Contract Report 2004-04

# HEC-6 Modeling of the Main Stem of the Kankakee River in Illinois from the Stateline Bridge to the Kankakee Dam

by
**Nani G. Bhowmik, Christina Tsai, Paminder Parmar, and Misganaw Demissie**

**Prepared for the
Illinois Department of Natural Resources
Office of Resource Conservation**

**February 2004**

Illinois State Water Survey
Watershed Science Section
Champaign, Illinois

A Division of the Illinois Department of Natural Resources

# HEC-6 Modeling of the Main Stem of the Kankakee River in Illinois from the Stateline Bridge to the Kankakee Dam


by
Nani G. Bhowmik, Christina Tsai, Paminder Parmar, and Misganaw Demissie
Watershed Science Section
Illinois State Water Survey



Prepared for the
Illinois Department of Natural Resources
Office of Resource Conservation

February 2004

# HEC-6 Modeling of the Main Stem of the Kankakee River in Illinois from the Stateline Bridge to the Kankakee Dam

by
Nani G. Bhowmik, Christina Tsai, Paminder Parmar, and Misganaw Demissie
Watershed Science Section
Illinois State Water Survey

## Abstract

This report is a continuation of the applied research initiated by Illinois State Water Survey (ISWS) researchers on the evaluation of the hydraulics, sediment transport, and hydrology of the Kankakee River basin in Illinois. For this specific project, HEC-6 modeling has been completed for the main stem of the Kankakee River in Illinois from the Stateline Bridge to the Kankakee Dam in Kankakee. The HEC-6 model originally developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers was adopted for application on the Kankakee River. The model has been run, calibrated, and verified for both the hydrologic component and the sediment component. Calibration for the hydrologic component consisted of a comparison of the measured yearly hydrographs with the computed values for three gaging stations on the river. The hydrologic component was verified for the same three gaging stations for two yearly hydrographs for two additional water years. The sediment component of the model was calibrated by using river cross-section data collected by the ISWS in 1980 and 1999. Finally, the calibrated and verified hydrologic and sediment components of the model were used to predict future changes in water surface elevations and thalweg elevations. This was done for a 20-year period from 1999, the last date for which river cross-section data are available.

**Keywords:** Hydraulics, Hydrology, Sediment Transport, Mathematical Modeling, Kankakee River, Illinois

# Contents

*Page*

# List of Figures

*Page*

*Page*

*Page*

## List of Tables

*Page*

# HEC-6 Modeling of the Main Stem of the Kankakee River in Illinois from the Stateline Bridge to the Kankakee Dam

by
Nani G. Bhowmik, Christina Tsai, and Misganaw Demissie
Watershed Science Section
Illinois State Water Survey

## Introduction

During the last two decades or more, the Illinois State Water Survey (ISWS) has completed several important research investigations on the hydrology, hydraulics, and sediment transport characteristics of the Kankakee River basin in Illinois. This research is described in Bhowmik et al. (1980), Demissie et al. (1983), and Bhowmik and Demissie (2000, 2001a, 2001b). Many other related reports on the Kankakee River have been completed, including Brigham et al. (1981), Gross and Berg (1981), Ivens et al. (1981), Kankakee River Basin Commission (1989), Mitsch et al. (1979), Phipps et al. (1995), and Terrio and Nazimek (1997). No detailed discussion of these past reports will be included in the present report.

### Background

Bhowmik and Demissie (2001b) provide a very concise "background" on the Kankakee River. Some materials from that report will be repeated here.

The Kankakee River flows westward from Indiana into Illinois. The headwaters are near South Bend, Indiana, and the mouth is at the confluence of the Kankakee River with the Des Plaines River where those two rivers join to become the Illinois River.

Of the 5,165 square miles in the Kankakee River drainage basin, 2,169 miles are in Illinois and 2,996 miles are in Indiana. The river has a total length of about 150 miles, with 59 miles in Illinois. Figure 1 shows the drainage basin of the Kankakee River.

Almost the entire main channel of the Kankakee River in Indiana was channelized by drainage improvement work beginning in the late nineteenth century and essentially completed by 1918. Today, that channel is essentially human-made, extending straight for many miles between small bends. All of the natural meanders were bypassed, although many remain today as oxbow lakes or marsh areas.

In Illinois, a small side channel dam exists at Momence, a larger dam at Kankakee, and an overflow dam at Wilmington, but most of the river remains a naturally meandering stream. A major tributary to the Kankakee River in Illinois is the Iroquois River, which joins the Kankakee River just below Aroma Park. The drainage basin of the Iroquois River also is split between the

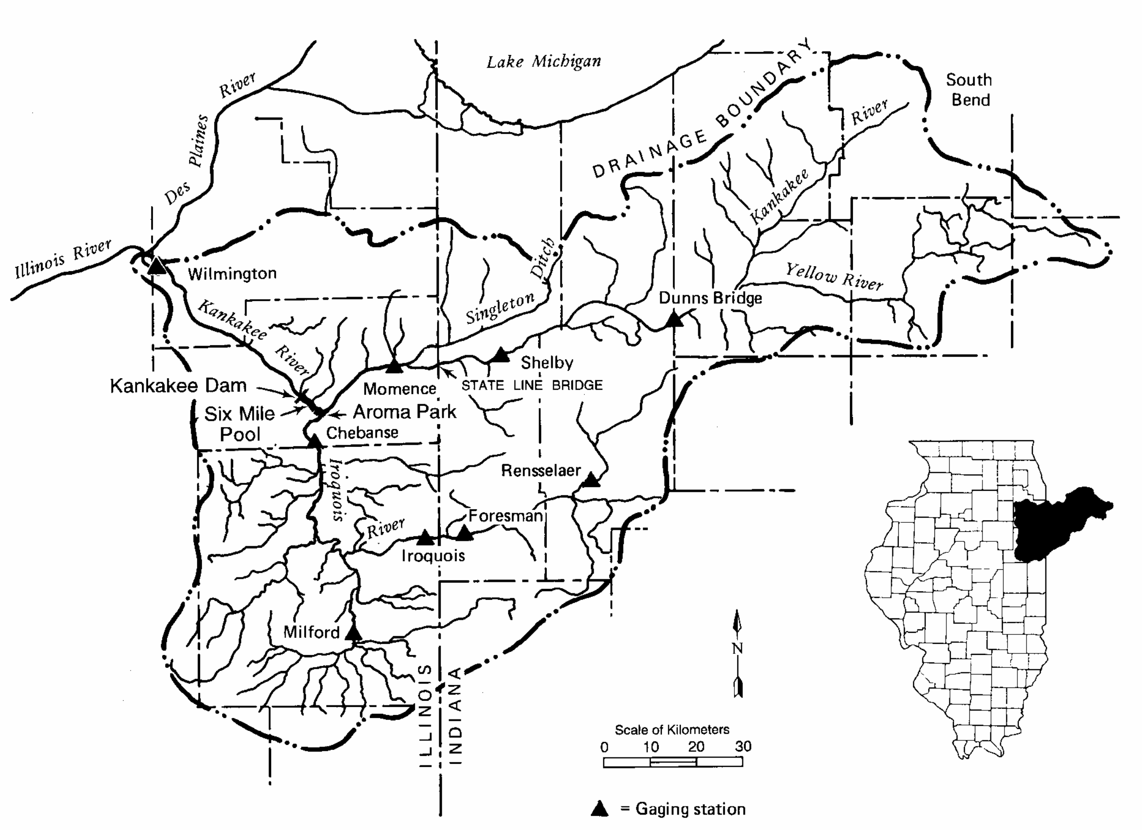



Figure 1. Drainage basin of the Kankakee River in Illinois and Indiana

states of Indiana and Illinois. Singleton Ditch, a channelized tributary, joins the Kankakee River just above Momence in Illinois.

Before channelization, much of the drainage area of the river in Indiana was wetland swamps and marshes called the "Kankakee/Grand Marsh". The Grand Marsh encompassed approximately 400,000 acres and ranged from 3 to 5 miles in width with a water depth of 1 to 4 feet for eight or nine months of the year (Bhowmik et al., 1980). The marshplain was only about 85 miles long, but the river course was about 250 miles long with an average slope of 5 to 6 inches per mile. The nature of the marsh caused the Kankakee River to alter its course often, resulting in the formation of a variety of meanders, oxbow lakes, sloughs, and bayous.

In Illinois, especially in Kankakee County, the river continues to be a scenic, cultural, and recreational resource. The reach between the state line and Singleton Ditch is a naturally meandering stream with a sandy bottom, traversing an area of timber and relatively undisturbed wetlands, commonly called the "Momence Wetlands."

The reach between the mouth of Singleton Ditch and Aroma Park is also a natural stream that traverses an area of alternating bedrock and sandy bottom. Between Aroma Park and the city of Kankakee, a deepwater area called Six-Mile Pool (actually 4.7 miles long) was formed by the construction of Kankakee Dam. The deeper water has long been used for water supply and recreational boating. Fine homes have been built adjacent to the river. The entire river in Kankakee County is noted for high-quality water, excellent sport fishing, and scenic beauty.

River basin management practices differ significantly between the two states and some important geological differences occur near the state line. The wetlands, a result of continental glaciation and river's dynamic action, occur mainly on the Indiana side of the state line except for the small area east of Momence. Areas of bedrock outcrops, where the glacial deposits are thin or absent, occur mainly on the Illinois side of the line. These bedrock outcrops in Kankakee County have long been an important factor in the hydraulic control of the river.

## Objectives and Scope

The main objectives of the present project were to validate and calibrate the HEC-6 model from the Hydrologic Engineering Center (HEC) for the main stem of the Kankakee River from the Stateline Bridge to Kankakee Dam (figure 1). Once calibrated and verified, the model can be used to test different management scenarios to handle sedimentation and sediment-related problems. The HEC-6 modeling work incorporates hydraulic modeling and sediment transport modeling for the same segment of the river. Both the hydraulic and sediment transport components of the HEC-6 model are one-dimensional. Thus, this modeling work encompasses the average changes and/or variabilities of the flow and river cross sections and profiles.

### Acknowledgments

The authors would like to extend their sincere thanks to the Illinois Department of Natural Resources (IDNR) for supporting this project under Award No. 001082. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the sponsor. Debbie Bruce, Project Director, and Jim Mick, IDNR, were extremely helpful throughout this study. Sincere appreciation is extended to Donald A. Arvin and Cheryl Silcox of the Indiana U.S. Geological Survey (USGS) from Indianapolis, Indiana, for their assistance in providing the hydraulic and sediment data from Indiana on the Kankakee River. Erin Bauer, ISWS, assisted in determination of reach lengths. Many ISWS staff actively participated in previous projects about the Kankakee River and made significant contributions.  Becky Howard prepared the final layout of the report, Eva Kingston edited the report, and Linda Hascall provided graphic support.

### Previously Collected and Available Data

It already has been pointed out that a number of research projects on the Kankakee River were completed during the last several decades. A significant amount of hydraulic, hydrologic, sediment transport, and bed and bank material data also were collected. Much of this previously collected data has been used in this research project. Notable among those data are those collected and reported by Bhowmik et al. (1980), Bhowmik and Demissie (2001b), and the flow data reported and available on the USGS Web page (http://il.water.usgs.gov).

# Theoretical Background of the Model

## HEC-6 Modeling

The one-dimensional continuous simulation HEC-6 model uses a sequence of steady flows to represent the discharge hydrograph. It is designed to simulate and predict changes in river profiles resulting from scour and/or deposition of sand, silt, and clay over moderate time periods. The model is designed to incorporate flow hydraulics, sediment transport, channel roughness, and related changes in boundary geometry into simulation work.

The use of HEC-6 modeling includes two sequential steps (USACOE, 1992): fixed-bed simulation and movable bed evaluation. The fixed-bed simulation is similar to the HEC-2 hydraulic simulation also developed by the HEC. In this phase of simulation, the HEC-6 model performs the hydraulic computation, which includes determination of water surface profiles and flow velocities at each cross section along the study reach. The water surface profile is calculated from downstream to upstream using the backward standard step method to solve the one-dimensional energy equation (USACOE, 1990).

The second step in the HEC-6 modeling simulation uses hydraulic parameters determined in the previous hydraulic computation (i.e., the fixed-bed simulation) to simulate movable bed quantification (i.e., to determine sedimentation and scour on the river). In this phase of simulation, the program computes the inflow sediment load, thalweg profiles, gradation of material in the active layer, and transport capacity for each cross section. Empirical transport equations are incorporated into the model for the above computation. Transport equations that could be used in HEC-6 modeling work include those given by 1) Toffaleti (1966); 2) Madden's modification of Laursen's relationship (1963); 3) Yang's stream power relationship for sands (1973); 4) DuBoy's transport function (ASCE, 1975); 5) the Ackers-White transport function (1973); 6) Colby's transport function (1964); 7) Meyer-Peter and Müller's formulas for bed-load transport (1948); and 8) the user-defined relationship and/or equations. Depending on the hydraulic, geologic, and sediment characteristics of a river, a suitable transport relationship can be selected from the above referenced equations.

The HEC-6 model accounts for two sediment sources: inflow sediment load and bed sediment sources and deposition. Inflow sediment loads normally are related to water discharge by sediment-discharge rating curves for upstream boundaries of the main stem, tributaries, and local inflow points.

The transport theory for sand and larger particles relates the transport rate to the gradation of sediment particles on the bed surface and hydraulic parameters. Several sand-and-gravel transport relationships can be used in the HEC-6 model.

After a particular sediment transport relation is chosen, the HEC-6 model calculates the outflow sediment load for the study reach and then modifies the volume of bed material to reflect scour or deposition. The sediment computation is carried out from upstream to downstream for a sequence of discretized hydrographs for a given boundary condition.

## HEC-6 Governing Equations

### *Hydraulics*

Flow hydraulics are determined by solving the one-dimensional energy equation using the standard step method. Then hydraulic parameters are calculated at each cross section from downstream to upstream for subcritical flow ranges for each successive discharge.

The equation used is:

$$WS_2 + \frac{\alpha_2 V_2^2}{2g} = WS_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \qquad (1)$$

where $g$ = acceleration of gravity; $h_e$ = energy loss; $V_1$, $V_2$ = average velocities at the upstream and downstream end of the reach, respectively; $WS_1$, $WS_2$ = water surface elevations at cross sections 1 and 2, respectively; $\alpha_1$, $\alpha_2$ = velocity distribution coefficients for flow also at cross sections 1 and 2, respectively.

### *Sediment Transport Relationship*

The equation used for modeling the scouring and deposition of sediments is the one-dimensional continuity equation of sediment, known as the Exner equation and given in equation 2:

$$\frac{\partial G}{\partial x} + B_o \frac{\partial Y_s}{\partial t} = 0 \qquad (2)$$

where $G$ = average sediment discharge rate (cubic feet per second or $ft^3$/sec); $x$ = distance along the channel length; $B_o$ = width of movable bed; $t$ = time; and $Y_s$ = depth of sediment in the control volume.

Note that all formulas presented in the HEC-6 model are for discharge of bed sediment under conditions of uniform steady flow and do not include wash load.

## Input Data Requirements

Input data needed for the HEC-6 model can be categorized into four main groups: river geometry, sediment characteristics, hydrology and hydrologic parameters, and downstream boundary conditions.  Discussions of these groups follow:

### *River Geometry*

Fixed-bed modeling using the HEC-6 model requires cross-section coordinates, reach length, and Manning’s *n* values. Movable bed modeling, in addition to the aforementioned data, requires the movable bed portion of each cross section and the depth of sediment layers.

Cross sections are specified as initial conditions in the modeling. Each cross section can be divided into three subsections: left bank floodplain, right bank floodplain, and main channel. Manning's *n* values are crucial in determination of a physically based model for further applications in the sediment component of the model. Manning's *n* value can be specified in two ways: static or fixed *n* values, or varying *n* values with either discharge or elevation in the main channel and the floodplain.

### *Sediment*

Sediment data necessary include sediment properties, inflow sediment load, and gradation of material on the channel bed in addition to fluid properties. Unit weights of the material and the transport capacity relationships to describe the bed load movement also are required.

The sediment load entering the upstream end of the geometric model is called the inflow sediment load. An inflow sediment load, including the suspended load and bed load, is necessary for each corresponding inflow water discharge. The inflow sediment load for natural rivers usually has ranges of grain sizes. Therefore, it is necessary to classify sediment material into groups to apply different transport theories.

The HEC-6 model specifies the gradation of sediment material in the streambed as a function of percent finer and grain size. Movable bed simulation subdivides the total depth of sediment material into two layers: active and inactive layers, as shown in figure 2. Sediment activities, including scour and deposition, occur in the active layer. Consequently, material is exchanged with the inactive layer based on equilibrium depth requirements.

Transport theory for sand and larger grain sizes relates the transport rate to the gradation of sediment particles on the bed surface and flow hydraulics. Several sand-and-gravel transport relationships are available in HEC-6 modeling formulations. Any one of these relationships can be used in modeling depending upon hydraulic, geometric, geologic, and sediment characteristics of the river. Reference to these equations has been provided previously.

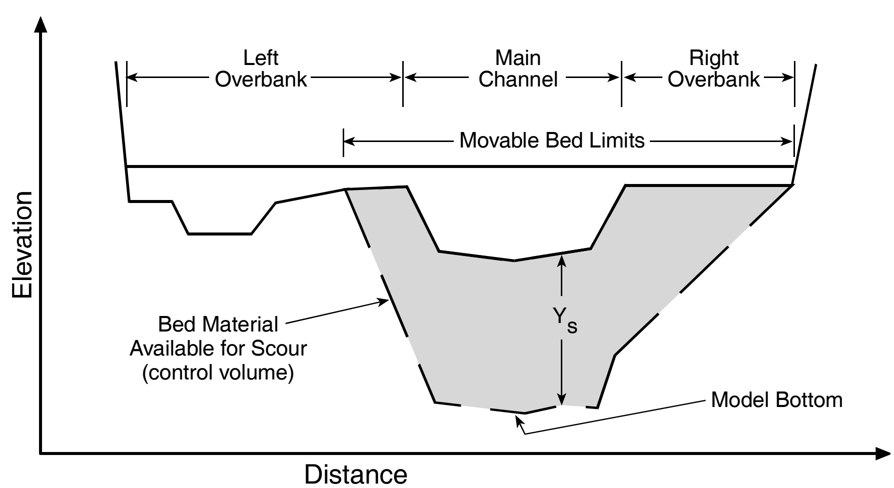



Figure 2. HEC-6 model formulation for a typical river cross section

Equations should be applied only to cases similar to those for which they have been used and verified previously. The model must specify other sediment properties such as grain size, grain shape factor, specific gravity, and fall velocity.

### *Hydrology*

The HEC-6 modeling uses parameters describing hydrology as inputs to simulate the hydraulics of flow and changes in river geometry. Hydrologic data inputs are composed of the following parameters:

- Water discharges for the main stem, tributaries, and all local inflow and outflow points. The HEC-6 model uses a continuous hydrograph as a sequence of discrete steady flows using the annual hydrograph.
- Temperatures and durations for the inflow water discharge.

The annual hydrograph can be estimated from the frequency analysis or the duration curve if a period of record of flows is not available. It is suggested, under this circumstance, that wet and dry year hydrographs be included in addition to the average year hydrograph.

### *Downstream Boundary Condition*

The downstream boundary condition consists of a stage hydrograph rating curve, or operating rule giving water surface elevation at the downstream end of the study reach.

## Model Limitations and Potential Use

The HEC-6 model is a one-dimensional sediment transport and sediment deposition and scour model. Bed material load equations are selected for different conditions, and use of these equations should be restricted to conditions and applications for which the equations were developed.

1) There is no provision for simulating the development of meanders or specifying a lateral distribution of sediment load across a cross section.

2) Bed forms are not simulated, but *n*-values are introduced as a function of the discharge or elevation, which indirectly considers the approximate bed forms.

3) The HEC-6 model does not simulate a lateral distribution of sediment across a stream cross section.

The HEC-6 model has been applied successfully to several hydraulic and sediment-related engineering problems. Its many potential applications were cited in Demissie et al. (1990):

- Reservoir sediment deposition, to determine volume and location of sedimentation.
- Degradation of streambed downstream of a dam.

- Long-term trends of scour or deposition in channels.
- Influence of dredging on the rate of deposition.
- Scour during floods.
- Development of scour channel after spillway failure.
- Impact of changes in the water-sediment mixture in natural streams, or of changes in the stream's boundary and hydraulics of flow.
- Impact of dams on a stream.
- Impact of channel contraction required to maintain navigation depths.

# HEC-6 Model Application for the Kankakee River

## Data Categories

Input data required for HEC-6 modeling of the Kankakee River have been subdivided into four categories: geometric, sediment, hydrologic, and downstream boundary conditions. A significant amount of hydraulic, hydrologic, sediment transport, and bed and bank data from the Kankakee River were collected and compiled in previous research activities (Bhowmik and Demissie, 2000, 2001b). Each category is described briefly. Readers are referred to Bhowmik and Demissie (2000, 2001b) for more detailed descriptions of the data.

### *Hydrologic Data*

The most important hydrologic data necessary for the HEC-6 model are streamflows at various locations. Detailed streamflow analyses from several streamgaging stations were conducted to determine the variability of low, average, and peak flows. Gaging stations for which streamflows were analyzed are shown (figure 3).

Based on the streamflow analyses (Bhowmik and Demissie, 2001b), annual flows in the Kankakee River near Wilmington ranged from a low of 1,450 cubic feet per second (cfs) in the drought years of 1931 and 1964 to a high of more than 10,380 cfs in 1993. Annual flows in the Kankakee River at Momence are less variable, ranging from 850 to 3,740 cfs, while the variability of annual flows in the Iroquois River at Chebanse is even greater, ranging from 425 to 5,160 cfs. The variability of flows in the Iroquois River watershed is significantly greater than that for the Upper Kankakee River and is more typical of streams throughout much of Central Illinois. Compilations of average flow data are available (Bhowmik and Demissie, 2001b) for the Kankakee River at Momence, Illinois; Wilmington, Illinois; and Shelby, Indiana; for the Iroquois River at Chebanse, Illinois and Foresman, Indiana; and for Sugar Creek at Milford, Illinois (see figures 1 and 3). Locations of all these gaging stations are shown (figure 4). Figures 5-7 illustrate flows at various locations and are reproduced from Bhowmik and Demissie (2001b). These three figures illustrate the relationships between average annual streamflows over time for gaging stations in the Kankakee River basin in Illinois (figure 5), flow duration curves for the same gaging stations (figure 6), and annual peak discharges for the same set of gaging stations in the Kankakee River basin in Illinois (figure 7). Table 1 shows drainage areas, river miles, and gaging station availabilities of all stations mentioned above and those to be used subsequently for modeling.

### *River Geometry*

**Historical Data.** Several agencies and organizations have collected river geometry data from the Kankakee River in Illinois since 1959 (Bhowmik and Demissie, 2001b). This study used the geometry data set collected in 1977 and 1978 by the Office of Water Resources, IDNR (Bhowmik et al., 1980) and that collected in 1980 by the ISWS (Bhowmik and Bogner, 1981). Table 2 provides the content, location, and ranges of those data.

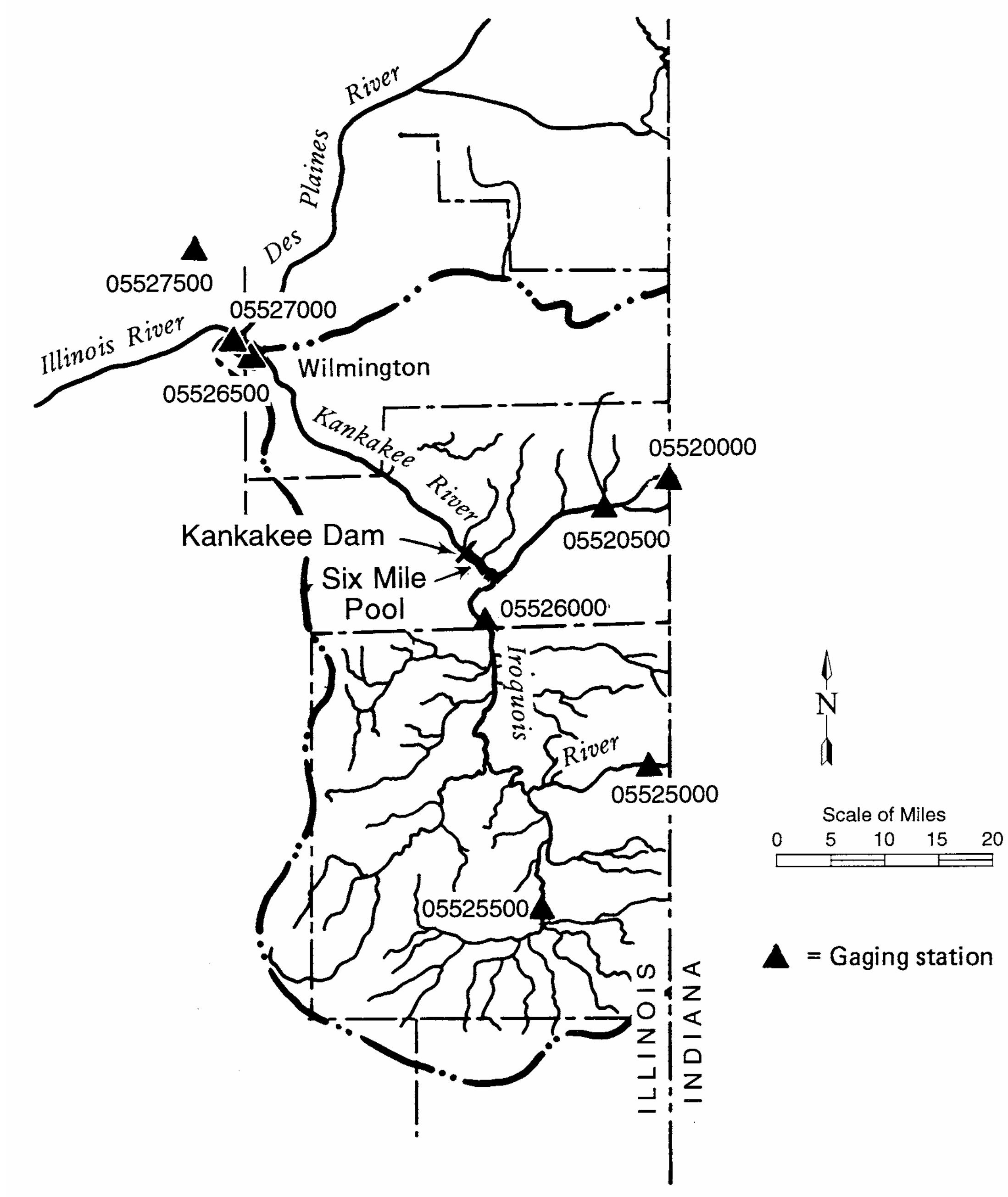



Figure 3. Streamgaging stations in the Kankakee River basin where streamflow analyses were completed (from Bhowmik and Demissie, 2000)

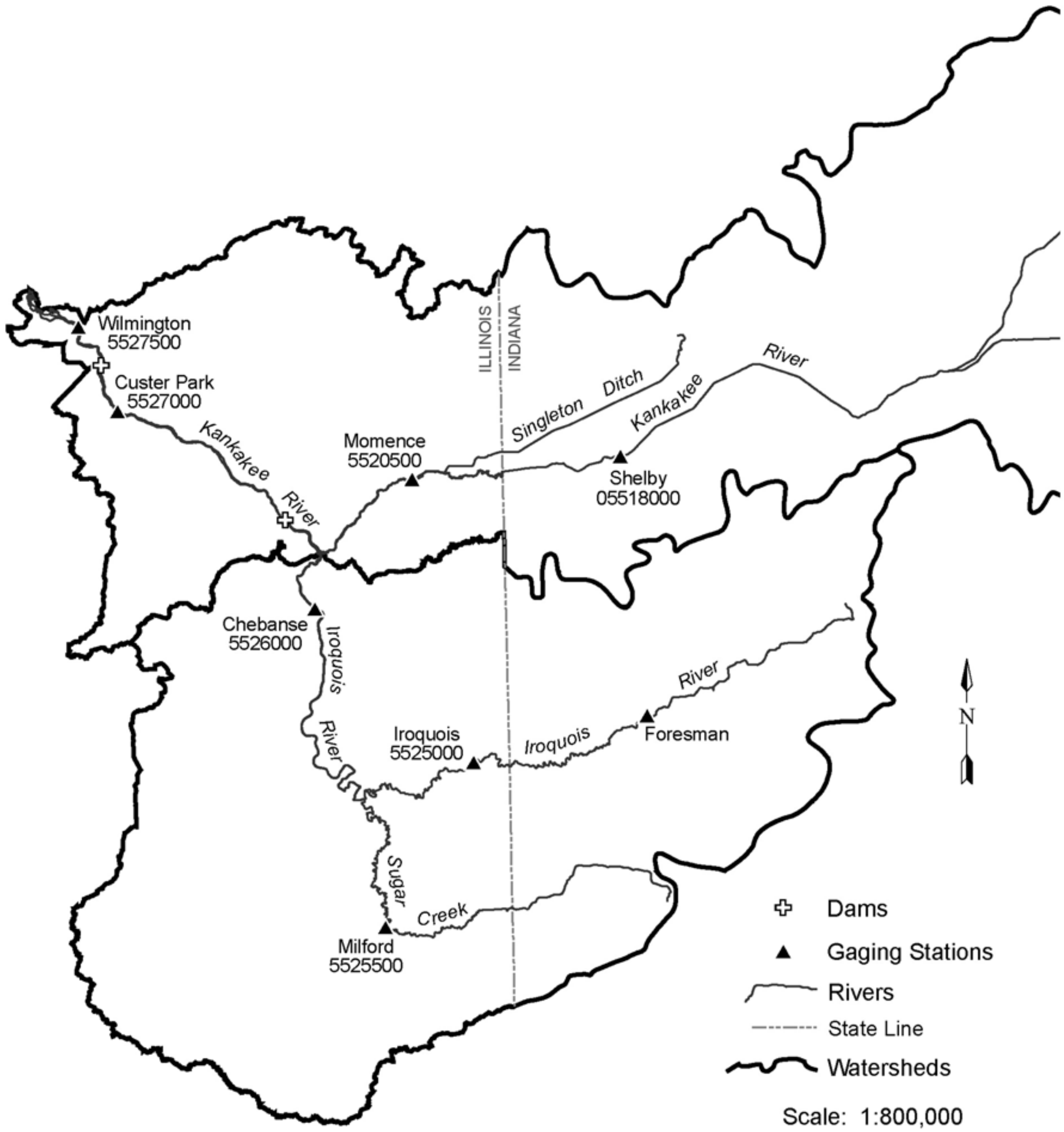



Figure 4. Sketch of the channel network of the Kankakee River in Illinois

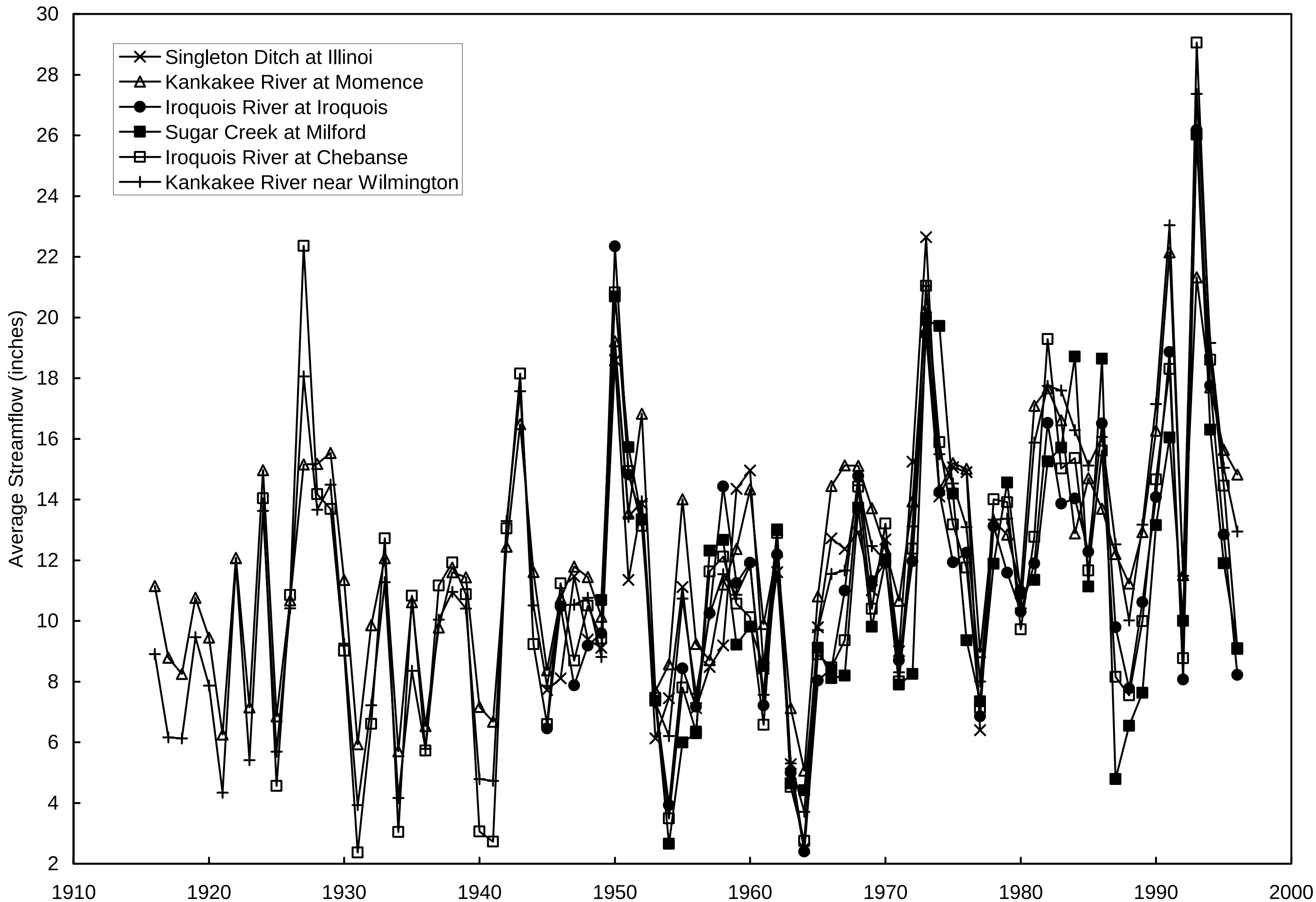



Figure 5. Average annual streamflows for gaging stations in the Kankakee River basin in Illinois (after Bhowmik and Demissie, 2001b)

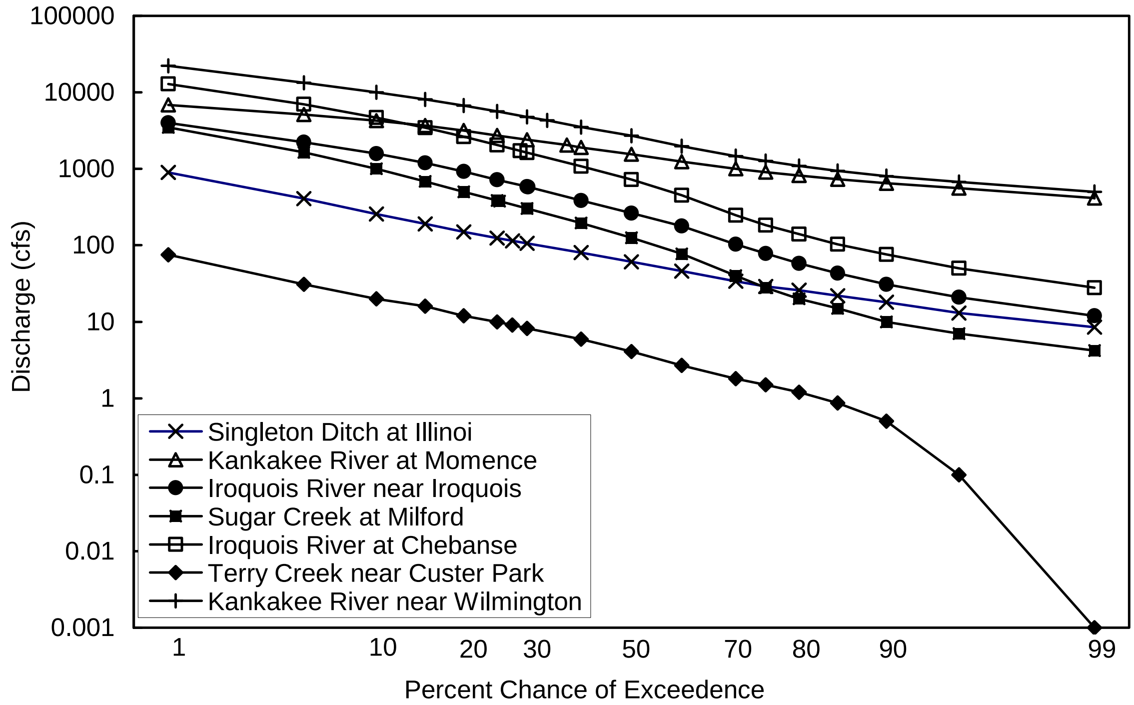
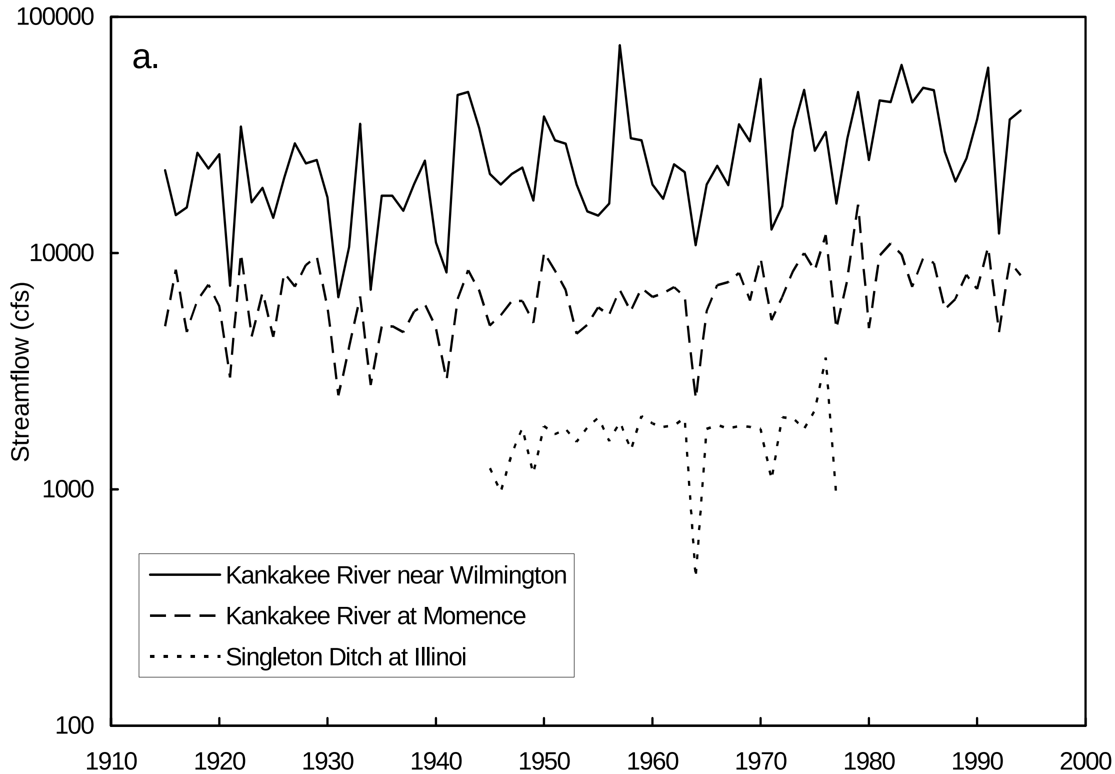



Figure 6. Flow duration curves (discharge vs. probability) for gaging stations in the Kankakee River basin in Illinois (after Bhowmik and Demissie, 2001b)



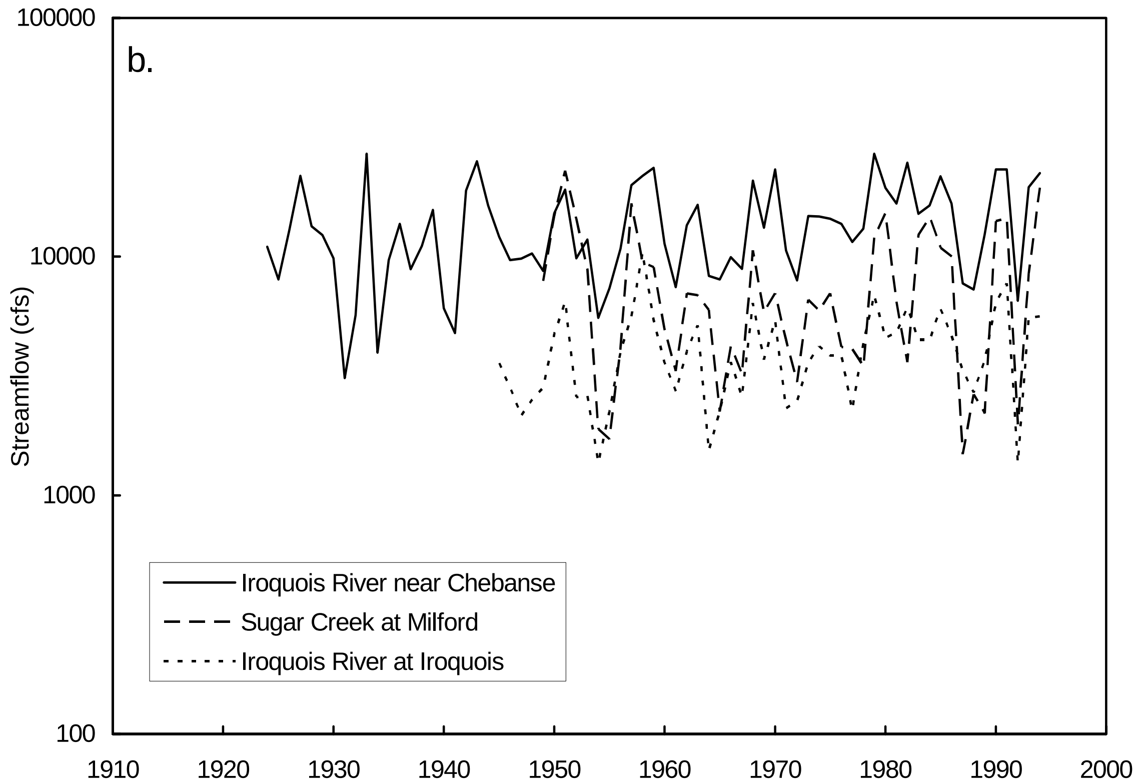




Figure 7. Annual peak discharges for gaging stations in the Kankakee River basin in Illinois (after Bhowmik and Demissie, 2001b)

**Table 1. Kankakee River in Illinois: Gaging Stations, Drainage Areas, and River Miles at Specified Location (see Figure 3)**

| *Name* | *Gaging station* | *Drainage area (sq mi)* | *River mile* |
|---|---|---|---|
| Wilmington | Yes | 5,150 | 5.7 |
| Kankakee Dam | No | 4,595 | 32.75 |
| Junction of the Iroquois River with the Kankakee River | No | 4,515 | 36.86 |
| Kankakee River just upstream of the mouth of the Iroquois River | No | 2,378 | 36.86 |
| Momence on the Kankakee River | Yes | 2,294 | 47.53 |
| Junction of the Singleton Ditch with the Kankakee River | No | 254 | 50.80 |
| Kankakee River at the Stateline Bridge | No | 1,920 | 57.2 |
| Kankakee River at Shelby, Indiana | Yes | 1779 | 67.9 |
| Mouth of the Iroquois River | No | 2,137 | 0 |
| Chebanse on the Iroquois River | Yes | 2,091 | 6.50 |
| Mouth of the Sugar Creek near Watseka | No | 138 | 33.0 |
| Iroquois River at Iroquois | Yes | 686 | 50.4 |
| Iroquois River at Foresman, Indiana | Yes | 449 | 72.77 |

**Table 2. Description of Historical Cross-Section Geometry Data**

| *Year* | *Agency* | *Location* | *Number of cross sections* |
|---|---|---|---|
| 1977 | OWR of IDNR | RM 37.15-RM 50.80 (Aroma Park to upstream of Momence) | 52 |
| 1978 | OWR of IDNR | RM 32.75-RM 36.86 (Six-Mile Pool) | 32 |
| 1980 | ISWS | RM 32.75-RM 36.96 (Six-Mile Pool) | 34 |
| 1980 | ISWS | RM 50.77-RM 58.19 (Momence wetland) | 36 |

**New Data.** The latest stream cross-section survey data collected by the ISWS from late 1998 through early 2000 were designated as year 1999 data (Bhowmik and Demissie, 2001b). For the first time, a complete set of 134 cross sections was collected for the main stem of the Kankakee River in Illinois from the Kankakee Dam (RM 32.75) to the Stateline Bridge (RM 58.19) on the Kankakee River. In addition, the ISWS recently collected a set of 64 cross sections from Watseka (RM 39.34) to the Stateline Bridge on the Iroquois River (RM 55.40), and these will be used in the modeling.

## Suspended Sediment Data

Suspended sediment data were collected by the U.S. Geological Survey at Wilmington (1979-1982, 1994-1995); Momence (1979-1981, 1994-1995); Iroquois (1979-1980, 1993-1995); and Chebanse (1979-1981, 1993-1995), and by the ISWS at Wilmington (1983-1993); Momence (1982-1988, 1991-1993); Iroquois (1981-1982); Chebanse (1982-1983); and Milford (1981-1982). Bhowmik et al. (1980) developed the variations and rating curves for daily water and sediment discharge at the above locations, and those relationships will be used in the HEC-6 modeling work. Table 3 gives the rating relationships for the suspended sediment loads (after Bhowmik et al., 1980).

## Bed and Bank Materials

Bhowmik and Demissie (2001a) reported bed material samples approximately every mile by scaling distances from 7.5-minute quad maps, and they collected bank samples on alternating sides of the channel at every fifth site. Bank samples generally were taken at the toe of the bank after removing approximately an inch of surface material to ensure samples contained undisturbed bank materials. A total of 82 mid-channel samples and 19 bank samples were collected. Areas with rock bottom could not be sampled.

Bhowmik et al. (1980) also collected bed material samples. They analyzed all samples to determine the frequency distributions of the median diameter, $d_{50}$, of the bed materials and the variations of $d_{50}$ along the centerline of the main stem of the river. These extensive datasets on bed material distributions will be used in the HEC-6 modeling. Figure 8 shows the frequency distribution of $d_{50}$ in millimeters (mm), and figure 9 shows the variations of $d_{50}$ along the centerline of the channel.

Data used in the HEC-6 modeling of the Kankakee River are summarized (table 4). For locations of the gaging stations and other information, see figures 1, 3, and 4.

## Hydraulic Simulation

This section describes the hydraulic simulation that was completed for this project. Historical flow data for the Kankakee River at Wilmington (05527500) were used to determine the discharge hydrograph at the downstream end of the study reach, i.e., the Kankakee Dam (RM 32.75). Corresponding discharges from tributaries or local flow were estimated by proportioning

**Table 3. Summary of Sediment Rating Curves for the Kankakee River (after Bhowmik et al., 1980)**

| *Station* | *m* | *n* |
|---|---|---|
| Foresman | 0.30 | 0.91 |
| Shelby | 0.038 | 1.18 |
| State Line | 0.43 | 0.78 |
| Illinoi | 0.040 | 1.29 |
| Iroquois | 0.023 | 1.37 |
| Chebanse | 0.0076 | 1.49 |
| Wilmington | 0.00056 | 1.67 |
| Momence | 0.0051 | 1.39 |

**Note:** $Q_s = mQ_w^{\,n}$

where $Q_s$ = suspended sediment load in tons per day, $Q_w$ = water discharge in cfs, and m and n are coefficients.

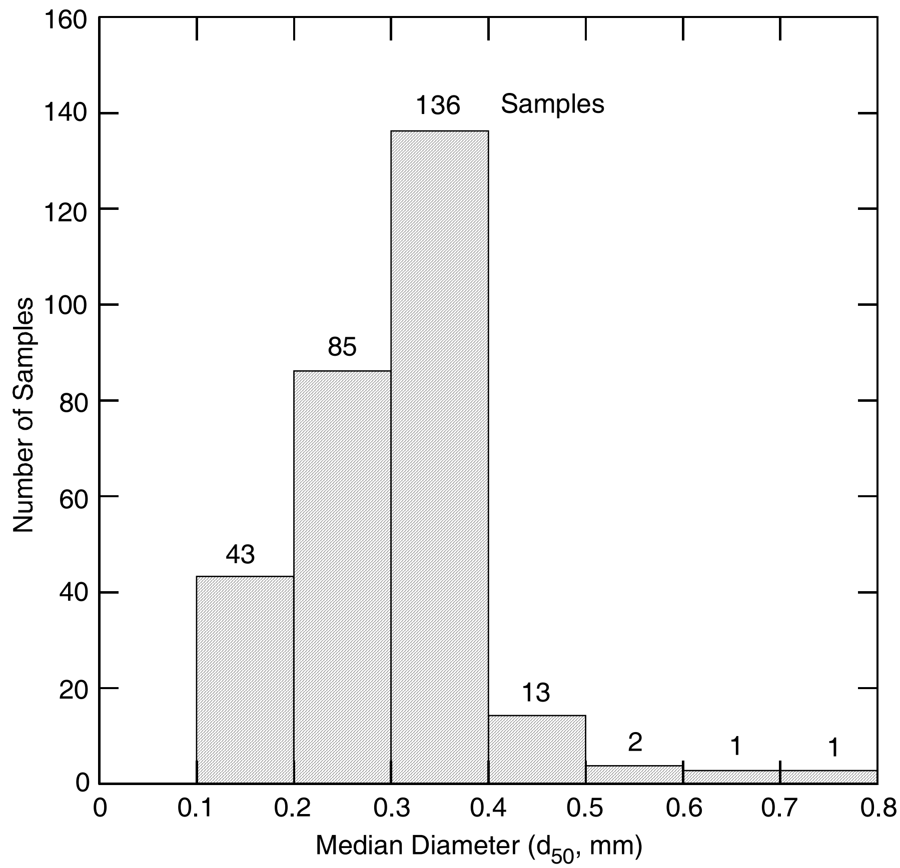



Figure 8. Frequency distribution of the $d_{50}$ sizes of the bed materials (Bhomwik et al., 1980)

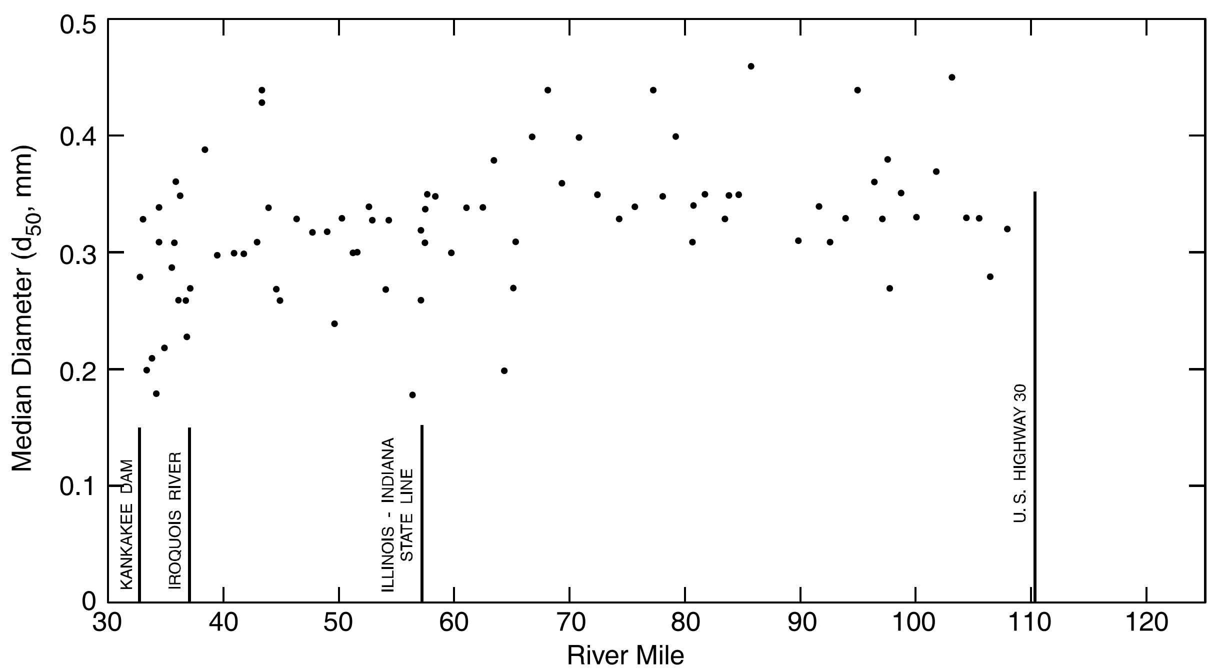



Figure 9. Median diameter $d_{50}$ of bed material versus distance along the centerline of the Kankakee River (Bhowmik et al., 1980)

**Table 4. Kankakee River Channel Network and Data That were Used in HEC-6 Model**

| *Data* | *Kankakee River* | *Iroquois River* |
|---|---|---|
| River miles | From Shelby (RM 67.9) to Kankakee Dam (RM 32.75) | From Stateline Bridge to Mouth |
| Year of cross section survey | 1999, 1980, 1978 | 2001, 1980, and 1978 |
| D/S boundary condition | Kankakee Dam | Confluence of Iroquois and Kankakee Rivers |
| USGS gaging stations | Momence (RM 47.53) and Shelby (RM 67.9) | Chebanse (RM 6.5) and Iroquois (RM 50.4) |
| Major tributaries modeled | Iroquois River (as a tributary) Singleton ditch (as a local flow) | Sugar Creek (as a tributary) |

the flows and the ratio of the watershed area of the specific tributary or tributaries to the overall watershed area. Specifically, the inflow discharge hydrograph for the Iroquois River at its mouth with the Kankakee River was determined by using historical data at Chebanse and proportionately increasing it to the river mouth. The inflow discharge hydrograph at Sugar Creek was computed from historical data at Milford. The inflow hydrograph for Singleton Ditch was determined based on historical data at Momence and Shelby (figure 4).

Use of annual flow records for a variety of conditions in the HEC-6 model aids in estimating possible scour/deposition patterns within the Kankakee River under various hydrologic conditions. For this purpose, flow hydrographs from Water Years (WY) 1996, 1998, and 1999 were used in an attempt to examine model performance under different hydrologic scenarios of particular interest for the present project. Water Years 1996 and 1999 represent a nearly bankfull flow, which normally corresponds to the 2-year flood peak discharge. Water Year 1999 represents a high-flow year. Table 5 shows the flows at various gaging stations corresponding to the three selected water years.

Discretization of the discharge hydrograph for computation purposes should be based on preservation of the total volume of water in the observed hydrograph. In HEC-6 modeling, shorter time steps must be used during flood events when large amounts of sediment are moving and the hydrograph is rapidly changing. Longer time steps are used during low-flow periods.

**Table 5. Average Flows (cfs) Corresponding to Simulated Water Year Hydrographs**

| *Year* | *Kankakee Dam* | *Singleton Ditch* | *Iroquois River at mouth* | *Sugar Creek* |
|---|---|---|---|---|
| 1996 | 3,796 | 508 | 1,429 | 327 |
| 1998 | 4,380 | 568 | 1,490 | 384 |
| 1999 | 6,338 | 571 | 2,967 | 846 |

The following sections present discretized discharge hydrographs at the downstream end of the main stem of the Kankakee River and inflow discharge hydrographs from the Iroquois River as a tributary, Sugar Creek as a sub-tributary, and Singleton Ditch as local flow.

### *Downstream Boundary Condition*

A water surface elevation must be prescribed at the downstream boundary of the model. The HEC-6 model has three options for specifying this downstream boundary condition: (1) a rating curve, (2) the water surface elevation, and (3) a combination of both. The present study uses the Kankakee Dam at the downstream boundary of the study reach. This modeling work uses the rating curve for this dam developed by Adams and Bonini (1986), shown in figure 10.

### *Calibration of HEC-6 Model Hydraulic Component*

Observed and discretized hydrographs are shown in figures 11-14 for the Kankakee Dam, Singleton Ditch, and local tributaries between Shelby (Indiana) and Momence (Illinois), the

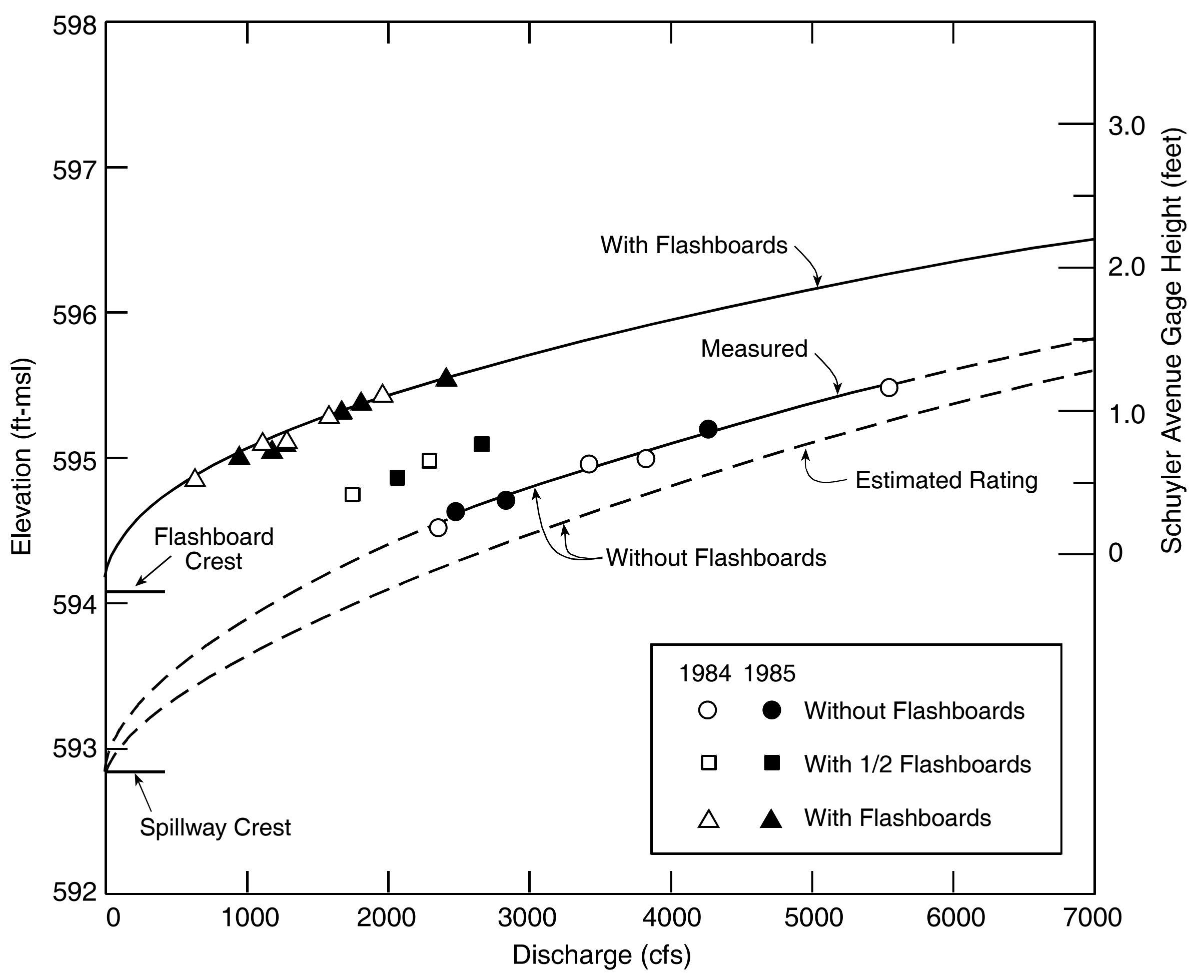



Figure 10. Discharge ratings for Kankakee Dam (after Adams and Bonini, 1986)

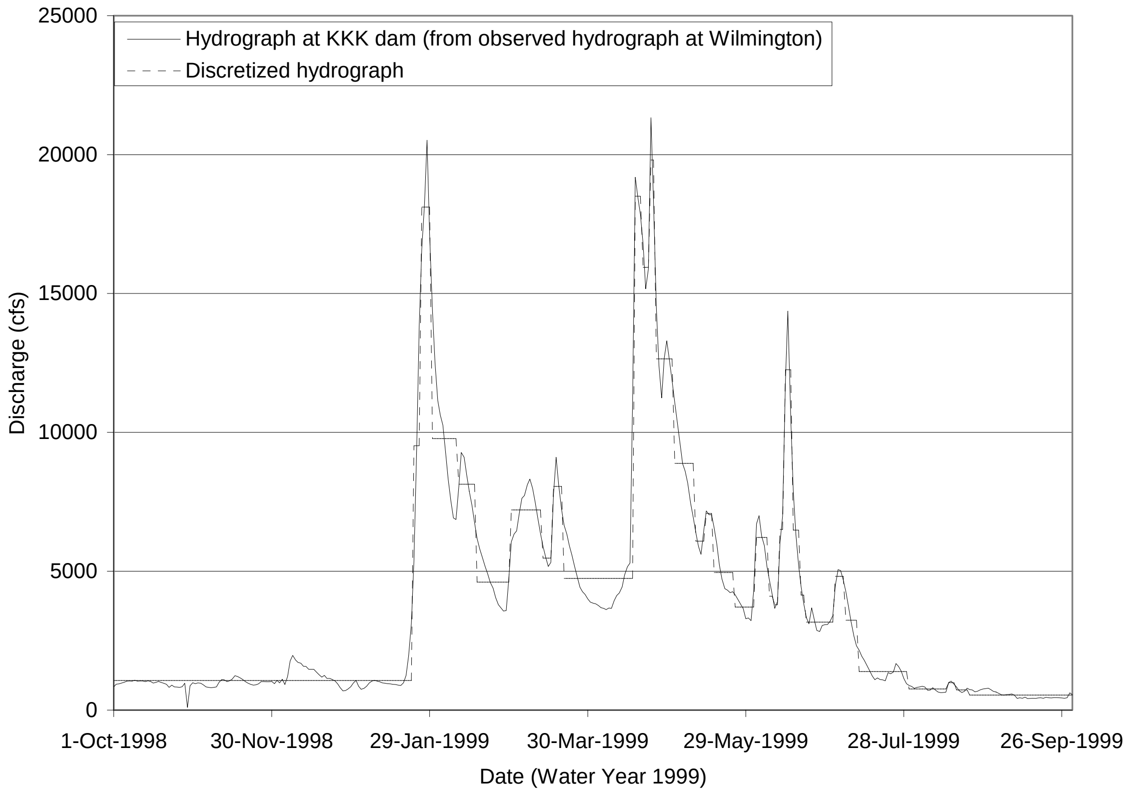



Figure 11. Discretized discharge hydrograph for the Kankakee River at Kankakee Dam, Water Year 1999

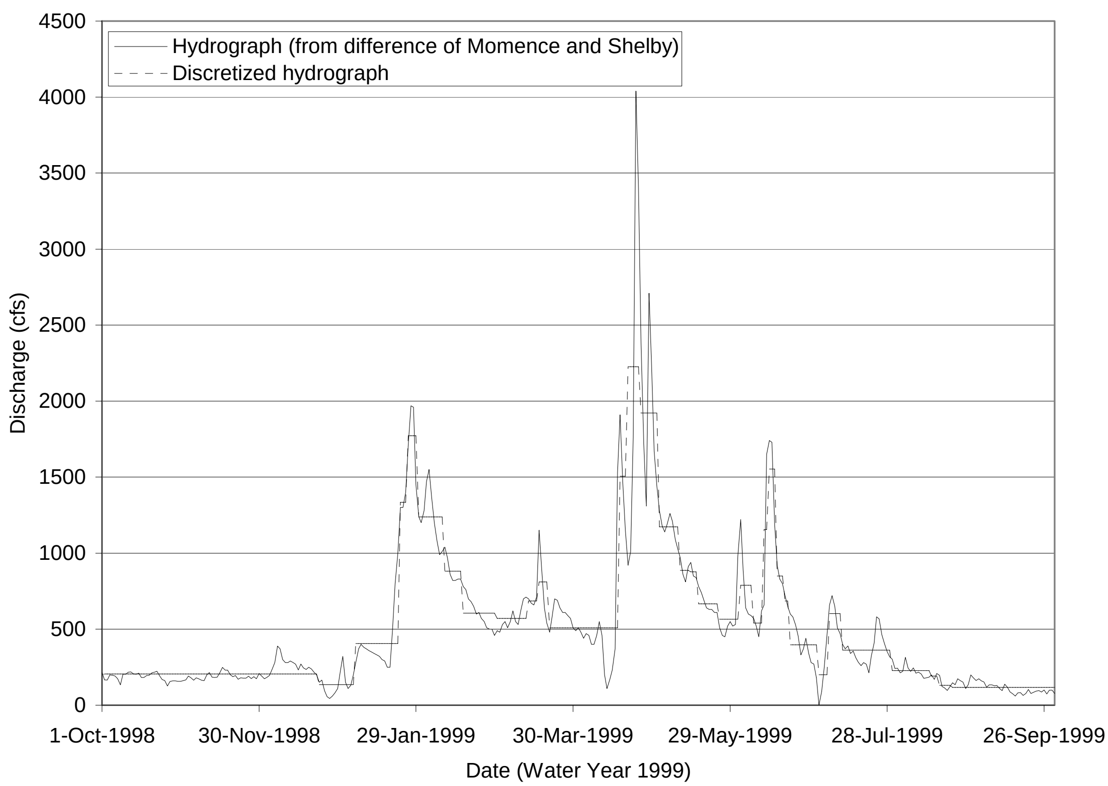



Figure 12. Discretized discharge hydrograph for Singleton Ditch and local tributaries from Shelby, Indiana, to Momence, Illinois, Water Year 1999

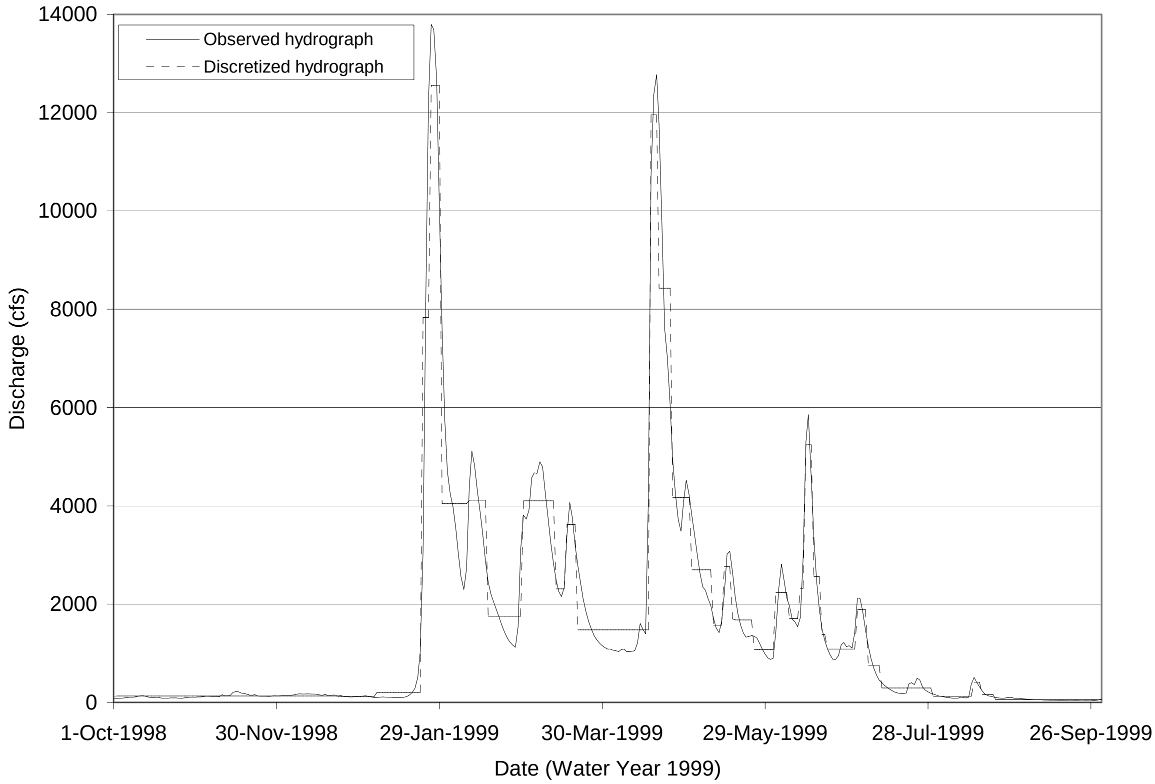



Figure 13. Discretized discharge hydrograph for the mouth of the Iroquois River, Water Year 1999

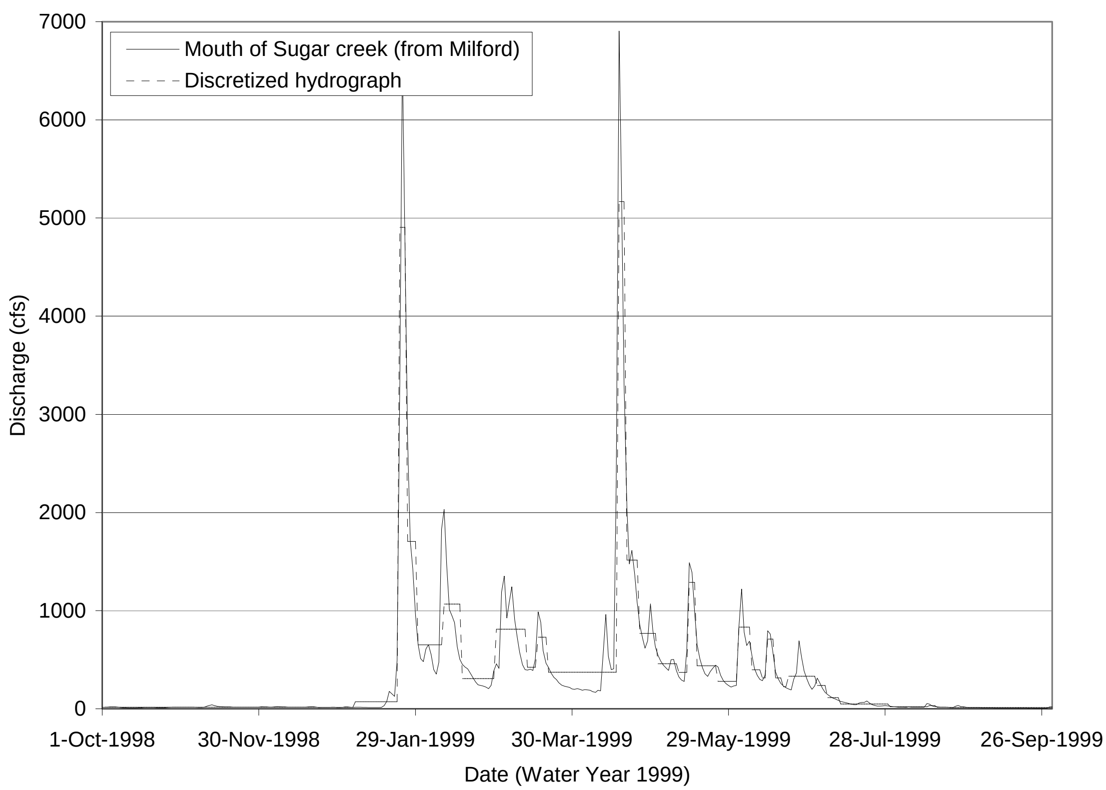



Figure 14. Discretized discharge hydrograph for Sugar Creek, Water Year 1999

mouth of the Iroquois River, and the mouth of Sugar Creek, respectively. These hydrographs are all for Water Year 1999 (October 1, 1998–September 30, 1999).

The hydraulic component of the HEC-6 model is calibrated by adjusting the Manning's *n* value so that the observed stage hydrograph and the computed stage hydrograph at the given gaging station fit well within desired accuracy. For the main stem of the Kankakee River, the study reach between the Kankakee Dam and Shelby, Indiana was subdivided into two segments:

- Segment 1: from the Kankakee Dam (RM 32.75.) to Momence, Illinois (RM 47.53)
- Segment 2: from Momence (RM 47.53) to Shelby, Indiana (RM 67.9)

The observed stage hydrograph for WY 1999 recorded by the USGS at the Momence and Shelby gaging stations were used to calibrate Manning's *n* values for segments 1 and 2, respectively.

For the Iroquois River, the observed stage hydrograph for WY 1999 recorded by the USGS at the Iroquois gaging station was used to calibrate Manning's *n* value. Comparisons of the stage hydrographs for the Iroquois River were made at the gaging stations at Chebanse (RM 6.5) and Iroquois (RM 50.43). In the calibration process, the computed water surface elevations were compared with the observed water surface elevations and patterns through adjustments of the Manning's *n* value to reflect reasonably the actual physical condition of the river.

In the present analysis, Manning's *n* values were assumed to vary with stage. These *n* values were characterized into three regions:

1) In-channel flow.
2) Transitional flow.
3) Overbank flow.

Bhowmik and Stall (1979) have shown that the hydraulic conveyance and average velocity will change in a composite river section depending upon whether or not the water spills over the bank and also with a change of depth and flows when the water covers the overbank areas. This is illustrated in figure 15 for two separate streams in Illinois. These illustrations show that when the overbank area is flooded initially, the flow velocity on the overbank area is quite low; i.e., the areas act initially like a storage channel rather than as a full conveyance channel. However, with an increase in flow and depth, the overbank area steadily starts to convey water and, at a certain flow, the main river and the overbank areas convey proportional amounts of flow. At that point, average velocities within the floodplain and the main river converges and becomes approximately the same. The hydrodynamic modeling work for a full water year, which contains both high and low flows, must reflect these changes in terms of the roughness coefficients at various flows and corresponding stages.

When the flow is in Region 1 (figure 15) and is mostly below the bankful stage even though some portions of the channel may have a lower bank, the water may still flow in the floodplain at a very low flow velocity, sometimes approximately equal to zero or no flow. In this instance, the Manning's *n* value will be large for the left and right floodplains. Within the main channel, flow velocity increases with an increase in stage, while Manning's *n* decreases with increasing stages. Region 2 is in a transitional phase (figure 15). With increasing stage in

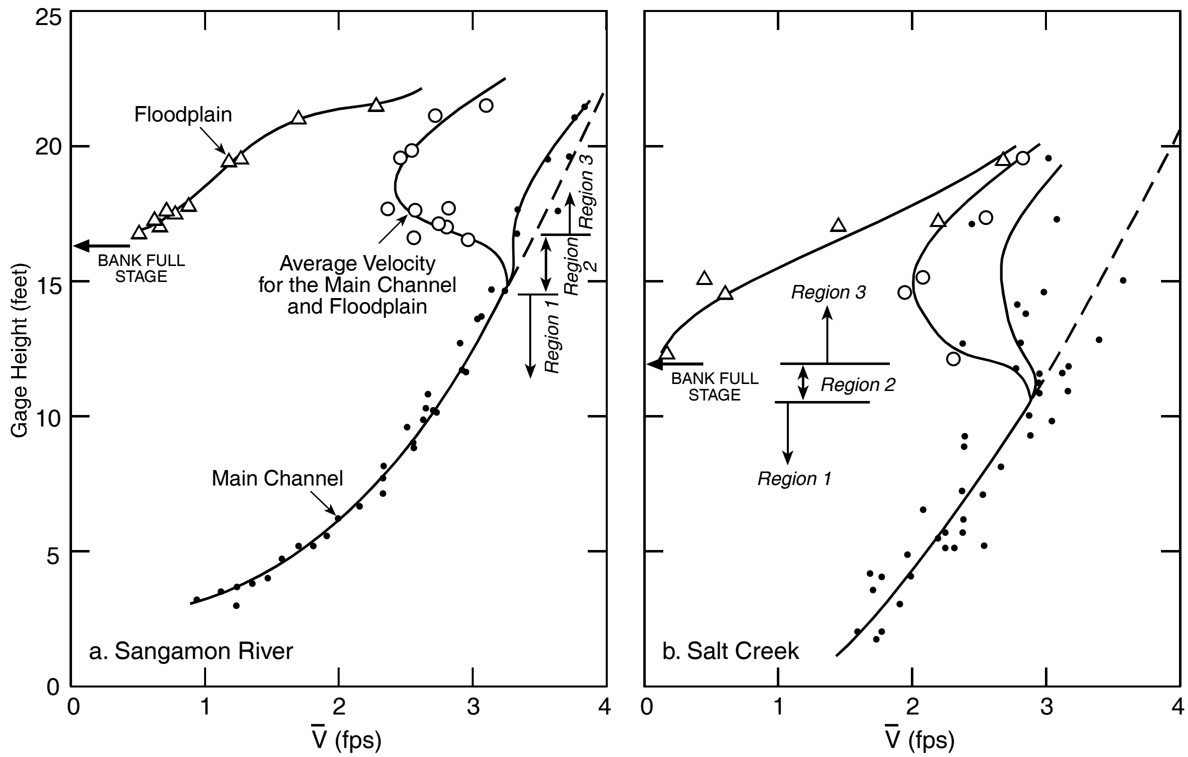



Figure 15. Variation of average velocity in main channel, floodplain, and composite cross section with stage (after Bhowmik and Stall, 1979)

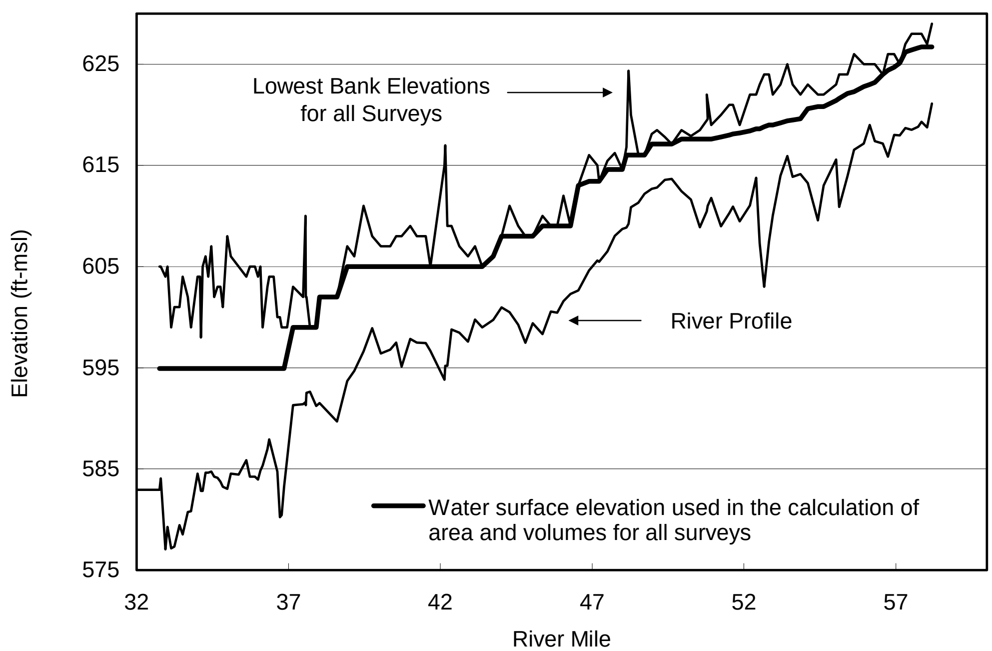



Figure 16. River profile, lowest bank elevations, and average of lowest water surface elevations from Kankakee Dam to the Stateline Bridge (after Bhowmik and Demissie, 2001b)

Region 3 (figure 15), the velocity within the channel and floodplains asymptotically approaches one single value. In other words, the Manning's *n* coefficient on the overbank areas and in the main channel may approach an identical value.

Some quantification of average bank elevations along the river is necessary to assign appropriate values of the Manning's roughness coeficient *n* to the two segments and the three regions mentioned previously (in-channel flow, transitional flow, and overbank flow). For this purpose, an illustration from Bhowmik and Demissie (2001b) and reproduced in figure 16 has been used. This figure shows the invert elevations, lowest bank elevation and average lowest bank elevations along the Kankakee River from the Kankakee Dam to the Stateline Bridge. Based on this illustration, whenever the water surface elevation stayed below the lowest bank elevation from RM 36.72 through RM 61.9, it was assumed that the water did not overflow the bank. The value of *n* changes as the river gradually spills over the bank with an associated increase in flood stages. Table 6 provides the *n* values at different stages and also for different

**Table 6. Manning's *n* Value vs. Elevation Table, Kankakee River from Kankakee Dam (RM 32.75) to Shelby, Indiana (RM 61.9)**

| *Elevation (msl-ft)* | *Main channel n-values* | *Left overbank n-values* | *Right overbank n-values* |
|---|---|---|---|
| **River Mile 32.75** | | | |
| 602.0 | 0.049 | 0.155 | 0.155 |
| 604.0 | 0.037 | 0.073 | 0.073 |
| 613.0 | 0.035 | 0.036 | 0.036 |
| **River Mile 36.72** | | | |
| 604.0 | 0.048 | 0.155 | 0.155 |
| 605.0 | 0.034 | 0.076 | 0.076 |
| 615.0 | 0.035 | 0.036 | 0.036 |
| **River Mile 43.38** | | | |
| 609.0 | 0.055 | 0.170 | 0.170 |
| 610.0 | 0.039 | 0.078 | 0.078 |
| 618.0 | 0.032 | 0.033 | 0.033 |
| **River Mile 47.17** | | | |
| 611.0 | 0.052 | 0.168 | 0.168 |
| 612.0 | 0.037 | 0.072 | 0.072 |
| 620.0 | 0.030 | 0.031 | 0.031 |
| **River Mile 48.28** | | | |
| 615.0 | 0.048 | 0.110 | 0.110 |
| 621.0 | 0.040 | 0.077 | 0.077 |
| 625.0 | 0.056 | 0057 | 0057 |
| **River Mile 53.2** | | | |
| 619.0 | 0.054 | 0.150 | 0.150 |
| 627.0 | 0.036 | 0.072 | 0.072 |
| 631.0 | 0.065 | 0.066 | 0.066 |
| 632.0 | 0.045 | 0.046 | 0.046 |
| **River Mile 61.9** | | | |
| 629.0 | 0.053 | 0.150 | 0.150 |
| 635.0 | 0.032 | 0.068 | 0.068 |
| 638.0 | 0.065 | 0.067 | 0.067 |

segments. In this modeling work, the Manning's *n* values were kept equal for both the left and right overbank areas. It was not possible to use different *n* values on these two overbank areas for which better quantification of the roughness was lacking.

As previously mentioned, to calibrate the hydrodynamic component of the model, the main stem of the river was subdivided into two segments. Segment 1 extends from the Kankakee Dam to Momence and was calibrated with the observed hydrograph at Momence for WY 1999. Figure 17 compares the computed stages for WY 1999 and those actually measured. This plot shows a very good match between the computed and observed stages for this 12-month period. Computed values were higher than those measured two times in the year, especially during very high flows. The comparison was very good at all other times, however.

The model calibration also was extended to the Shelby gaging station in Indiana, for which computed and measured stages are shown (figure 18). Except for a high-flow event in June and a low-flow event in January 1999, the computed and measured stages throughout the entire water year are quite good.

The hydrodynamic component of the HEC-6 model also was calibrated for WY 1999 for the Iroquois River at Iroquois (figure 19). This comparison at the Iroquois station for the Iroquois River also indicates that computed stages are relatively higher than measured stages for the same period for the June 1999 flooding event.

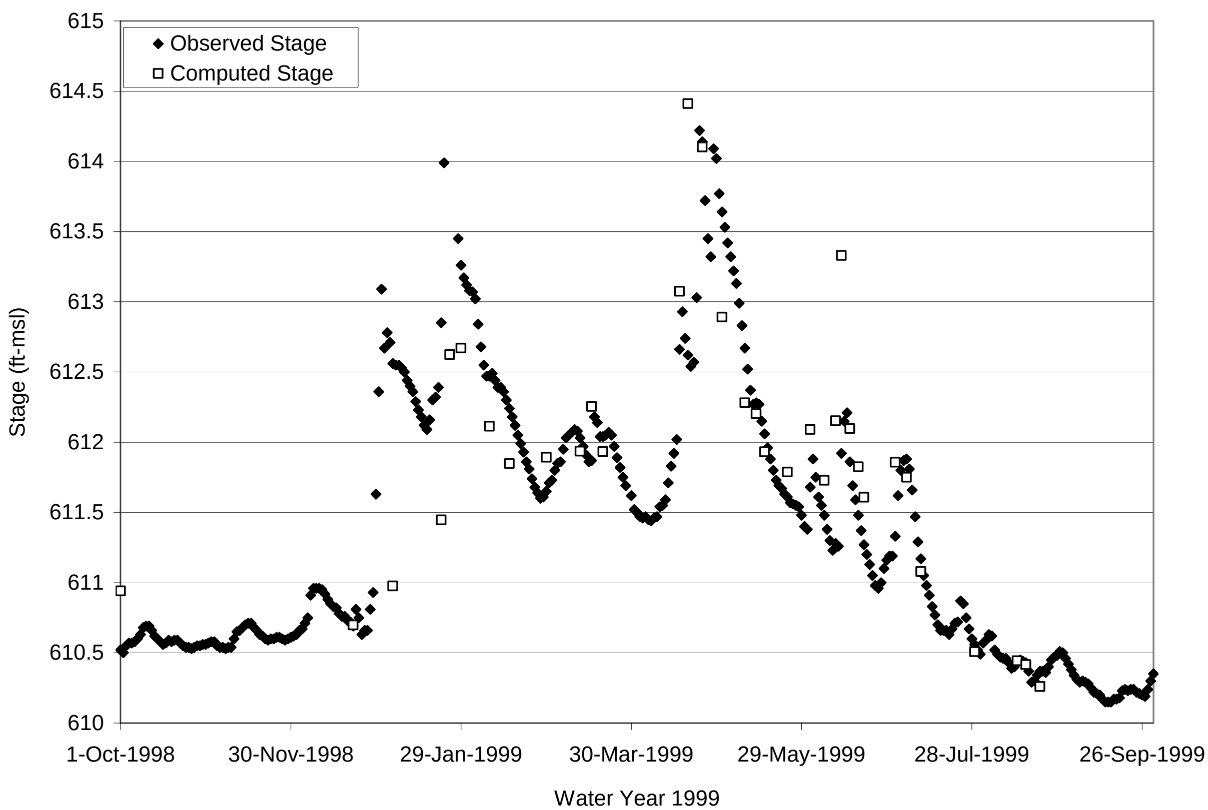



Figure 17. Computed and observed stage hydrograph for the Kankakee River at Momence, Illinois for Water Year 1999 (calibration for fixed-bed modeling)

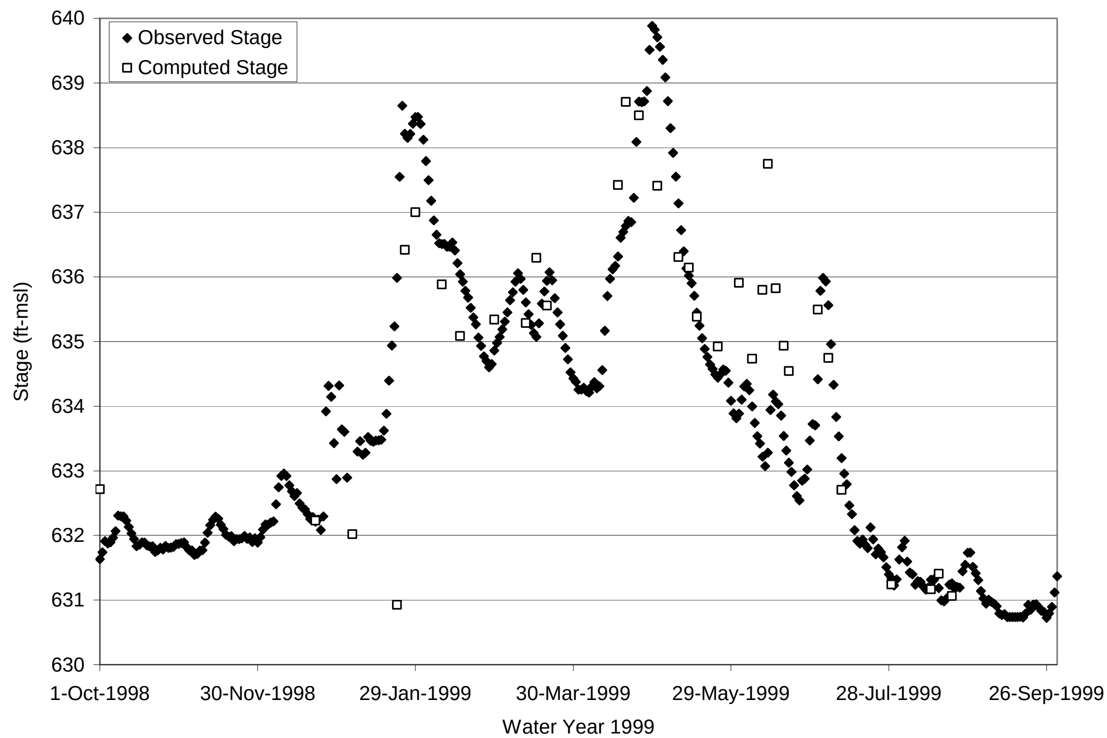



Figure 18. Computed and observed stage hydrograph for the Kankakee River at Shelby, Indiana, Water Year 1999 (calibration for fixed-bed modeling)

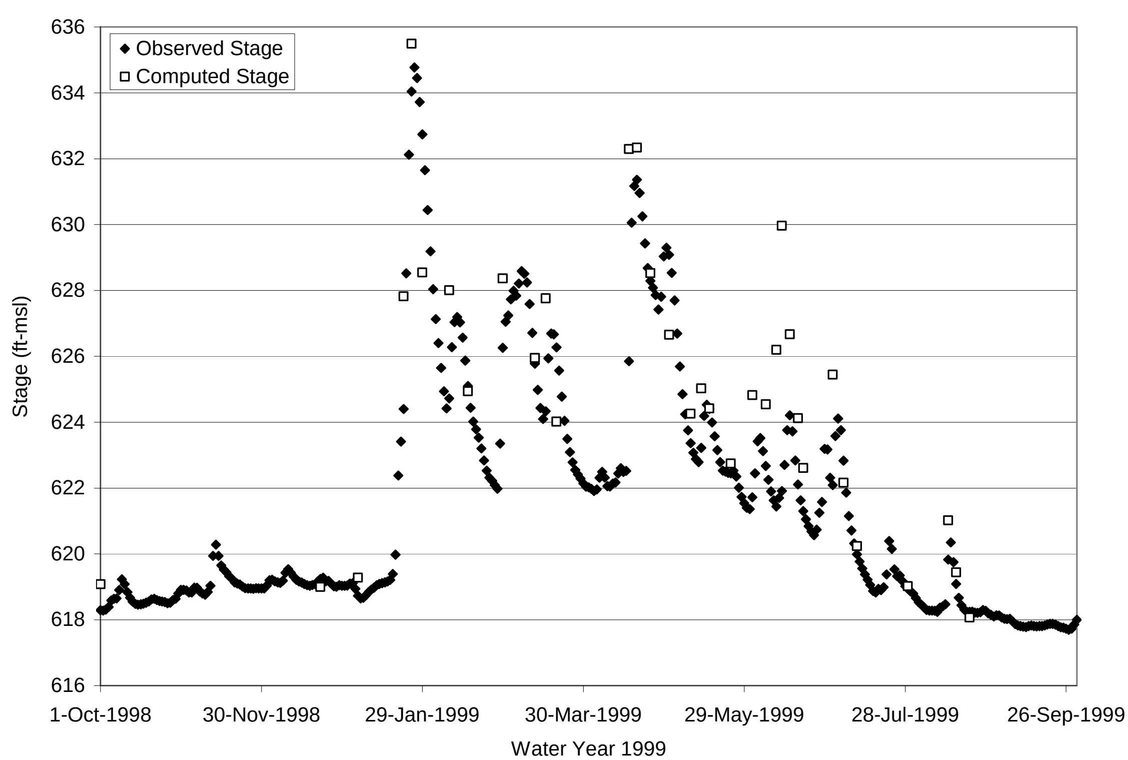



Figure 19. Computed and observed stage hydrograph for the Iroquois River at Iroquois, Illinois, Water Year 1999 (calibration for fixed-bed modeling)

### *Verification of HEC-6 Model Hydraulic Component*

The calibrated HEC-6 fixed-bed model was verified using WY 1996 stage hydrographs. The model with selected Manning's *n* values determined from the model calibration process and with the given geometric and hydraulic parameters was used to compute the water surface elevations at the Kankakee River at Momence and Shelby, and at the Iroquois River at Chebanse and Iroquois. Figures 20-23 provide the observed discharge hydrographs with discretization at the downstream end of the main stem of the Kankakee River, and the inflow discharge hydrographs from the Iroquois River as a tributary, Sugar Creek as a sub-tributary, and Singleton Ditch as a local inflow.

Figures 24-27 compare the computed stage hydrographs and the observed stage hydrographs for WY 1996 for the stations at Momence, Shelby, Iroquois at Chebanse, and Iroquois at Iroquois, respectively. As can be seen in these figures, the model performed quite well most of the time and in WY 1996, except from mid-January 1996 to February 1996 at Momence, and a portion of May-June 1996 at the Iroquois River at Chebanse and Iroquois. These figures show that the computed and measured stages for these verification runs are quite good for the Iroquois River stations. They are also quite good for the Momence and Shelby gaging stations except for two high-flow events near days 250 and 300 for WY 1966. During these two events, the computed stages are higher than those measured in the field. These higher values can be explained by the fact that the reach of the river from Momence through the Stateline Bridge still contains some of the original wetlands with broad and shallow floodplains.

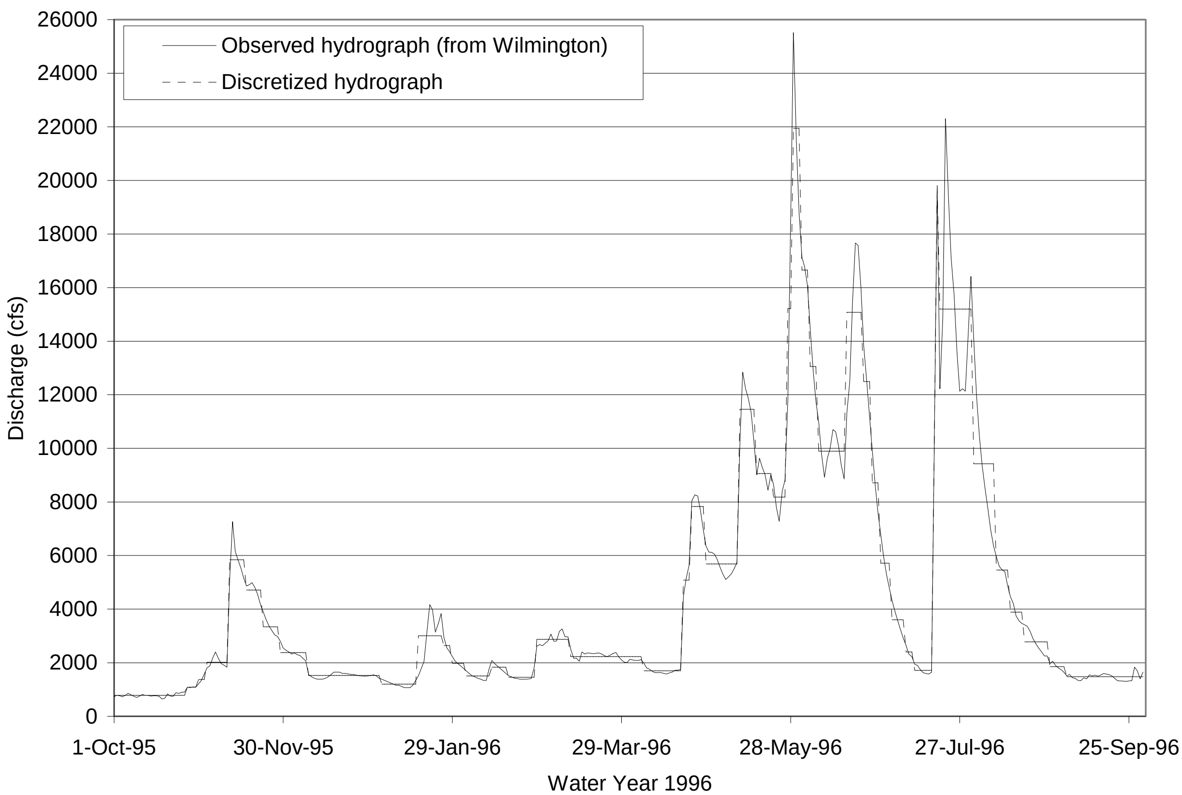



Figure 20. Discretized discharge hydrograph for the Kankakee River at Kankakee Dam, Water Year 1996

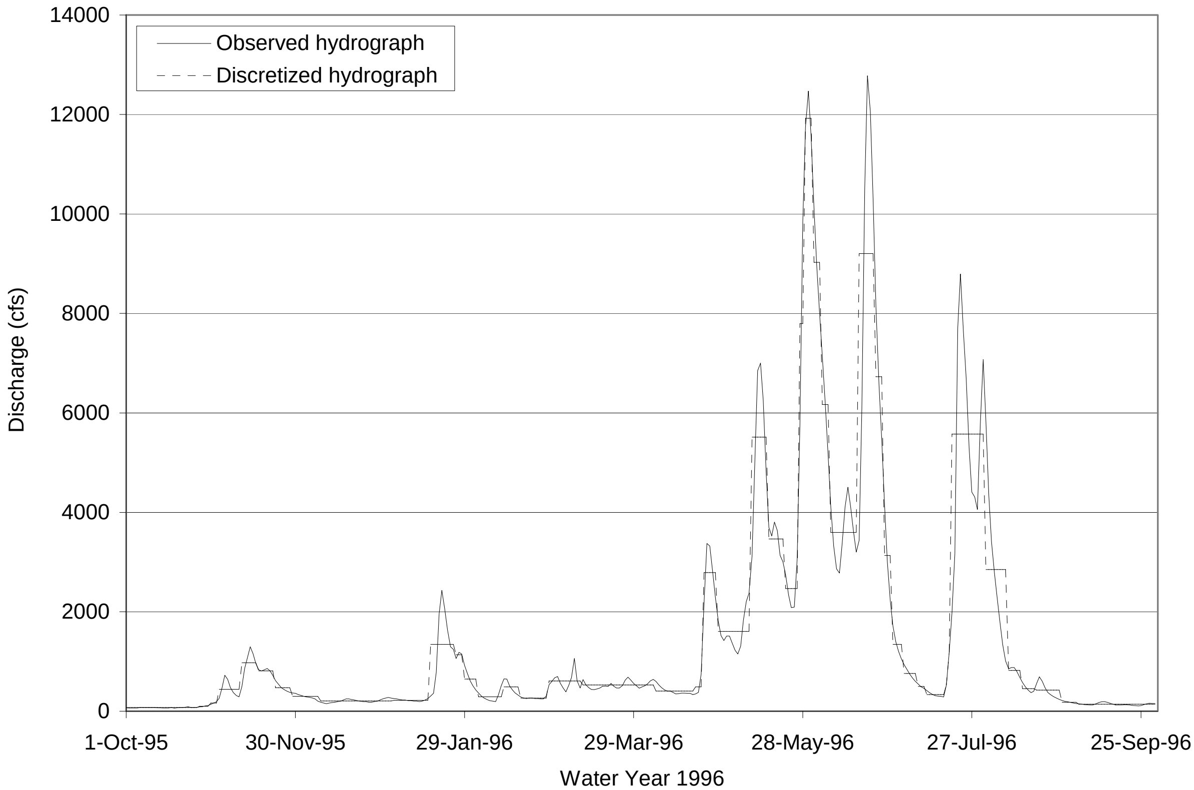



Figure 21. Discretized discharge hydrograph for the mouth of the Iroquois River, Water Year 1996

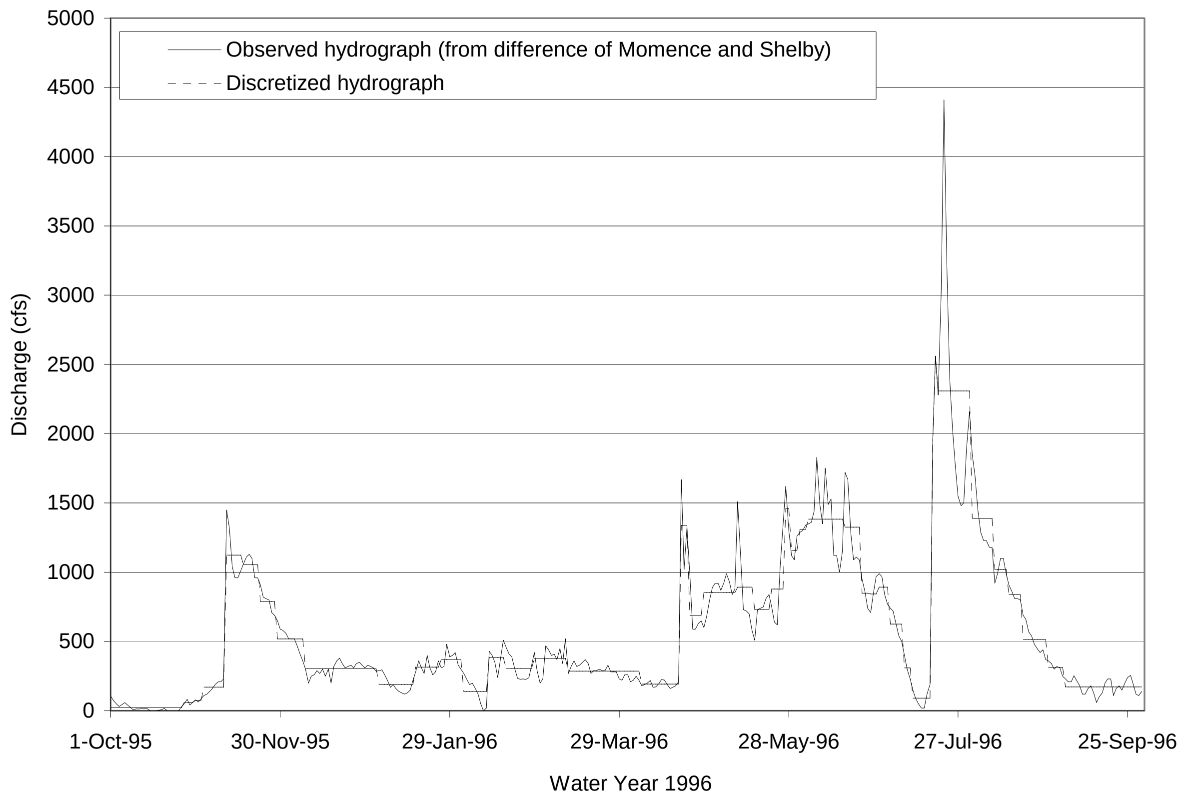



Figure 22. Discretized discharge hydrograph for Singleton Ditch and local tributaries between Shelby, Indiana, and Momence, Illinois, Water Year 1996

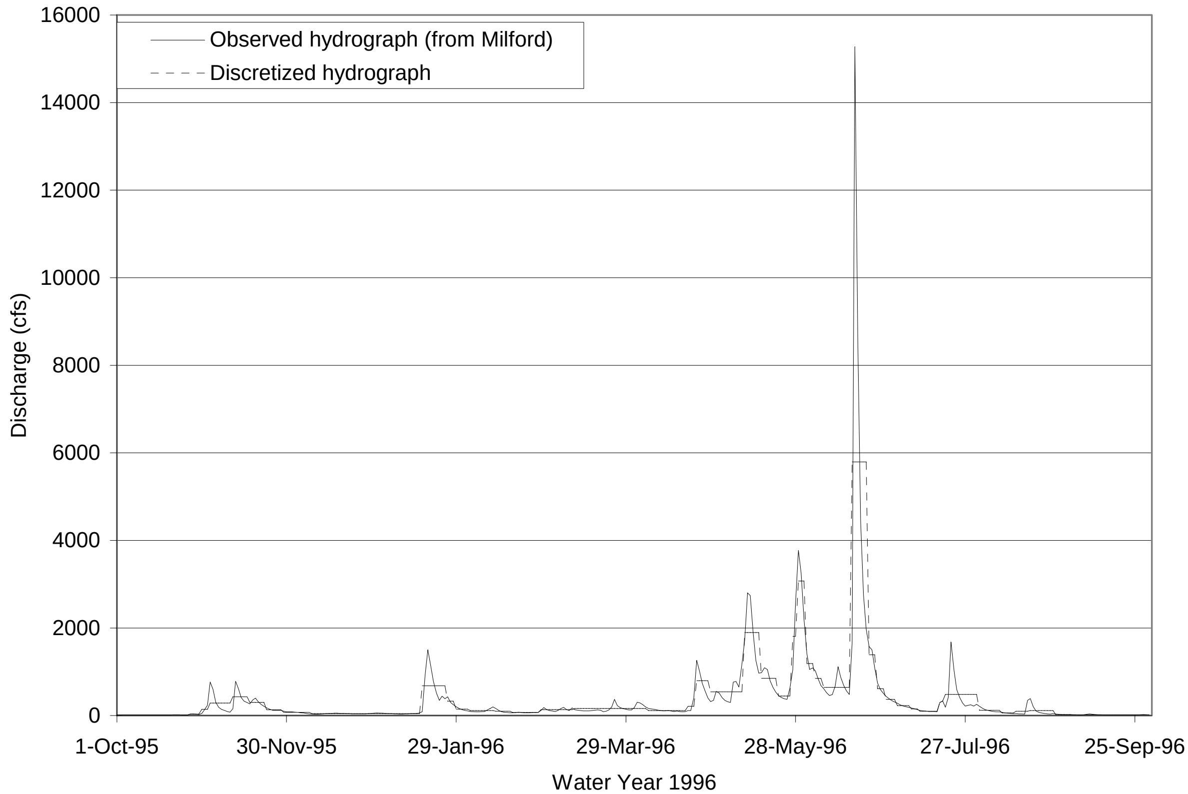



Figure 23. Discretized discharge hydrograph for Sugar Creek, Water Year 1996

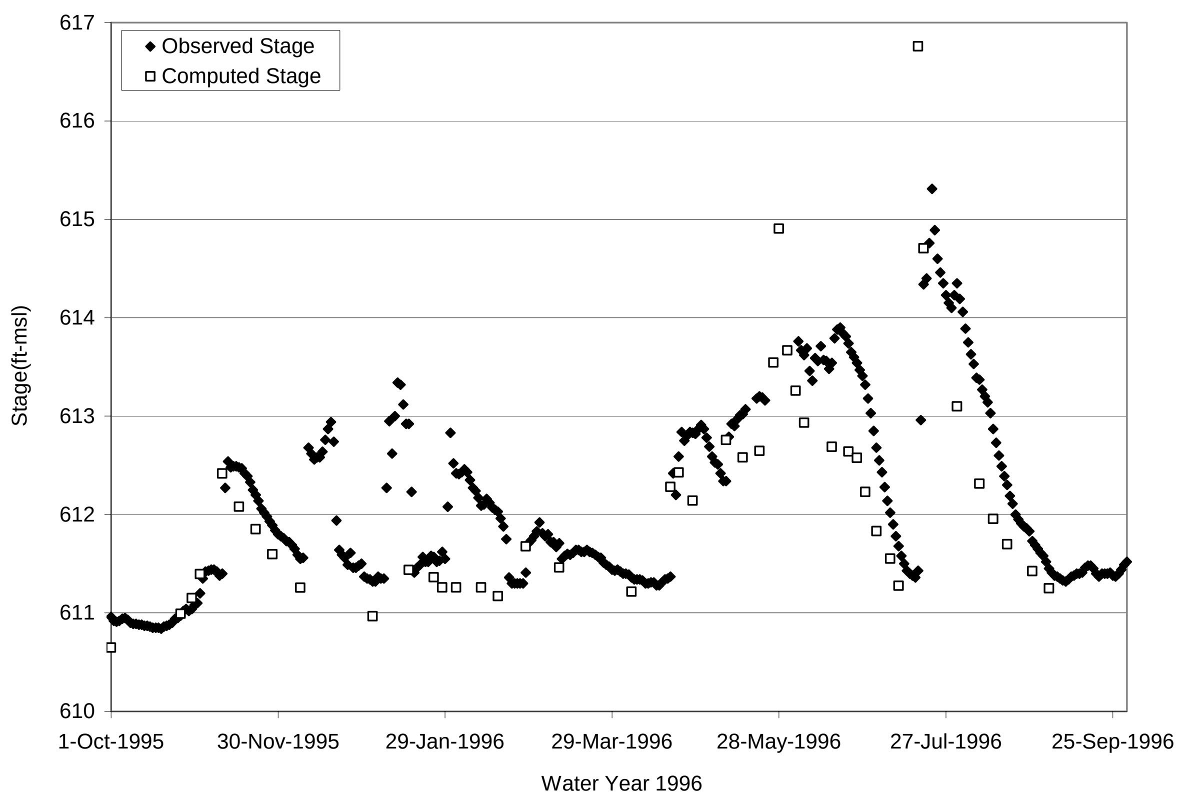



Figure 24. Computed and observed stage hydrograph for the Kankakee River at Momence, Illinois, Water Year 1996 (verification for fixed-bed modeling)

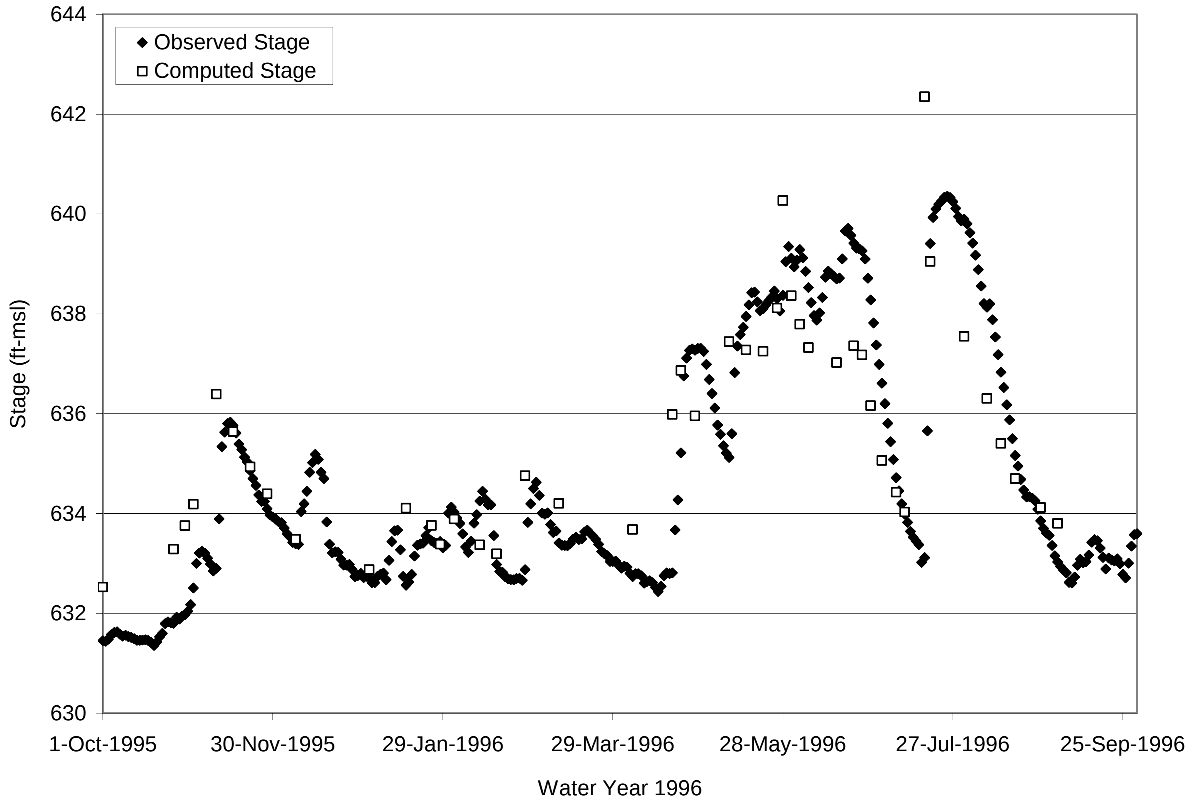



Figure 25. Computed and observed stage hydrograph for the Kankakee River at Shelby, Indiana, Water Year 1996 (verification for fixed-bed modeling)

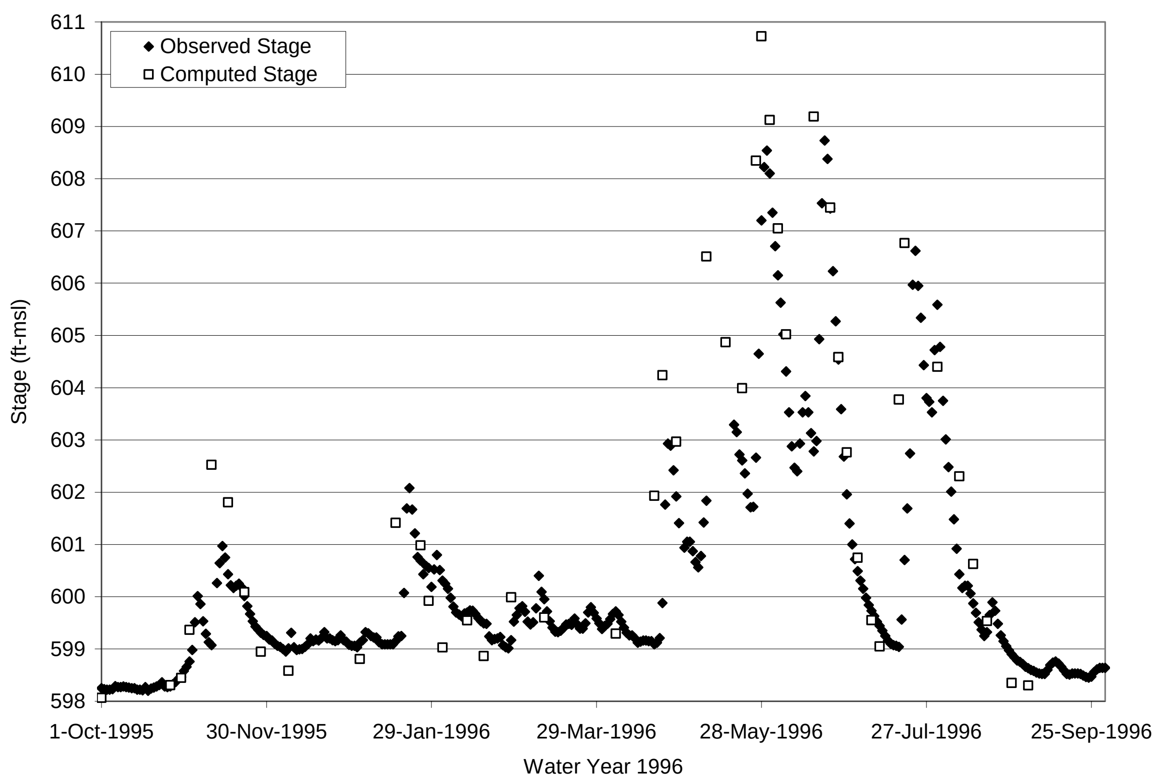



Figure 26. Computed and observed stage hydrograph for the Iroquois River at Chebanse, Illinois, Water Year 1996 (verification for fixed-bed modeling)

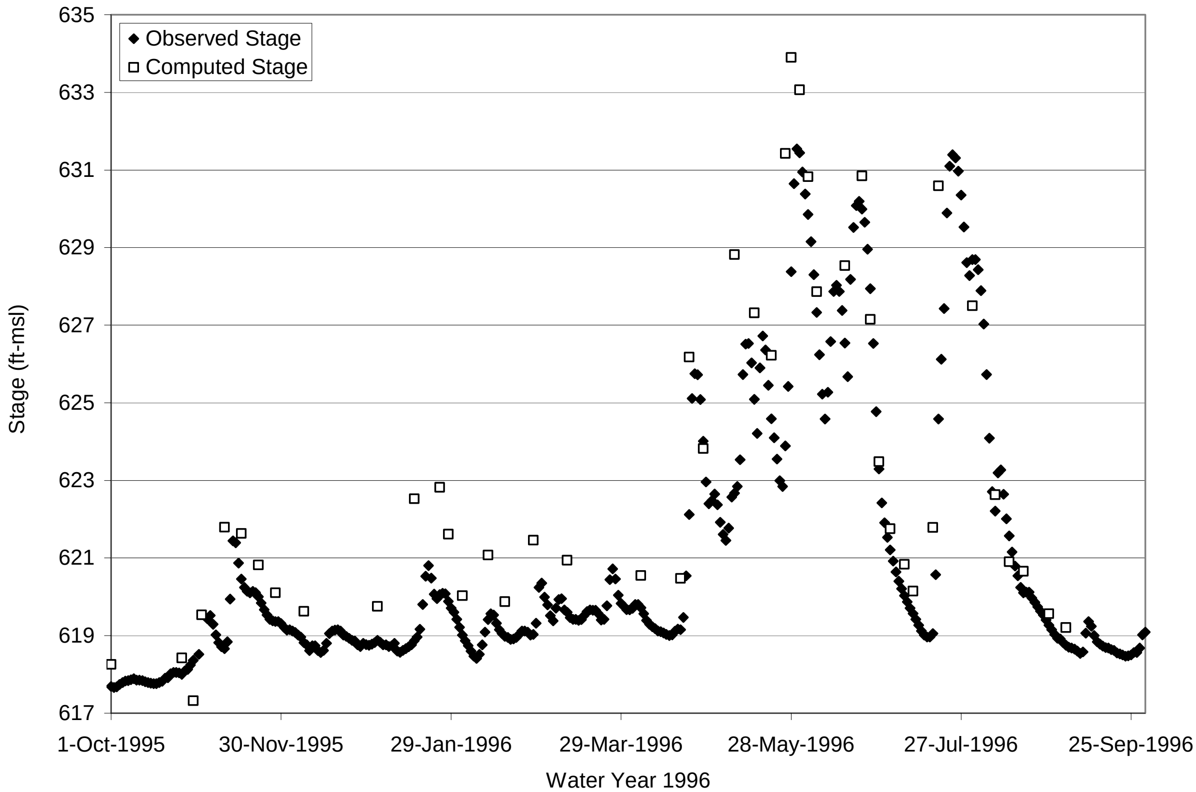



Figure 27. Computed and observed stage hydrograph for the Iroquois River at Iroquois, Illinois, Water Year 1996 (verification for fixed-bed modeling)

These broad areas will store and convey some water, thus decreasing the stages during high-flow events. The present modeling exercise simply did not reproduce this interaction. The model simply forced all the waters to be routed through the main channel, resulting in higher stages than those actually present at those locations.

The model also was verified using WY 1998 data. Figures 28-31 provide the observed and discretized discharge hydrographs at the downstream end of the main stem of the Kankakee River, and the inflow discharge hydrographs for the mouth of the Iroquois River, Sugar Creek as a sub-tributary, and Singleton Ditch as a local flow. Computed and measured stage hydrographs for WY 1998 for stations at Momence, Shelby, and Chebanse, respectively, are shown (figures 32-34). Even though there are several high-flow events in WY 1998 (see figures 32-34), the model predicted very well all stages generated by the high- and low-flow events. Thus, it appears that the model with the present roughness values can be used to simulate scour and deposition of sediments, and possibly for future prediction purposes.

## Scour and Deposition Simulation

The movable bed simulation of the HEC-6 model can be used to obtain two specific results: water surface elevations and sediment transport showing the changes in bed elevations. Water surface elevation changes already have been discussed for the gaging stations at Momence, Shelby, Chebanse, and Iroquois. As in the fixed-bed simulation, the historical data

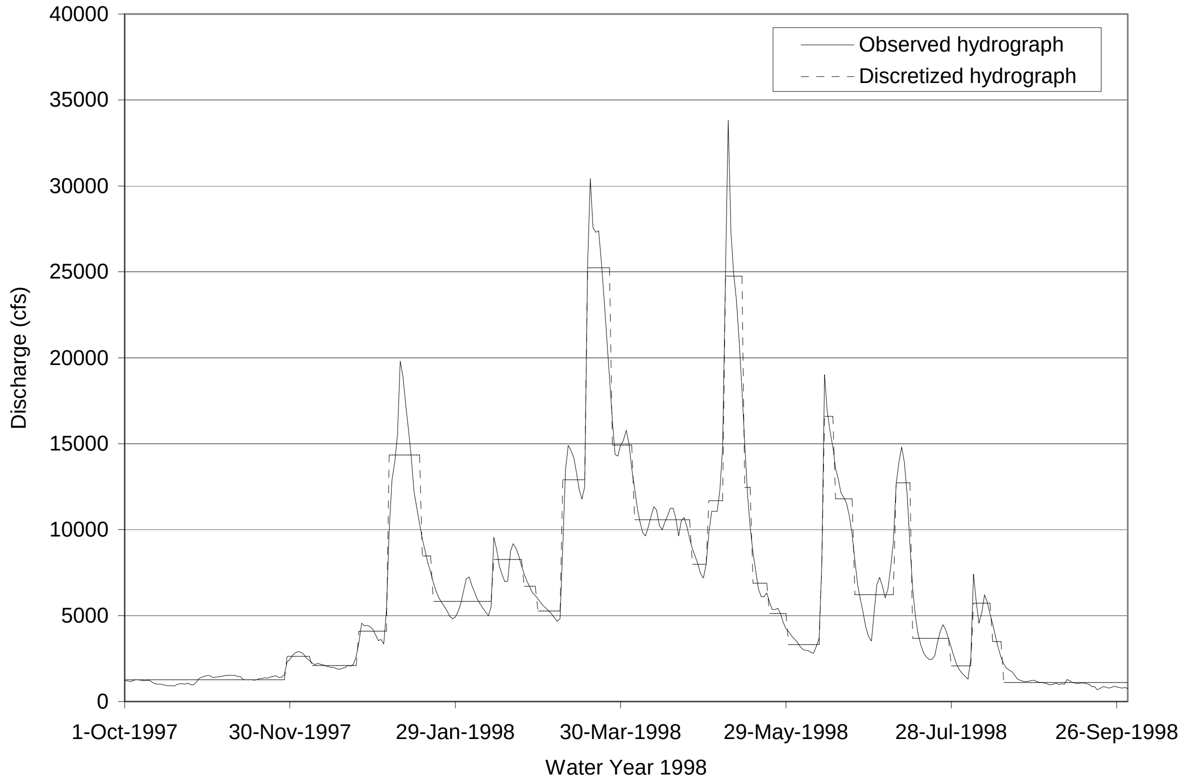



Figure 28. Discretized discharge hydrograph for the Kankakee River at Kankakee Dam, Water Year 1998

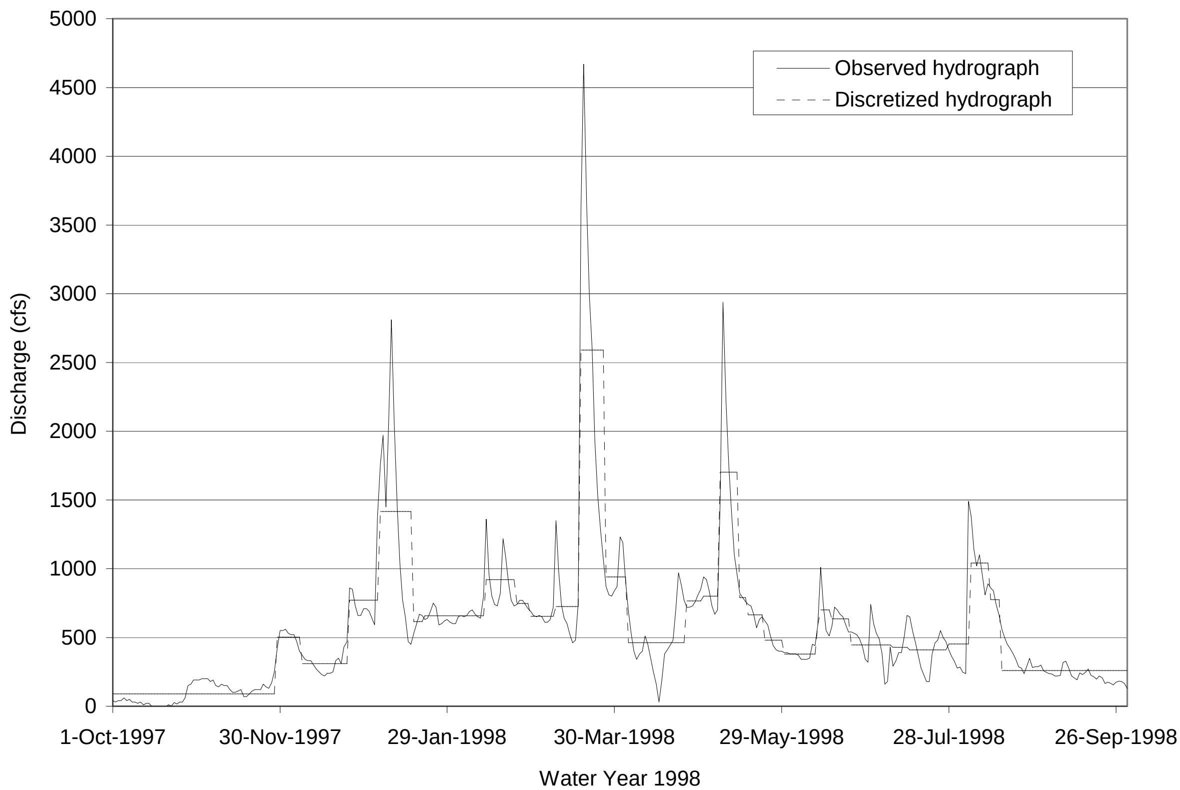



Figure 29. Discretized discharge hydrograph for Singleton Ditch and local tributaries between Shelby, Indiana, and Momence, Illinois, Water Year 1998

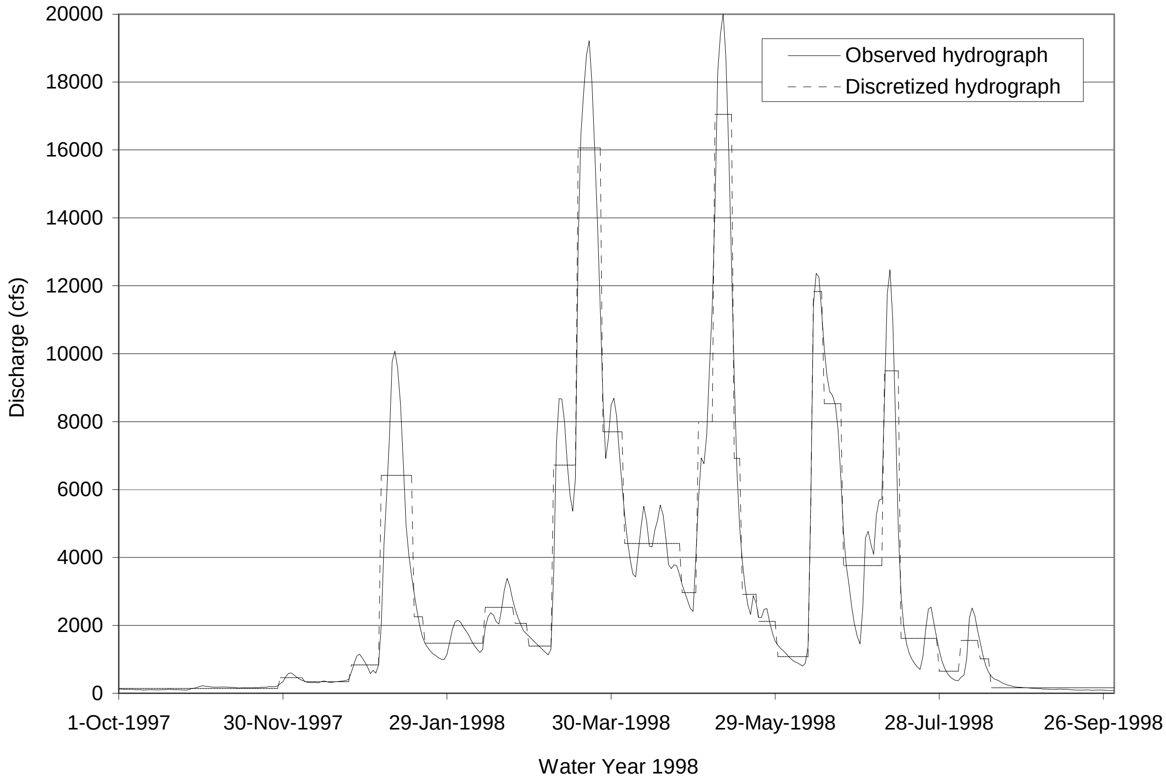



Figure 30. Discretized discharge hydrograph for the Iroquois River, Water Year 1998

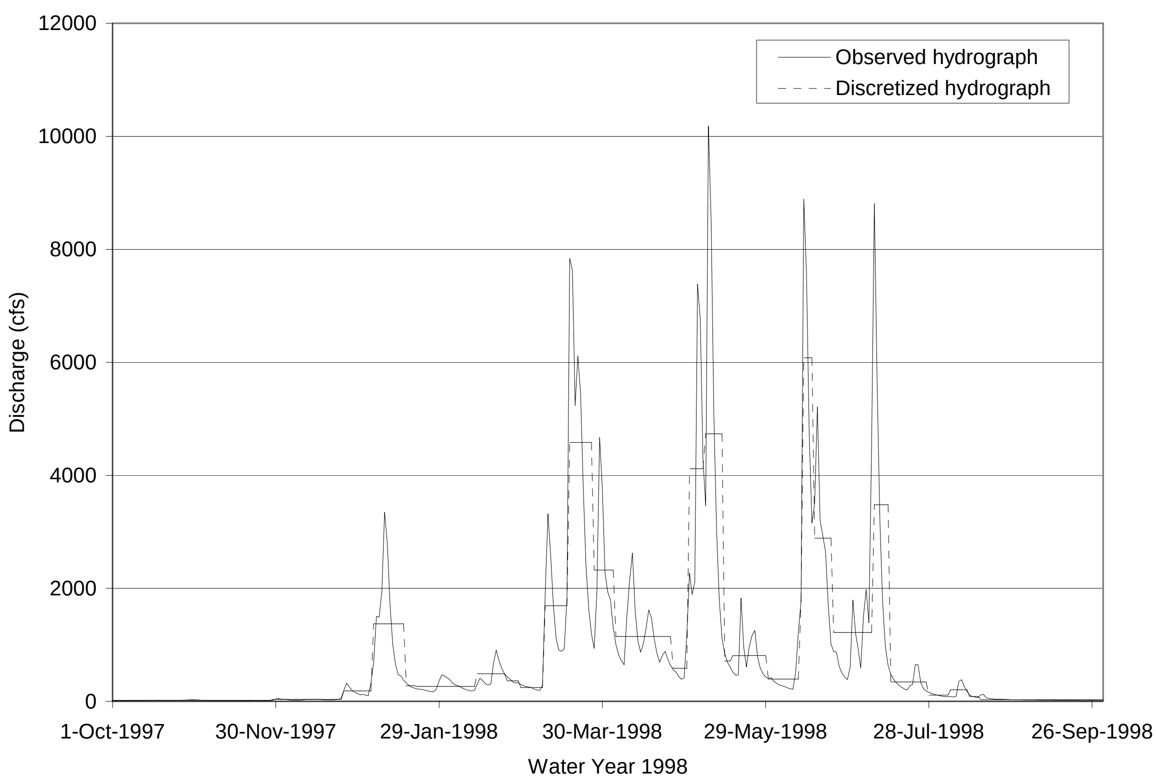



Figure 31. Discretized discharge hydrograph for Sugar Creek, Water Year 1998

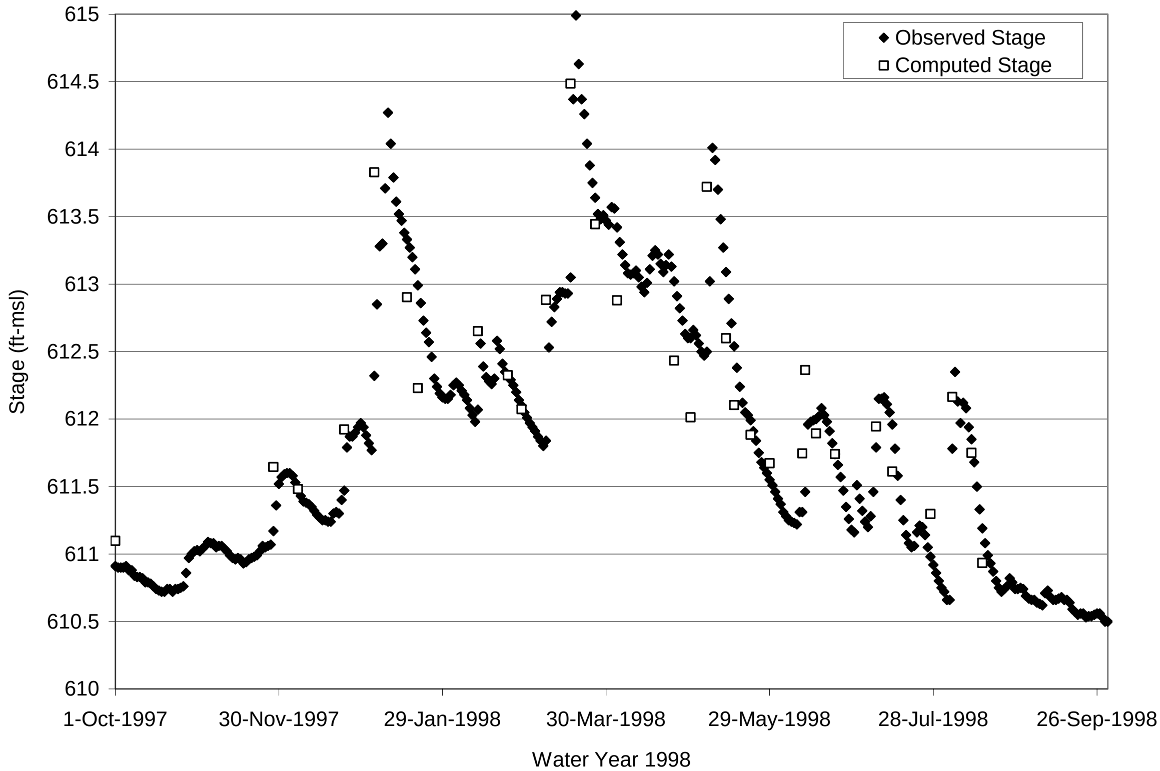



Figure 32. Computed and observed stage hydrograph for the Kankakee River at Momence, Illinois, Water Year 1998 (verification for fixed-bed modeling)

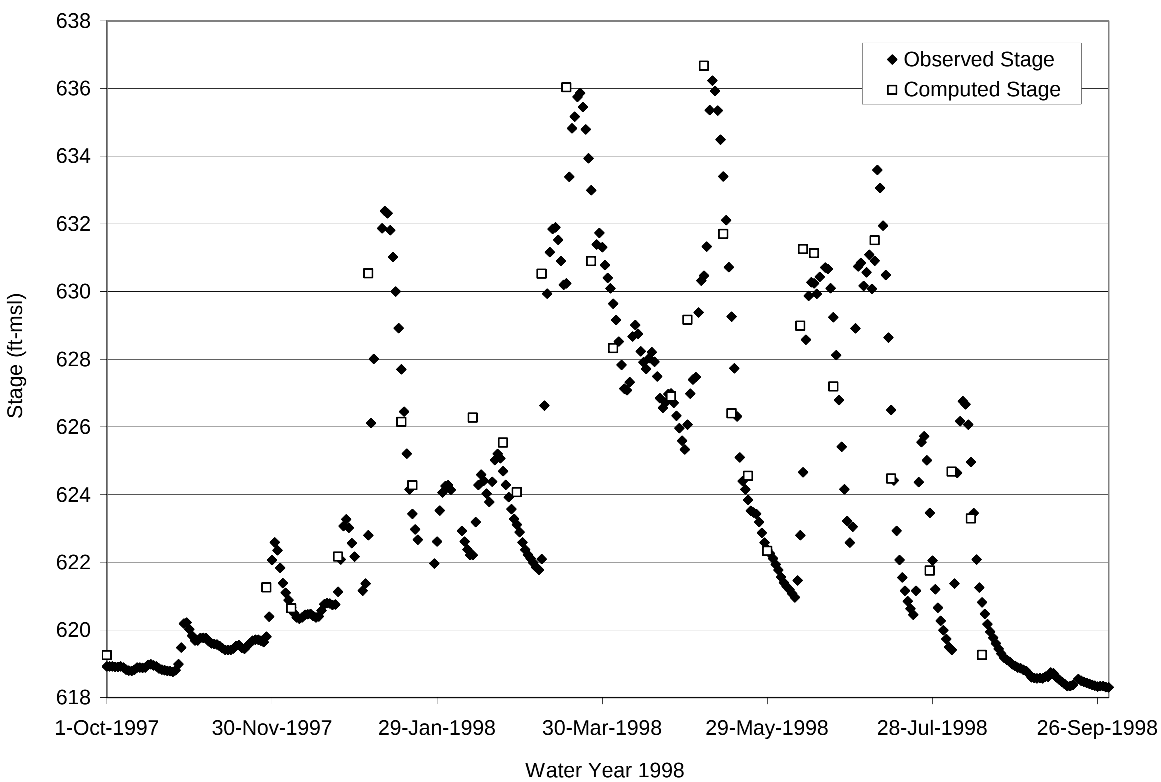



Figure 33. Computed and observed stage hydrograph for the Iroquois River at Iroquois, Illinois, Water Year 1998 (verification for fixed-bed modeling)

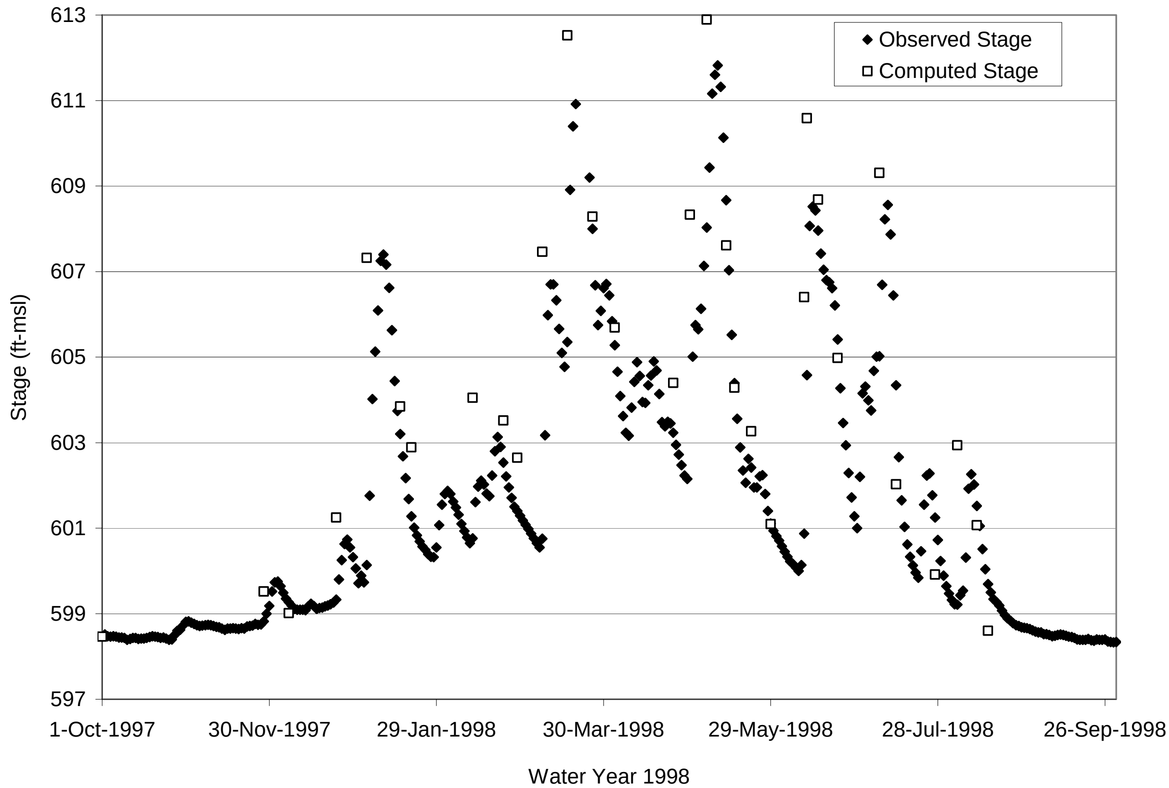



Figure 34. Computed and observed stage hydrograph for the Iroquois River at Chebanse, Illinois, Water Year 1998 (verification for fixed-bed modeling)

for the Kankakee River at Wilmington were used to determine the discharge hydrograph at the downstream end of the study reach, i.e., the Kankakee Dam. The inflow discharge hydrograph for the Iroquois River was determined from historical data at Chebanse. The inflow discharge hydrograph for Sugar Creek was computed from historical data at Milford, and that for Singleton Ditch was determined jointly from historical data at Momence and Shelby.

For sediment transport analysis, scour and sedimentation along the main stem of the Kankakee River are calibrated using the long-term historical hydrologic record (WY 1981-1999) and surveyed cross-section data from 1978, 1980, and 1999. Again, stream geometry data from 1978 and 1980 were combined to obtain river cross-section data extending from the Kankakee Dam to the Stateline Bridge. Running the model requires sediment inflow hydrographs from the upstream end of the study reach, including the main stem of the Kankakee River, the Iroquois River, and Sugar Creek. Sediment rating curves computed by Bhowmik et al. (1980) at the Kankakee River at Shelby, Indiana, at the Iroquois River at Iroquois, and the Singleton Ditch at Illinois represent the upstream sediment inflow conditions, respectively. The calibrated HEC-6 model then estimates the scour and/or sedimentation conditions of the river under different hydrologic conditions.

The following sections present results of the HEC-6 modeling, including both the surface water elevations and bed elevations changes.

***Suspended Sediment Data***

In HEC-6 modeling, the following sediment data are needed for movable bed simulation: 1) inflow sediment concentration, 2) grain size classes, 3) sediment inflow to be determined by using selected transport theory, and 4) sediment inflow from tributaries. Descriptions of these data follow:

***Sediment Load***

Total sediment load is composed of suspended load and bed load. In HEC-6 modeling, the total load must be specified for sediment transport, scour, and deposition analysis. Bed load generally consists of larger particles, which are transported through saltation, rolling, or sliding within the bed layer. Because it is very difficult to measure the bed load, it usually is estimated by increasing the suspended load by a certain percentage. The suspended sediment concentration is determined from samples of water-sediment mixture collected at a designated station. The inflow sediment load into a study reach is composed of two components: the inflow sediment load from the upstream end of the main stem, and that from the tributaries or local flow.

Regression equations for the suspended sediment correlating with water discharge developed at different locations on the Kankakee River basin were discussed and provided in table 3. These relationships are based on previous work (Bhowmik et al., 1980).

To estimate the total sediment load, the suspended sediment load is generally increased by 10 to 20 percent to account for the contribution of the bed load to the total load. These percentages are based on experiences of the researchers and research conducted on the Kankakee River (see Bhowmik et al., 1980). Bed load generally consists of larger particles, which are transported through saltation, rolling, or sliding in the bed layer. In this study, it was assumed that during high flows, the total sediment load is 10 percent bed load and 90 percent suspended sediment load; in low flow where the transport capacity decreases, and bed load transport is expected to be very low, it was assumed that the total sediment load consists of 5 percent bed load and 95 percent suspended sediment load.

***Bed Material Size Distributions***

The aggradation or degradation of a riverbed profile depends on the amount and size of sediment inflow relative to the transport capacity of the river. Inflow sediment loads enter the upstream boundary and also come from tributaries and local inflow points. These sediment loads should include the total load: bed load plus suspended load.

Tables 7-10 provide the particle size distributions of the inflow sediment loads, based on the data collected by Bhowmik et al. (1980). During high-flow conditions, Bhowmik et al. (1980) found that 80 percent of the sediment load at Momence consists of sand, and 20 percent consists of silt and clay.

The four types of sand are very fine sand, fine sand, medium sand, and coarse sand. All sizes are given in millimeters (mm). On the other hand, during low-flow conditions, the transport

**Table 7. Particle Size Distribution of Inflow Sediment Loads in the Kankakee River at Momence during High-Flow Conditions**

| *Particle sizes* | | *Percent content* |
|---|---|---|
| Clay | | 15.0 |
| Silt | | |
| Very fine | (0.004-0.008) | 3.0 |
| Fine | (0.008-0.016) | 1.5 |
| Medium | (0.016-0.031) | 0.5 |
| Coarse | (0.031-0.0625) | 0.0 |
| Sand | | |
| Very fine | (0.062-0.125) | 4.5 |
| Fine | (0.125-0.250) | 65.5 |
| Medium | (0.25-0.5) | 10.0 |
| Coarse | (0.5-1.0) | 0.0 |

**Table 8. Particle Size Distribution of Inflow Sediment Concentration in the Kankakee River at Momence during Low-Flow Conditions**

| *Particle sizes* | | *Percent content* |
|---|---|---|
| Clay | | 71.25 |
| Silt | | |
| Very fine | (0.004-0.008) | 14.25 |
| Fine | (0.008-0.016) | 7.125 |
| Medium | (0.016-0.031) | 2.375 |
| Coarse | (0.031-0.0625) | 0.0 |
| Sand | | |
| Very fine | (0.062-0.125) | 5.0 |

**Table 9. Particle Size Distribution of Suspended Sediment Load in the Iroquois River at Iroquois during High-Flow Conditions**

| *Particle sizes* | | *Percent content* |
|---|---|---|
| Clay | | 80.0 |
| Silt | | |
| Very fine | (0.004-0.008) | 4.0 |
| Fine | (0.008-0.016) | 6.0 |
| Medium | (0.016-0.031) | 4.0 |
| Coarse | (0.031-0.0625) | 2.0 |
| Sand | | |
| Very fine | (0.062-0.125) | 4.0 |

**Table 10. Particle Size Distribution of Inflow Sediment Concentration in the Iroquois River at Iroquois during Low-Flow Conditions**

| *Particle sizes* | | *Percent content* |
|---|---|---|
| Clay | | 81.667 |
| Silt | | |
| Very fine | (0.004-0.008) | 4.083 |
| Fine | (0.008-0.016) | 6.125 |
| Medium | (0.016-0.031) | 4.083 |
| Coarse | (0.031-0.0625) | 2.042 |
| Sand | | |
| Fine | (0.062-0.125) | 2.0 |

capacity of the river decreases. Therefore, the total sediment load was assumed to consist of 5 percent bed load and 95 percent suspended load. Table 8 gives the detailed particle size distribution based on research by Bhowmik et al. (1980). That research also found that during low flows about 95 percent of the suspended sediment load consists of silt and clay, and 5 percent consists of sand.

For the Iroquois River at Iroquois, the particles of the suspended load carried by the river consist of silt and clay during spring, summer, and fall (Bhowmik et al., 1980). This is in contrast to the suspended load carried by the Kankakee River at Momence, where the major part of the suspended load during the spring flood was sand (Bhowmik et al., 1980). Thus, during high-flow conditions, the suspended sediment load at the Iroquois gaging station is assumed to be 96 percent silt and clay, and 4 percent sand. During low-flow conditions, the transport capacity of the river decreases, and the suspended load is assumed to be 98 percent silt and clay, and 2 percent sand.

### *Bed and Bank Materials*

Bhowmik and Demissie (2000) and Bhowmik et al. (1980) characterized the particle size distributions of bed and bank material samples. Those reports contain detailed results from these analyses. Bed material samples for the main stem of the Kankakee River consisted primarily of sand. Bhowmik and Demissie (2000) concluded that the bed materials of the Kankakee River from the Kankakee Dam to the U.S. Highway 30 in Indiana were fine to medium sand, except at a region of rocky bed downstream of Momence. Sampling of bed materials for the Iroquois River was not as extensive as for the Kankakee River. Most samples were collected at two gaging stations, the Iroquois River at Iroquois and the Iroquois River at Chebanse (Bhowmik et al., 1980). Bed materials at both stations are coarser particles than those from the Stateline Bridge and at other Illinois stations. At a few Iroquois River locations, the riverbed consists of gravel. Near the confluence of the Iroquois River with the Kankakee River, the bed is essentially sandy in character.

### *Sediment Transport (Bed Load) Relationships*

The sediment transport component of the HEC-6 model requires selection of an appropriate transport equation, a significant component in modeling the transport mechanism of the sand and gravel. Yang and Wan (1991) reviewed several sediment transport models and concluded that models by Yang, Toffaleti, Einstein, Ackers and White, Colby, Laursen, Engelund and Hansen provide more or less similar results. The HEC-6 model has the option of selecting four transport equations for modeling the bed load sediment transport with a sandy bed similar to the main stem of the Kankakee River: those of Yang, Toffaleti, Ackers and White, and Meyer-Peter and Müller, respectively. The Toffaleti formula is based on extensive data from several rivers with bed sediments of fine to medium sand, and flume data with bed sediment of median grain sizes, 0.3 mm-0.93 mm (ASCE, 1975). Toffaleti's (1966) relationships were developed for rivers depths from less than 1 foot to more than 50 feet. Flow depths in flume ranged from 2 inches to 2 feet. Yang's (1973) stream power for transport of sand also was used in this study. Simons and Senturk (1977) suggested that Colby's (1964) sand relationship can be applied to rivers with flow depth of 10 feet or less. The Meyer-Peter and Müller equation (1948) is based upon data with little suspended load.

## Calibration of HEC-6 Model Sediment Component

The HEC-6 model needs to be calibrated to ensure that parameters selected for modeling the scouring and sedimentation patterns of the river are appropriate. Calibration for thalweg elevations was performed using historical hydrologic data from WYs 1981-1999 and measured cross-section data from 1978, 1980, and 1999. Again, cross-section data from 1978 were combined with data collected in 1980 to obtain a complete set of river cross sections from the Kankakee Dam to the Stateline Bridge. This set of data is called the 1980 data. Computed thalweg elevations then are compared with those cross-sectional data measured in 1999.

The model run for a 20-year period uses the measured hydrograph for the same period. Initially, measured daily hydrographs for each station were averaged for the entire period, 1981-1999. This averaging process produced an average hydrograph for Kankakee Dam, the Iroquois River, Singleton Ditch, and Sugar Creek (figure 35).

Approximating an annual hydrograph with 15 to 25 discharge segments normally is acceptable for moderate to large rivers. In general, the larger the discharge, the shorter its duration, because larger discharges carry more sediment and result in larger bed movements, increasing the possibility of numerical oscillations. Discharge hydrographs shown in figure 35 were subdivided into a 25-subdivision sequence.

### *Surface Water Elevations*

Figure 36 presents water surface elevations along the study reach computed for WYs 1981-1999. The observed water stage recorded on the Kankakee River on September 30, 1999 was 610.35 feet at Momence (RM 47.53) and 631.37 feet at Shelby. The computed stage at Momence and Shelby compares favorably with observed data.

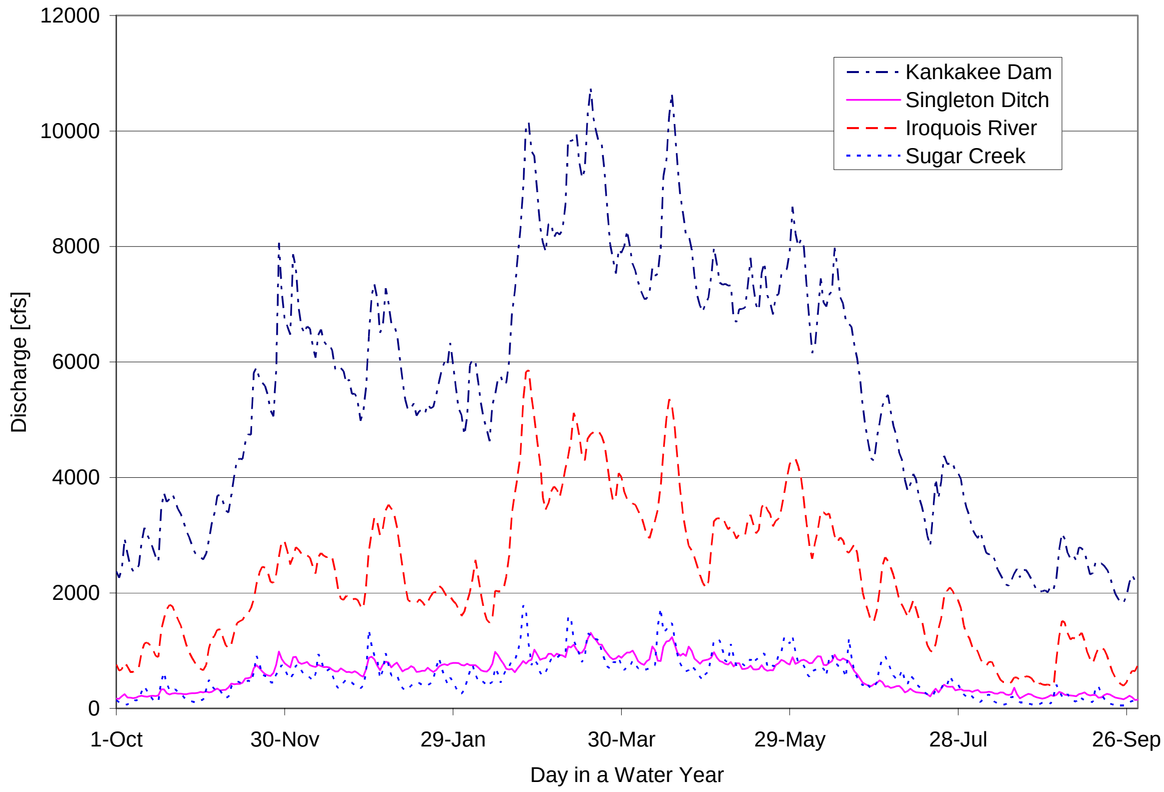



Figure 35. Average annual discharge hydrograph for the Kankakee River at Kankakee Dam, the Iroquois River, Singleton Ditch, and Sugar Creek, 1981-1999

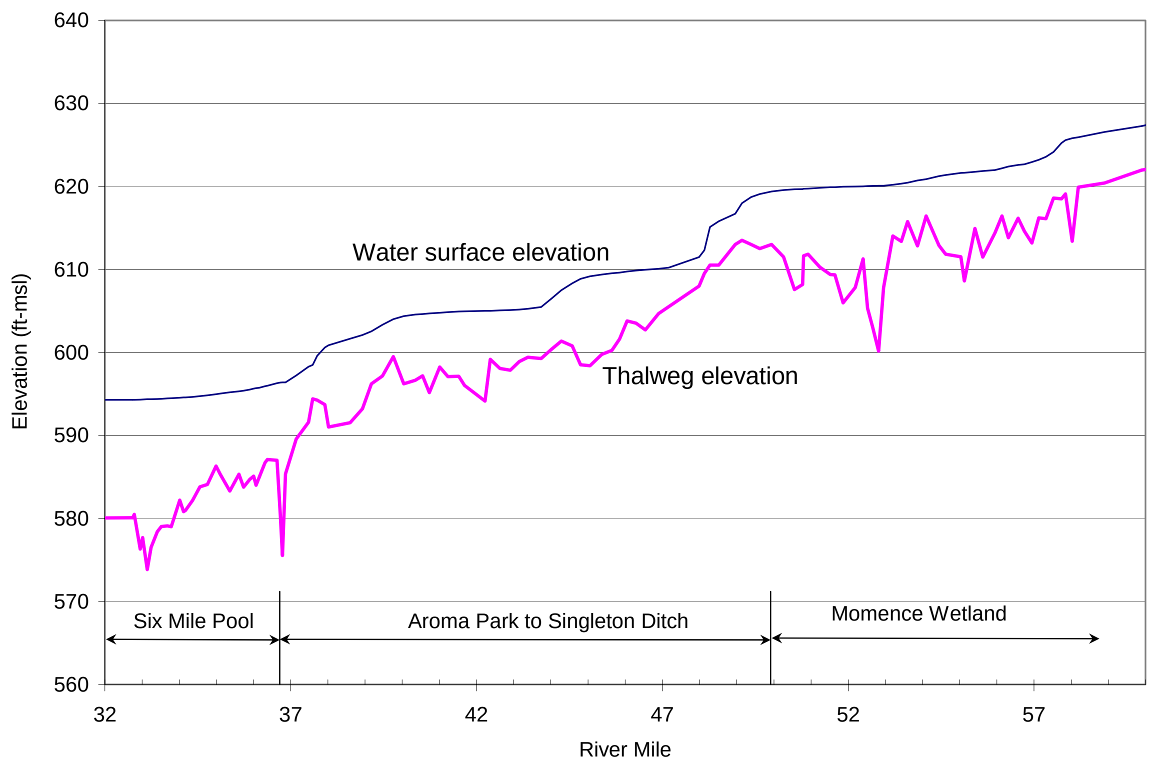



Figure 36. Computed water surface elevation and thalweg elevation for the Kankakee River from Kankakee Dam to Shelby, Indiana, Water Year 1999 (calibration for movable bed simulation, 1981-1999)

*Sediment Transport*

The main stem of the Kankakee River from Kankakee Dam to the Stateline Bridge modeled by the HEC-6 can be subdivided into three segments according to their hydraulic characteristics and geometric conditions.

**Segment 1: Six-Mile Pool (RM 32.75-37.00).** Previous studies generally showed that Six-Mile Pool has been subject to aggradation since 1959 (Bhowmik and Demissie, 2001). Figure 37 illustrates the differences in cross-sectional area data between 1959, 1968, 1978, 1980, and 1999. Figure 38 indicates that the pool is accumulating sediments from just upstream of the dam at RM 32.75 through RM 33.14, scour at or near RM 33.24 to RM 33.41, heavy sediment deposition from RM 33.41 through RM 36.37, some scouring at or near RM 36.72 and RM 36.78, and deposition upstream of RM 36.86.

**Segment 2: Aroma Park to Singleton Ditch (RM 37.00-50.80).** At many locations within the reach from Aroma Park to Singleton Ditch, especially close to Momence, the river flows on a rocky substrate. Figure 38 shows the river aggrading at a few locations, some scour at other locations, and no change in riverbed elevations since 1966 at other locations.

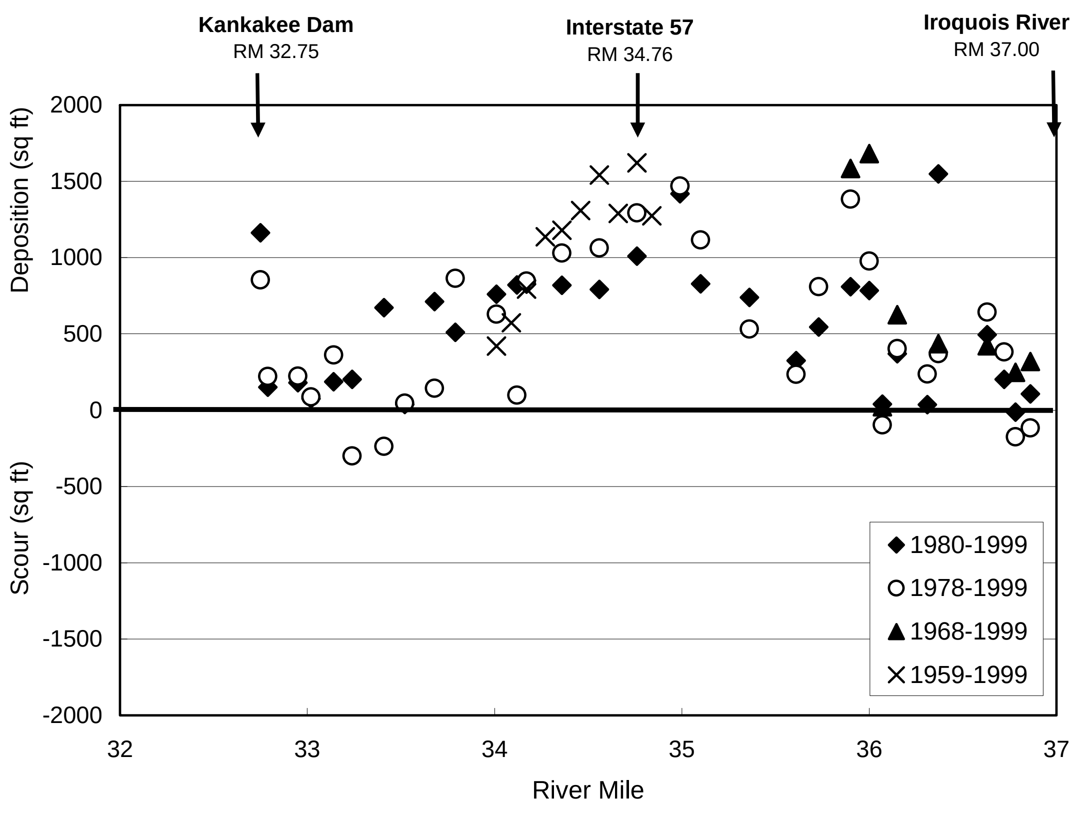



Figure 37. Changes in cross-sectional areas within Six-Mile Pool between 1959, 1968, 1978, and 1980, compared with cross sections collected in 1999 (after Bhowmik and Demissie, 2001)

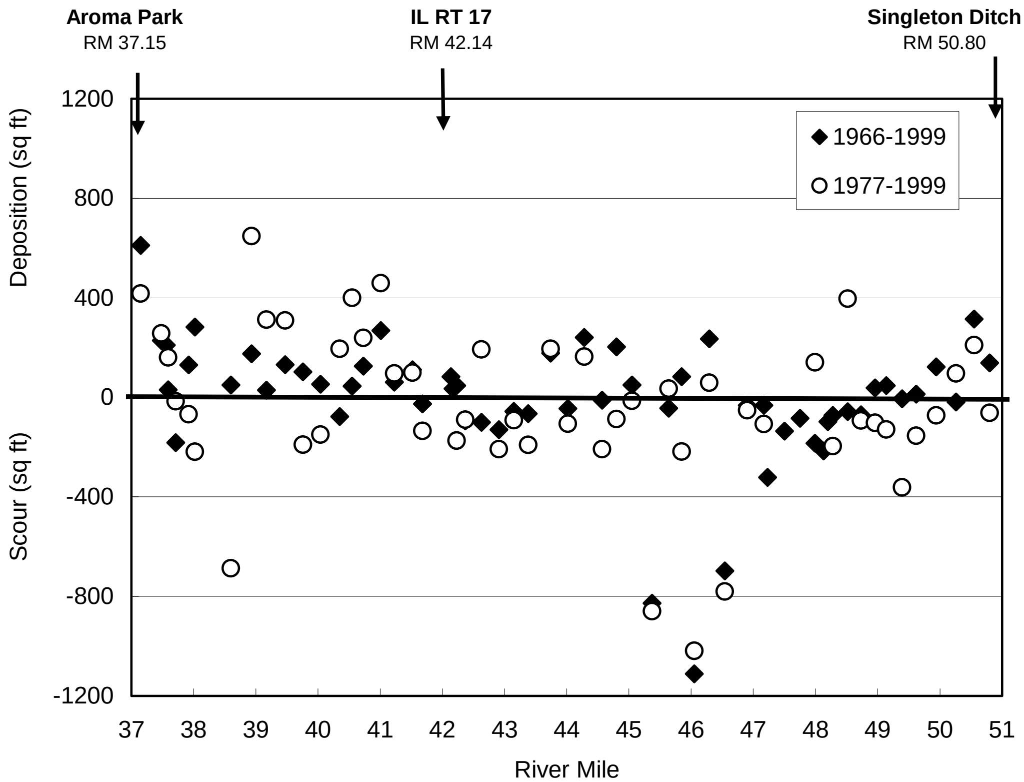



Figure 38. Changes in cross-sectional area in the reach from Aroma Park to Singleton Ditch between 1966 and 1977 compared with cross sections collected in 1999

**Segment 3: Momence Wetland (RM 50.80-58.19).** Based on the previous studies (Bhowmik and Demissie, 2001), the Momence Wetland consists of the reach from Singleton Ditch (RM 50.80) to the Stateline Bridge (RM 58.19). Major portions of the Momence Wetland have very low floodplains that flood frequently. Examination of figure 39 shows that this reach of the Kankakee River, in general, is depositing sediment even though scouring does occur at a few locations.

### *Calibration for Movable Bed Simulation*

The next several illustrations show the calibration of the movable bed component of the HEC-6 model for the main stem of the Kankakee River. Figure 40 shows the thalweg elevations of the main stem from the Kankakee Dam to Shelby, Indiana using Toffaleti's (1966) method in the HEC-6 program. Figures 41-42 provide similar comparisons using the Ackers and White (1973) and the Meyer-Peter and Müller's (1948) methods, respectively. From these illustrations, it appears that all three methods predict the 1999 thalweg elevations quite well when computations start in 1981. Therefore, it appears that any of the three equations could be used to predict changes in riverbeds for future anticipated conditions.

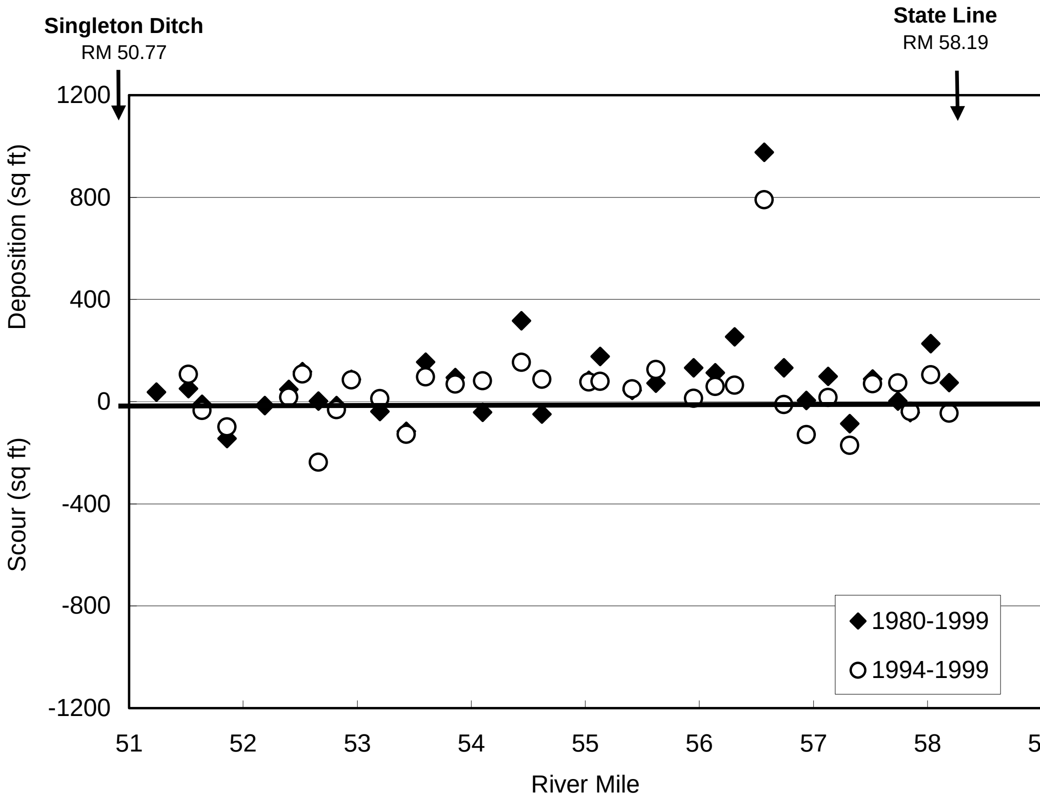



Figure 39. Changes in cross-sectional area within Momence Wetland between 1980 and 1994 compared with cross sections collected in 1999

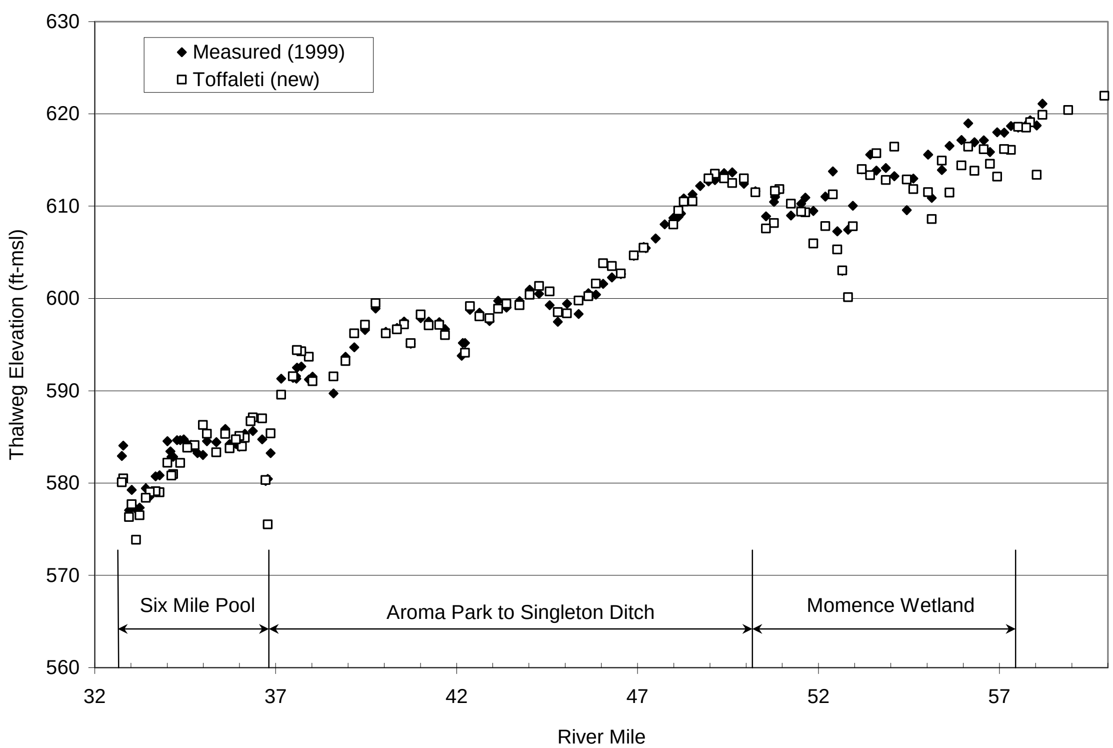



Figure 40. Computed and observed thalweg elevation of the Kankakee River from Kankakee Dam to Shelby, Indiana, Water Year 1999 by Toffaleti's (1966) method (calibrated for movable bed simulation, 1981-1999)

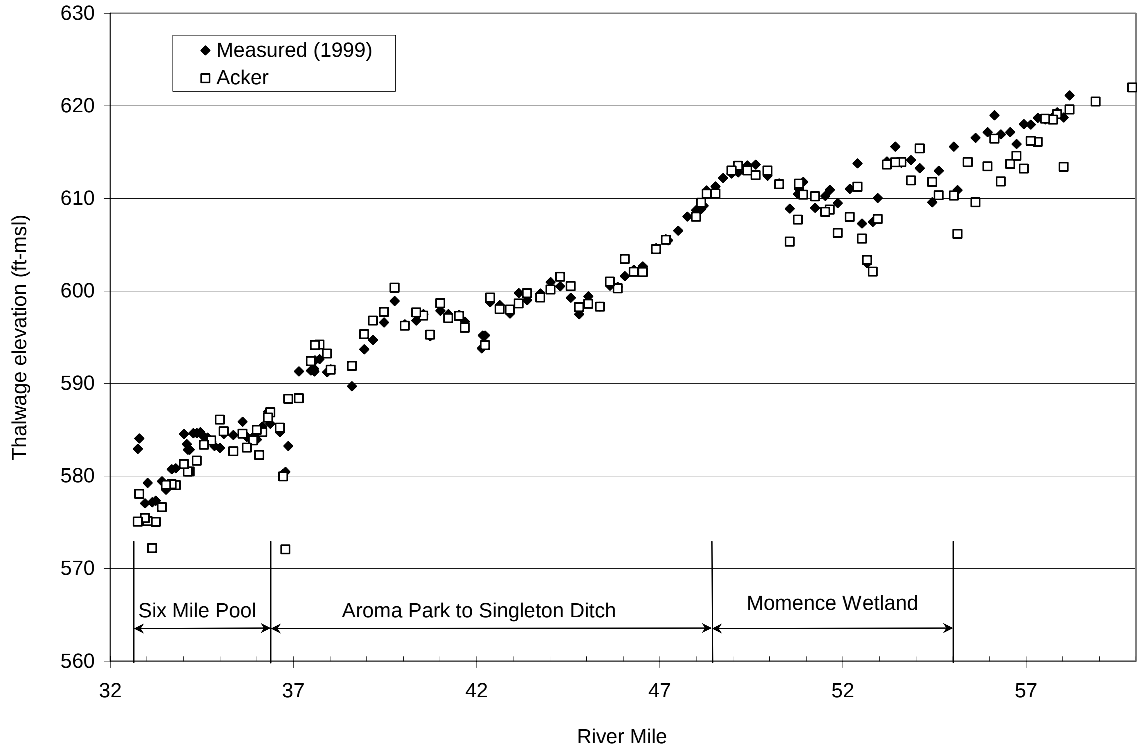



Figure 41. Computed and observed thalweg elevation of the Kankakee River from Kankakee Dam to Shelby, Indiana, Water Year 1999 by Acker and White's (1973) method (calibrated for movable bed simulation, 1981-1999)

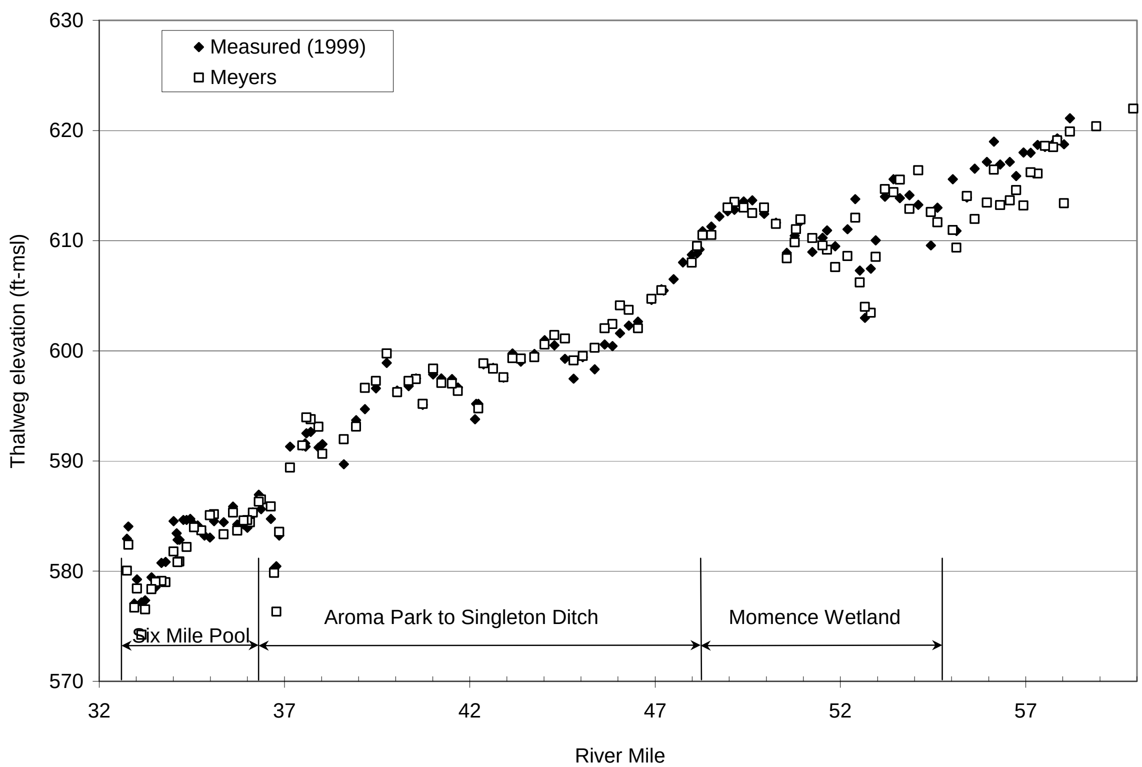



Figure 42. Computed and observed thalweg elevation of the Kankakee River from Kankakee Dam to Shelby, Indiana, Water Year 1999 by Meyer-Peter and Müller's (1948) method (calibrated for movable bed simulation, 1981-1999)

## Probable Changes in the Future

The calibrated HEC-6 model was used to estimate probable changes in river cross sections upstream of the Kankakee Dam over a 20-year period. For this prediction, it was assumed that future flow on the Kankakee River will be similar to the average daily hydrograph for the last 20 years. This is a major assumption and, as such, the results presented here must be viewed simply as a probable trend, not an absolute certainty. It is quite possible that the Kankakee River basin may be subjected to major flooding and droughts within the next 20 years or so, thus changing sediment transport and deposition patterns of this basin than that existed in the past.

Figure 43 shows two river cross sections within Six-Mile Pool near the city of Kankakee. Figure 43a shows a cross section at RM 33.14 upstream of the Kankakee Dam. This figure shows four cross-sectional profiles, one each for 1978, 1980, 1999, and a probable cross section for 2019. This illustration indicates that it is quite probable that the river at this location may remain more or less the same as it has since 1978.

Figure 43b shows the river cross section at RM 34.01, again within Six-Mile Pool. Past measured river cross sections from 1959, 1978, 1980, and 1999 are shown with a probable river cross section for 2019. Deposition has been taking place in this area since 1959, and model results show that similar deposition may be expected in the future.

The HEC-6 model results also were the basis for some general remarks (see "Remarks") regarding the probable deposition and/or scour potential of this river in the future. It appears that for a zone just upstream of Kankakee Dam, the river may undergo minor deposition and scour in the future. However, the segment of the river from about RM 33.24 to RM 35.10 has the potential for sediment deposition within the next 20 years. A portion of the river slightly below its confluence with the Iroquois River may have some scour in the future. However, in and around the Iroquois River and Spring Creek, the river has the potential for sediment deposition over the next 20 years.

The segment of the river from about 1.5 miles downstream of Momence and upstream of Spring Creek may go through both scour and deposition just as it has in the past. There is a good possibility that the reach below Momence and for about 1.5 miles may face aggradation in the future. The area upstream of Momence through the Stateline Bridge has the potential for both aggradation and some degradation, depending upon channel location and orientation and how extensive wetlands of the main channel interact with floodplains.

In order to arrive at a better definition of sediment scour or deposition within this reach, much more detailed river cross sections extending beyond the probable 1 percent flow frequency floodplains must be collected. These data must be supported by a two-dimensional modeling exercise. This area of the river consists of a complex mixture of river geometry; oxbow lakes; low, medium, and high river curvatures; extensive low-lying floodplains; dense vegetation; mature, immature, and dead trees, etc. Quantification of future probable changes will require much more land surveying, including quantification of land covers supported by a two-dimensional hydrodynamic model with a sediment transport component.

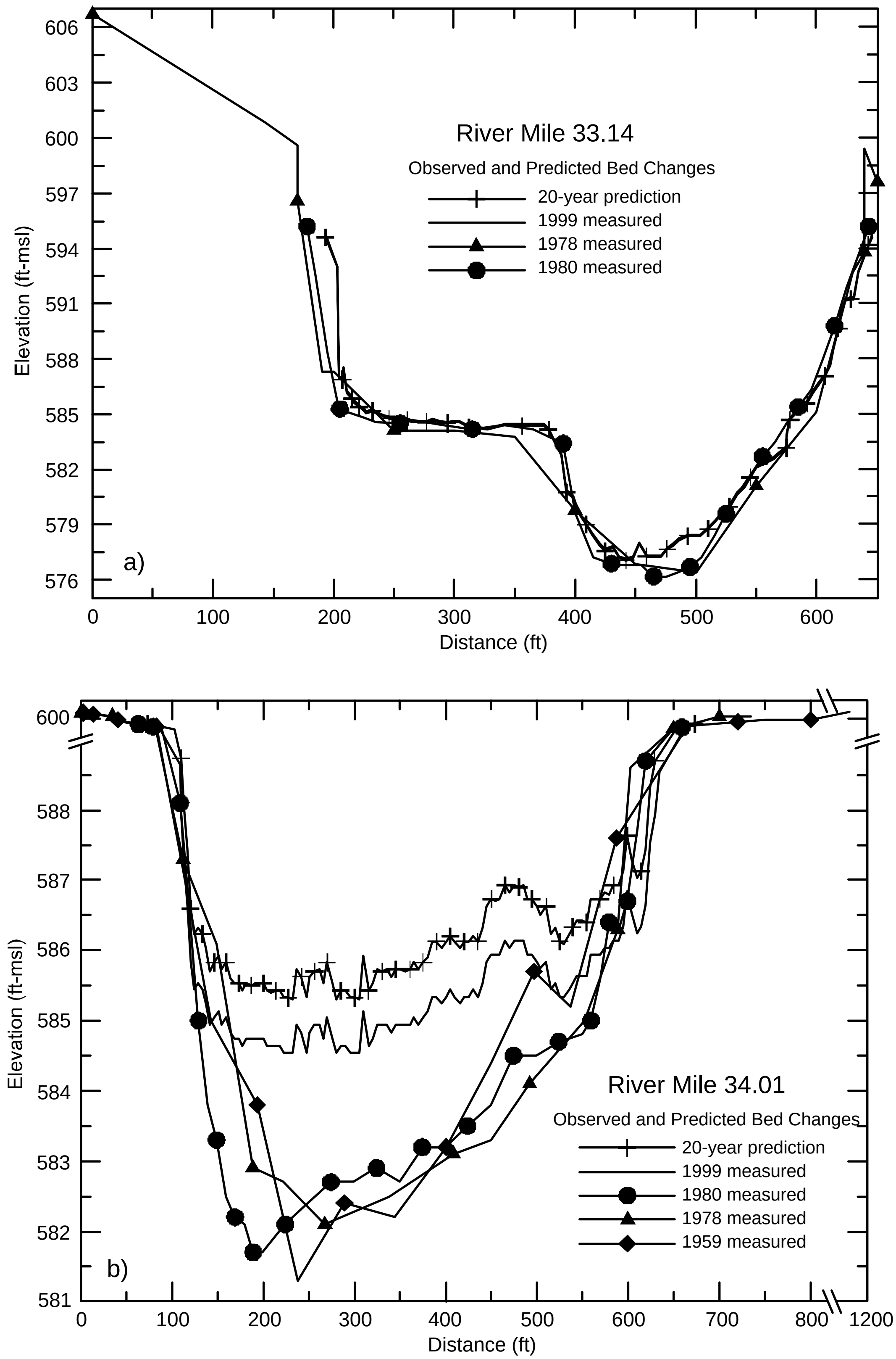



Figure 43. Past and predicted cross-sectional changes within Six-Mile Pool of the Kankakee River at a) RM 33.14 and b) RM 34.01

## Remarks

The previous illustrations show how the calibrated HEC-6 model could be used to estimate future changes in river geometries. These illustrations do not show riverine changes that would occur once a specific action is implemented at a certain location. However, if a specific action is contemplated, calibration, verification, and use of a two-dimensional model are recommended to estimate site-specific variabilities. Site-specific activities could include construction of a flow-splitting device, side-channel retention basin, removal of sediments from tributary mouths, removal of sand bars at specified locations, flow alteration devices within the main channel, channel stabilization devices, etc. These and other actions will require the use of a two-dimensional hydrodynamic model with a sediment component to illustrate velocity structure and consequent erosion or deposition patterns within a river cross section or a selected reach. The one-dimensional HEC-6 model only illustrates what could happen at a river cross section uniformly across the whole width of the river.

Natural river flows, erosion, and sedimentation processes are all three dimensional in nature. Three-dimensional modeling is not yet ready for universal application in natural streams and rivers. However, two-dimensional modeling is very good, and numerous applications of two-dimensional models have been made for natural streams and rivers. It also should be cautioned that any and all modeling will provide an estimate of what could happen for a certain activity or actions in a river. These types of results are never absolute. Modeling results must be interpreted by professionals in the field to arrive at logical, feasible predictions within the boundaries of the present knowledge base and riverine environment, including physical characteristics and hydraulic, geologic, and climatic constraints.

## Summary

The Kankakee River basin in Illinois has undergone tremendous change over the last 125 years. The main stem of the river in Indiana was channelized from the late 1880s through early 1910. Land use in both states also changed within the same period of time. Several major research activities already have been conducted on this basin over the last 25 years, and most of that research has been cited in this report.

Channelization in Indiana has been associated with an increased sediment load at downstream reaches, especially in Illinois. Sediment loads, including sedimentation patterns, already have been estimated previously and reported.

The present project was initiated to calibrate, verify, and show the application of the U.S. Army Corps of Engineers Hydrologic Engineering Center HEC-6 model. This one-dimensional hydraulic and sediment transport model can provide a guide on changes that can occur within a river channel in response to some anticipated action or actions.

For the present project, the HEC-6 model was calibrated for three different water years: low-, medium-, and high-flow conditions. The calibrated model also was verified for two other water years. Both the fixed-bed model component and the movable bed component were calibrated and verified. Existing flow records and river cross-sectional data from the 1980s through 1999 were used in this process. Results showed a very good correlation between the measured and computed parameters.

In order to show the potential application of this calibrated model for the main stem of the Kankakee River from Kankakee Dam to the Stateline Bridge, potential future changes were computed for 20-year periods. It was assumed that existing 1980-1999 flow would remain the same for the next 20 years. The predicted results give an average scenario across the whole width of the river, not a time representation of a natural river. However, a one-dimensional model still provides a general idea of what could happen in the river in the immediate future. Even though flows in natural rivers are essentially three-dimensional, three-dimensional models cannot be applied easily. However, two-dimensional models can provide very good results. Thus, in order to determine site-specific changes within any river for any anticipated action or actions, a two-dimensional hydrodynamic model must be used along with much more detailed surveying of floodplains, especially for the area of the river from Momence through the Stateline Bridge.

## References

Ackers, P., and W.R. White. 1973. "Sediment Transport: New Approach and Analysis." *Journal of the Hydraulics Division,* ASCE **99** (HY11):2041-2060.

Adams, J. R., and A.P. Bonini. 1986. *Kankakee Dam Discharge Characteristics*. Illinois State Water Survey Contract Report 383, Champaign, IL.

American Society of Civil Engineers (ASCE). 1975. *Sedimentation Engineering*. Manuals and Reports on Engineering Practice, No. 54, ASCE, New York, NY.

Bhowmik, N.G., and W.C. Bogner. 1981. *Sediment Transport and Hydraulics of Flow in the Kankakee River—Illinois: Phase II*. Illinois State Water Survey Contract Report 282, Champaign, IL.

Bhowmik, N.G., A.P. Bonini, W.C. Bogner, and R.P. Byrne. 1980. *Hydraulics of Flow and Sediment Transport in the Kankakee River in Illinois*. Illinois State Water Survey Report of Investigation 98, Champaign, IL.

Bhowmik, N.G., and M. Demissie. 2000. *Kankakee River Basin in Illinois: Hydraulics, Hydrology, River Geometry, and Sand Bars*. Interim Report. Illinois State Water Survey Contract Report 2000-03, Champaign, IL.

Bhowmik, N.G., and M. Demissie. 2001a. *Bank Erosion Survey of the Main Stem of the Kankakee River in Illinois and Indiana.* Illinois State Water Survey Contract Report 2001-01, Champaign, IL.

Bhowmik, N.G., and M. Demissie. 2001b. *River Geometry, Bank Erosion, and Sand Bars within the Main Stem of the Kankakee River in Illinois and Indiana*. Illinois State Water Survey Contract Report 2001-09, Champaign, IL.

Bhowmik, N.G., and J.B. Stall. 1979. *Hydraulic Geometry and Carrying Capacity of Floodplains*. Water Resources Center Research Report 145, University of Illinois at Urbana-Champaign, IL.

Brigham, A.R., L.B. Suloway, and L.M. Page. 1981. *The Effects of Sedimentation on Aquatic Life of the Kankakee River, Phase II: Quantitative Studies and Threatened, Endangered, and Rare Species.* Illinois Department of Energy and Natural Resources Document No. 81/37, Chicago, IL.

Colby, B.R. 1964. *Practical Computations of Bed-Material Discharge*. Proceedings, ASCE **90** (HY2).

Demissie, M., N.G. Bhowmik, and J.R. Adams. 1983. *Hydrology, Hydraulics, and Sediment Transport, Kankakee and Iroquois River.* Illinois State Water Survey Report of Investigation 103, Champaign, IL.

Demissie, M., D.T. Soong, and R. Camacho. 1990. *Cache River Basin: Hydrology, Hydraulics and Sediment Transport. Vol 2: Mathematical Modeling*. Illinois State Water Survey Contract Report 485, Champaign, IL.

Gross. D.L., and R.C. Berg. 1981. *Geology of the Kankakee River System in Kankakee County, Illinois.* Illinois State Geological Survey Environmental Geology 92, Champaign, IL.

Ivens, J.L., N. G. Bhowmik, A.R. Brigham, and D.L. Gross. 1981. *The Kankakee River: Yesterday and Today*. Illinois State Water Survey Miscellaneous Publication 60, Champaign, IL.

Kankakee River Basin Commission. 1989. *Kankakee River Master Plan: A Guide for Flood Control and Land Use Alternatives in Indiana*. KRBC, Indianapolis, IN.

Madden, E.B. 1963. “Channel Design for Modified Sediment Regime Conditions on the Arkansas River.” Paper No. 39, *Proceedings of the Federal Interagency Sedimentation Conference,* Miscellaneous Publication No. 970, Agricultural Research Service, U.S. Government Printing Office, Washington, D.C., pp. 335-352.

Meyer-Peter, E., and Müller, R. 1948. *Formulas for Bed-Load Transport*. International Association of Hydraulic Research, 2nd Meeting, Stockholm, Sweden.

Mitsch, W.J., M.D. Hutchinson, and G.A. Paulson. 1979. *The Momence Wetlands of the Kankakee River in Illinois: An Assessment of Their Value, A Descriptive and Economic Approach to the Appraisal of Natural Ecosystem Function*. Document 79-17. Illinois Institute of Natural Resources, Division of Environmental Management, Chicago, IL.

Phipps, R.L., G.P. Johnson, and P.J. Terrio. 1995. *Dendrogeomorphic Estimate of Changes in Sedimentation Rate along the Kankakee River Near Momence, Illinois*. U.S. Geological Survey Water Resources Investigation 94-4190, Urbana, IL.

Simons, D.B., and F. Senturk. 1977. *Sediment Transport Technology*. Water Resources Publications, Fort Collins, CO.

Terrio, P., and J.E. Nazimek. 1997. *Changes in Cross-Section Geometry and Channel Volume in Two Reaches of the Kankakee River in Illinois, 1959-94*. U.S. Geological Survey Water Resources Investigations Report 96-4261, Urbana, IL.

Toffaleti, F.B. 1966. *A Procedure for Computation of Total River Sand Discharge and Detailed Distribution, Bed to Surface*. Technical Report No. 5, Committee on Channel Stabilization, U.S. Army Corps of Engineers, Vicksburg, MI.

U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC). 1990. *Computing Water Surface Profiles with HEC-2 on a Personal Computer*. Training Document No. 26, Davis, CA.

U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC). 1992. *Guidelines for the Calibration and Application of Computer Program HEC-6*. Training Document No. 13.

Yang, C.T. 1973. “Incipient Motion and Sediment Transport.” *Journal of the Hydraulics Division*, ASCE **99**(HY10):1679-17

Yang, C.T., and S. Wan. 1991. Comparisons of Selected Bed-Material Load Formulas. *Journal of Hydraulic Engineering,* ASCE **117**(8):973-989.

Illinois State WATER Survey (1895)

ILLINOIS DEPARTMENT OF NATURAL RESOURCES

ILLINOIS