hydraulic model. A difficult part of the calibration/verification process is to obtain boundary conditions, the stages and flood discharges at the upstream and/or downstream ends of the study reach. To obtain a complete calibration and verification, observations at multiple locations along the channel reach covering a wide range of flow conditions are needed. Calibrating and verifying the HEC-RAS Blackberry Creek model was difficult because of the complex channel network system and with only the single streamflow-gaging station near the watershed outlet with sufficient record (Yorkville station).

The calibration and verification of the HEC-RAS Blackberry Creek model became possible with the availability of HWMs along the creek, the inundation map, and the hydrologic simulation of the July 17-18, 1996, event. If the HSPF-simulated discharges were reasonably close to the field conditions along the creek, and the stages simulated by HEC-RAS corresponding to those discharges were successfully compared to observed discharges, then the HEC-RAS model could be confidently applied to simulate other events. Discharges simulated by HSPF with the NEXRAD rainfall were used for the comparison.

An additional approximation has to be specified about the timing of the fly-over video and the simulated flood-peak discharges used in the hydraulic model. The fly-over was conducted in the afternoon of July 18, 1996. According to the simulated flow time series, the flood peaked at the headwaters about 8-9 hours ahead of that at the Yorkville station (subbasin 208 peaked at 14:00 hours on July 18; the simulated and observed flood peaked at the Yorkville station at approximately 22:00 hours on July 18; see figure 17). Because steady-state flow was simulated with the hydraulic model, the delay in flood propagation caused by channel storage could not be considered. It was not reasonable to use discharges at each location corresponding to the time of the fly-over for estimating flood elevations and for developing the inundation map. Therefore, the flood-peak discharge of each subbasin was distributed to cross sections in that subbasin to simulate flood elevations and for developing the inundation map.

High Water Marks

The HEC-RAS simulated flood stages for July 1996 were compared to the HWMs (table 16). The flood-stage differences, defined as KDOT HWMs minus simulated river stages, along Blackberry Creek are plotted in figure 20. The comparisons generally are reasonable, except at two locations. There was a 3.72 ft drop from the upstream to downstream side of Scott Road Bridge in the KDOT HWMs that caused a 3.26 ft difference between the observed and simulated altitudes at the downstream side of the bridge. The downstream side of the Route 56 Bridge also had a large (3.39 ft) difference between observed and simulated HWMs. These two locations are excluded from table 16 and figure 20. Possible physical reasons for the discrepancies are changes in channel geometry (cross sections at both locations were surveyed in 2000-01), or temporary debris jams or vegetation differences that led to different flow resistances. The differences (especially in the Lake Run tributary) also could have been caused by using flood-peak discharges in each subbasin in the hydraulic model.

Although adjusting the Manning's coefficients could modify the flood water-surface elevations and improve the comparison, adjustments were not done because the Manning's coefficients were determined based on field reconnaissance and will be used for other flood discharges. The HWM comparisons showed that discharge-stage characteristics of Blackberry Creek could be accurately simulated with the HEC-RAS model.

Inundation Map

Whereas HWMs are used commonly in model verification, they are point data (limited coverage) that cannot be applied throughout the area. An inundation map presents the same type of information as HWM but for wider areas and the map edges are considered line data.

An inundation map was constructed from the video of the July 1996 flood (observed inundation map). The inundation map included portions of the Lake Run tributary watershed developed by the Kane County Department of Water Resources (Paul Schuch, Kane County Department of Water Resources, written commun., 2001) and East Run tributary watershed and other locations developed by the USGS during this study. Comparisons to an inundation map based on simulated data were done at locations where HWMs were not available. Comparisons in the Lake Run and East Run tributary watersheds are presented in figures 21 a, b. Comparison for the main-stem channel in subbasin 223 and in subbasin 270 downstream of Jericho Road Bridge are presented in figures 21 c, d. Considering the timing of peak stages in observed and simulated conditions, and the information available for developing the observed inundation map, the modeling results can be considered reasonable.

Table 16. Comparison of high water marks (HWMs) observed on July 18, 1996, and simulated water-surface elevations at various locations on Blackberry Creek, Ill.

[ft, feet; the Kane County Department of Transportation (DOT) engineers marked the HWMs after the July 17-18, 1996, storm and surveyed in 1998.]

Kane County DOT Survey Location (Locations are listed in downstream order)	Observed (ft above NAVD88)	Simulated (ft above NAVD88)	Observed – simulated (ft)
Blackberry Creek at Hughes Road Bridge, upstream	745.25	745.40	-0.15
Blackberry Creek at Hughes Road, downstream	744.85	745.12	-.27
Blackberry Creek at Main Street Bridge, upstream	730.96	730.31	.65
Blackberry Creek at Scott Road Bridge, upstream	708.48	708.40	.08
Blackberry Creek at Bliss Road Bridge, downstream	690.50	688.69	1.81
Blackberry Creek at Route 56 Bridge, upstream	683.34	681.55	1.79
Blackberry Creek at Jericho Road Bridge, upstream	668.83	667.88	.95
Blackberry Creek at Jericho Road Bridge, downstream	667.27	667.69	-.42

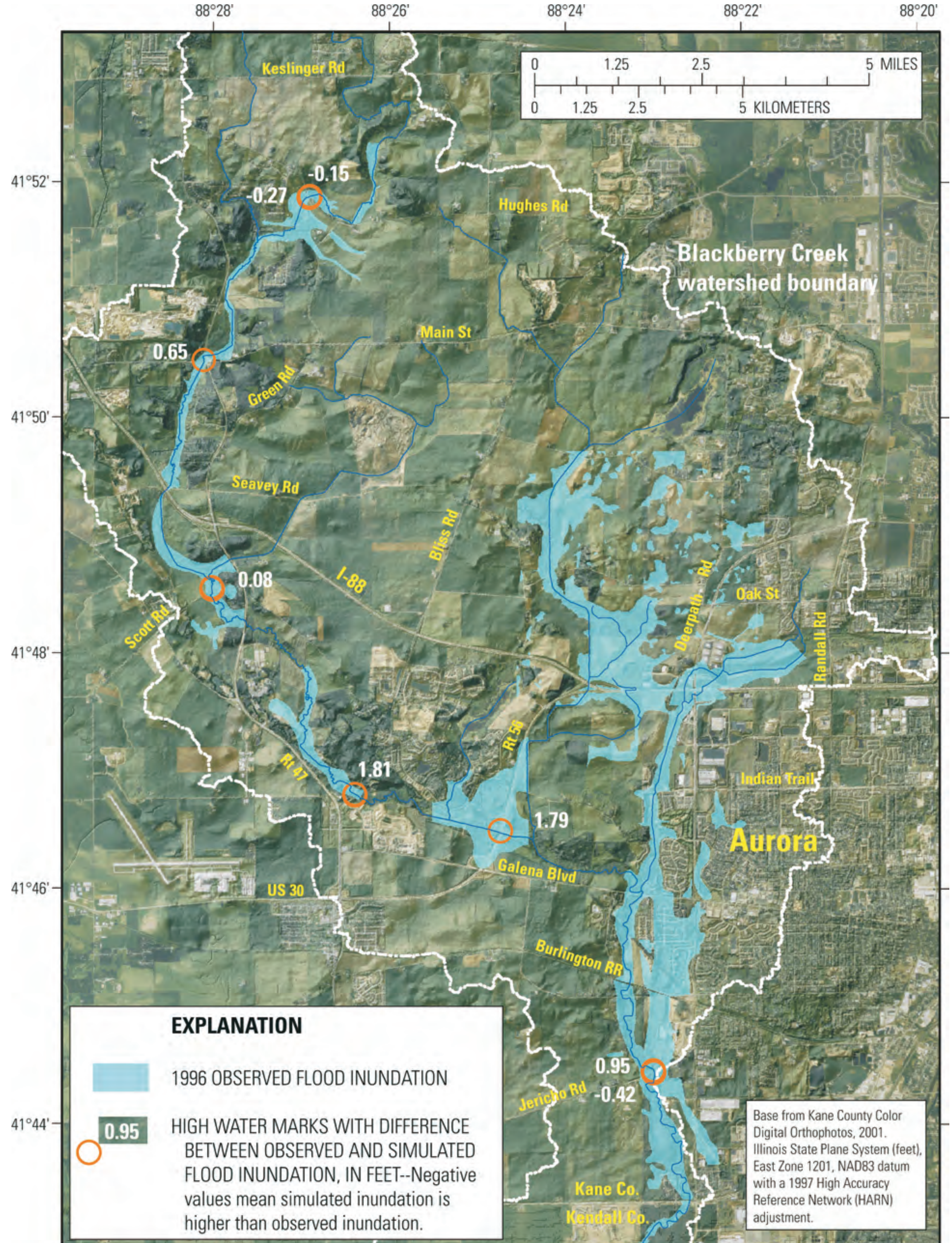


Figure 20. Differences between observed and simulated water-surface elevations at locations surveyed by Kane County Department of Transportation for the July 1996 flood event, Blackberry Creek watershed, Ill.

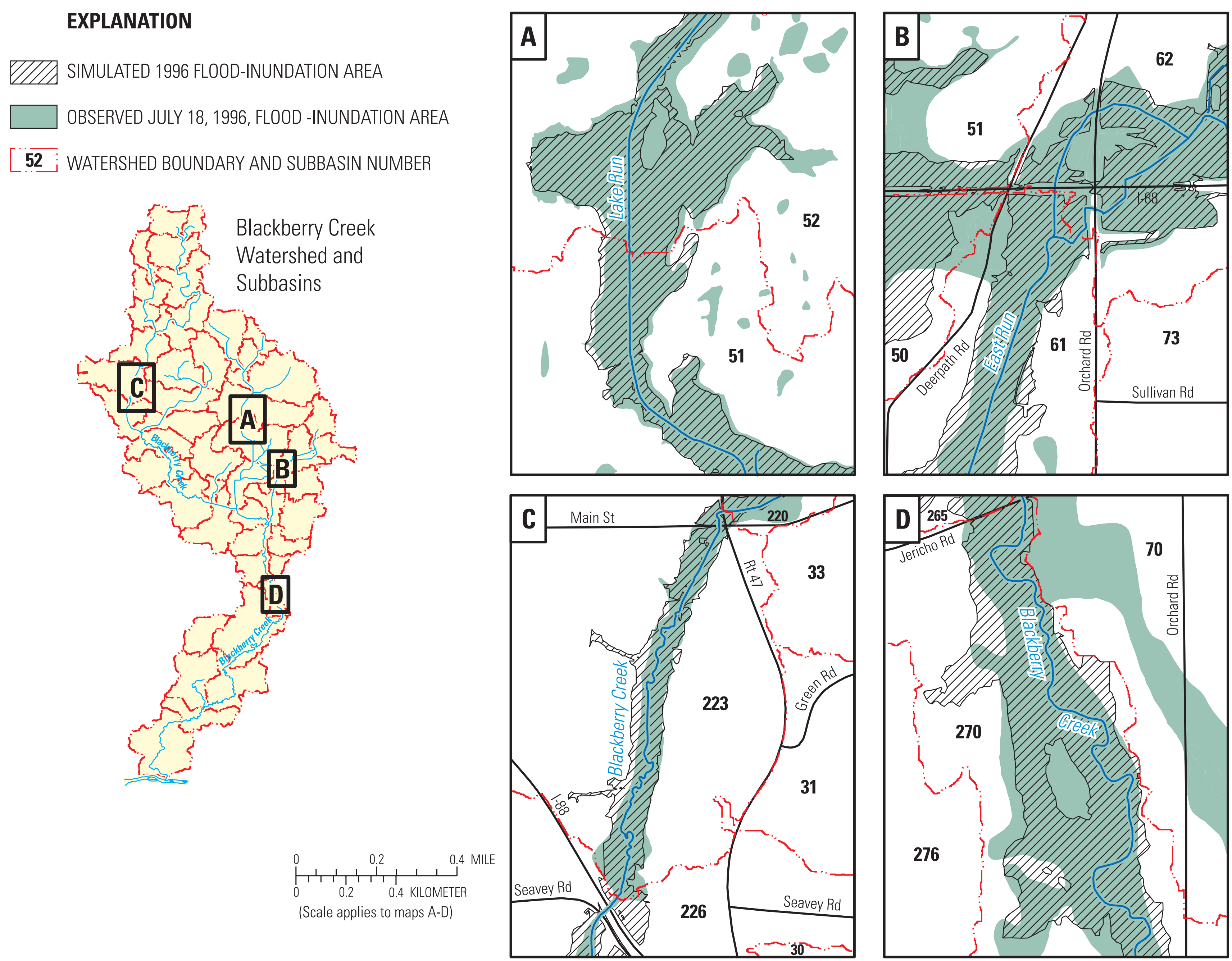


Figure 21. Comparison of observed and simulated inundation maps of the July 17-18, 1996, flood using Next Generation Radar (NEXRAD) rainfall data as input into the hydrologic model at (A) subbasins 52 and 51 of Lake Run tributary, (B) subbasins 62 and 61 of East Run tributary, (C) subbasin 223, and (D) subbasin 270 downstream of the Jericho Road Bridge, Blackberry Creek, Ill. The image used to create the observed inundation map was taken the afternoon of July 18, 1996.

FLOOD-HAZARD ANALYSIS

The resulting flood elevations from the hydraulic model were mapped for the 100- and 500-year flood plains and for the 100-year floodway (CD-ROM). This mapping allowed flood-hazard areas to be determined. The FEMA designation for the areas within the 100-year flood-plain boundary, areas between the 100-year and 500-year flood-plain boundaries, and areas within the 500-year flood-plain boundaries are Special Flood Hazard Areas, Areas of Moderate Flood Hazard, and Areas of Minimal Flood Hazard, respectively. These maps are not FEMA approved FIRMs and are subject to revision. The procedures for determining and plotting the flood plains and floodways are discussed in appendix C. The flood-hazard boundaries of each tributary and the main stem are displayed in plate 1 on the CD-ROM. A table with 100-year flood magnitudes distributed to each cross section, with selected hydraulic characteristics from the hydraulic model analysis, is presented on the CD-ROM.

Tributary F Watershed

Tributary F watershed is a headwater subbasin located at the northern corner of the Blackberry Creek watershed (plate 1). Tributary F watershed has a drainage area of 0.57 mi^2 and local altitudes ranging from about 1,010 ft above NAVD 88 at the watershed divide to about 830 ft at the junction with the main stem of Blackberry Creek. The land cover (Luman and other, 1996) and the areas within the 100- and 500-year flood plains are presented in table 17.

Primary land use of the watershed was grassland, cropland and wooded and forested land; residential developments were noted in hilly areas north of Route 38. The area included in the hydraulic model starts north of Route 38 from a hilly area through a depression area upstream of Route 38, where the channel is a grass waterway with wooded banks. The channel south of Route 38 flows through agricultural fields.

Hydraulic analysis showed that the culvert at Route 38 would constrict flow at higher magnitudes. The section of Route 38 near the culvert would be overtopped by the 500-year flood determined in this study. The flood plain upstream of Route 38 and at the main-stem junction covers primarily agricultural areas.

Tributary D Watershed

The drainage area of tributary D watershed is approximately 2.58 mi^2 and local altitude varies from about 910 ft above NAVD 88 at the watershed divide to about 742 ft at the main-stem junction of Blackberry Creek. In the hydrologic model analysis, the tributary D watershed was divided into subbasins 22, 21, and 20 (plate 1). Most residential areas are located in subbasin 22, east of Route 47, south of Route 38, and north of BCNW Railroad. However, residential developments are also present between Keslinger and Hughes Roads along Route 47 and along Kenmar Road. The land cover (Luman and other, 1996) and the areas within the 100- and 500-year flood plains are presented in table 18.

The area included in the hydraulic model begins upstream of the BCNW Railroad in subbasin 22. The channel is a mostly channelized grass waterway flowing through farmlands upstream of Kenmar Road. Downstream from Kenmar Road, the channel meanders through a wooded area with steep valley slopes until the junction with the Blackberry Creek main stem.

The culverts at BCNW Railroad would cause flow to back up upstream and could be overtopped by a 500-year flood. The culvert at Keslinger Road and bridge at Hughes Road would constrict flow and cause flow to back up upstream and causing flooding of agricultural lands. The bridge at Kenmar Road is at a lower altitude

Table 17. The 1996 land cover (by area and percentage) and areas included in the 100- and 500-year flood plains in tributary F of the Blackberry Creek watershed, Kane County, Ill.

[--, not applicable]

Land-Cover Category	Area (acres)	Percentage of Total Area	Acres in 100-year flood plain	Acres in 500-year flood plain
Cropland	97.03	26.41	23.24	24.52
Wooded and Forested Land	83.33	22.68	--	--
Grassland	167.00	45.45	1.72	2.31
High Density Urban	1.74	.47	--	--
Low Density Urban	15.48	4.21	--	--
Medium Density Urban	1.03	.28	--	--
Transportation	1.82	.50	.02	.29
Wetland	--	--	--	--
Barren and Exposed Land	--	--	--	--
Total	367.43	100.00	24.98	27.12

Table 18. The 1996 land cover (by area and percentage) and areas included in the 100- and 500-year flood plains in tributary D of the Blackberry Creek watershed, Kane County, Ill.

[--, not applicable]

Land-Cover Category	Area (acres)	Percentage of Area	Acres in 100-year flood plain	Acres in 500-year flood plain
Cropland	908.23	55.00	45.51	57.03
Wooded and Forested Land	47.54	2.88	3.14	4.43
Grassland	556.35	33.69	22.30	30.47
High Density Urban	26.51	1.60	.19	.48
Low Density Urban	44.19	2.68	--	--
Medium Density Urban	27.50	1.66	--	--
Transportation	22.40	1.36	.11	.11
Wetland	18.66	1.13	8.45	8.72
Barren and Exposed Land	--	--	--	--
Total	1,651.38	100.00	79.70	101.24

than both the 100- and 500-year flood elevations. The extent of the 100- and 500-year flood plains was limited by the valley section of the channels. Channel meandering and debris in wooded reaches could cause higher flood stages downstream from the Kenmar Road Bridge to the junction with the Blackberry Creek main stem.

Tributary C Watershed

The drainage area of the tributary C watershed is approximately 7.03 mi^2 with local altitude varying from about 800 ft above NAVD 88 at the watershed divide to about 705 ft at the junction with the main stem of Blackberry Creek. The tributary C watershed is divided into four subbasins with subbasins 33 and 32 being the two, side-by-side headwater sections (plate 1). A golf course, built in 2002, crosses both subbasins 33 and 31 north of Seavey Road; otherwise, agriculture and pastures were the primary land cover at the time of the study (2000-04). The land cover (Luman and other, 1996) and the areas within the 100- and 500-year flood plains are presented in table 19.

The hydraulic model coverage in subbasin 33 begins from Main Street as the north fork and Green Road as the west fork. The two forks join and flow around the golf-course property and then the stream joins tributary C. Channel-bed slope along the north fork in the subbasin 33 was steep, dropping from 770 ft above NAVD 88 to 726 ft, compared to from 734 ft to 726 ft of the west fork, or from 752 ft to 717 ft over the length of channel in subbasin 32. Most of the channel has been straightened in tributary C.

Various low-lying areas were mapped with the largest one in subbasin 32. Most of the land in tributary C watershed was agricultural land at the time of this study except for an area in subbasin 30 west of I-88 and near the junction with the main stem of Blackberry Creek. The 100- and 500-year flood plains delineated in this study could inundate residential areas.

Table 19. The 1996 land cover (by area and percentage) and areas included in the 100- and 500-year flood plains in tributary C of the Blackberry Creek watershed, Kane County, Ill.

[--, not applicable]

Land-Cover Category	Area (acres)	Percentage of Area	Acres in 100-year flood plain	Acres in 500-year flood plain
Cropland	3,453.36	76.78	255.47	325.60
Wooded and Forested Land	221.67	4.93	9.43	11.12
Grassland	702.57	15.62	60.20	72.97
High Density Urban	10.87	0.24	.39	.40
Low Density Urban	2.98	0.06	--	--
Medium Density Urban	0.74	0.02	--	--
Transportation	44.03	0.98	.84	1.32
Wetland	61.59	1.37	42.09	43.09
Barren and Exposed Land	--	--	--	--
Total	4,497.81	100.00	368.42	454.50

Prestbury Tributary Watershed

Prestbury tributary watershed was divided into two subbasins in this analysis. Residential land use is present in both subbasins. There are two connected lakes in the watershed. The total drainage area is 2.14 mi^2 with local altitude varying from about 724 ft above NAVD 88 at the drainage divide along I-88 to about 676 ft at the junction with the Blackberry Creek main stem. The land cover (Luman and other, 1996) and the areas within the 100- and 500-year flood plains are presented in table 20.

The area covered by the hydraulic model begins at the upper lake in subbasin 41 and ends at the junction with the Blackberry Creek main stem (plate 1). The two lakes provided appreciable storages and flow is released only through a culvert with a drop inlet at the lower lake in subbasin 40. Bottom slopes of the two lakes were small, but the culvert has a drop of approximately 7 ft over 100 ft. The area downstream from the lower lake is relatively small and has a small slope. The flood quantiles estimated for the two subbasins were small compared to other subbasins, as shown in table 15.

Because of the flat topography near the Blackberry Creek main-stem junction, floods at the 100- or 500-year recurrence intervals would inundate areas near the junction, currently developed as a golf course. The upper and lower lakes are connected through a long pipe. This area could also be subject to inundation at higher flood discharges determined in this study.

Lake Run Tributary Watershed

Lake Run tributary is the largest tributary to Blackberry Creek with a drainage area of 13.42 mi^2 and local altitude varying from about 870 ft above NAVD 88 at the drainage divide to about 670 ft at the junction with the Blackberry Creek main stem. Lake Run tributary watershed was divided into eight subbasins, numbered 57 to 50 in the analysis. Nelson Lake is the largest water body in the Blackberry Creek watershed and is located in subbasin 53 (plate 1). Residential areas in subbasin 53 were located mostly in the area east of Nelson Lake Lane. During the course of this study, new subdivisions were under construction along the Fabyan Parkway in subbasin 56, along the north side of the Main Street in both subbasins 55 and 53; and along the Deerpath Road in subbasin 52. The land cover (Luman and other, 1996) and the areas within the 100- and 500-year flood plains are presented in table 21.

The majority of the streams in Lake Run tributary have been channelized, except for some reaches in subbasin 57 (plate 1). The area simulated by the hydraulic model begins at headwater sections in subbasins 57, 56, and 53 and ends at the junction with Blackberry Creek main stem in subbasin 50. Overall, the channel through subbasin 57 had a steeper slope than other headwater sections and bed slopes gradually flattened out after the junction upstream of subbasin 52. Nelson Lake has a large surface area with 3 to 5 ft of water depth and provides appreciable storage in subbasin 53. Surface-water outflow from Nelson Lake was measured by Curry and others (Illinois State Geological Survey, 2001), who determined the outflow for 1999 and 2000 period was nearly zero. Flood quantiles presented in table 12 increase in the downstream direction except for subbasins 51 and 50, an area of flat topography.

A split flow area at the southeastern corner of Interstate 88 and Route 56 was analyzed and included here. Using the DEM and the inundation image of the 1996 flood event, the sources of flooding for this area were determined to include split flow from Lake Run over the low banks south of Route 56 and overland flows from the north that overtopped I-88. The overland flows from north of I-88 resulted when the low-lying area was filled with flood water from the Lake Run tributary.

Table 20. The 1996 land cover (by area and percentage) and areas included in the 100- and 500-year flood plains in the Prestbury tributary of the Blackberry Creek watershed, Kane County, Ill.

[--, not applicable]

Land-Cover Category	Area (acres)	Percentage of Area	Acres in 100-year flood plain	Acres in 500-year flood plain
Cropland	440.95	32.23	0.30	0.33
Wooded and Forested Land	88.57	6.47	6.42	7.21
Grassland	505.70	36.97	12.81	17.78
High Density Urban	17.87	1.31	--	--
Low Density Urban	108.60	7.94	4.13	4.67
Medium Density Urban	24.77	1.81	.01	.69
Transportation	21.67	1.58	.38	.83
Wetland	159.90	11.69	122.48	125.11
Barren and Exposed Land	--	--	--	--
Total	1,368.03	100.00	146.53	156.62

Table 21. The 1996 land cover (by area and percentage) and areas included in the 100- and 500-year flood plains in the Lake Run tributary of the Blackberry Creek watershed, Kane County, Ill.

[--, not applicable]

Land-Cover Category	Area (acres)	Percentage of Area	Acres in 100-year flood plain	Acres in 500-year flood plain
Cropland	4,949.88	57.63	474.74	621.17
Wooded and Forested Land	365.95	4.26	17.79	20.33
Grassland	2,657.68	30.94	301.06	355.50
High Density Urban	50.68	.59	.71	.77
Low Density Urban	47.07	.55	.50	.63
Medium Density Urban	2.79	.03	.49	.56
Transportation	93.39	1.09	4.34	5.45
Wetland	398.23	4.64	201.07	218.01
Barren and Exposed Land	22.79	.27	--	--
Total	8,588.46	100.00	1,000.70	1,222.44

In order to estimate the flows in the Lake Run tributary watershed, two additional tributaries were added to the model simulation: Patterman East and Patterman West. Lateral structures were used to estimate the flows from Lake Run to the Patterman tributary, and from the Patterman tributary to north of I-88. The overall hydraulic verification was done by comparing the inundation area for the 1996 event similar to those presented earlier (fig. 21). Because only the Podolski reach, located south of I-88, is of interest, only the result for the Poldolski tributary is presented.

There are various low-lying areas shown in plate 1. Expansive flood plains are shown in the lower portion of the Lake Run tributary, but there is no urban development in this flood plain. The bridge at Tanner Road is at a lower altitude than the 500-year flood elevation, and the bridge at Hankes Road is at a lower altitude than both the 100- and 500-year flood elevations.

East Run Tributary Watershed

The drainage area of East Run tributary watershed is 4.50 mi^2 and local altitude varies from about 736 ft above NAVD 88 at the drainage divide to about 668 ft at the junction with the Blackberry Creek main stem. East Run tributary watershed was divided into five subbasins in the hydrologic analysis. This watershed was undergoing urban development during the course of the study. Compared to the other tributaries, the watershed has more urban development and less wooded and forested land. The land cover (Luman and other, 1996) and the areas within the 100- and 500-year flood plains are presented in table 22.

Subbasins 64 and 63 had larger drainage areas and channel bed slopes than those at downstream subbasins (subbasins 62 and 61). After entering subbasin 60, the flow was slowed by the even smaller slope and storage of the lake in the golf course. The area simulated in the hydraulic model begins from upstream of the culvert

Table 22. The 1996 land cover (by area and percentage) and areas included in the 100- and 500-year flood plains in the East Run tributary of the Blackberry Creek watershed, Kane County, Ill.

[--, not applicable]

Land-Cover Category	Area (acres)	Percentage of Area	Acres in 100-year flood plain	Acres in 500-year flood plain
Cropland	1,394.55	48.42	110.94	135.41
Wooded and Forested Land	38.53	1.34	3.04	3.48
Grassland	862.22	29.93	61.65	77.38
High Density Urban	54.15	1.88	.17	.61
Low Density Urban	126.78	4.40	1.04	1.83
Medium Density Urban	46.72	1.62	2.77	3.07
Transportation	46.76	1.62	1.71	2.78
Wetland	310.79	10.79	199.16	209.40
Barren and Exposed Land	--	--	--	--
Total	2,880.50	100.00	380.48	433.96

on Oak Street in sub-region 64 (plate 1), where housing development was observed during the study period (2000-04). Passing through Oak Hill South subdivision and through agricultural fields north of I-88, the channel width varied from 1 to 2 ft downstream of Oak Street to 5 to 10 ft at downstream of subbasin 62 partly because of changing bed slopes. Two channel reaches were simulated in subbasin 62; the south branch is the continuation of East Run; whereas the north branch starts downstream of the farm road and flows through farm fields. Water spilling from East Run over a low bank area at downstream of a detention pond in Oak Hill South subdivision could be the primary source of flood flows for the north branch.

The detention pond north of I-88 area was built after the U.S. Department of Agriculture, Soil Conservation Service 1989 study and various culverts were added after the 1996 flood. At present (2005), the detention pond drains through two paths: one draining to an outlet at south then passing underneath I-88, then Orchard Road and west; the other path drains to an outlet at west side of the pond, passing underneath Orchard Road to a new development area, then southward through I-88. The two paths rejoin and flow through a wetland-marsh restoration to Sullivan Road, a new road built during the course of the study. Between Sullivan Road and Indian Trail Road, in subbasin 61, the channel becomes obscured in the wide flood plains-prairie field and diminished in size. Field reconnaissance found a natural ditch less than 1 ft wide. The ditch drains to a pond, located at north of the Indian Trail Road, through a 1-ft diameter concrete pipe.

A concrete pipe connects the pond to the lake in the golf course. Another flow path is through two 16-ft by 10-ft box culverts east of the concrete pipe. The flow-through lake west of the Fairway Homes and Orchard Valley subdivision in subbasins 61 and 60 was constructed in the early 1990s. The outlet of the lake consists of two 6-ft corrugated metal pipes under Hankes Road, which follows a natural channel before the junction with Blackberry Creek. Diversions from the pond occurred during the July 1996 event (Al Rae, Blackberry Creek watershed resident, oral commun., 2003).

With the detention developments in the tributary, flood-peak discharges from East Run to the main stem of Blackberry Creek were low in relation to the size of the drainage areas (table 12). However, the flood durations could be prolonged if development in upstream area continues. Flooding hazards in subbasins 63 and 62 were primarily in present agricultural land. Inundation of a residential area along Deerpath Road west of the golf-course lake in subbasin 60 resulted at higher estimated flood discharges.

Main Stem of Blackberry Creek

The main channel of Blackberry Creek watershed was divided into 20 subbasins (17 in Kane County) for the analysis. Overall, the total drainage area of the main stem is 33.74 mi^2 and local relief varies from about 950 ft at the drainage divide to about 660 ft at the county line to about 585 ft at the junction with the Fox River. The land cover (Luman and other, 1996) and the areas within the 100- and 500-year flood plains are presented in table 23.

Subbasin areas that contribute flows to the main stem are generally small after the tributaries are separated. Estimated flow quantiles, shown in table 12, generally increased from upstream to downstream; however, noticeable increases occurred after junctions with tributaries D, C, and Lake Run. Stream channels could have been subject to some modifications but natural meandering patterns remained in most of the main stem, except for reaches in subbasins 226, 236, 240, and 250 (plate 1).

Flood-hazard areas are noted along Pouley Road in subbasin 213, downstream from the junction with tributary C in subbasin 230, upstream of Bliss Road bridge in

Table 23. The 1996 land cover (by area and percentage) and areas included in the 100- and 500-year flood plains in the main stem of the Blackberry Creek watershed, Kane County, Ill.

[--, not applicable]

Land-Cover Category	Area (acres)	Percentage of Area	Acres in 100-year flood plain	Acres in 500-year flood plain
Cropland	11,115.08	51.48	349.86	467.85
Wooded and Forested Land	1,825.34	8.45	264.12	287.25
Grassland	6,689.14	30.98	614.00	736.23
High Density Urban	202.98	.94	.22	.85
Low Density Urban	515.64	2.39	6.22	12.40
Medium Density Urban	191.72	.89	3.56	4.90
Transportation	227.34	1.05	9.27	15.68
Wetland	629.51	2.92	249.67	265.89
Barren and Exposed Land	195.43	.90	--	--
Total	21,592.18	100.00	1,496.92	1,791.05

subbasin 236, downstream of the junction with Lake Run tributary in subbasin 250, downstream from the junction with East Run tributary in subbasins 260, 265, and in the residential area upstream of Route 30 in subbasin 270. The bridges at Smith Road, Ke-De-Ka Road, and Galena Road are at a lower altitude than the 500-year flood elevation, and the bridges at Route 47, Scott Road, and Densmore Rd are at a lower altitude than both the 100- and 500-year flood elevations.

SUMMARY

The Blackberry Creek watershed in Kane County, Illinois, has undergone rapid urbanization in recent decades. The population and urbanized lands in the watershed are projected to double from the 1990 condition by the year 2020. Flood-induced damage has occurred more frequently in recent years in urban areas of the watershed, and there are concerns about the effect of urbanization on flood peaks and volumes, future flood-mitigation plans, and potential effects on the water quality and stream habitats.

To address some of the issues listed above, the U.S. Geological Survey (USGS), in cooperation with the Kane County Department of Environmental Management and Illinois Department of Natural Resources–Office of Water Resources, as well as Federal Emergency Management Agency, conducted a flood-hazard study during 2000-04 of the Blackberry Creek watershed. This report describes the procedures used in developing the hydrologic model, estimating flood-peak discharge magnitudes and recurrence intervals for flood-hazard analysis, developing the hydraulic model, and presents a map of the 100- and 500-year flood plains and 100-year floodway. The USGS is using a continuous hydrologic simulation/flood-frequency approach to generate the flood quantiles used in the hydraulic model. This study demonstrates the successful application of this approach with the goal of promoting use of this advanced technique for flood-hazard studies in other watersheds.

The hydrologic model, Hydrological Simulation Program–FORTRAN (HSPF), was used in this study to perform the simulation of continuous water movement through various land uses in the watershed. The hydrologic model was developed from a recent digital elevation model, and from soil and land-use data. Observed precipitation and other meteorologic time series were input to the hydrologic model to supply a continuous streamflow time series at various locations in the watershed. The hydrologic model parameters were obtained with the use of the expert system program HSPEXP, and were evaluated further with coefficient of model-fit efficiency and correlation coefficients on monthly flow volumes and visual examination of monthly peak-flow discharges. The hydrologic model had correlation and model-fit coefficients of 0.92 and 0.81 for the calibration and verification period, respectively. Results indicate that simulated flow volumes, peak discharges, and flow hydrographs are, in general, in good agreement with the observed data. The capability of the hydrologic model to simulate an extreme flood was verified with the July 17-18, 1996, flood event using precipitation input determined with the Thiessen method and Next Generation Radar (NEXRAD) Stage III analysis.

Flood-frequency analysis was applied to an annual maximum series to determine flood quantiles in subbasins for flood-hazard analysis. The simulated annual maximum series was determined from the long-term streamflow series (water years 1950-99) continuously simulated with the HSPF model. Simulated flood quantiles were compared to observed flood quantiles at the Yorkville streamflow-gaging station. The simulated flood quantiles at locations inside the watershed other than the Yorkville streamflow-gaging station were compared to those determined in the 1989 U.S. Department of Agriculture study and using the USGS regional flood-frequency equations. These comparisons confirmed that the flood quantiles estimated as part of the present study are reasonable. The 100- and 500-year flood discharges were then used in the hydraulic model.

The HEC-RAS hydraulic model was used to determine the 100- and 500- year flood elevations throughout Blackberry Creek watershed. Encroachment analysis was also performed using HEC-RAS to determine the floodway. The model was calibrated and verified using high water marks and observed inundation maps for the July 17-18, 1996, flood event. Considering the timing of peak stages in observed and simulated conditions, and the information available for developing the observed inundation map, the model-simulation results can be considered reasonable. Using GIS techniques, the flood elevations from the hydraulic model were digitally mapped for the 100- and 500-year flood plains and the 100-year floodway. This map is presented for each tributary and main stem of Blackberry Creek.

Results indicate that the 100-year flood plain on Blackberry Creek tributaries ranged from 23 acres for tributary F (a headwater subbasin at the northeastern corner of the Blackberry Creek watershed) to about 1,000 acres for the Lake Run tributary watershed (the largest tributary to Blackberry Creek). For the 500-year flood plain, the inundated area ranged from approximately 22 acres in tributary F to 1,222 acres in the Lake Run tributary. The simulated 100-year and 500-year flood plains in the main stem of Blackberry Creek covered 1,497 and 1,791 acres, respectively. Based on 1996 land-cover data, most of the land in the 100-year and 500-year flood plains was cropland, forested and wooded land, and grassland. A relatively small percentage of urban land was in the 100-year and 500-year flood plains.

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GLOSSARY

100-year flood—the magnitude of a flood-peak discharge having 1-percent probability of being equaled or exceeded in any given year.

500-year flood—the magnitude of a flood-peak discharge having 0.2-percent probability of being equaled or exceeded in any given year.

Annual exceedance series—a flood series organized by the high floods of the record regardless of the year but the number of events is equal to the number of years.

Annual maximum series—a flood series organized by the highest flood of each water year.

Areas of Moderate Flood Hazard—areas between the 100- and 500- year flood-plain boundaries.

Areas of Minimal Flood Hazard—areas above the 500-year flood plain.

Digital Elevation Model—a Digital Elevation Model (DEM) is a digital file consisting of terrain elevations for ground positions at regularly spaced horizontal intervals.

Flood frequency—instantaneous flood magnitude expressed with an associated exceedance probability or recurrence interval, indicating this magnitude has the given percent of probability been equaled or exceeded in any given year. Flood frequencies are obtained from flood-frequency analysis using statistical methods on observed or synthetic flood series. Note that flood frequencies are statistical quantities that are subject to change when data and/or techniques are updated.

Flood plain—lowland and relative flat areas adjoining inland water bodies and those other areas subject to flooding (adopted from Federal Emergency Management Agency, 1986). Those areas include detached special flood-hazard areas, ponding areas, and other similar areas.

Floodway—the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the 100-year flood without cumulatively increasing the water-surface elevation more than a designated height. In Illinois, this designated height is 0.1 foot. This height differs from the height adopted by most other States (1 foot). In addition to designated height, the State of Illinois also has specified that the increase in flood storage or velocity is less than 10 percent.

Ineffective flow area—areas that are inundated but do not convey flows in the downstream direction.

Special Flood Hazard Areas—areas within the 100-year flood-plain boundary.

STATSGO—State soil geographic database. State general soil maps made by generalizing the detailed soil-survey data. The level of mapping is designed to be used for broad planning and management uses covering State, regional, and multi-State areas. STATSGO data are designed for use in geographic information system (GIS). STATSGO data are available in the USGS Digital Line Graph (DLG-3) optional distribution format. NRCS soil map symbols are not normally carried within the DLG-3 file; however, these map symbols are made available as a unique ASCII file when NRCS soils data are distributed in the DLG-3 format. STATSGO data are also available in Arc/Info 7.0 coverage and GRASS 4.13 vector formats (*http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/index.html*). Accessed December 12, 2005.

SSURGO—Soil Survey Geographic dataset. The most detailed level of soil mapping done by NRCS. SSURGO digitizing duplicates the original soil-survey maps. This level of mapping is designed for use by landowners, townships, and county natural resource planning and management. SSURGO data are designed for use in a geographic information system (GIS). The map extent for SSURGO dataset is a soil-survey area, which may consist of a county, multiple counties, or parts of multiple counties. A SSURGO dataset consists of map data, attribute data, and metadata. SSURGO map data are available in modified DLG-3 optional and Arc interchange file formats. Attribute data are distributed in ASCII format with DLG-3 map files and in Arc interchange format with Arc interchange map files. Metadata are in ASCII format (*http://www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/index.html*). Accessed December 12, 2005.

Water Year (WY)—a water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends and includes 9 of 12 months. For example, WY 2004 is from October 1, 2003, to September 30, 2004.

APPENDIX A—Benchmarks Used in This Study

Survey controls in the watershed were established by the Illinois Department of Natural Resources-Office of Water Resources (IDNR-OWR) and benchmark points were established by Smith Engineering Consultants, Inc., using the differential (also known as real-time kinematic (RTK)) global positioning system technique (Bill Rice, Illinois Department of Natural Resources-Office of Water Resources, written commun., 2001). The benchmark network was referenced to present (2000-01) Kane County and Illinois Department of Transportation (IDOT) first-order control stations along with U.S. Geological Survey (USGS) benchmarks. The Kane County and IDOT stations were held in the adjustment using NAVD88 altitudes. The USGS benchmarks originally were established on NGVD29 and benchmark elevations were converted to NAVD88 using the CORPSCON program. The final survey control was based upon NAVD88 and checked within 0.1 foot with the available USGS benchmark NAVD88 values.

Blackberry Creek Control Survey, Kane County (survey by Smith Engineering Consultants, Inc. in 2001)

STATION NAME	LATITUDE (Degrees, Minutes, Decimal Seconds)	LONGITUDE (Degrees, Minutes, Decimal Seconds)	NAD83 (1997) NORTHING, feet	NAD83 (1997) EASTING, feet	NAVD88 ALTITUDE, feet	ELLIPSOID HEIGHT
KA01	41º54'13.02815"N	88º26'35.18503"W	1907487.76	954367.15	852.50	744.07
KA02	41º53'21.30201"N	88º26'35.56259"W	1902252.00	954331.89	819.61	711.22
KA03	41º52'53.82998"N	88º26'58.08045"W	1899473.49	952625.00	828.36	719.99
KA04	41º52'53.97877"N	88º27'42.87570"W	1899493.38	949236.56	815.02	706.66
KA05	41º52'05.80106"N	88º27'03.93830"W	1894612.56	952175.23	811.85	703.49
KA06	41º52'18.53974"N	88º27'37.92330"W	1895905.65	949605.86	814.61	706.25
KA07	41º51'11.10504"N	88º24'52.58298"W	1889064.66	962108.21	758.36	649.98
KA08	41º51'43.26010"N	88º24'52.88649"W	1892319.44	962088.32	785.67	677.28
KA09	41º51'58.22618"N	88º27'37.18117"W	1893849.40	949658.97	788.32	679.97
KA10	41º51'58.19769"N	88º28'03.67118"W	1893849.57	947654.69	801.06	692.72
KA11	41º50'44.69659"N	88º28'02.39124"W	1886409.58	947739.92	751.39	643.07
KA12	41º50'38.83648"N	88º25'28.78049"W	1885801.17	959365.42	761.25	652.90
KA13	41º50'38.11571"N	88º26'14.08465"W	1885732.11	955936.37	769.50	661.15
KA14	41º49'18.19860"N	88º28'29.87296"W	1877657.56	945645.51	717.19	608.88
KA15	41º48'46.75849"N	88º28'24.74761"W	1874474.55	946028.38	706.78	598.48
KA16	41º48'15.35408"N	88º27'09.06483"W	1871287.15	951754.99	710.22	601.92
KA17	41º47'53.08540"N	88º26'38.24596"W	1869030.00	954086.15	728.36	620.06
KA18	41º43'21.03030"N	88º22'33.21431"W	1841476.31	972631.65	666.23	557.98
KA19	41º44'29.98625"N	88º22'50.08442"W	1848456.60	971356.21	665.03	556.77
KA20	41º45'06.24804"N	88º22'51.59164"W	1852127.04	971243.99	670.85	562.59
KA21	41º46'08.78989"N	88º24'48.84912"W	1858464.07	962362.21	707.12	598.85
KA22	41º46'27.20391"N	88º24'43.62497"W	1860327.55	962759.78	680.23	571.95
KA23	41º46'51.50351"N	88º24'34.59360"W	1862786.53	963446.27	694.19	585.90
KA24	41º47'23.54176"N	88º24'24.63355"W	1866028.77	964203.63	686.68	578.39
KA25	41º48'37.33456"N	88º24'18.28677"W	1873497.65	964690.64	698.28	589.95
KA26	41º49'43.80006"N	88º24'07.84285"W	1880224.65	965486.92	702.70	594.35
KA27	41º50'47.64114"N	88º23'33.78626"W	1886684.74	968069.66	706.68	598.28
KA28	41º50'49.54554"N	88º24'01.08774"W	1886879.03	966003.51	726.69	618.30
KA29	41º50'44.04225"N	88º24'34.30474"W	1886324.08	963489.02	732.99	624.62

Kane County survey by Smith Engineering Consultants, Inc. in 2001

STATION NAME	LATITUDE (Degrees, Minutes, Decimal Seconds)	LONGITUDE (Degrees, Minutes, Decimal Seconds)	NAD83 (1997) NORTHING, feet	NAD83 (1997) EASTING, feet	NAVD88 ALTITUDE, feet	ELLIPSOID HEIGHT
KA30	41º49'39.30287"N	88º25'49.28516"W	1879776.85	957806.66	722.53	614.20
KA31	41º49'18.54602"N	88º27'01.40211"W	1877682.64	952344.04	715.55	607.23
KA32	41º48'57.09405"N	88º27'16.26922"W	1875512.83	951215.33	717.60	609.30
KA33	41º45'56.76918"N	88º22'41.65287"W	1857240.33	971999.98	676.79	568.51
KA34	41º46'34.62884"N	88º23'07.77987"W	1861073.57	970022.40	674.67	566.38

Kane County survey by Smith Engineering Consultants, Inc. in 2001 (cont.)

STATION NAME	LATITUDE (Degrees, Minutes, Decimal Seconds)	LONGITUDE (Degrees, Minutes, Decimal Seconds)	NAD83 (1997) NORTHING, feet	NAD83 (1997) EASTING, feet	NAVD88 ALTITUDE, feet	ELLIPSOID HEIGHT
KA35	41º47'12.51824"N	88º23'07.96989"W	1864908.72	970010.33	699.90	591.60
KA36	41º47'44.44423"N	88º22'32.32762"W	1868138.78	972712.01	700.46	592.14
KA37	41º48'26.05067"N	88º21'59.91354"W	1872349.09	975168.83	710.99	602.64
KA38	41º46'04.96245"N	88º24'14.20454"W	1858074.36	964987.11	704.51	596.24
IL-KANE-34-38-8	41º43'42.60815"N	88º19'00.10894"W	1843657.95	988791.16	668.57	560.30
IL-KANE-25-38-7	41º44'23.27295"N	88º23'11.12055"W	1847778.01	969761.08	667.77	559.52
SUGAR AZIMUTH	41º45'18.16117"N	88º26'11.58285"W	1853346.16	956086.84	696.16	587.88
IL-KANE-19-38-8	41º45'53.80400"N	88º22'28.71782"W	1856939.71	972980.05	671.38	563.10
KAN47-2B	41º47'29.71036"N	88º27'38.17249"W	1866670.27	949543.70	721.98	613.69
IL-KANE-6-38-7	41º47'41.61164"N	88º29'19.50665"W	1867887.53	941869.87	722.92	614.61
USGS 2RGW 1963	41º47'42.81799"N	88º22'45.85829"W	1867974.70	971687.04	704.60	596.28
IL-KANE-32-39-8	41º49'08.36242"N	88º20'39.80236"W	1876630.32	981236.28	730.81	622.42
IL-KANE-26-39-7	41º49'51.29294"N	88º24'49.08744"W	1880985.79	962365.19	734.64	626.29
IL-KANE-20-39-7	41º50'29.22552"N	88º28'07.37079"W	1884844.18	947360.57	727.52	619.21
IL-KANE-16-39-7	41º51'51.49034"N	88º26'52.76400"W	1893162.87	953018.73	748.29	639.93
IL-KANE-18-39-8	41º51'56.02211"N	88º22'19.75289"W	1893603.11	973675.98	707.91	599.46
IL-KANE-12-39-6	41º52'51.25425"N	88º30'11.50842"W	1899237.15	937992.95	839.50	731.16
KAN47-3A	41º54'04.80518"N	88º28'19.71427"W	1906666.87	946461.57	904.74	796.35

Kendall County, Illinois Department of Natural Resources-Office of Water Resources Survey in 2001

STATION NAME	LATITUDE (Degrees, Minutes, Decimal Seconds)	LONGITUDE (Degrees, Minutes, Decimal Seconds)	NAD 83 (1997) NORTHING, feet	NAD 83 (1997) EASTING, feet	NAVD 88 ALTITUDE, feet	ELLIPSOID HEIGHT
B50	41º41'12.37791"N	88º25'45.37334"W	1828466.081	958045.596	643.27	535.01
BRISTOL	41º40'00.76154"N	88º31'05.92808"W	1821256.894	933708.678	645.54	537.14
KA18	41º43'21.03029"N	88º22'33.21431"W	1841476.306	972631.654	666.17	557.92
IL-KANE-25-38-7	41º44'23.27294"N	88º23'11.12055"W	1847778.013	969761.084	667.66	559.40
KE01	41º42'55.14083"N	88º22'40.90849"W	1838856.114	972046.839	661.68	553.44
KE02	41º42'42.91773"N	88º23'03.73987"W	1837619.877	970314.593	662.17	553.93
KE03	41º42'24.24117"N	88º23'34.39712"W	1835730.963	967988.144	661.26	553.01
KE04	41º41'43.28699"N	88º24'26.06817"W	1831588.699	964065.377	651.76	543.51
KE05	41º41'29.50152"N	88º24'21.92063"W	1830193.096	964378.842	651.32	543.08
KE06	41º40'44.29038"N	88º24'36.12543"W	1825617.862	963297.091	646.86	538.63
KE07	41º40'32.21338"N	88º25'09.60703"W	1824397.855	960755.225	650.69	542.45
KE08	41º40'29.44330"N	88º26'39.00846"W	1824125.223	953970.565	646.53	538.25
KE09	41º40'09.87719"N	88º26'30.13042"W	1822143.934	954641.800	638.38	530.12
KE10	41º39'37.49002"N	88º27'32.90639"W	1818872.262	949872.752	635.17	526.89
KE11	41º39'28.72072"N	88º26'51.20695"W	1817980.250	953036.716	637.56	529.30
M20	41º31'54.71323"N	88º26'00.71974"W	1772022.598	956815.674	648.00	539.64
ZAUB	41º47'35.84882"N	88º19'50.01696"W	1867265.924	985006.189	692.95	584.60

APPENDIX B—Analysis of Flow Diversion at Jericho Lake, Montgomery, Ill.

Introduction

The analysis of flow diversion at Jericho Lake was conducted in cooperation with the University of Illinois at Urbana-Champaign, Civil and Environmental Engineering Department, Hydrosystems Laboratory as part of a special graduate study program. *The following model analysis and results are summarized from Garcia (2001).* Overall, the flow patterns/diversions at Jericho Lake were analyzed using the two-dimensional, finite-element, surface-water, modeling system (FESWMS, Froehlich, 1989). The two-dimensional flow analysis was needed because the flows in lateral and longitudinal directions affect the amount of diversion from the creek to the lake. FESWMS is an interface in the Surface-water Modeling System (SMS) (Environmental Modeling Systems, Inc., 1994). The FESWMS also is an accepted computer model by Federal Emergency Management Agency (FEMA) for National Flood Insurance Program usage (Federal Emergency Management Agency, 2003).

Jericho Lake is located on the east side of Blackberry Creek just south of Jericho Road, an area within the jurisdiction of Montgomery, Ill. (fig. B1). The lake was created from a sand-gravel quarry excavation in the 1950's. Abandoned in the late 1970's, the quarry was opened to the public as a recreational area in 1981 under the management of the Fox Valley Park District (Timothy Harbaugh, Kane County, oral commun., 2000). The lake has a surface area of 22 acres; the maximum depth is approximately 26 feet (ft) with an average depth of 14 ft. The quarry excavation altered local drainage patterns such that, even though Jericho Lake lies outside of the Blackberry Creek watershed, flooding in Blackberry Creek could inundate the lake area because of low topographic gradients. As a result, the lake is included in the 100-year flood plain of Blackberry Creek (U.S. Department of Agriculture, Soil Conservation Service, 1989).

During the 1983 and 1996 floods, flows overtopped the bank of the southeastern corner of the lake, flowed through fields and overtopped Orchard Road causing flood damage in Montgomery, Ill. The goal of the diversion study was to provide information about the nature of the flooding, and to determine the amount and frequency of streamflow diverted out of Blackberry Creek watershed. The following two analyses were taken to achieve this goal: 1) simulation of the diversion to determine the source(s) and occurrences of diversion, and 2) estimation of the amount of diversion at 100- and 500-year levels.

Input data requirements for FESWMS simulation include topography, channel geometry, descriptions of hydraulic structures, hydraulic parameters, such as Manning's coefficient and dynamic viscosity coefficients, and discharge data. However, the study area needed to be defined before data collection and model simulation. Field reconnaissance was conducted to identify flow paths from Blackberry Creek to Jericho Lake and out of Jericho Lake, and to assess topographic and flow-resistance characteristics of the study area.

Possible flow paths from Blackberry Creek to Jericho Lake, evident in the inundation map of the 1996 July flood, were: 1) an area with low bank elevations connecting the two water bodies near the northwestern corner of the lake, 2) a small ditch located at the southwestern corner of the lake, and 3) from the north side of the lake when flows overtopped the Jericho Road embankment. Paths 1 and 2 were identified during the field reconnaissance and were verified with information provided by local residents.

Path 3 was verified with video taken during the 1996 flood event by a local resident (Terry Bennett, Blackberry Creek watershed resident, written commun., 2001) that documented strong current flowing from north to south over Jericho Road, and the overtopped flows entering the lake through a flat area between the lake and Jericho Road. The area north of Jericho Road at this section is an open, low-lying area east of the junctions of the Aurora Chain-of-Lakes tributary with Blackberry Creek. Possible sources of flood water to this area include: 1) overbank flow from the Aurora Chain-of-Lakes tributary including overflow from East Run pond that passes through the Cherry Hill and Lakeside of Sans Souci subdivisions and 2) overbank flow from Blackberry Creek. At the Jericho Road section, there also is a 3-ft by 3-ft concrete box culvert, located approximately 900 ft east of Jericho Road Bridge that drains flows from north to south.

When flow exited Jericho Lake through a low bank area located at the southeastern corner of Jericho Lake, the overtopped lake water flowed into an open field that leads to the culverts on Orchard Road (fig. B1). In the open field there was another small ditch (abandoned railroad track) that could lead diverted flow back to Blackberry Creek south of Jericho Lake.

Data

The bed and bank materials and bank vegetation were observed and noted for determining the Manning's roughness coefficients (*n*-values). The extent and density of various vegetation were assessed using aerial photographs. The Manning's roughness coefficients then were determined with reference to tabulate values (Chow, 1959) and assigned to each element type.

The 2001 version of the digital elevation model (DEM) was used to describe topographic characteristics of the study area. The 1985 surveyed cross sections (U.S. Department of Agriculture, Soil Conservation Service, 1989) from Jericho Road to the U.S. Highway 30 Bridge, were used for describing the Blackberry Creek channel. Topographic data for the inflow low bank section, the connecting and departing ditches, and the lake outflow section were surveyed. Bathymetry of Jericho Lake was determined from a map provided by the Fox Valley Park District (written commun., 2001).

The Montgomery streamflow-gaging station (station 05551675), located upstream of the Jericho Lake study area, began operation after 1998. Available flood information for the area was limited to video taken during the July 17-18, 1996, flood. For the purposes of estimating incoming flow to Blackberry Creek, it was assumed that the rating curve at the Montgomery station could be used for estimating flows through the bridge at normal flow conditions.

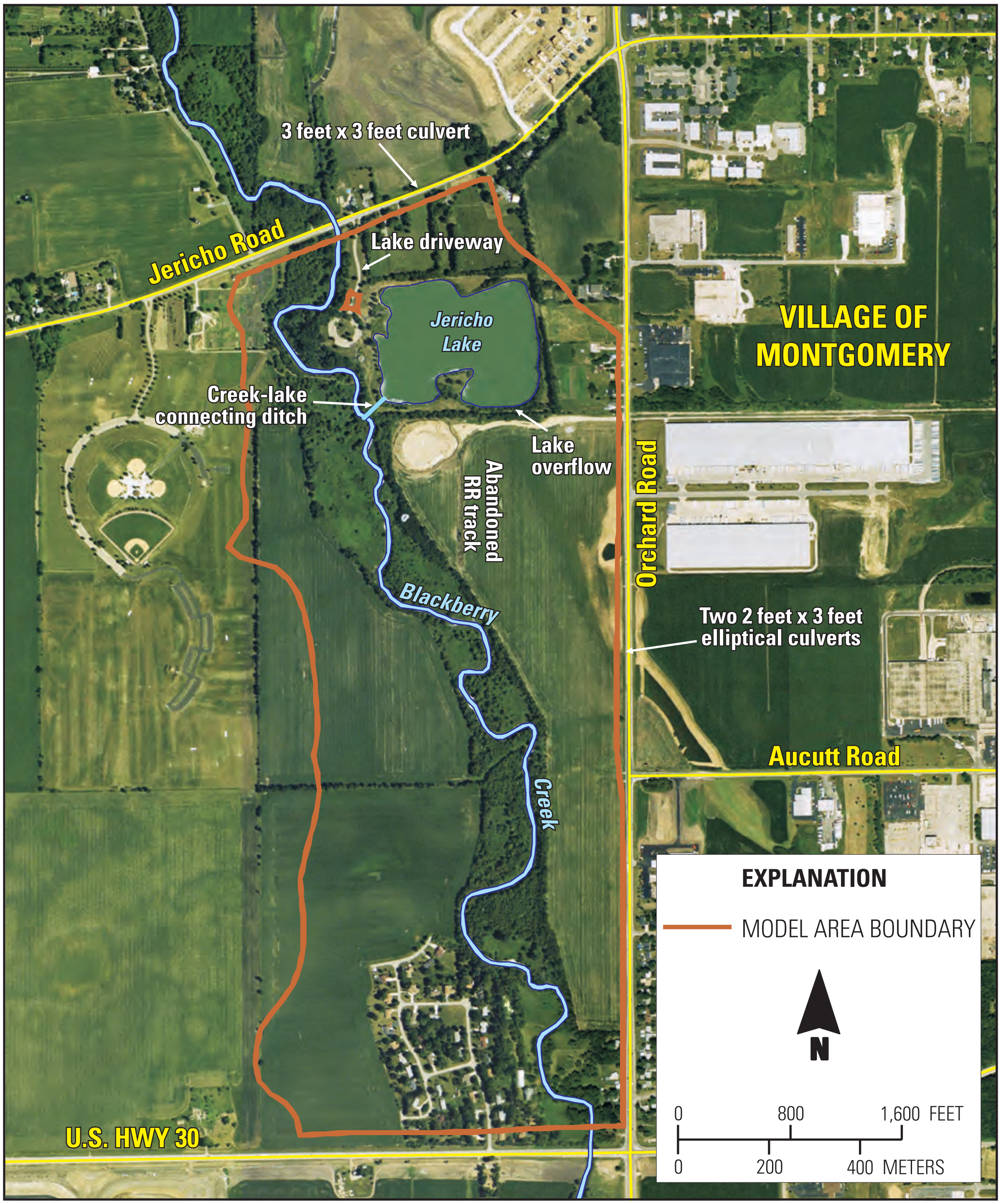

Figure B1. Study area for the Jericho Lake Diversion, Kane County, Ill.

Model Development

The Jericho Lake diversion was simulated with Jericho Road as the northern boundary, U.S. Highway 30 as the southern boundary, Orchard Road as the eastern boundary, and the open field outside the 500-year flood plain delineated in the U.S. Department of Agriculture, Soil Conservation Service 1989 study as the western boundary (fig. B1). A reach of Blackberry Creek, approximately 1.7 mi long, was included. The downstream boundary was set a reasonable distance away from the Jericho Lake area to minimize errors caused by inaccuracy in specifying the downstream boundary conditions. The FESWMS diversion model simulation was conducted and completed in 2001 before the 2001 cross-section surveys were completed. Therefore, results of diversion analysis were presented with NGVD29, different from the results presented in the body of the report.

The following seven types of element properties were used to describe hydraulic and topographic characteristics in the Blackberry-Jericho area: main channel, grasslands, crop fields, houses, lawn, woods, and lake. Boundaries of these element-property types were delineated with the aid of the digital orthophoto quadrangle (DOQ) and field reconnaissance.

Only triangular, six-node quadrilateral elements were used. Nodal elevations were determined by using a point coverage map with 10 ft nodal spacing generated by combining the 2-ft contour map and the lake-survey data. In order to describe the channel geometry of Blackberry Creek, interpolation between 10 surveyed cross sections was used. A second point coverage with 5-ft nodal spacing was generated for the channel. The two point-coverage maps were combined to reproduce the geometry of the entire terrain and channel. The topographic data were processed and generated using ArcInfo 8.0 (Environmental System Research Institute, 2001).

Upstream boundary conditions were specified at two locations. The first location represented inflows through and over the Jericho Road Bridge, and the second location represented the inflows through the culvert and over the road embankment.

Tangential flow (zero-normal flow) was assigned to the two lateral (eastern and western) boundaries. Tangential flow means that simulated flows were parallel to the edge of the elements defining the boundaries and there are no outflows from these boundaries. An exception to the tangential flow occurred at the eastern boundary at a location where two 2-ft by 3-ft elliptical concrete culverts pass underneath Orchard Road (fig. B1). Instead of using culvert elements, outflowing weir nodes were used. This assignment was done because outlets of the culverts were not in the mesh coverage; also, weir flow probably was dominant when overflow occurred. At the downstream boundary (upstream of the Route 30 bridge), stage was assigned as the boundary condition. The lake was assumed to fill to its capacity and not store any water in the simulations.

Model Calibration and Verification

The only information available for investigating the diversion in this area was the discharge corresponding to the highest overtopping flow condition described in the video of the July 1996 event. Therefore, this event was used for calibrating and verifying the Blackberry Creek-Jericho Lake FESWMS model and the analysis was conducted in steady-state mode.

The maximum water-surface elevation on top of Jericho Road was assumed to be 667.9 ft above NGVD 29, based on various landmarks shown in the video. The same elevation also was applied to the Jericho Road Bridge section. At this stage, the mean depth on top of the bridge was 0.56 ft. Therefore, flow through the Jericho Road Bridge was estimated by computing pressurized flow through the bridge opening and weir flow over the road (note the stage difference between upstream and downstream of the bridge was estimated to be 1 ft at the time of computation). The estimated maximum discharge was approximately 4,828 cubic feet per second (ft^3/s) for the pressurized flow through the bridge opening and 1,095 ft^3/s for the overflow above the bridge, which gave the total inflow at the bridge location be 5,920 ft^3/s.

A similar method was used to determine the maximum discharge at the embankment overtopping/culvert location. The estimated difference in water-surface elevation between upstream and downstream of the culvert was approximately 2.5 ft and the discharge corresponding to the pressurized culvert flow was approximately 100 ft^3/s. To determine the flow over the road, weir length over the road corresponding to a 0.68 ft depth was used and the estimated discharge was approximately 2,050 ft^3/s. The total inflow at the culvert boundary was estimated to be 2,150 ft^3/s.

The downstream boundary at Highway 30 was unknown, and no high water mark (HWM) was available at this location. A HWM was available at a house in a subdivision west of Blackberry Creek, in a close proximity to Blackberry Creek at Route 30. This reference stage was used to extrapolate a discharge (as discharge was above the 500-year flood), using the rating curve estimated by U.S. Department of Agriculture, Soil Conservation Service (1989). The extrapolated water-surface elevation was determined to be 663 ft, and was assigned to the downstream boundary. The outflow at the eastern boundary was computed as weir flow.

Besides the Manning's roughness coefficient, another parameter adjusted in two-dimensional flow model calibration/verification is the eddy viscosity coefficient, ε. This parameter was calibrated twice in this study. Results from this study showed that the computed water-surface elevations were most sensitive to changes in the *n*-value for the wooded flood plain and least sensitive to changes in *n*-value for the channel. However, subsequent model runs indicated that, unlike the *n*-values, the ε values calibrated for the July 1996 flood event could not be used in other flow discharges as the numerical model diverged. Higher ε value had to be used at lower inflow discharges. Using higher ε values reduced the ability of flow to move laterally as it traveled downstream and resulted in slightly higher simulated water-surface elevations for the July 1996 event. To offset the increased water-surface elevation, the *n*-values in the lawn and wooded area were reduced. The effect on the magnitudes of diverted flow from the creek to the lake was minimal with the modified *n* and ε values. The two sets of parameters are presented in table B1. Parameters from the second calibration were used in the subsequent analyses. Model verification was done by comparing the simulated and observed inundation extents. The inflow and outflow paths of Jericho Lake can also be observed in figure B2.

Model Analysis

The amount of diversion is a function of the inflow discharge, downstream stage, and hydraulic conditions of Blackberry Creek and diversion channels. A monograph, based on the concept of a hydraulic performance graph (Yen and Gonzalez, 2000), was developed with the calibrated FESWMS Blackberry Creek-Jericho Lake model. A monograph is based on numerous simulations with designed combinations of upstream and downstream boundary conditions. The monograph was used to determine the magnitude of diversion from Blackberry Creek to Jericho Lake in the Blackberry Creek HSPF model. The monograph was developed without considering overflow from the Jericho Road/culvert site. This overflow was estimated using weir flow approximation.

In generating the monograph (fig. B3), the range of simulated inflow was from 1,900 to 5,100 ft^3/s, which corresponded to flood quantiles of 5- and 500-years, respectively, estimated by the U.S. Department of Agriculture, Soil Conservation Service (1989), with a 400 ft^3/s increment. Therefore, the monograph represents only the total diverted flow from Blackberry Creek to Jericho Lake. The downstream stages varied from 659.4 to 663.0 ft with a stage interval of 0.2 ft.

The x-axis is the downstream stage at Route 30, the y-axis is the magnitude of diversion, and each curve represents an inflow discharge from the Jericho Road Bridge. To estimate a diversion from Blackberry Creek for a flood event, first determine the downstream stage and locate it on the x-axis. Second, move up vertically to the intersection with the curve corresponding to the inflow magnitude (users may need to interpolate between streamflow curves given here). Finally, move horizontally to the left to read the diverted flow magnitude from the y-axis. The jumps in the inflow curves were caused by sudden expansion of submerged cross-sectional area in the ditch from the channel to the flood plain at those stages. For discharges greater than 5,100 ft^3/s, the diversion amount was interpolated from the simulation of the July 1996 flood event.

During the FESWMS model simulation runs, it was evident that the ditch at the southwestern corner of the lake conveyed most of the diverted water from Blackberry Creek to Jericho Lake. Different from the simulated 1996 July flood event, a small amount of flow could move back to the open field through the abandoned railroad ditch because of backwater effects (when downstream stages were higher than that in the open

Table B1. Values of Manning's roughness coefficient (n) and eddy-viscosity coefficient (ε) per element type for the first and second calibrations of the Finite-Element, Surface-Water Modeling System (FESWMS) Blackberry Creek-Jericho Lake model, Kane County, Ill.

[ft, feet; ft^2/s, square feet per second]

Element types	First Calibration		Second Calibration	
	n ($ft^{1/6}$)	ε (ft^2/s)	n ($ft^{1/6}$)	ε (ft^2/s)
Channel	0.030	120	0.030	624
Grassland	.070	120	.060	624
Crop field	.065	120	.060	624
Houses	.100	120	.100	624
Lawn	.025	120	.020	624
Woods	.070	120	.060	624
Lake	.010	120	.010	624

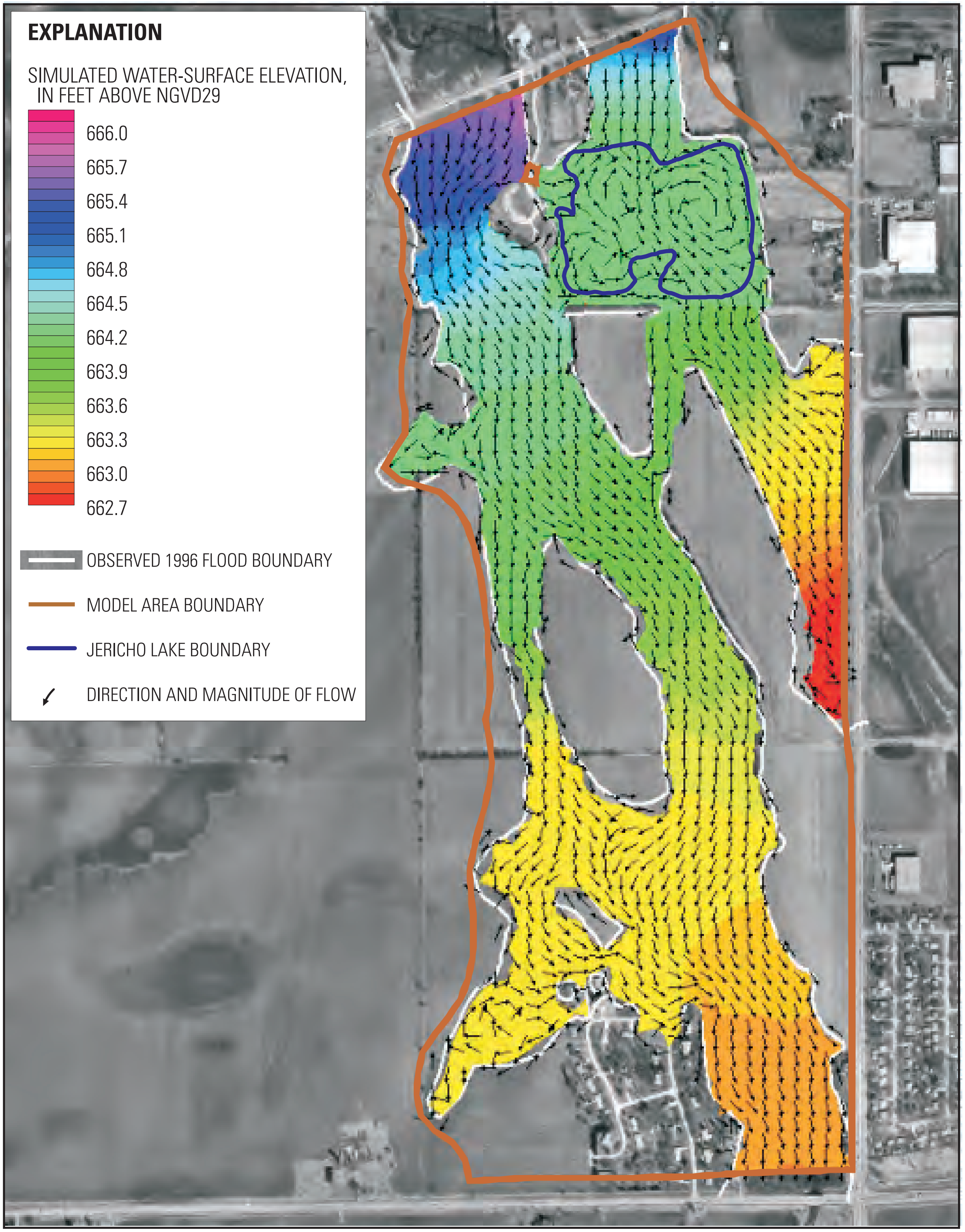

Figure B2. Comparison of observed and simulated inundation by the Finite Element Surface Water Modeling System (FESWMS) Blackberry Creek-Jericho Lake model and observed inundation for the July 1996 event in Blackberry Creek, Kane County, Ill.

field). In estimating the total amount of diversion from Blackberry Creek to Jericho Lake, flows through both ditches were counted.

Flood-Frequency Estimates of Diverted Flow from Jericho Lake

Results from the FESWMS analysis can be used to estimate the total diverted flow from Blackberry Creek to Jericho Lake. However, the total diverted flow out of Jericho Lake was not determined in the FEWSWM analysis because of the lack of information for floods other than the July 17-18, 1996, event north of Jericho Road. An alternative approach was used to estimate the total diverted flow out of Jericho Lake based on the Hydrological Simulation Program–FORTRAN (HSPF) model simulation. The approach involved using the flood-frequency analysis on the simulated total diverted flood-peak series to estimate flood magnitudes and recurrence intervals. The simulation steps and assumptions used in this approach are described below.

Steps

1. Overflow at East Run pond, diversions from north of Jericho Road, and from Blackberry Creek to Jericho Lake were built into the routing tables of the HSPF model. In HSPF simulation, these overflow and diverted flow were assigned to four time series as: 1) flow overtopped East Run pond, subbasin 60, then passed through the Cherry Hill and Lakeside of Sans Souci subdivisions and entered the Aurora Chain-of-Lakes tributary at subbasin 70, 2) flow diverted from a low-lying area north of Jericho Road. Two major sources of flows to the low-lying area were Blackberry Creek (subbasin 265) and Aurora Chain-of-Lakes tributary (subbasin 70), in which the overflow from subbasin 60 was included; and 3) total diverted flow from Blackberry Creek (subbasin 270).
2. When the long-term hydrologic simulation (WY 1950-99) was completed, the corresponding time series were added, and the annual peaks of the total diverted flows were determined from the summed time series.
3. Recurrence intervals of these peak events were assigned and a flood-frequency curve was determined from the peak-flow data.

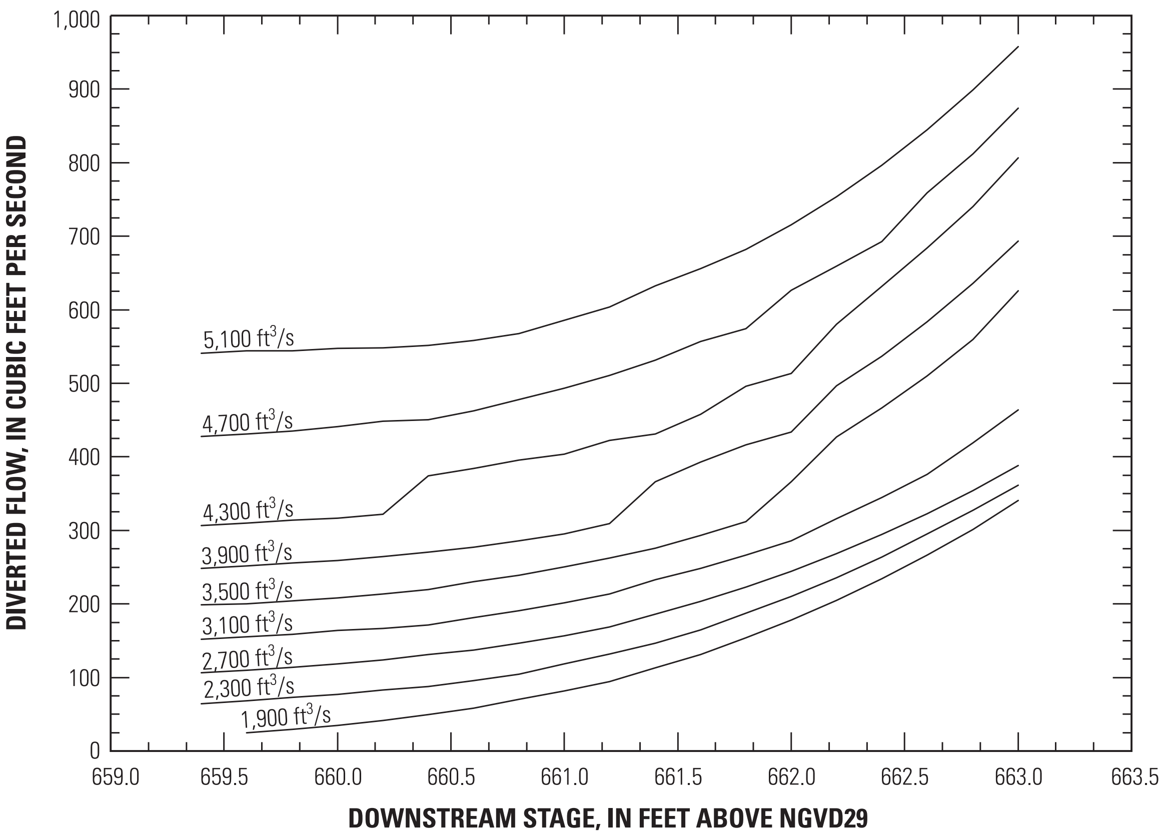

Figure B3. Monograph for estimating magnitudes of total diverted flow in cubic feet per second (ft^3/s) from Blackberry Creek to Jericho Lake, Kane County, Ill. Note the downstream stages (x-axis) were referenced in NGVD29.

Assumptions used

1. Jericho Lake was assumed full to its capacity in the simulation. This assumption was also used in the FESWMS analysis.
2. The amount of diversion at subbasin 270 was estimated using monographs shown in figure B3. The amount of diversion from north of Jericho Road was estimated with a broad-crest weir function where the profile of the Jericho Road surface was used as the weir. Flow contributions from both Blackberry Creek (subbasin 265) and Aurora Chain-of-Lakes tributary (subbasin 70) were estimated by assigning a ratio to each subbasin. The ratios were evaluated by comparing them with the computed flood elevations (from the HEC-RAS modeling) at these subbasins. After this evaluation was completed, the amount of diversion from each subbasin was used to prepare the respective routing table. The amount of diversion from the pond along East Run tributary (subbasin 60) was estimated with a broad-crest weir function. At this time, the crest elevation at the pond berm was used in the evaluation.
3. The total diverted flow time series was the sum of individual diversion time series; no flow routing was computed. Considering the relatively short distance] from Jericho Road to the lake (less than 1 mile), this assumption was considered reasonable, especially during large floods. However, the flows from East Run pond moved a longer distance than the flows from Jericho Road and flood peaks and timing would be different. The East Run tributary diversion was only a small portion of the total diversion. This time series was added to the outflow of Aurora Chain-of-Lakes tributary at subbasin 70. The time series from subbasins 70, 265, and 270 then were summed to form the total diversion flow series where annual peaks were organized.
4. The overflow and diversion are not hydrologic events. Therefore, it is not correct to use an available formula (such as the Weibel formula; Chow, 1964) to estimate the recurrence intervals of these peaks in the total diverted-flow series (series contains many zeros corresponding to years with lower flow where no diversion resulted). An appropriate way to approximate the recurrence intervals of total diverted flows was to use those of the Blackberry Creek main stem at these locations (for example, the recurrence interval at subbasin 270).
5. The peak discharge of total diverted flow for the July 1996 event in the simulated flood-peak series was replaced with the re-constructed peak discharge from the FESWMS analysis. It was assumed that the results simulated with the FESWMS model were more accurate than those results simulated with the HSPF model.

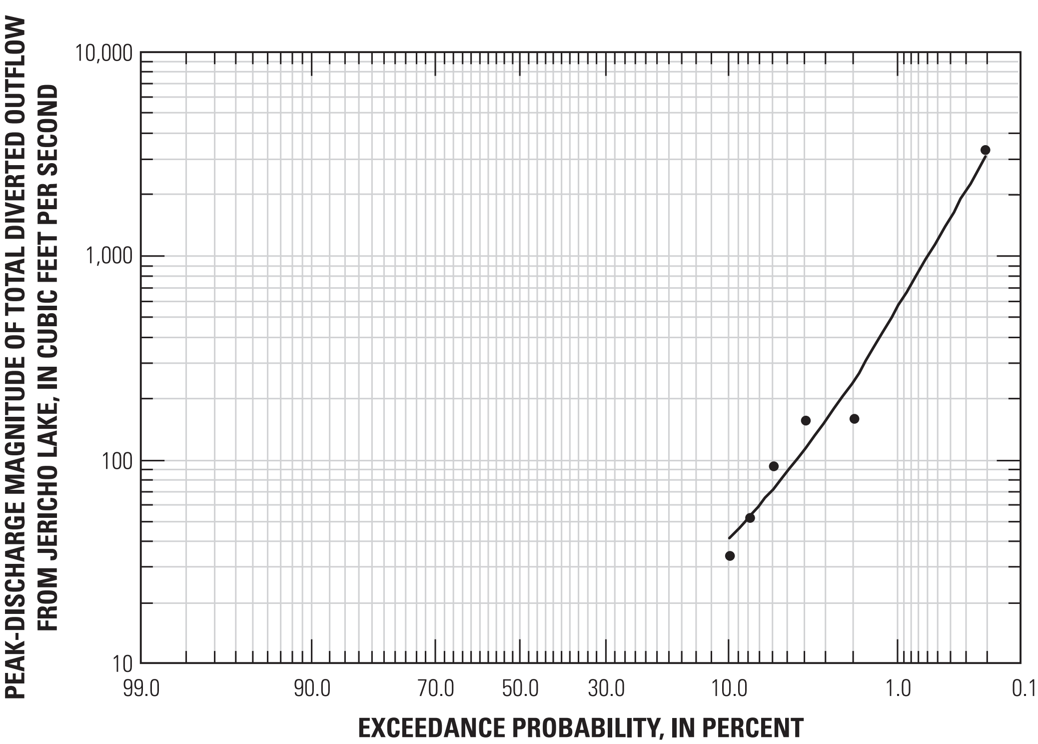

Figure B4. Frequency analysis for total diversions from Jericho Lake near Montgomery, Illinois.

The flood-frequency curve for the total diverted flow from Jericho Lake was determined using a power function as shown in figure B4. Based on the fitted frequency curve, outflow from Jericho Lake with a magnitude of 100 ft^3/s (corresponding to the culvert flow at Jericho Road) or higher would result for a flood on Blackberry Creek with recurrence interval of 25 years or higher. This corresponds to a flow of 2,030 ft^3/s or higher at Yorkville streamflow station, or a flow of 1,970 ft^3/s or higher at Montgomery streamflow station. From this analysis, the estimated total diverted flood-peak discharges corresponding to the 500-, 100-, 50-, and 25-year events are 3,000, 550, 250, and 120 ft^3/s, respectively (fig. B4).

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APPENDIX C—Flood-Plain and Floodway Delineation Procedures

Flood-Plain Delineation

The following procedures were used for delineating flood plains in this study. The automated mapping was conducted using ArcGIS v9.0 (Environmental Systems Research Institute, 2004).

1. **Prepare Data:**
    I. Create a point layer representing the cross sections in ArcGIS that cut through the established stream centerline,
    II. Assign the targeted *T*-year flood elevation determined from a water-surface modeling software (HEC-RAS was used in this study) to the points of each corresponding cross section.
2. **Generate Inundation:**
   Generate a water-surface Triangulated Irregular Network (TIN) using all of the cross sections with the assigned flood elevations. The TIN then is converted to a raster grid for comparison with the watershed digital elevation model (DEM). The contiguous inundated surface area that intersects the stream centerline represents the flood plain corresponding to the *T*-year flood plain (that is,
   Flood Elevation Grid minus DEM ≥ 0.0).

3. **Evaluating the Mapped Floodplain:**
   Review and resolve discrepancies by comparing the mapped width of the flood plain at each cross section to that determined by the HEC-RAS model. Discrepancies may result from:
    I. Operation errors,
    II. Discrepancies in location of cross sections in HEC-RAS and in ArcGIS layer,
    III. Limited spatial coverage of cross-section data, for example, at a bend,
    IV. Discrepancies in surveyed elevation and local DEM on the flood plains, specification of levees and/or ineffective areas in the HEC-RAS model,
    V. Other problems.
4. **Interpolation Between Cross Sections:**
   Evaluate inundation areas between cross sections for excess ponding or inadequate coverage that is created in the automated process through TIN interpolation. If sufficient evidence can be shown that an area will be inundated, such as the elevation at the edge of the inundated area is consistent with the adjacent cross-section water-surface elevations, the area is included.
5. **Fill Holes in the Flood Plain:**
   The final stage is to fill in the “islands” or “holes” in the flood-plain coverage. The holes are created because of higher ground elevations are presented in the flood plain. As there was no document found to specify a cut-off value of which holes were to be filled, for this study, all the holes smaller than 3.0 acres were filled.

The inundated areas along the tributaries and main stem were determined together because the stages at junctions with tributaries on the main stem are known in a whole watershed study.

Floodway Determination

Regulatory floodway delineation was based on the flood-plain-encroachment principle and is subject to pre-determined allowable increase level. The state of Illinois has developed guidelines for defining floodways. According to the **Section 3708.60c <u>Delineation of the Regulatory Floodway</u> of Part 3708** *Floodway Construction in Northern Illinois* (Illinois Department of Natural Resources, 2003), “The regulatory floodway boundaries are determined by hydraulic and hydrologic analyses, which calculate that portion of the floodplain that must be preserved to store and discharge floodwaters without causing damaging or potentially damaging increases in flood stage and flood velocities or loss of flood storage which would result singularly or cumulatively in more than a 0.1 ft increase in flood stage or a 10 percent increase in velocity.”

The criteria used to determine the floodway along the Blackberry Creek were no more than 0.1 ft increase in flood stage, no more than 10-percent increase in total velocity, and no more than 10-percent decrease in volume. In the HEC-RAS encroachment analysis, floodways along each tributary or main stem were determined separately. For each tributary, the downstream elevation started with the computed 100-year flood stage described above.

The following floodway-mapping procedure details the process of translating HEC-RAS results (the placement of encroachment points closest to the stream center station) into a map within a digital environment. The objectives of the floodway-delineation process were to preserve the width of the floodway at the cross sections, and ensure the interpolated floodway between the cross sections follows the topography of the ground-surface terrain.

1. **Calculate Floodway Width:**
    I. Determine Coordinates of Encroachment Points Along each cross section, identify the placement and elevation of the encroachment points closest to the stream center station for the left-hand-side (LHS) and right-hand-side (RHS) encroachments. This calculation was performed with a spreadsheet program that utilized the surveyed cross-section coordinates as known ground points as well as the x-coor-

dinate of the encroachment points to calculate the elevations of the encroachment points.

II. Compute LHS and RHS Floodway Widths
Compute the distance from the stream center station to the encroachment points for the LHS and RHS, the sum of which yields the floodway width.

2. **Create Cross-Section Lines for Floodway Mapping:**
If not already available, create a line coverage in ArcGIS to accurately depict the cross section lines as represented in the HEC-RAS model. Split the lines using the stream centerline coverage so the LHS and RHS floodways are partitioned.
3. **Map Floodway Station Points:**
Reduce the length of the split cross-section lines from the exterior extents of each line to represent the width of the floodway on either side of the stream centerline. Create station points at the exterior ends of the resulting floodway lines that represent the floodway boundaries. Assign elevations to the floodway station points by extrapolating the elevation data from the DEM grid.
4. **Modify For DEM Errors:**
When the floodway station points are located in the channel area of the DEM, interpolated elevations may not be very accurate. In order to create a floodway using the best of the elevation data, the floodway station points are separated based on the maximum and minimum elevation values at each cross section.
5. **Generate TIN:**
Generate separate artificial water-surface TINs for each of the minimum and maximum elevation point sets; thus, representing the elevations at which the interior extent of the encroachments meet the ground surface. Then convert each TIN to a raster grid for comparison with the watershed DEM; those areas under each TIN that have an artificial water surface greater than or equal to the DEM elevation (that is, **Artificial Water Surface Grid minus DEM ≥ 0.0**).
6. **Floodway Interpolation:**
For ease of interpolation, two layers were created from the minimum and maximum elevation floodway coverages; a union and an intersection of the two layers. A final floodway cover is interpolated using the union and intersection layers by tracing the edge of the coverage that intersects the floodway station points. This method retains the floodway width at each cross section, whereas the interpolation between cross sections is based on the topography of the ground-surface terrain.
7. **Quality Analysis:**
Evaluate and correct the floodway boundaries, as necessary.

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