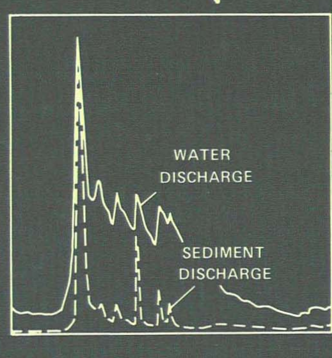
[redacted]

ISWS/RI-98/80
REPORT OF INVESTIGATION 98
STATE OF ILLINOIS
ILLINOIS INSTITUTE OF NATURAL RESOURCES

Hydraulics of Flow and Sediment Transport in the Kankakee River in Illinois

by NANI G. BHOWMIK, ALLEN P. BONINI,
WILLIAM C. BOGNER, and RICHARD P. BYRNE



ILLINOIS STATE WATER SURVEY
CHAMPAIGN
1980

REPORT OF INVESTIGATION 98

Hydraulics of Flow and Sediment Transport in the Kankakee River in Illinois

**by NANI G. BHOWMIK, ALLEN P. BONINI,
WILLIAM C. BOGNER, and RICHARD P. BYRNE**

Title: Hydraulics of Flow and Sediment Transport in the Kankakee River in Illinois

Abstract: The hydraulics of flow and sediment transport in the Kankakee River in Illinois were investigated in a 2-year study. The progression of river channelization in Indiana and the behavior of the river in the straightened portion in Indiana and the nonstraightened portion in Illinois were reviewed. Historical data regarding peak, average, and low flows for six gaging stations were analyzed to identify trends. Both deposition and scour occurred at various places on the main stem of the river in Illinois between 1968 and 1978. Median diameters of bed materials of the river ranged from 0.2 to 0.4 mm. Extensive suspended sediment, bed load, and water discharge data were collected and analyzed, and regression equations were developed between water discharge and suspended sediment discharge. For about 60 to 80 days during storm events, the river carries about 80 percent of the yearly sediment load. A number of active sand bars were surveyed. One sand bar near the state line appears to be forming and crossing the state line once a year. A hydrographic map of the Six Mile Pool was developed. A number of preventive and remedial measures to reduce sediment load are outlined in the report.

Reference: Bhowmik, Nani G.', Allen P. Bonini, William C. Bogner, and Richard P. Byrne. Hydraulics of Flow and Sediment Transport in the Kankakee River in Illinois. Illinois State Water Survey, Champaign, Report of Investigation 98, 1980.

Indexing Terms: Bed load, bed materials, deposition, flows, hydraulics, hydrographic maps, Kankakee River, resistance, sand bars, scour, sediments, sediment transport, suspended load.

STATE OF ILLINOIS
HON. JAMES R. THOMPSON, Governor

INSTITUTE OF NATURAL RESOURCES
FRANK H. BEAL, M.U.P., Director

STATE WATER SURVEY DIVISION
STANLEY A. CHANGNON, JR., M.S., Chief

CHAMPAIGN
1980

Printed by authority of the state of Illinois
(12-80-800)

CONTENTS

PAGE

Abstract . . . 1
Introduction . . . 2
  Plan of the report . . . 2
  Acknowledgments . . . 2
Background analysis . . . 3
  Flow hydraulics and sediment transport . . . 4
    Bed form and flow resistance . . . 4
    Incipient motion . . . 7
    Sediment load . . . 10
      Bed load . . . 10
      Suspended load . . . 13
    Total load . . . 15
Historical perspective . . . 16
  Early period . . . 16
  Period of channelization . . . 19
Data collection . . . 28
  Drainage basin . . . 28
  River reconnaissance . . . 29
  Types of data . . . 30
  Suspended sediment load . . . 34
  Bed load . . . 35
  Bed materials . . . 36
  Sand bar monitoring . . . 37
  Hydraulic data . . . 37
Analyses of data . . . 40
  Background analyses . . . 40
    Flow duration . . . 40
    Peak flow . . . 43
    Average discharge . . . 48
    Low flow . . . 50
    Precipitation analysis . . . 52
    Cross-sectional data . . . 56
  Present data analyses . . . 61
    Bed and bank materials . . . 61
    Sediment discharge . . . 70
      Suspended load . . . 70
      Generalized analysis — suspended load . . . 93
      Variation of historical suspended sediment load . . . 97
      Bed load . . . 97
    Sand bar monitoring . . . 102
    Changes in river regime . . . 112
    Hydrographic map of the Six Mile Pool . . . 115
Suggested preventive and remedial measures . . . 119
Summary and conclusions . . . 121
References . . . 126
Notations . . . 131
Appendices . . . 133

Hydraulics of Flow and Sediment Transport in the Kankakee River in Illinois

by Nani G. Bhowmik, Allen P. Bonini, William C. Bogner, and Richard P. Byrne

ABSTRACT

The hydraulics of flow and sediment transport in the Kankakee River in Illinois were investigated in a 2-year study. An historical review of the Kankakee River Basin over the last few hundred years showed the progression of river channelization in Indiana about 65 years ago and the behavior of the river in the straightened portion in Indiana and the nonstraightened portion in Illinois. An analysis of the historical data related to peak flows, average flows, and low flows for six gaging stations showed a trend of increasing peak flows at Shelby and Momence, with a similar trend of increasing average flows at Momence and Wilmington. Flow data from other stations did not show any trends. A comparison of the cross-sectional data between 1968 and 1978 for the main stem of the river in Illinois showed both deposition and scour at various places. An analysis of more than 300 bed material samples indicated that the median diameters of the bed materials of the river range in size from 0.2 to 0.4 mm.

Extensive suspended sediment, bed load, and water discharge data were collected and analyzed. Regression equations between water discharge and sediment discharge for all the stations have been developed. The river carries silt and clay during low flow periods, and sand and small quantities of silt and clay during high flow periods. During storm events, for a period of about 60 to 80 days, the river carries almost 70 to 80 percent of the yearly sediment load at all' the gaging stations. It is estimated that the river carried about 131,000 tons of sediment load at Wilmington in water year 1979. In relative terms, the Iroquois River watershed contributed more suspended sediment load per square mile of drainage area than the main stem of the Kankakee River. Bed load data collected at a few locations ranged from 1 to 2 percent of the total yearly suspended load at those stations.

A number of active sand bars have been surveyed, and one sand bar near the state line appears to be forming and crossing the state line once a year. The total amount of bed load moved as sand bar at the state line was about 9 to 14 percent of the total load at this location. A hydrographic map of the Six Mile Pool has been developed. A number of preventative and remedial measures to reduce the sediment load have been identified and outlined in the report.

INTRODUCTION

The hydraulics of flow in a natural stream and its sediment transport characteristics are the two basic phenomena that determine its geometric and plan form shape. There are many variables that affect the hydraulics of flow and the nature of sediment transport in a river. Any change or alteration in some of the main variables can generate a chain reaction that may be detrimental to the total system of "river flow." Streams and rivers are subjected to a number of man-made constraints, and sometimes the effects of these constraints may not show up for a long time.

The behavior, characteristics, and nature of streams are somewhat different depending upon whether they are flowing in a steep gradient, such as those found in the mountainous areas of the country, or in a flat terrain, such as those found in the Midwest. The materials through which a river flows, the characteristics of the watershed, the rainfall-runoff pattern from the basin, the constraints imposed by humans, and the geology of the watershed are some of the factors that determine the hydraulic and sediment transport characteristics of the river.

Many investigators have worked in this broad field of hydraulics of flow and sediment transport in streams. However, there has been very little research in which a comprehensive data collection program has been combined with a detailed analysis of the data. Most of the work has been fragmental, in that either the hydraulic data or sediment data were collected from one or two locations. The present research was undertaken to collect a set of precise hydraulic and geometric data from the Kankakee River Basin in Illinois at various locations to understand the mechanics of flow and the sediment transport capability of the river. This report will present some quantitative data regarding the sediment load in the river, hydraulic characteristics of the river, and its geometric shape. It will also present some historical analyses of the hydrology and hydraulics of flow in the river. Detailed data for this project were collected for a period of one year.

Plan of the Report

This report is divided into six main sections: Background Analysis, Historical Perspective, Data Collection, Analyses of Data, Suggested Preventive and Remedial Measures, and Summary and Conclusions. Also provided are listings of the references cited and the notations used. Appendices detail the basic data collected for the project.

Acknowledgments

This work was accomplished as part of the regular work of the Illinois State Water Survey and was initiated with the administrative guidance of William C. Ackermann, Chief Emeritus. When Chief Ackermann retired, the project was completed under the administrative guidance of Stanley A. Changnon, Jr., Chief.

The project was initiated when Richard J. Schicht, now Assistant Chief, was Head of the Hydrology Section. Mr. Schicht was extremely helpful during the early phases of the research and also added many valuable comments during the conduct of the project. He also reviewed the rough draft of this report.

Many Water Survey employees helped in the collection and analysis of the data. They are: Dave Kisser, Kevin Falk, Mike Demissie, Al Wehrmann, Steve Deckard, and Ming Lee.

The Division of Water Resources (DOWR) of the State of Illinois supplied the cross-sectional data for the river from Singleton Ditch to Kankakee. These data were collected by the DOWR in 1967-1968 and in 1977-1978. At the request of the Water Survey, the Division of Water Resources collected additional sounding data from 13 cross sections of the Six Mile Pool in the spring of 1978. Their cooperation and help are appreciated.

Personnel from the Champaign District Office of the U.S. Geological Survey collected sediment data from four gaging stations. Larry Toler, District Chief, and Tim Lazarro were helpful in arranging all the data collection programs for the four gaging stations. The U.S. Geological Survey Office at Indianapolis also supplied some flow and sediment load data for the Kankakee River in Indiana.

Most of the sediment samples collected by Water Survey personnel were analyzed by Daily Analytical Laboratories of Peoria. Some of the samples were analyzed by the Water Quality Section of the Water Survey.

Several graduate and undergraduate students from the University of Illinois worked on this project. They are: Rose Mary Roberts-Prelas, Perwez Shaikh, Niranjan Hoskote, and Tim Pilat.

The late Eugene Rudecki, Secretary of the Kankakee River Conservancy District, provided valuable assistance during the field data collection program.

Many citizens from the Kankakee and Momence area were very helpful and cooperative in the field data collection program, and the Kankakee *Daily Journal* was helpful in providing background materials related to the Kankakee River.

Dave Jones of the Illinois Institute of Natural Resources and engineers from the Illinois Division of Water Resources reviewed the rough draft of this report. Their comments and reviews are appreciated.

Many employees of the Water Survey were helpful in this project. Marcia Nelson and Adele Douglass helped in the library search; Pam Lovett and Pam Morrissey typed the rough draft; John Brother, Jr., William Motherway, Linda Riggin, Mary Carlson, and Tammy Stearns prepared the illustrations. J. Loreena Ivens made an editorial review and determined the format; Gail Taylor edited the report; and Marilyn J. Innes prepared the camera copy.

BACKGROUND ANALYSIS

This research deals with the hydraulics and sediment transport characteristics of a river basin. The basic mechanics of flow and the sediment transport mechanics must remain valid for any river flowing through alluvial materials. Thus, this section of the report discusses the theoretical background regarding flow hydraulics and sediment transport mechanics, and it is followed by a section that presents an historical perspective of the Kankakee River.

Flow Hydraulics and Sediment Transport

Most of the major rivers of the world flow through alluvial materials consisting mainly of sand and silt. The flow of water in these alluvial channels has been studied by various researchers for many years. In a sand bed channel, the flow velocity, the turbulence associated with the flow velocity, and the patterns of the secondary circulation all have the capability and the opportunity to mold the shape of the channel. Researchers have tried to express the characteristics of flow in alluvial channels in terms of theoretical relationships. In many instances their attempts have been successful, whereas others have met with failure. The flow in a natural channel, however, is obviously affected by so many variables that a clear, straightforward analysis is not possible unless one resorts to some acceptable simplifications and assumptions.

As a result of all the constraints in an alluvial channel, a velocity distribution with both lateral and vertical components is developed. These velocity components vary in time and space. The longitudinal water surface slope, or the hydraulic gradient, also constantly adjusts to reflect the constraints of the channel geometry on the flow in a natural channel. This variability of the water surface profile is more pronounced for flow around a bend than it is for a straight reach of the river.

Bed Form and Flow Resistance

Flow resistance in an alluvial channel is a function of many variables (Simons and Richardson, 1971). Some of the important variables are: velocity V, depth D, slope of the energy grade line S_e, density of the water-sediment mixture p_f, dynamic viscosity of the water-sediment mixture μ, gravitational constant g, fall diameter of the bed material df, standard deviation of the particles a, shape factor of the particles S_p, shape factor of the reach of the river S_R, shape factor of the cross section of the river S_c, and seepage force on the bed of the river f_{ss}.

These variables in turn will determine the bed form in an alluvial channel flowing on a sand bed. The bed forms that may be present in an alluvial river can be classified into eight categories. These bed forms are shown in figure 1 (Simons and Richardson, 1971) for bed materials having a median diameter d_{50} less than 0.6 mm. Whenever the median diameter is more than 0.6 mm, dunes will form rather than ripples after the bed materials begin to move.

The first three bed forms shown on the left side of figure 1 are called "lower flow regime." The last bed form on the left side is called "washed-out dunes" or the transition zone, and the four bed forms on the right side are called "upper flow regime." Table 1 shows the classification of bed forms under different conditions.

In the lower flow regime, the resistance to flow is large and sediment transport is small. For most of the stable channels formed in alluvial materials, the dominant feature of the bed form is "dunes with ripples superimposed." Total resistance to flow is a function of the bed roughness. On the other hand, in the upper flow regime, the resistance to flow is small, the sediment transport is large, and the Froude number F is usually greater than 1. The Froude number expresses the ratio between the inertial force and the gravitational force and is given by equation 1.

$$F = V/(gD)^{1/2} \qquad (1)$$

The flow passes through a critical stage whenever the numerical value of F is 1.

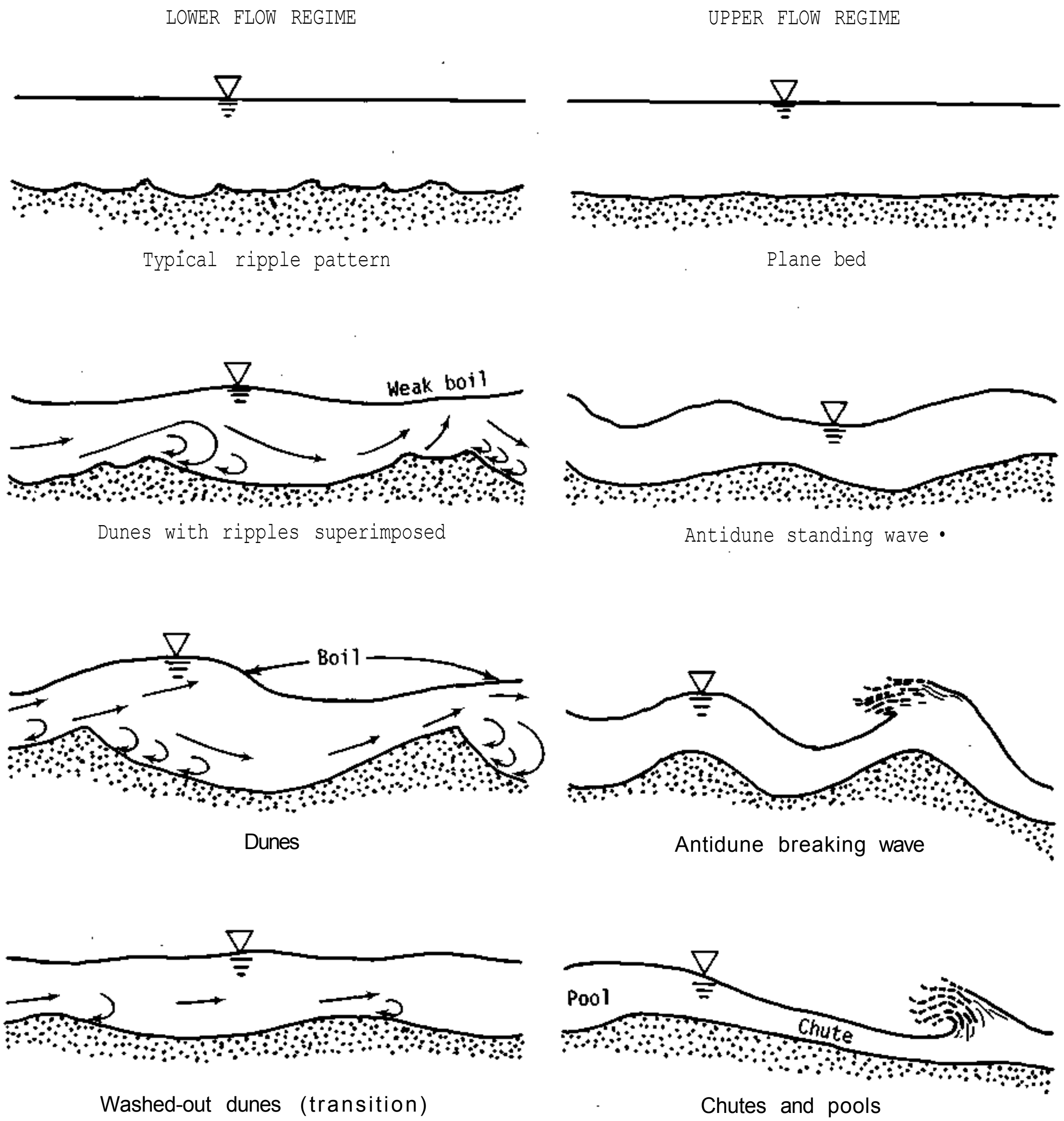


Figure 1. Typical bed forms in an alluvial sand bed channel

Table 1. Classification of Bed Forms and Other Information*

Bedform	*Bed material concentrations (ppm)*	*Mode of sediment transport*	*Type of roughness*	*Roughness* $C_f/\sqrt{g}$ **
Lower Flow Regime				
Ripples	10-200			7.8-12.4
Ripples on dunes	100-1,200	Discrete steps	Form roughness	
Dunes	200-2,000		predominates	7.0-13.2
Transition				
Washed-out dunes	1,000-3,000		Variable	7.0-20.0
Upper Flow Regime				
Plane beds	2,000-6,000		Grain	16.3-20
Antidunes	2,000+		roughness	10.8-20
Chutes and pools	2,000+	Continuous	predominates	9.4-10.7

**From Simons et al., in Graf (1971)*
***C_f is Chezy's Coefficient*

In a sand bed channel the bed forms that can develop for any flow condition may or may not remain the same across the whole width of the channel. In some instances the bed form can be a combination of ripples, dunes, or plane and dunes as one passes from one side of the river to the other (Simons and Richardson, 1971). This was observed in a large river during low flow stages. The median diameter d_{50} of the bed material was 0.17 mm.

Turbulent flow in a rigid boundary open channel is independent of the viscous drag, i.e., the viscosity of the water has a minimal effect on the flow resistance in the channel. However, this is not really true in the case of flow in alluvial streams with sediment movement. Here the viscosity of the fluid may change because of the change in water temperature or the change in the concentration of fluid-sediment mixture. This change in viscosity may change the bed form, which in turn will change the resistance to flow. Thus, a sand bed channel that has a dune bed during summer or fall may change to a plane bed during the late fall as the temperature decreases. This was found to be true for the Missouri River between Sioux City, Iowa, and Omaha, Nebraska (U.S. Army Corps of Engineers, 1968), where the average depth decreased by about 1 foot for the same discharge when the temperature dropped by about 31 degrees Fahrenheit in a period of 1 month. The bed form was found to have changed from dune bed to plane bed, indicating a decrease in the magnitude of the resistance to the flow.

This short analysis indicates that the determination of the resistance to flow in an alluvial sand channel is a very complex subject. The true effects of the various variables are not yet fully understood. Attempts have been made by a number of investigators to estimate a resistance coefficient for flow in an open channel. One of the simplest equations is the Darcy-Weisbach formula (Chow, 1959), developed for flow in pipes. The Darcy-Weisbach friction factor f is given by equation 2.

$$f = 8gRS_e/\overline{V}^2 \quad (2)$$

where R is the hydraulic radius and V is the average flow velocity. Equation 2 can also be written as

$$f = 8V_*^2/\overline{V}^2 \quad (3)$$

where V_* is the shear velocity and is equal to $(gRS_e)^{1/2}$. By manipulating equation 3 one can obtain

$$\bar{V}/V_* = (8/f)^{1/2} \tag{4}$$

Simons and Richardson (1971) have indicated that the variables S_e, D, df, ω, g, and p_f will determine not only the magnitude of f but also the bed configuration in an alluvial sand bed channel. Here Ω is the fall velocity of the bed materials, and the other variables are as defined previously.

Two of the most widely used equations, called uniform-flow formulas, are used to compute the average velocity in a stream when hydraulic and geometric characteristics are either estimated or measured in the field. Chezy's formula is given by equation 5.

$$\bar{V} = C_1 (RS_e)^{1/2} \tag{5}$$

where C_1 is a factor indicating the resistance to flow and is called Chezy's C_1 . Equation 5 can be modified as follows.

$$\bar{V} = [C_1/(g)^{1/2}](gRS_e)^{1/2} = [C_1/(g)^{1/2}]V_*$$

Therefore, $\bar{V}/V_* = C_1/(g)^{1/2}$, and from equation 4 we obtain

$$\bar{V}/V_* = C_1/(g)^{1/2} = (8/f)^{1/2} \tag{6}$$

Equation 6 indicates that Chezy's C_1, Darcy-Weisbach friction factor f, and the ratio of the mean velocity to the shear velocity are all interrelated.

Manning's equation given by equation 7 below is one of the most widely used equations in river hydraulics around the world.

$$\bar{V} = (1.49\, R^{2/3} S_e^{1/2})/n \tag{7}$$

where n is the coefficient of roughness and is also called Manning's n. Comparison of equations 5 and 7 indicates that Chezy's C_1 is related to Manning's n by equation 8.

$$C_1 = (1.49R^{1/6})/n \tag{8}$$

Therefore,

$$C_1/(g)^{1/2} = (1.49R^{1/6})/n(g)^{1/2} = \bar{V}/V_* = (8/f)^{1/2} \tag{9}$$

It must now be clear that all the resistance-to-flow equations described so far are related to one another in some way.

Over the last 50 to 70 years researchers have worked to determine the numerical values of n for anticipated flow conditions in open channels. Chow (1959) has summarized most of the research work that was done through the mid-1950s. He has shown a number of photographs of flow in open channels with corresponding n values. Barnes (1967) also has compiled a list of n values for flow conditions in channels of varied characteristics, which are shown by color photos of the flowing stream.

Incipient Motion

Motion of the bed material begins when the hydrodynamic forces exerted on the individual particles are large enough to dislodge the particles from the bed. There are three modes of transport: 1) translation, 2) lifting, and 3) rotation. Translation is defined as the movement of the bed particles in a sliding motion. Because of an imbalance of the fluid forces, the bed particles are sometimes lifted off the bed and may be entrained in the main body of the water. That is when particles are said to be transported by lifting. Whenever the lifting forces are not enough to lift the particles out of

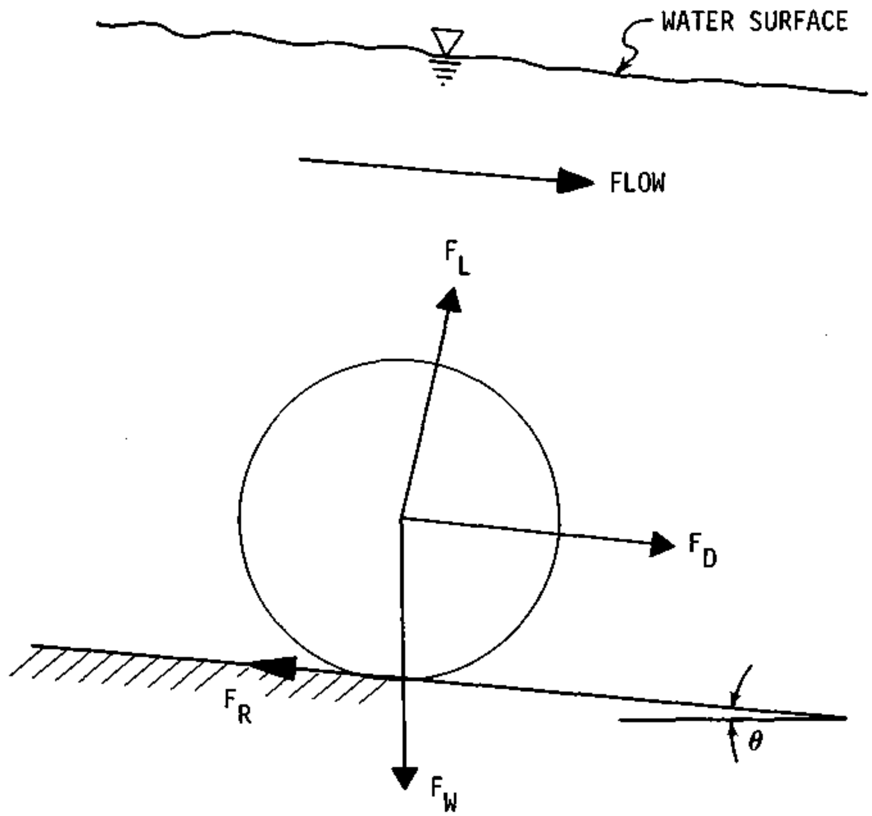


Figure 2. Simple force balance on a particle on the bed of a stream (not to scale)

the bed and the gradient of the bed is just right, the particles may move in the downstream direction just by rotating on the bed due to the fluid forces. This mode of transport of the sediment is called rotation.

Figure 2 is a simple diagram for cohesionless, loose, solid particles on the bed. Here, F_D is the drag force; F_L is the lift force; F_w is the submerged weight of the particle being considered; F_R is the bed resistance force; and *d* is the angle the bed makes with the horizontal. In the simplest analysis, whenever the component of the resultant of F_w and F_R parallel to F_D is less than the value of F_D, the particle will start to move or translate in the downstream direction. Thus for translation to occur, an imbalance between resistance forces and frictional forces is implied. However, in order for rotation of the particle to occur, moments taken around the point of contact between the particle and the bed have to be unequal. A particle will lift upward whenever F_L is greater than the resultant component of all the forces acting in the opposite direction from F_L.

In a real life situation, interparticle forces, seepage forces, and wave forces must be considered. In an analysis of the stability of particles on the bed of a stream, all these forces should be considered, their relative magnitudes estimated, and stability parameters developed. Such an analysis was done by Bhowmik (1968).

In an alluvial stream, all the above forces may act on the bed particles. Sometimes a particle may be lifted out of the bed and the higher velocity water may carry it in the downstream direction, keeping it in suspension. At other times, the drag force may be high and the particle either rolls or translates in the downstream direction. In a sand bed channel, the drag force may be the dominant force that moves the bed particles, whereas for an alluvial stream flowing on a bed of coarse particles, the lift force may be the dominant force in moving the bed particles.

The number of particles involved in the motion of a stream bed is enormous, and looking at the motion of individual particles becomes impossible. In 1936, Shields chose to look at the sediment particles in aggregate rather than individually (Graf, 1971). Shields applied the concept of shear velocity in obtaining a representative flow velocity. Using particles of uniform grain size on a flat bed, Shields plotted dimensionless shear stress as a function of boundary Reynolds number (figure 3). This functional relationship is

$$\tau_c/[(\gamma_s - \gamma_w)d_s] = fct(d_s V_*/\nu) \tag{10}$$

where τ_c is the critical shear stress, γ_s is the unit weight of sediment, γ_w is the unit weight of water, d_s is the representative size of the bed particle (usually taken to be d_{50}), and ν is the kinematic viscosity of water. The term d_{50} indicates that size of the bed particles of which 50 percent are finer.

Because of the statistical nature of both turbulence and the distribution of particle shapes and sizes, the beginning of motion is hard to define. In general, smaller particles are moved first. Turbulent fluctuations may cause the shear force at a point for a particular instant to be higher, thus making it possible to move a larger particle. Also of significance is the length of the period of fluctuations as compared to the response time of the particles (Lane and Kalinske, 1939). For example, if a particle has a large response time, a turbulent fluctuation of short duration will not cause motion.

Shields arbitrarily used a mean critical shear stress to represent the general beginning of motion. The value chosen was large enough to exclude the intermittent motion of individual particles before general movement occurs. Because of the observations just stated concerning the statistical nature of turbulence and particle distribution, Grass suggested that Shields' curve is not unique, but only one of a family of curves depending on the flow boundary conditions (Grass, 1970).

Once the critical condition for motion has been reached, no particle will remain continually in motion. A continuous exchange between particles in motion and the bed occurs even at advanced stages of transport. At advanced stages of transport, grain diameter d_s is no longer a good representation of the bed roughness. The influence of bed forms on the sediment motion needs to be considered (Brown, 1950).

There have been many attempts to modify and improve the work of Shields. Gessler (1971) modified Shields' curve, removing the increase in critical shear stress due to the existence of bed forms. Shulits and Hill (1968) divided Gessler's modifications into four regions and developed an equation for each region. Lane (1955) used a considerable amount of field data and developed a critical shear stress diagram summarizing the results of most important studies. Lane's work points out that the critical shear stress for clear water is considerably lower than that for water-sediment mixtures. Chien (1954) has compared many of the critical shear stress formulas, showing that the

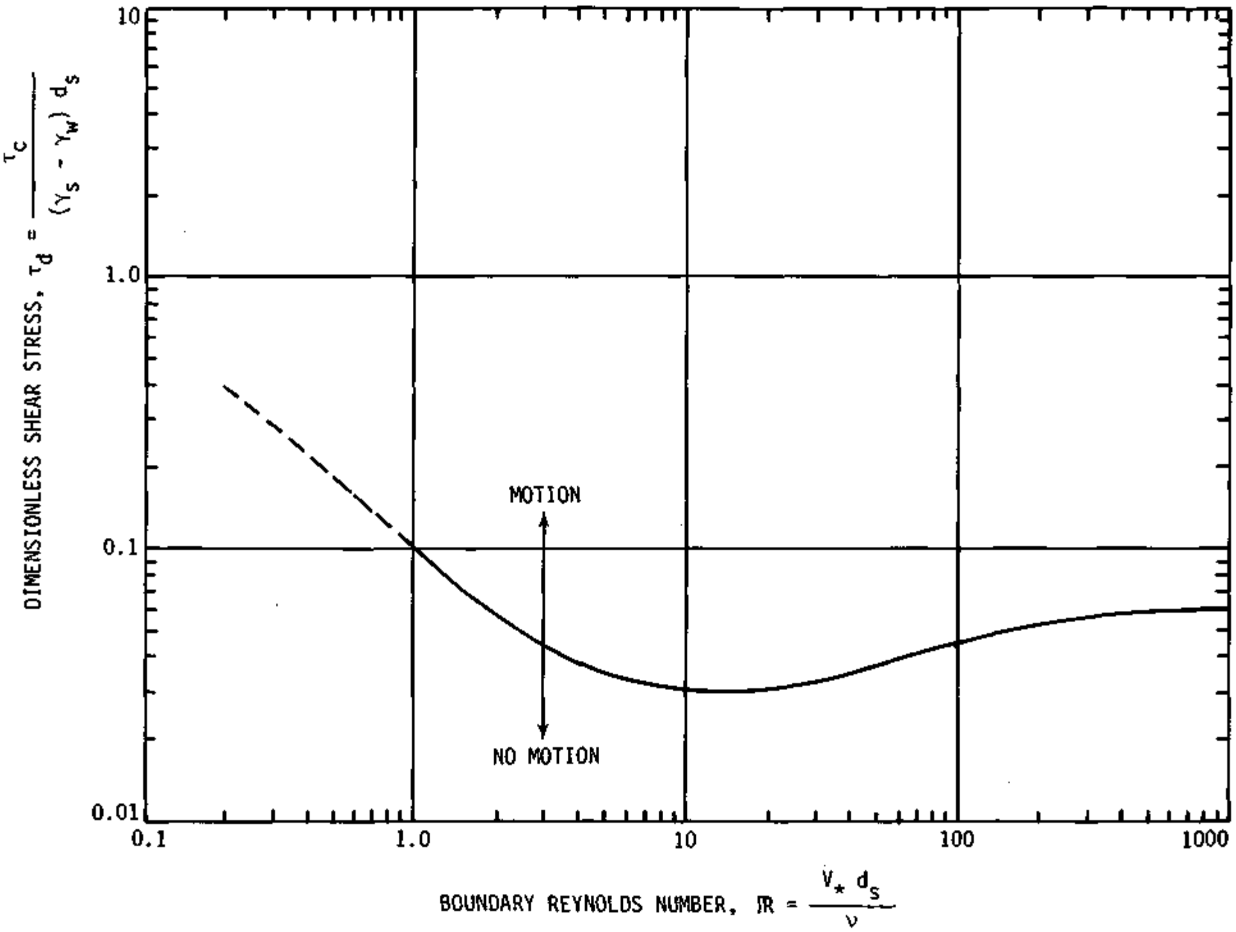


Figure 3. Shields' diagram

differences in them are due to the various definitions of critical shear stress used by different researchers.

Sediment Load

For the purpose of analysis, the total sediment load is often split into two parts: bed load and suspended load. Bed load is defined as that sediment in the bed layer moved by saltation (jumping), rolling, or sliding. The bed layer is a flow layer several grain diameters thick immediately above the bed. The bed layer thickness is usually taken as 2 grain diameters (Einstein, 1950). Suspended load is defined as that sediment load that is moved by upward components of turbulent currents and that stays in suspension for a considerable time.

There is no sharp division between saltation and suspension. The distinction is made between the two different methods of hydraulic transport: movement due to shear force and movement due to suspension (Simons and Senturk, 1977).

Bed Load. There are many bed load equations that can be used to predict sediment transport rates of different grain sizes. These equations predict the transport capability of the stream, which generally equals the available supply of sediment from the upslope. Whenever the supply of sediment is less than the transport capability of the stream, the transport capacity of the river will exceed the available supply. In such an instance, bank erosion or bed scour may occur.

There are essentially three slightly different but related approaches to the bed load problem. They are: 1) the du Boys-type equations, considering a shear stress relationship; 2) the Schoklitsch-type equations, considering a discharge relationship; and 3) the Einstein-type equations, based upon statistical considerations of the lift force (Graf, 1971). A discussion of these three approaches follows.

In 1879, du Boys (Graf, 1971) assumed that sediment moves in m layers of thickness d' because of the shear stress τ_o acting on it. The bottom layer is the layer in which the shear force balances the resistance force between layers.

$$\tau_o = C\mu \, md' (\gamma_s - \gamma_w) \tag{11}$$

where $C\mu$ is the coefficient of friction and the other variables are as previously defined.

Du Boys assumed a linear velocity distribution between the bottom and mth layers. At the critical condition $m = 1, \tau_c = (1/m)\tau_o$, which leads to the equation given below for bed load discharge per unit width q_b of the stream.

$$q_b = \chi \tau_o [\tau_o - \tau_c] \tag{12}$$

where χ is a characteristic sediment coefficient defined as

$$\chi = d'V_s/2(\tau_c)^2 \tag{13}$$

and V_s is the velocity increment between sediment layers.

For equation 12 to be used properly, the characteristic sediment coefficient χ needs to be determined correctly. Several researchers have developed empirical relationships for χ. Schoklitsch (1914) developed a relationship between x and γ_s for uniform grains of various sizes of sand. Donat (Graf, 1971) analyzed work by Gilbert (1914), and Straub (Graf, 1971) analyzed work by other researchers. Both of them found a definite relationship between x and grain size d_s. Chang (1939) suggested that x could be expressed as a function of Manning's roughness coefficient n. Chang, Simons, and Richardson (1967) showed a functional relationship between x and the angle of repose ϕ of the bed material.

O'Brien and Rindlaub (1934) and the U.S. Waterways Experiment Station (1935) independently generalized du Boys' equation and obtained equation 14 given below.

$$q_b = \chi' [\tau_o - \tau_c]^{m_1} \tag{14}$$

where χ' is a function of median diameter and Manning's n, and m_1 is a function of median diameter. The U.S. Waterways Experiment Station (1935) showed that for sand with $0.025 < d_s < 0.560$ mm, the range of m_1 is $1.5 < m_1 < 1.8$.

Shields (Graf, 1971) developed a dimensionless relationship of the same general form as du Boys' equation. This semi-empirical equation is given by equation 15.

$$[q_b(\gamma_s - \gamma)]/(qS_e\gamma) = 10[(\tau_o - \tau_c)/(\gamma_s - \gamma)d_s] \tag{15}$$

where q is the water discharge per unit width and all other parameters are as previously defined. The factor of 10 was empirically determined and reflects the range of scatter.

Kalinske (1947) considered the effect of turbulence on bed load motion. He developed a dimensionless form of the bed load equation given by equation 16.

$$q_b / V_* d_s = fct(\tau_c / \tau_o) \tag{16}$$

Schoklitsch (1914) proved du Boys' theory of sliding layers to be wrong, but his experimental data could be well represented by du Boys' equation. In addition, Schoklitsch stated that the average bed shear stress is a poor criterion when applied to field computations because the shear distribution across the channel cross section is quite non-uniform. He suggested an equation for bed load of the form given by equation 17.

$$q_b = \chi''(S_e)^k (q - q_c) \tag{17}$$

where χ'' is a new characteristic sediment coefficient, q_c is the water discharge at which the material begins to move, and k is an empirically determined exponent. Just as du Boys' equation related bed load movement to excess shear stress $(\tau_o - \tau_c)$, Schoklitsch's equation relates bed load movement to excess power designated by $(q - q_c)$.

Schoklitsch (1914) empirically determined $k = 3/2$ and developed a relationship between χ'' and grain size d_s. The critical discharge q_c was determined to be a function of both grain size and energy slope S_e.

The bed load relationship developed by MacDougall (1934) can be rearranged to be of the same form as equation 17 with $1.25 < k < 2.0$. Gilbert (1914) also came up with an equation similar to equation 17 based on his experimental data.

Recently, Barekyan (1962) proposed a bed load equation using average velocity $\bar{V}$. His equation is given below.

$$q_b = 0.187\, \gamma [\gamma_s / (\gamma_s - \gamma)]\, q\, S_e [(\bar{V} - \bar{V}_c)/\bar{V}] \tag{18}$$

where $\bar{V}_c$ is the average critical velocity and the other terms have already been defined. Earlier, Forchheimer (1914) and Donat (Graf, 1971) developed equations of similar form, using du Boys' equation and expressing the average velocity according to Chezy's equation.

Du Boys-type equations and Schoklitsch-type equations, although developed independently from different concepts, are actually not independent. They can be related through the use of Manning's, Chezy's, or similar open channel flow equations. The empirical constants that are developed are functions of Manning's n, Chezy's C_1, the distribution of sediment particles, and the properties of the particles. Before a particular bed load equation is used, the assumptions and conditions for which it was developed should be compared to the situation being analyzed.

The work of Einstein (1942, 1950) differed considerably from the earlier work of du Boys and Schoklitsch. The two major differences are: 1) the critical condition criterion is avoided, since this condition is very difficult to define; and 2) bedload transport is related to fluctuations in velocity (turbulence) rather than to average velocity. From experiments, Einstein found that a steady and intensive exchange of particles exists between the bed material and the bed load. Particles move along the bed in a series of quick steps with relatively long rest periods between steps. For stable conditions, the rate of deposition must equal the rate of erosion.

The concept on which Einstein developed his bed load function is described as follows: The number of particles of a given grain size that are deposited over an area is dependent on the rate at which the given grain size moves through the area, the particle size, and the particle weight. The number of particles of a given grain size that are eroded depends on both the availability of that particle size and on the turbulence of flow. Einstein related the exchange time between the bed and bed load to the particle fall velocity. In addition, the probability of a particle eroding, p, was related to the step length.

Setting the rate of deposition equal to the rate of erosion yields a relationship for the probability of erosion. Since the probability of erosion depends on the hydrodynamic lift and particle weight, Einstein developed and plotted a functional relationship between these forces and particle characteristics. This relationship is given by equation 19.

$$A_* \Phi_* = fct(B_* \psi) \tag{19}$$

where

$$A_* = (k_1 k_3)/(k_2 \lambda)$$

$$\Phi_* = (i_s/i_b)(q_b/\gamma_s)\{[\rho/\rho_s - \rho)] (1/gd_s^3)\}^{½} = (i_s/i_b)\Phi$$

$$B_* = k_2/C_L k_1 67.5$$

$$\psi = [(\rho_s - \rho)/\rho](d_s/SR_h')$$

Here i_s is the fraction of bed load in a given grain size, i_b is the fraction of bed sediment in a given grain size, ρ is the density of water, ρ_s is the density of sediment, λ is a constant with a value of about 100, S is the gradient, and R_h' is the hydraulic radius with respect to the grains (which is the only part of the hydraulic radius affecting sediment transport). C_L is a lift coefficient, and k_1, k_2, and k_3 are particle shape factors. For spherical particles $k_1 = k_2 = \pi/4$, and $k_3 = \pi/6$. All other parameters were defined previously. A_* and B_* are constants to be determined experimentally.

Later, Einstein (1950) replaced his empirical relationship ψ with an analytical relationship ψ_*, developed from the law of logarithmic velocity distribution. Values of $A_* = 43.5$ and $B_* = 0.143$ were obtained from data of Gilbert (1914) and Meyer-Peter et al. (Graf, 1971). Brown (1950) modified Einstein's approach and developed a functional relationship between Φ and $1/\psi$, which is similar to Shields' relationship.

It must be stated here that bed load is hard to define. All bed load equations are empirical or semi-empirical in nature and have some similarities. When these equations are applied, care should be taken to limit their use to similar flow conditions and particle characteristics. The above equations involve many constants that were determined experimentally, and the appropriate reference should be consulted to determine under what conditions they apply.

Suspended Load. Suspended load is defined as that sediment surrounded by fluid that stays in suspension for an appreciable length of time. Sediment particles settle because of their weight, but fluid turbulence counterbalances this motion. Just as there exists an active exchange betwen bed material and bed load, there is an active exchange between bed load and suspended load.

The suspended load per unit width of channel q_s is

$$q_s = \gamma_s \int_a^D \overline{V}\,\overline{C}\,dy \tag{20}$$

where V and C are the time averaged velocity and concentration distributions, and a is the thickness of the bed layer. The total suspended load for a stream can be obtained by integrating equation 20 across the width of the stream.

For stable conditions the amount of sediment settling must be counterbalanced by upward sediment flow due to diffusion. Therefore

$$\omega C + \epsilon_s(dC/dy) = 0 \tag{21}$$

where ω is the particle fall velocity, ϵ_s is the sediment diffusion coefficient, C is the concentration of sediment, and y is the depth of water from the bed. Integrating equation 21 yields

$$C = C_a \exp[-\omega \int_a^y (dy/\epsilon_s)] \tag{22}$$

where C_a is the concentration of sediment with fall velocity ω at a level "a" above the bed (O'Brien, 1933).

Rouse used the fact that the sediment diffusion coefficient is equal to a constant times the momentum diffusion coefficient (Jobson and Sayre, 1970) to develop equation 24 given below. Using the Prandtl-von Karman velocity relation

$$\epsilon_s = \beta\kappa V_*(y/D)(D-y) \tag{23}$$

Equation 22 becomes

$$C/C_a = \{[(D-y)/y]\ a/(D-a)\}^{z_1} \tag{24}$$

where

$$z_1 = \omega/\beta\kappa V_* \tag{25}$$

Here β is a constant and κ is the von Karman constant (Rouse, 1937). Several researchers have shown that for fine particles $\beta = 1$ (i m p l $\epsilon_s = \epsilon_m$) and for coarse particles $\beta < 1$. Einstein and Chien (1954) established a relationship of β with particle size. Von Karman's constant κ is equal to 0.4 in open channel flow without sediment but is reduced for sediment laden flow (Vanoni and Nomicos, I960; Einstein and Chien, 1954). In general, many researchers have found agreement with equation 24, but the values of z_1 have been determined by fitting the data and not from theory. Equation 24 is used in equation 20 to determine q_s.

Lane and Kalinske (1941) assumed $\beta = 1$ and $\kappa = 0.4$ and determined a vertically averaged sediment diffusion coefficient. They developed the equation

$$C/C_a = \exp\{-(15\omega/V_*)[(y-a)/D]\} \tag{26}$$

which worked well for field data mainly from wide channels. Equation 20 can be integrated directly with equation 26. The results are

$$q_s = qC_aP_L \exp(15\omega a/DV_*) \tag{27}$$

where P_L is the ratio of $\overline{C}$ to C near the bed.

Einstein (1950) developed a method for computing suspended load, assuming $\beta = 1$ and $\kappa = 0.4$. He replaced the overall shear velocity V* with the shear velocity due to grain roughness only. He also obtained the reference concentration C_a from the relationship between bed load and suspended load. Brooks (1963) assumed the velocity defect relation and obtained an equation similar to Einstein's relationship. Einstein and Abdel-Aal (1972) modified the Einstein method to consider the effects of suspended sediment on κ.

Chang et al. (1967) applied a velocity distribution obtained from Prandtl's mixing length theory to determine

$$C/C_a = A_1\ \{(y/D)^{1/2}/[1-(1-y/d)^{1/2}]\}^{2z_1} \tag{28}$$

where $A_1 = \{[1 - (1 - a/D)^{½}] / (a/D)^{½}\}^{2z_1}$. Chang et al. then used equation 28 in equation 20 to obtain the suspended load.

When attempting to determine the suspended load one must remember that only the suspended load due to bed material is calculated from the above equations. Wash load is determined by available upslope supply rate.

Total Load

The total load can be obtained from the sum of the bed load and suspended load. Some researchers have done work on obtaining total load directly, and not as a sum of two components. Actually the total load that can be predicted is the total bed material load, which is made up of particle sizes that can be found in the bed. The wash load is made up of particles finer than those found in the bed and is dependent on the supply available from the watershed.

Einstein (1950) developed a relationship for total load that combined his equations for bed load and suspended load discussed previously. Colby and Hembree (1955) modified Einstein's procedure to utilize field measurements of velocity and suspended sediment. Since measured values of suspended sediment are used in the modified Einstein procedure, this methodology gives the total load including wash load. Toffaleti (1969) based his work on that of Einstein (1950) and Einstein and Chien (1954). He developed a procedure for determining total load by replacing the actual channel dimensions with an equivalent rectangular channel and at the same time dividing the depth into four regions.

Bagnold (1966) developed an equation for total load based on the concept of energy balance by combining relationships he developed for bed and suspended load. Chang et al. (1967) determined total load by integrating expressions for bed and suspended load across the width and summing the results. They used a du Boys-type equation for the bed load and an equation similar to Einstein's for suspended load.

Lane and Kalinske (1941) used their equation for suspended sediment to predict total load by selecting the reference point at the bed ($a = 0$). Laursen (1958) chose a direct approach to determining total load by developing a functional relationship between sediment discharge and flow condition.

Colby (1957) developed a relation similar to but much simpler than the modified Einstein procedure. He developed semi-empirical relationships dependent on the same field measurements necessary for the modified Einstein procedure. Bishop et al. (1965) also modified Einstein's approach by reasoning that the shear intensity parameter ψ can be used to predict the intensity of bed material transport. More recently, Shen and Hung (1971) developed a relationship for total load using regression analysis. They assumed that since the transport phenomenon is so complex, it is better to use a regression analysis of all available data than to try to describe sediment motion under all conditions.

Still, the question remains of how to determine the total load if some field data are available. If the hydraulic and the suspended sediment load data are available, the total suspended sediment load can be computed. In many instances, especially in the case of streams flowing on sandy beds, it is easy to measure the suspended sediment load. However, the present instrumentations are not yet well enough developed to measure the bed load. For cases such as these, an empirical relationship is needed to determine the total load based on the hydraulic data and the measured suspended sediment load. Simons and Senturk (1977) have indicated that for a large and deep river, the amount of bed load may be about 5 to 25 percent of the suspended load. Total bed load may be small in these rivers, but is important since bed load influences the bed stability and determines the bed and grain roughness of the channel.

HISTORICAL PERSPECTIVE

Early Period

The Pottawatomi Indians called the Kankakee River Ti-yar-ac-ke, "wonderful land." The French had a variety of names for it, includingThe-a-ki-ki and Quin-que-que. The contemporary name for the river, Kankakee, appears to be an English version of this later French word (Paddock, 1883; Houde and Klasey, 1968).

The first white men to descend the Kankakee River were the French explorers De La Salle and Father Hennepin in December 1679. They explored its entire length after portaging from the St. Joseph River (Houde and Klasey, 1968). The river they found looked far different from the one that exists today. The present plan view of the river is shown in figure 4.

Their point of entry was near present day South Bend. From there, down to what is now Momence, Illinois, De La Salle's party wound its way through more than 240 miles of a marshy, sandy maze of meanders, oxbows, and sloughs that were teeming with a variety of wildlife. This area would later become known as the "Grand Marsh" (Morrison, 1976). Downstream, below a limestone outcropping at Momence, the river had higher gradient and probably appeared much the same as it does today.

Around the time of De La Salle's expedition, the Kankakee River was inhabited by the Pottawatomi Indians who took full advantage of the marsh and established winter residence there. They hunted, fished, and trapped the various forms of wildlife that were found in abundance. The marsh was also relied upon as a natural refuge from the fierce Iroquois nation (Morrison, 1976).

Soon after the French explorers passed along the Kankakee, the hunters, trappers, and traders began to arrive. These were the first white men to inhabit the area. They lived a life similar to that of the Pottawatomi, spending the winter months harvesting some of the tens of thousands of waterfowl and furbearing animals that inhabited the Grand Marsh. As more white people began to establish themselves in the Kankakee Basin, it became apparent that there would no longer be a place for the Pottawatomi Indians. The Federal Government formalized this transition through the treaties of 1832 and 1836 (Meyer, 1936).

Pioneer settlers began to arrive during the early part of the 1800s. Their presence began to establish the primary features along the Kankakee River as we know them today. Gurdon Hubbard, a fur trader and one of the first to settle along the Kankakee River, established a trail between Chicago and Danville that crossed the Kankakee at a shallow ford about one mile upstream from where Momence is now located. This site was one of two practical places to cross the river at that time. It was called Upper

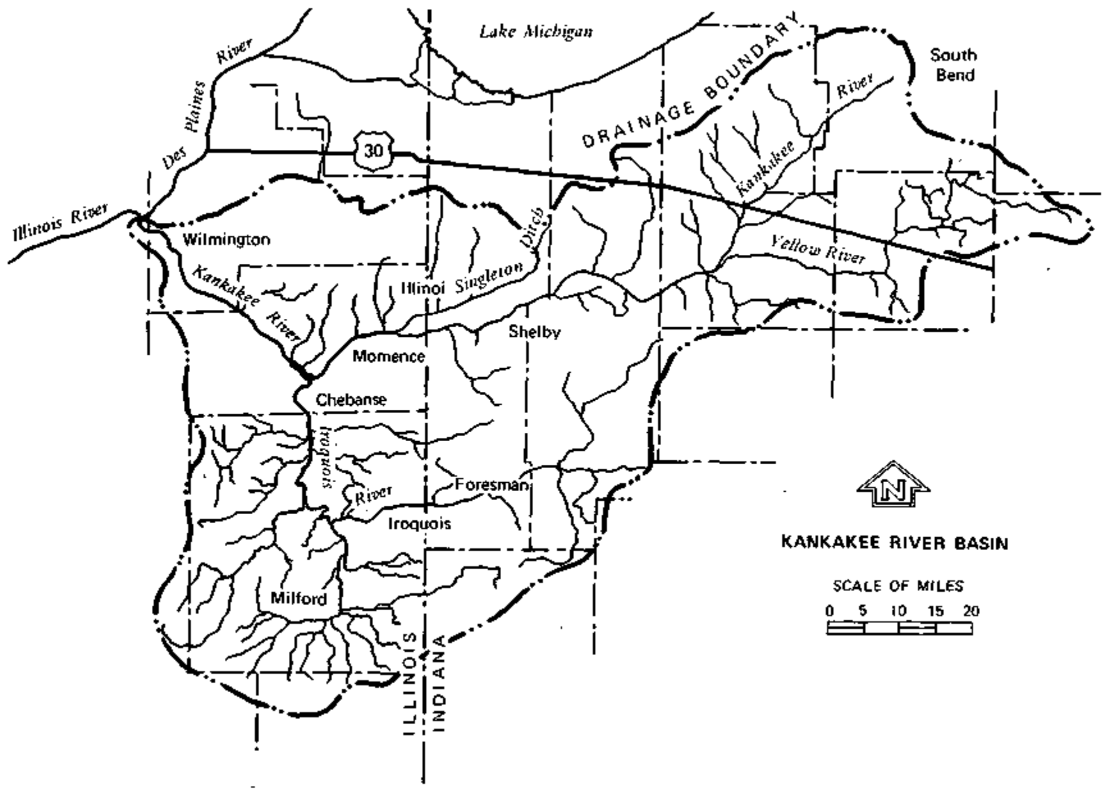


Figure 4. Kankakee River Basin

Crossing or Hill's Ford. The other ford site, located about a mile downstream, was called Lower Crossing. The two became centers for traffic, joining the northern and southern portions of the basin (Houde and Klasey, 1968; Morrison, 1976).

In the 1840s a bridge was built at Upper Crossing, but it was twice destroyed by ice jams. The establishment of the town of Momence at the Lower Crossing and the destruction of the bridge caused the Upper Crossing to disappear (Houde and Klasey, 1968; Morrison, 1976).

Momence was only one of a series of settlements that developed along the Kankakee River and the fringes of the Grand Marsh in the early 1800s (Houde and Klasey, 1968). At that time they were rugged pioneer settlements inhabited by people who adjusted to the restrictions and limitations of their environment (Meyer, 1936). In addition, the marsh was home to the frontier trapper and hunter as well as a hideout for counterfeiters, outlaws, and horse thieves (Morrison, 1976). The growth of these communities, along with the establishment of the prairie farmer, had an irreversible impact upon the river.

By the mid-1800s, a distinct metamorphosis had occurred. A new breed of individual was becoming a dominant force in the area. These people wanted to exploit the lands and natural resources surrounding the Kankakee River and marsh. They were the logger, the sportsman, the stock farmer, and any others who could find something of commercial value on the river or in the marsh (Meyer, 1936).

The first persons to utilize the Kankakee River were those that valued it as a source of power. These individuals built dams and mills for processing grains and cutting timber. Their mills were usually associated with the settlements along the river (Houde and Klasey, 1968).

Long before the pioneer settlers arrived, the Kankakee River had been used as a means of transportation. The advent of the railroad and the increasing demand for an inexpensive means of transporting raw materials to the marketplace made riverboat traffic increasingly popular. There were flatboats, sternwheelers, and steamboats. They traveled upstream of Momence and into the marsh, carrying sightseers, hunters, and cargo (Houde and Klasey, 1968; Morrison, 1976). They traveled downstream to Kankakee and the railroad, or down to the Illinois and Michigan Canal and to Chicago with their barges loaded with farm products (Houde and Klasey, 1968).

The Kankakee Company, formerly known as the Kankakee and Iroquois Navigation and Manufacturing Company, was formed around 1871 to increase and improve riverboat traffic along the Kankakee River. It proposed to open the Kankakee and Iroquois Rivers to boat traffic for 170 miles (70 miles in Indiana). The plan called for building a series of locks and dams that would create a slack water navigational channel with a minimum water depth of 5 feet to connect commercial traffic with the Illinois and Michigan Canal and Chicago. The dams were also to be used to generate water power (Kankakee Company, 1871). The only part of the river where this plan became a reality was a 33-mile stretch upstream from the confluence with the Illinois River. Later, most of these locks and dams were destroyed and never replaced (U.S. House of Representatives, 1916).

The Kankakee River was also a source of recreation for the residents along the river and for vacationers from Chicago. There was ice skating in the winter and swimming, picnics, and boat rides in the summer (Houde and Klasey, 1968).

The 1870s marked the arrival of another business dependent upon the river for its product: several companies were organized to harvest the ice that formed on the river. The clear waters of the Kankakee, combined with the usually cold winters, created a layer of clear ice that measured as much as 18 inches thick. At times, more than 60,000 tons of this ice were harvested in a single season (Houde and Klasey, 1968).

The thick, clear ice that formed every winter was more than just a source of profit for the ice companies. Every spring it became a potential source of destruction and economic loss. Ice jams and flooding were common occurrences along the Kankakee River. Early settlers' accounts suggest that during the early 1830s flooding that occurred near the city of Kankakee sent flood waters out to the lower end of the area where the downtown is now located (Houde and Klasey, 1968). A series of severe floods occurred in the 1850s, causing some flood stages to rise 18 to 20 feet above the low water level near the mouth of the river (U.S. House of Representatives, 1931). In addition, there are records that indicate that a series of ice jams and floods occurred between 1860 and 1890 that damaged or destroyed several bridges and buildings on the Kankakee and twice flooded the town of Momence in two feet of water (Houde and Klasey, 1968).

The Grand Marsh created its own history. By the 1880s its reputation as a "hunter's paradise"had spread to the East Coast and beyond. Presidents Grover Cleveland

and Theodore Roosevelt hunted in the Grand Marsh. There was enough interest in the area to cause sportsmen's clubs from New York, Boston, Philadelphia, Washington, and Chicago to build hunting lodges there for their wealthy members. These lodges created jobs and income for the local residents as guides and employees of the lodges (Morrison, 1976). The tens of thousands of waterfowl and other forms of wildlife were also harvested for the commercial markets of Chicago and New York (Mahoney, 1978).

Period of Channelization

Although people had been using the Kankakee River throughout the 1800s, nothing had as great and irreversible an impact upon it as did the efforts of those who wanted to drain the lowlands and the Grand Marsh.

The Grand Marsh was a distinct and natural ecosystem. An account of the area by Meyer (1936) describes it best:

> Marsh prairies of aquatic sedges and grasses, grazing areas; wild rice sloughs, scenes of countless wild geese and ducks; flag ponds, lined with muskrat homes; a narrow but almost uninterrupted swamp forest, full of game, rimming a meandering river teeming with fish; wet prairies made humanly habitable by the interspersion of sandy island oak barrens, many of them surmounting the highest flood waters — such was the general physical set-up of the "natural" Kankakee.

Before channelization the Grand Marsh encompassed approximately 400,000 acres and ranged from 3 to 5 miles in width with a water depth of from 1 to 4 feet for eight or nine months of the year. The marsh plane was only about 85 miles long, but the river course was about 250 miles in length with an average slope of 5 to 6 inches per mile. The nature of the marsh caused the Kankakee River to alter its course continuously, resulting in the formation of a variety of meanders, oxbow lakes, sloughs, and bayous (Meyer, 1936; U.S. Department of Agriculture, 1909). Figure 5 shows the nature of the Grand Marsh before channelization.

Attempts to drain these lands for improved agricultural use took many forms. The early pioneer farmers drained small portions of land by digging ditches, first by hand and later with the help of oxen and horses (Meyer, 1936). One of the earliest organized efforts to drain swampland was attempted in 1853 by the State of Indiana. Their goal was to drain the 5 by 7 mile Beaver Lake, which was south of the Kankakee River. The ditch they constructed to the river was not very successful in draining the lake, which receded only 100 feet from its original shore. In 1874 this same ditch was deepened by a wealthy landowner named Lemuel Milk, who succeeded in reducing the lake area by only 0.25 square mile (Houde and Klasey, 1968).

During the 1860s the Illinois Central Railroad tried to drain portions of its land that were in swampy areas, again with very little success (Houde and Klasey, 1968). There appeared to be two factors limiting the successful drainage of the lands. First was the lack of proper equipment for the effective and efficient digging of drainage ditches. Closely related to this were the prohibitive costs of drainage work, due to inadequate technologies (House and Klasey, 1968).

By the mid-1880s legislation that provided for the formation of drainage districts had been enacted. These districts were given the power to levy taxes for the

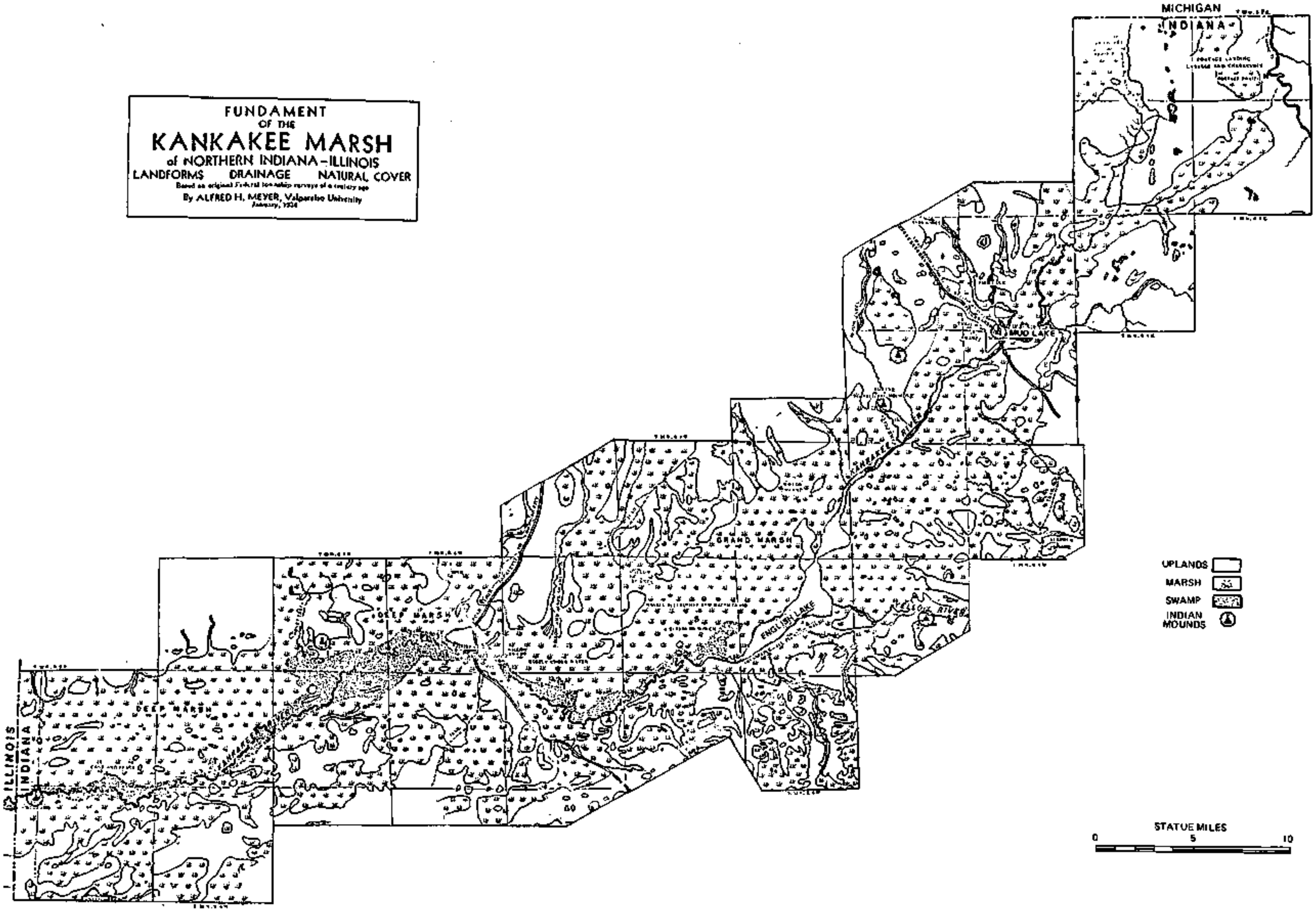


Figure 5. The Grand Marsh of the Kankakee River prior to channelization

financing of drainage work (Houde and Klasey, 1968). The invention of the steam dredge, which allowed the digging of deep, wide drainage ditches, also helped overcome the previous obstacles to draining the lands (Morrison, 1976). In Illinois and Indiana, most of the drainage work could then be done under the authority of the various drainage districts. In 1866, Singleton Ditch in Indiana (figure 4) became one of the first to be constructed under this new authority. Ackerman, Hayden, and Brown ditches were also built around that time (Division of Waterways, 1954).

Again, this drainage work was only partially successful in reclaiming the swamplands. It was thought that the key to adequate drainage was the lowering or removal of the limestone rock ledge near Momence, Illinois (Morrison, 1976).

In 1878 and 1879 the U.S. Army Corps of Engineers conducted a survey of the Kankakee River to analyze the improvement of the river for navigation. This work was reported by Major Jared A. Smith, Corps of Engineers (U.S. House of Representatives, 1879; U.S. Senate, 1880). In reporting his findings, Smith made reference to two points of interest. In his first report (U.S. House of Representatives, 1879) he stated that the water was so clear that he was able to see fish swimming in the stream "as well as minute objects on the bottom in a depth of 5 feet. . ." He also commented that although the rock ledge near Momence was considered "a great obstacle to the drainage of the lands in Indiana," he believed that due to the greater than average slope of the river for several miles above the rock ledge, the removal of this ledge "would accomplish little or nothing for the drainage of lands so far above . . . "

Major Smith's second report (U.S. Senate, 1880) seemed to favor the construction of a navigation channel to Momence. He indicated that there were several strong objections to that idea as well as to the idea of rebuilding the dams at Momence for the navigation project.

In 1882 the Indiana Legislature directed Professor John L. Campbell to survey the Kankakee Valley from its source down to Momence to determine an effective method of draining the marsh lands. Campbell suggested the following plan (U.S. House of Representatives, 1916):

> First, the construction of a better main channel than now exists for the flow of the river; second, the straightening and deepening of the beds of the streams emptying into the main stream; and third, the digging of a large number of lateral ditches through the swamps to the improved channels.

In 1889 and 1891, the State of Indiana, convinced that the rock ledge was the key to their drainage problems, appropriated a total of $65,000 for the widening and deepening of the channel near Momence. This work, done in 1893, created a channel 8,649 feet long, 300 feet wide, and 2-Vi feet deep, and required the removal of 66,447 cubic yards of rock (U.S. Department of Agriculture, 1909; U.S. House of Representatives, 1916 and 1931).

Upon completion of the work at Momence, various public and private groups began to channelize the main river along its uppermost reaches. By 1906, 46 miles of the main channel had been straightened, from its source near South Bend to the west end of Starke County. The work was organized in the following manner: the first 7 miles were built by private landowners without the help of the Indiana drainage laws; the next section, Miller ditch, was 7.75 miles in length; the third section, 5.5 miles long, was constructed by the Kankakee Improvement Company; the fourth section, 9.1 miles long, was called the Place Ditch; the fifth section, constructed by the Kankakee River Reclamation Company, was 16.7 miles long (figure 6). The channel had a bottom width of 8 feet at the upper end and 50 feet at the lower end (U.S. Department of Agriculture, 1909; U.S. House of Representatives, 1916 and 1931).

The U.S. Army Corps of Engineers (U.S. House of Representatives, 1916) reported that the work done on the upper portion of the Kankakee River failed to accomplish its goals adequately and that it created some new problems downstream of the work. The Corps suggested that 1) the design and implementation lacked a comprehensive plan and the cooperation of the interested parties, 2) the resultant successful drainage of about one-third of the acreage did not necessarily justify the amount spent, and 3) the improved channel increased the rate of runoff so as to cause problems of increased discharge and flooding downstream of the drainage works (also USDA, 1909).

It soon became apparent that the only solution to the newly created problems downstream was to continue the straightening of the river. This, along with lateral ditch construction, was expected to reclaim more lands for productive use.

As reported in 1916 (U.S. House of Representatives), the U.S. Army Corps of Engineers concluded that the cooperation of the United States in the planned improvements of the Kankakee River for drainage and flood protection could not be justified in terms of the benefits to navigation. They did, however, discuss various plans to improve drainage of the remainder of the upper valley. The Corps referred to the three plans for improvement cited in U.S. Department of Agriculture Circular 80 (1909). They agreed that the third plan, as detailed by the USDA, was the most favorable. This plan called for the straightening and enlarging of the present channel from the confluence of the Yellow River to the rock ledge at Momence, without the construction of levees to assist in the control of flow. The Corps also recommended an extensive survey of the area to determine the cost and exact design of the channel. In addition to making this proposal, the Corps stated its opinion that a comprehensive, coordinated plan would need to be devised for this project to accomplish its goals.

It was noted in the Corps' report that the work had already begun in the area. Marble Ditch was being constructed from the west line of Starke County to an area about 7 miles east of the Illinois-Indiana state line. This channel was to follow the line recommended by USDA Circular 80 (1909) and would result in the straightening and deepening of the river. A continuation of Marble Ditch had been proposed to carry the channelized flow to the state line. The only work planned for downstream from the state line was the removal of more of the Momence rock ledge.

It was on this last part of the plan that the Corps received the most input from private landowners. Most of them believed that the removal of the ledge at Momence was important. The approval and cooperation of the State of Illinois was required, but Illinois was not receptive. It was hoped that the United States would become involved for the purpose of improving navigation and would use their authority to remove the rock ledge. As was noted previously, the United States declined to participate because the work proposed could not be justified for navigation purposes (U.S. House of Representatives, 1916).

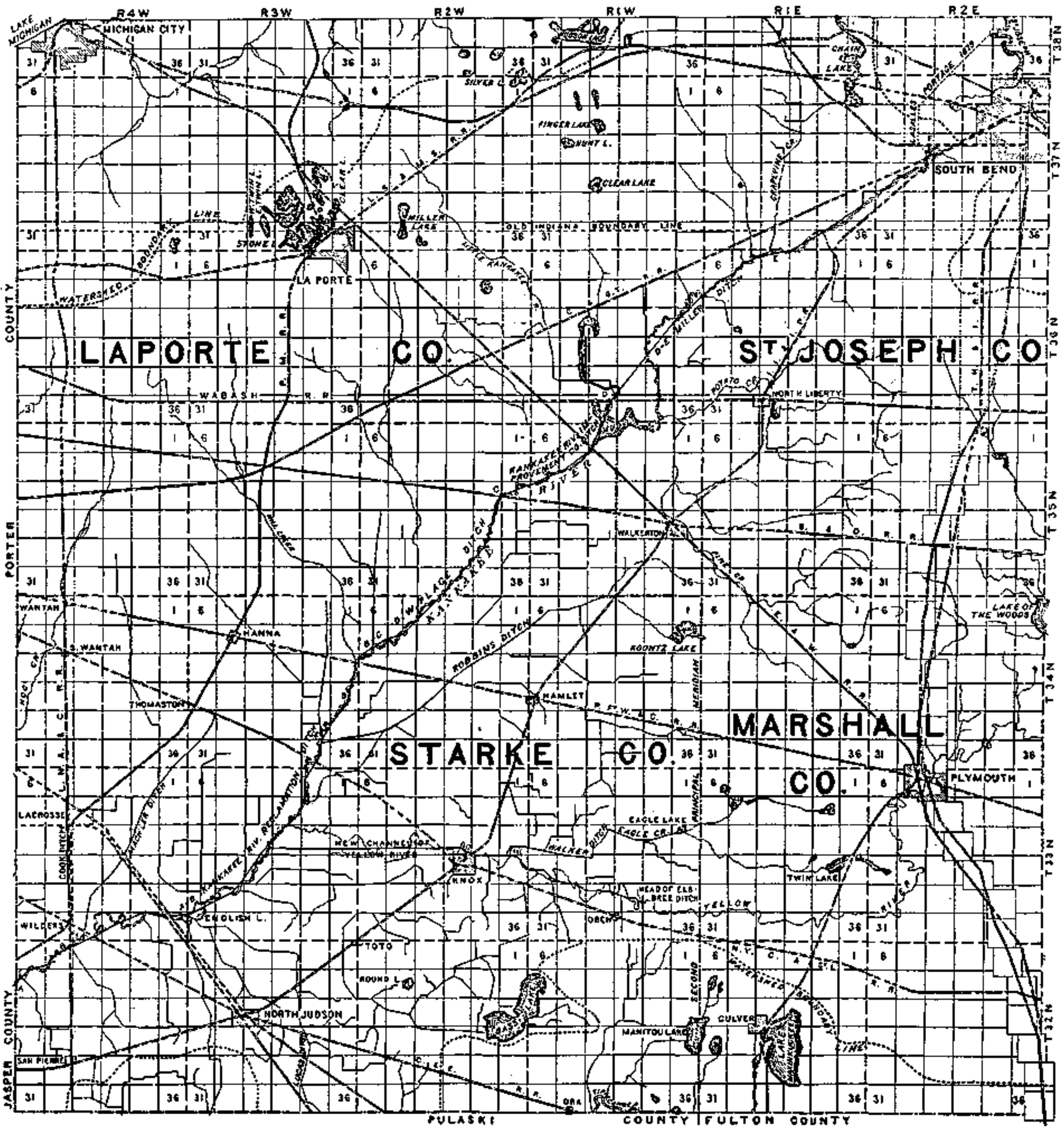


Figure 6. Channelization of the upper reaches of the Grand Marsh (USDA, 1909)

In Indiana, the channelization went ahead as planned and was completed in 1917. The old channel, 250 miles of meandering river, had been replaced by a straightened, deepened channel 82 miles long, extending from near South Bend to the Illinois state line (figures 6 and 7). Below this point, except for the work done at the rock ledge at Momence in 1893, the river remained in its natural form. In Indiana, the average slope of the river had been changed from 0.45 foot per mile to 0.83 foot per mile. The improved drainage affected nearly 400,000 acres of swamp and 600,000 acres of marginal land at a cost of about $1.2 million (U.S. House of Representatives, 1916 and 1931).

The Grand Marsh had finally been "reclaimed." However, the accomplishment was not greeted with enthusiasm by everyone. There was concern in Illinois about the impact of the change on the downstream reaches of the river (Morrison, 1976). For years many have questioned the wisdom of destroying this vast natural ecosystem. As early as 1920, this was pointed out when Reed (1920) wrote:

> Fields of corn and wheat stretch over the reclaimed acres, for the utilitarian has triumphed over beauty and nature's providence for his wild creatures. The destruction of one of the most valuable bird refuges on the continent has almost been completed, for the sake of immediate wealth. The realization of this great economic wrong must be left to future generations.

Soon after the channelization was completed, it became apparent that the drainage problem had not been completely solved. Severe flooding still occurred east of the Momence rock ledge, and the removal of additional rock was discussed. In 1927 the Momence and Yellowhead Drainage District removed boulders that obstructed flow from an area just upstream of the rock ledge (U.S. Army Corps of Engineers, 1979). This was the only work done on the main channel. The focus of the work in the Kankakee Basin after the channelization of 1917 was directed toward the construction of levees to contain the flood water and toward the improvement of lateral ditches for increased drainage (U.S. Army Corps, 1979).

There was one study done by the Corps of Engineers in 1931 that focused its attention on the main channel. The purpose of this study (U.S. House of Representatives, 1931) was to assess the benefits of any additional work done on the river for improving navigation, flood control, power development, and irrigation. The Corps concluded that the Federal Government could not justify its involvement in terms of making improvements to benefit the areas reviewed.

The Corps did make recommendations for anyone interested in controlling floods, reclaiming marshlands, and improving drainage. They first noted that most of the drainage and severe flood problems occurred upstream of Momence. The suggested improvements included: the rebuilding or lengthening of 14 bridges in Indiana that obstructed flow in the main channel and the floodplain, the construction of levees in Indiana between Shelby Bridge and Baums Bridge, the enlarging of the channel through Momence and the rock ledge, and the enlarging and improving of the main channel for 58 miles upstream of Momence in order to benefit land in Indiana. The Corps noted that the last two improvements would need to be done in combination or the desired beneficial effect of improved drainage would not be achieved (U.S. House of Representatives, 1931).

The analysis of the proposed improvements did not discuss the potential impact, if any, upon the lower reaches of the river. The Corps did point out that the pre-

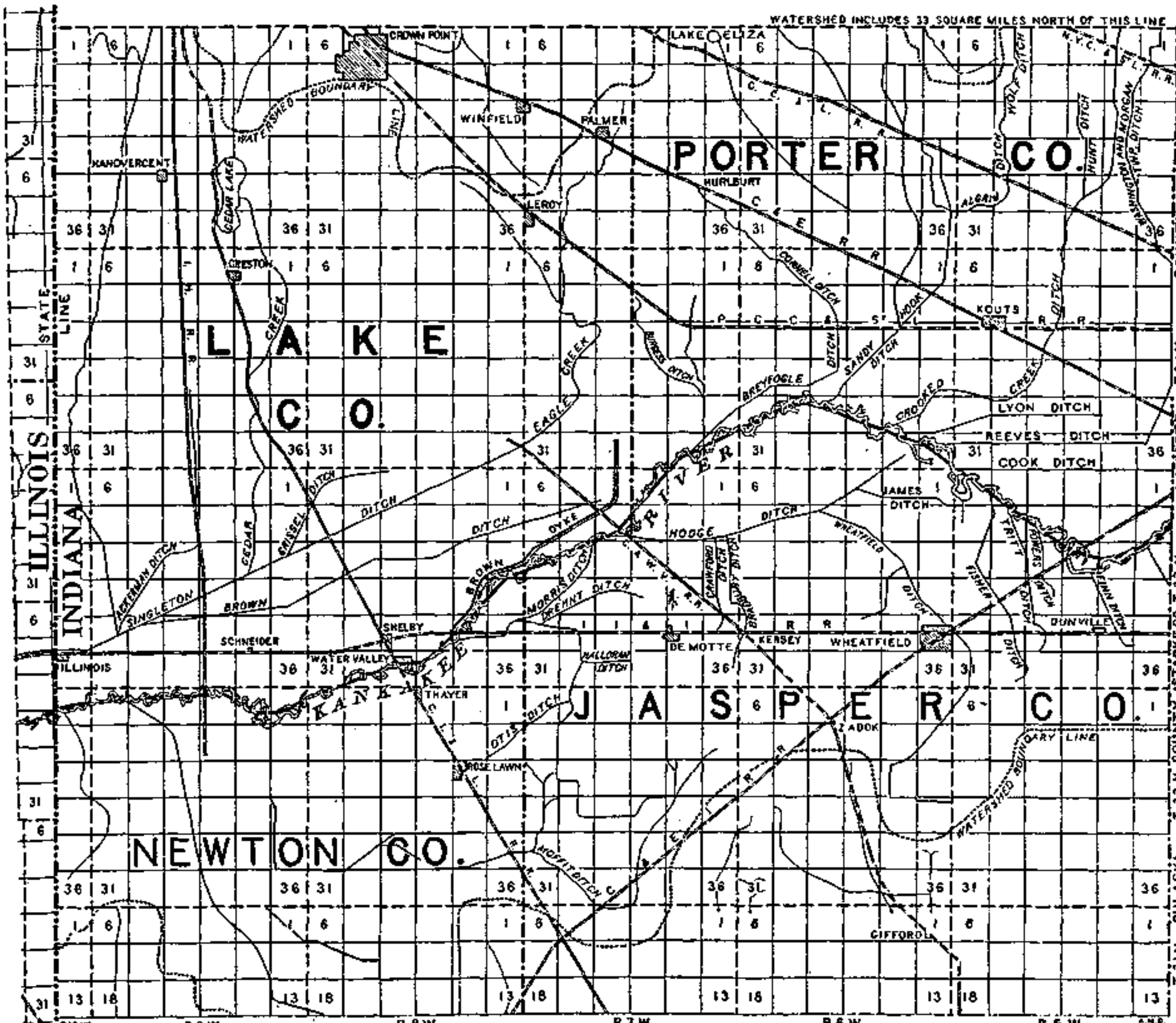


Figure 7. Proposed channelization of the lower reaches of the Grand Marsh (USDA, 1909)

vious channelization in Indiana had increased the flow so that sand and silt were being carried downstream into Illinois, depositing among trees, and creating numerous sand bars in the river bed. The straightened channel in Indiana had little effect below Momence because of the increased slope downstream (U.S. House of Representatives, 1931).

There appears to have been continued interest in the Kankakee River in the mid-1900s. In 1941, the Corps of Engineers conducted a study (U.S. Army Corps of Engineers, 1941) that reviewed the improvements that would be necessary to control flooding along the Kankakee River. These improvements included lowering the rock ledge at Momence, constructing a movable dam to maintain low flow levels, cleaning the river of sand bars, opening the outlets of sloughs, and enlarging and straightening portions of the river from Momence to the state line.

The Corps analyzed these proposed improvements and concluded that the work should not be done. It was estimated that the costs far exceeded any possible benefits.

While making their assessment, the Corps made note of two points of interest. First, large quantities of sand had been deposited between the state line and Momence due to channel erosion upstream. The increased silting had reduced low flow depths to less than 1 foot between the state line and Momence. However, the rate of siltation below the state line had since decreased. This, according to the Corps, indicated that the straightened channel in Indiana was stabilizing (U.S. Army Corps of Engineers, 1941).

In addition, the report noted that the removal of the rock ledge at Momence could have an adverse effect upon the river by increasing siltation downstream, although no important damage was likely to occur. The Corps' unfavorable review resulted in the abandonment of the proposed improvements.

In 1947, the Illinois Department of Transportation, Division of Water Resources, investigated the possibility of replacing the collapsed dam at Aroma Park to restore the recreational channel up to Momence (Kankakee River Basin Task Force, 1978). This plan was never implemented.

In 1955, a move was also under way in Illinois to form the Momence Conservancy District with the power to levy taxes and protect the river. Plans were made to remove some of the sand from the river, but this goal was never realized because of a lack of interest and funds (Morrison, 1976). Through the mid-1960s there appears to be no record of any major studies to reduce flooding or improve drainage along the main channel.

In 1967, the Illinois Department of Public Works and Buildings, Division of Waterways, published a comprehensive report on the Kankakee River Basin in Illinois (Division of Waterways, 1967). This study reviewed several areas, including water supply, water-oriented recreation, water quality control, flood damage control, and agricultural drainage.

General recommendations and conclusions were made for all the areas reviewed. In particular, it was suggested that the rock ledge through Momence be lowered, which would serve two purposes: 1) it would increase the length of the recreational waterway, and 2) the excavated channel would improve drainage and reduce flooding upstream of Momence. It was noted that the channel work could not be economically justified for the purpose of improved drainage and flood control.

The study also recommended that a lock and dam be constructed just upstream of the confluence of Yellowhead-Singleton Ditch. The purpose of this dam was to maintain the water level up to the state line at the same level as that before any excavation had occurred downstream (Division of Waterways, 1967). Conservation and environmental groups strongly objected to these proposals, and the project was subsequently dropped from consideration (Kankakee River Basin Task Force, 1978).

By the mid-1970s, attention was again focused on the Kankakee River and the drainage of its surrounding lands. The Indiana Department of Natural Resources, in cooperation with the U.S. Soil Conservation Service, published a report on the Kankakee

River Basin in 1976 (Indiana Department of Natural Resources, 1976). The report identified the problems and needs of the basin, including land use and management for agriculture, flooding, soil erosion, adequate drainage systems, increased land-based recreational opportunities, and protection and maintenance of natural water areas and prime wetlands.

Five alternative solutions were developed and presented. None of these alternative plans received the consensus approval of the public. A combination of the various plans was formulated and presented as the "Suggested Plan," which contained 15 elements, including the following recommendations (from Indiana Department of Natural Resources, 1976):

> Channel work on 26 miles of the Kankakee River from Ind. Route 223 in St. Joseph County to U.S. Route 30, and 49 miles of wide levees (with no channel work) along the Kankakee River from U.S. Route 30 to U.S. Route 41, for flood prevention and drainage.
>
> Channel work on 13 selected tributaries of the Kankakee River in Indiana for flood prevention and drainage.
>
> Accelerated land treatment program, which includes installation of conservation measures to reduce erosion and adequately treat 426,400 acres.
>
> Accelerated land treatment program, which includes installation of on-farm resource management systems to adequately treat 247,500 acres of cropland for drainage.
>
> Change of about 12,650 acres of erosion and drought hazard cropland to non-cropland for reduction of erosion and sedimentation, and for adequate treatment of land within its capability (in addition to the land treatment program).
>
> Protection of about 5,000 acres of existing classified wetland.
>
> Amendment or adoption of flood plain zoning ordinances, building codes, and similar regulations for all identified flood prone areas in the basin, and allowance of eligibility for flood insurance.

In 1977, in response to continued flooding problems on the Kankakee River, the Indiana General Assembly created a 24-member Kankakee River Basin Commission to coordinate a comprehensive development plan for the basin. This commission was given a small operating budget and had no authority to implement its plan (Kankakee River Basin Task Force, 1978). The commission relied upon the Indiana report of 1976, and in particular used the "Suggested Plan" as a basis for formulating its plan (U.S. Army Corps of Engineers, 1979; Mahoney, 1978).

Increased public concern in Illinois over the impact of the proposed work in Indiana, as well as the creation of the commission in Indiana, prompted Illinois Governor James R. Thompson to appoint the Illinois Kankakee River Basin Task Force in June 1977 (Kankakee River Basin Task Force, 1978).

The Illinois Task Force conducted public hearings to collect information from the residents of the basin and reported its findings and recommendations based on input from the hearings and technical information received from various state agencies (Kankakee River Basin Task Force, 1978).

In general, the Task Force recommended that the State of Illinois "maintain the Kankakee River as a low density recreation and scenic river" by keeping it "in the most natural condition possible." The Task Force believed that Indiana's plan to manage the basin for improved agricultural drainage was in conflict with the policy goals of

Illinois. The Task Force also warned that a cautious approach must be taken in any plans to modify the Kankakee River in Illinois physically, due to the limited amount of information available.

The Task Force made recommendations in 10 areas of interest, including sediment and sedimentation in the Kankakee River Basin, water quality, flooding and flood control, natural areas, and outdoor recreation. The first area, sediment and sedimentation, was of major concern to the citizens of the Kankakee River Basin. There was special concern about the present and future impact of sediment in the Kankakee River and about the effect of proposed work in Indiana on this problem.

The Task Force noted that there was a question of the magnitude and source of the sediment problem in Illinois and that there was a need to better understand the mechanism of sediment transport in the Kankakee River Basin. The Task Force recommended that "the Illinois State Water Survey begin immediately to monitor sediment and bed load movement at the state line and elsewhere in the Basin."

The Task Force also recommended that the State Water Survey analyze the monitoring data and the hydrology of the Kankakee River system and "suggest alternative remedial strategies." Finally, the Task Force suggested that the State Water Survey receive input from citizens of the Kankakee Basin while making its investigation.

In summer 1978, the then Illinois Institute for Environmental Quality, which is presently within the Illinois Institute of Natural Resources, funded the State Water Survey for a 2-year research project on the Kankakee River. It was postulated that basic data would be collected for a period of one year and that these data would then be analyzed and the results reported to the public. This report summarizes the 2-year study by the Water Survey.

DATA COLLECTION

Before the initiation of this study, it had been mentioned repeatedly that basic data related to sediment load on the Kankakee River in Illinois were nonexistent and that any future planning of the water resources of this river basin could not be made intelligently if some basic information from the field was not gathered. The Governor's Task Force on the Kankakee River (1978) recognized this and recommended the establishment of a basin-wide sediment and hydraulic monitoring data network. On the basis of these recommendations and with assistance from citizens in the river basin, a monitoring program was initiated in summer 1978. It was decided that the field data related to water discharge and sediment in transport would be collected for a period of one year, from October 1, 1978, through September 30, 1979, which coincided with the Water Year concept of the U.S. Geological Survey. A description of the basin and the data collection program is given below.

Drainage Basin

The drainage basin of the Kankakee River and the locations of some of its more important gaging stations are depicted in figure 8. The total drainage area of the Kankakee River at its mouth at the Illinois River is 5,165 square miles. The drainage area at

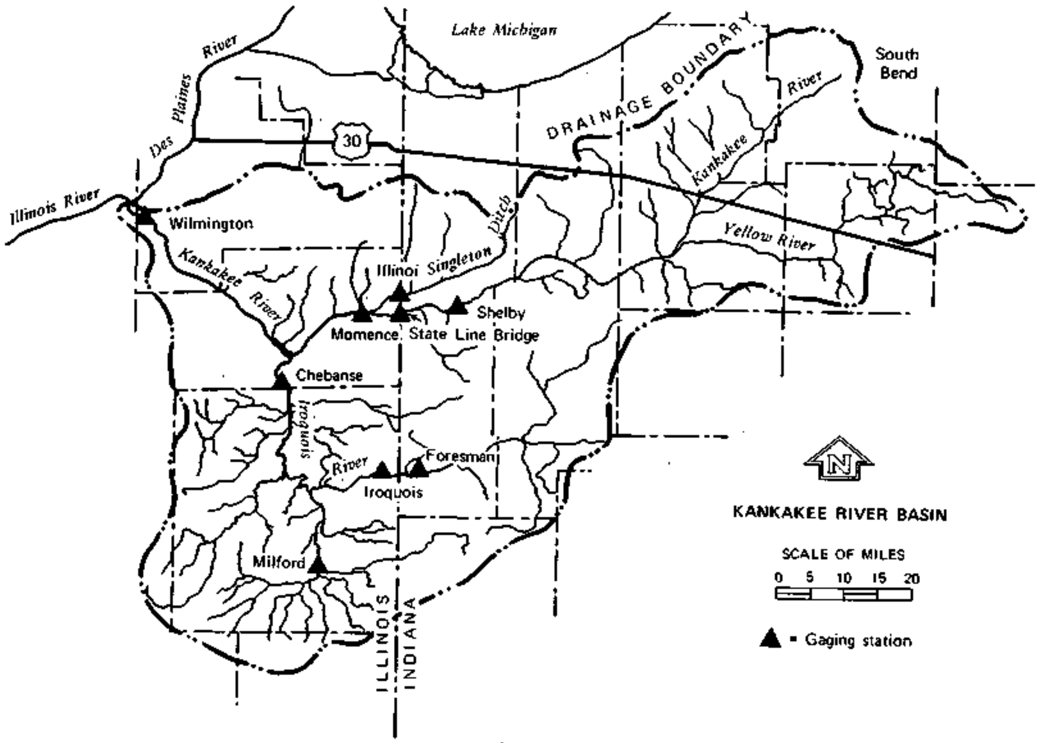


Figure 8. Drainage basin of the Kankakee River and associated gaging stations

the Wilmington gage is 5,150 square miles, which is 99.7 percent of the total drainage area of the Kankakee River. The drainage area of the Kankakee River at the Illinois-Indiana state line is 1,920 square miles; The drainage area of the Singleton Ditch at the Illinois-Indiana state line is 220 square miles, whereas the drainage area of the Kankakee River at the Momence gaging station below its confluence with the Singleton Ditch is 2,294 square miles (Healy, 1979). Thus, about 93 percent of the drainage area at the Momence gaging station is located in Indiana. Similarly, for the gaging station on the Iroquois River at Iroquois, 95 percent of the drainage area is located in Indiana. The geologic features of the drainage basin are discussed in a parallel study by the Illinois State Geological Survey (Gross and Berg, 1980).

River Reconnaissance

Before the start of the study, it was decided that the researchers and field personnel should be made fully aware of the present conditions of the river. A total of six trips were taken on the river for this purpose. Each trip covered only a part of the river, ranging from a few miles to 30 miles or more at a time.

The first trip, sponsored by the Kankakee River Basin Commission of Indiana, was taken on September 6-7, 1978, and covered approximately 60 miles of the river from U.S. Highway 30 in Indiana to the Illinois-Indiana state line. During this trip no data were collected. The second trip was taken on October 24-25, 1978, and the reach of the river from Highway 30 to Route 49 in Indiana was covered. During this trip, extensive bed and bank material samples were collected.

The third trip, taken on October 31-November 1, 1978, covered the river from the Illinois-Indiana state line to the Kankakee River State Park in Illinois. The fourth trip was taken on October 25-26, 1979, and covered the river from Indiana Route 49 to Momence, Illinois. During these two trips, extensive bed and bank material samples were also collected.

The fifth trip was taken in Illinois on February 28, 1980, to observe the movement of sand bars. The sixth trip was taken in Indiana on April 15, 1980, to observe channel and levee conditions; it covered about 10 miles of the river upstream from the Illinois state line.

All along the length of the river in Indiana, the bank materials consist mainly of sand with some silt and clay. Trees and vegetation grow along the river, and as a result the banks are very stable along most reaches. Such a stable segment of the river is shown in figure 9a. However, whenever the banks are devoid of trees and vegetation the banks are unstable and bank erosion is present. Such an unstable reach of the river is shown in figure 9b.

It has been mentioned previously that the river in Indiana has been channelized. However, along most reaches of the river in Indiana, the river looks remarkably like a natural stream. Trees and vegetation are growing, and the river is very stable and basically clear of any extensive debris. Figures 10a and 10b contrast the channel configurations above and below the State Line Bridge. In Indiana, the river follows a straight alignment extending a few miles at a time, whereas in Illinois the river follows a meandering pattern similar to the one shown in figure 10b.

During *the* trip taken in October 1979, it was noticed that at a few places in Indiana the levees of some of the ditches had been repaired. Such a case is shown in figure 11. Figure 11a shows the drainage ditch at its junction with the Kankakee River. The photograph was taken from a boat on the Kankakee River. Figure 11b shows the view of the ditch just around the bend shown in figure 11a. It is apparent that a flap valve is controlling the flow from the drainage channel into the ditch shown in figure 11a. The levee has been repaired, and upon examination it was apparent that the dredged materials were just dumped on top of the levee. It was the consensus of the investigators that before fall 1980 most of these dredged materials would have eroded and been deposited in the ditch or would have moved downstream in the Kankakee River. The river trip taken on April 15, 1980, supported this belief.

During all the trips, extensive field notes and many photographs were taken to observe the pattern and changes in the river characteristics.

Types of Data

A thorough examination of the study goals convinced the researchers that a critical analysis should be made before actual field data were collected. It was easy to postulate that sediment data should be collected, and that the sediment discharge in a stream is affected by the hydraulic characteristics of the river and by the type of sediment materials available for transport either from the watershed or from the stream

a. Stable river

b. Bank erosion

Figure 9. Kankakee River in Indiana

a. Looking upstream in Indiana

b. Looking downstream into Illinois

Figure 10. Kankakee River at the state line

a. Looking into the ditch from the Kankakee River

b. Just around the corner from (a)

Figure 11. Typical levee repair of a tributary drainage ditch

itself. Therefore, data related to sediment load, hydraulic characteristics of the stream, and the type of sediment in the river had to be collected. In order to quantify the long-term sediment load in a river, data must be collected for a substantial period of time, ranging from 5 to 15 years or more. However, because of the 2-year time limit placed on the research it was decided that data should be collected for only a single year. *Therefore, in reviewing the data, the analyses, and the conclusions of this report, readers must remember that the data base is extremely short and that the conclusions and interpretations must be judged accordingly.*

Since one of the main objectives of the study was to monitor sediment load from Indiana, it was decided that the gaging stations at Momence (above which 93 percent of the drainage area is in Indiana) and at Iroquois (above which 95 percent of the drainage area is in Indiana) would be the two main index stations. In addition to these two stations, the gaging station near Wilmington would be considered as an index station. About 99.7 percent of the drainage basin of the Kankakee River is above the Wilmington gage. A gaging station at Illinoi on the Singleton Ditch and a new station on the Kankakee River at the State Line Bridge were to be sub-stations where data would be collected less frequently. Just before the data collection program was initiated, funding became available from another source to collect data from the Chebanse gaging station on the Iroquois River. The locations of these stations are indicated in figure 8.

The following types of data were collected from the index gaging stations (Momence, Iroquois, Wilmington, and Chebanse):

1) Suspended sediment samples daily (more frequently during flood events)
2) Daily stage records
3) Detailed velocity distribution data about once a month
4) Bed material samples from the stream

From the Illinoi station on the Singleton Ditch and the State Line Bridge station on the Kankakee River, the following types of data were collected:

1) Suspended sediment samples once every two weeks (more frequently during flood stages)
2) Stage records
3) Detailed velocity distribution data during most field trips
4) Bed material samples

In addition to the above data, bed load samples were collected at the State Line Bridge, Iroquois, and Chebanse stations, especially during flood stages.

Bed material samples from the main stem of the river from U.S. Highway 30 in Indiana to the Kankakee River State Park in Illinois were also collected. Table 2 gives a description of the gaging stations where data were collected.

Suspended Sediment Load

The suspended sediment samples were collected utilizing the standard procedure given by Guy and Norman (1970). A Depth-Integrating Suspended Sediment Sampler, the US DH-59, was used to collect the suspended sediment samples. This sampler works on the principle that the sampled water is collected at the same rate as the velocity of the surrounding stream. The sampler is lowered into the water at a constant rate to 3

Table 2. Gaging Station Locations and Descriptions

Station number	*Location*	*Watershed area (sq mi)*	*Length of record for water discharge*	*Average discharge (cfs)*	*Average discharge 1979 (cfs)*	*Sediment data collection**	*Slopes measured*
05518000	Kankakee River at Shelby, IN	1779	1924-Present	1580	1699	A(1963)	
05520000	Singleton Ditch at Illinoi, IL** (abandoned 1977)	220	1946-1977	179		C	yes
05520500	Kankakee River at Momence, IL	2294	1916-Present	1930	2171	B	yes
05524500	Iroquois River near Foresman, IN	449	1950-Present	370	398	A(1968)	
05525000	Iroquois River at Iroquois	686	1945-Present	536	586	B	yes
05526000	Iroquois River near Chebanse, IL	2091	1925-Present	1610	2144	B	yes
05527500	Kankakee River near Wilmington, IL	5150	1916-Present	4090	5074	B	yes
	Kankakee River at State Line Bridge**	1920				C	

**A = long term monthly sediment data available (year collection initiated)*
B = daily sediment data available for year of study only
C = sediment data from temporary stations
*** = stations temporarily monitored by SWS for one year*

inches above the bed of the stream and then is withdrawn at a constant rate. The sample is collected as long as the sampler is in the water and the water is moving. This sampler works fairly well as long as the sampler is not lowered or retrieved at more than about 60 percent of the flow velocity. For all the index stations, one daily sample was normally collected near the center of the stream. However, once every six weeks and more frequently during flood seasons, about 10 to 12 samples were collected across the width of the stream in order to calibrate the sampling site at the center of the stream. This detailed sampling was needed to find out whether or not the sample collected from the centerline of the stream was measuring an average suspended sediment concentration of the stream at that particular station. The detailed samples are often used to adjust the daily samples to reflect an average concentration in the stream cross section. For detailed methodology, the reader is referred to the publication by Guy and Norman (1970).

Similarly, suspended sediment samples were collected from the gaging stations at Illinoi and the State Line Bridge.

Bed Load

The bed load carried by a stream can be determined either by measuring the sediment moving near the bed or by monitoring the movement of bed forms such as sand bars.

A review of available instrumentation for bed load measurement indicated that basically one field instrument is available for measuring the bed load (Hubbell, 1964; Helley and Smith, 1971). This is an experimental bed load sampler called the Helley-Smith Bed Load Sampler; its development and limitations are given by Helley and Smith (1971). This sampler was designed for sampling coarse materials where the diameter of the bed materials varies from 2 to 10 mm and the flow velocity ranges up to 10 feet per second. The mesh opening of the collection bag is 0.25 mm; therefore, when the median diameter of the bed materials is less than 0.25 mm, the mesh may get clogged or some of the bed load collected inside the bag may pass through. Figure 12 shows a photograph of this sampler hanging from a 3-wheel base on the deck of a bridge.

The Helley-Smith sampler was used to collect bed load samples from three sites: the Kankakee River at the State Line Bridge, Iroquois River at Iroquois, and Iroquois River near Chebanse. Many attempts were made to collect samples from the Iroquois River near Chebanse and at Iroquois, but no substantial amount of samples was ever collected. However, quite a few samples were collected at the State Line Bridge station. During high flows, a considerable amount of fine sand was observed to be moving at this station.

Bed Materials

Bed material in any river is the material that is found on the bed of the river. Depending on the hydraulic characteristics of the river, some sorting of these materials may occur over a period of time. Quantification of the bed materials is needed to evaluate the hydraulic and sediment transport characteristics of the river.

Bed material samples were collected from the main stem of the Kankakee River from U.S. Highway 30 in Indiana through the Kankakee River State Park in Illinois. Most of these samples were collected during two boat trips taken down the river in October-November 1978 and October 1979. Two separate methods were used to collect these samples.Whenever the depth of water was less than about 2 feet and flow velocity was low, an ordinary shovel was used to collect the samples. If field personnel are very careful, an almost undisturbed sample can be collected by this method. Figure 13a shows a sample collected by a shovel.

The other method involved the use of a standard U.S. Geological Survey sampler called the US BMH-60. The operating procedure and the description of this equipment are given by Guy and Norman (1970). This sampler worked out exceedingly well in collecting the bed material samples from the bed of the Kankakee and Iroquois Rivers. Figure 13b shows a sample collected by this sampler.

Bed material samples also were collected at the gaging stations and in special areas such as the Six Mile Pool, a few places on the Iroquois River, and a few sand bars in Illinois. Some bank material samples from the river in Indiana were also collected by scraping the materials from the top layer of the bank.

Table 3 provides a summary of the data collected from the river. The suspended sediment samples for Momence, Iroquois, Chebanse, and Wilmington were collected by the U.S. Geological Survey. Data from other stations were collected by the Water Survey.

Figure 12. Helley-Smith Bed Load Sampler

Sand Bar Monitoring

While traveling the Kankakee River by boat, investigators observed that there were a number of sand deposits or sand bars in the river in Illinois, some of which extended from a few hundred feet to about one mile long. Although quantification of these sand bars was not one of the objectives of the present project, a decision was made to survey a few of these sand bars and monitor them for a period of time to observe and document their movement. Figure 14 shows the locations of the major open river sand bars in Illinois. Sand bars 2, 3, and 4 and the one near the state line were surveyed in detail to develop contour maps. Table 4 indicates the dates when the various sand bars were surveyed. Contour maps of these sand bars and the adjoining river bed were developed. Figure 15 shows two sand bars, one near Koops Island (figure 14) and the other one in the Six Mile Pool in Illinois.

The sand bar shown near the state line (figure 14) initially was observed during the regular data collection trip in July 1979. Since this sand bar was observed to be moving rapidly in the downstream direction, it was decided to monitor it very closely. The downstream progression of the bar was monitored quite frequently, and it was observed that the bar was moving at the rate of about 1.5 feet per day. Detailed hydrographic maps of this sand bar were developed for two times in 1979. Other hydraulic data, such as flow velocity, water surface slope, and the pattern of bed material distribution in the front and rear of this bar also were collected.

Hydraulic Data

The hydraulic data collected for this project basically consist of velocity distribution data, collected at various gaging stations to determine the discharge at those

a. Sample collected by shovel

b. Sample collected by US BMH-60

Figure 13. Bed material sample collection

Table 3. Summary of Sediment Samples Collected

Station	Bed material[1]	Bank material[1]	Suspended sediment: Water Survey	Suspended sediment: US Geological Survey	Suspended sediment: Total	Bed load
Kankakee River-Indiana	134	20				
Kankakee River-Illinois	52					
Kankakee River-Six Mile Pool	45					
All Sand Bar Samples	90					
Iroquois River-Illinois	3					
Kankakee River-Wilmington				270	270	
Kankakee River-Momence			11	298	309	
Iroquois River-Chebanse	9			323	323	60
Iroquois River-Iroquois	5			306	306	40
Kankakee River-State Line Bridge	19		74		74	77
Singleton Ditch-Illinoi	5		74		74	

[1] *Total number of documented samples*

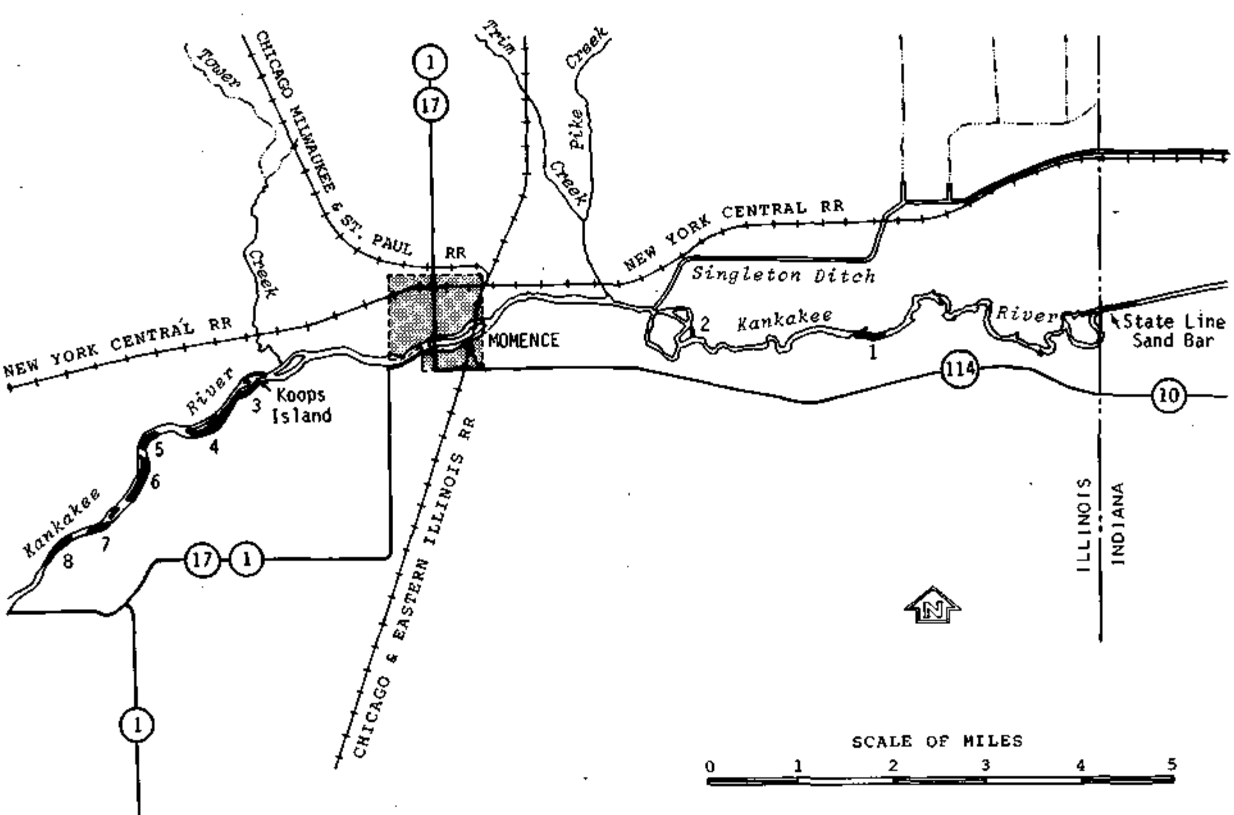


Figure 14. Locations of major open river sand bars in Illinois

Table 4. Sand Bar Surveying

Sand bar name/number	*Dates*	*Comment*
State Line	July 25, 1979	Detailed survey
State Line	Nov. 5-6, 1979	Detailed survey
2	Sept. 18-20, 1979	Detailed survey
3	Aug. 29-30, 1979	Detailed survey
4	Oct. 3-16, 1979	Detailed survey

locations, and water surface slopes at a few locations. The discharge data collected at the State Line Bridge and at Illinoi on the Singleton Ditch were used to develop stage discharge relationships for those locations.

Detailed velocity distribution data at several cross sections were collected near the State Line Bridge so that the mechanics of movement of the sand bar near the bridge could be investigated in detail. All the velocity data were collected following the procedure given by Buchanan and Somers (1969).

Water surface slope data were collected for the gaging station at Illinoi on the Singleton Ditch, Chebanse and Iroquois on the Iroquois River, and Wilmington and Momence on the Kankakee River.

ANALYSES OF DATA

The data analyzed for the present investigation consisted of historical data and field data collected in water year 1979. Some of the data analyzed were collected by other state and federal agencies. The analyses of the data are divided into two broad areas: an analysis of the data collected before water year 1979, and an analysis of the data collected specifically for the present project in water year 1979.

Background Analyses

Flow Duration

It is important to analyze the historical data for a gaging station to determine the characteristics of the flow of the station. Flow duration analysis is an analysis that can be made to get an indication of the percentage of time that any particular flow is equaled or exceeded. The techniques of determining flow duration are given by Searcy (1959).

Flow duration curves for gaging stations at Shelby (1929-1977), Foresman (1950-1977), Momence (1916-1977), Singleton Ditch at Illinoi (1946-1977), Iroquois (1945-1977), Chebanse (1926-1977), and Wilmington (1916-1977) have been developed and are provided in figure 16. The average flow for the period of record and (except for Singleton) for water year 1979 are also shown for each station.

Flow duration curves show the amount of flow that is present at a location for a certain duration in a year. In the case of flows of shorter duration — that is, flood discharges — the flow duration curve at a station becomes a good indication of the amount of drainage area that is contributing flow to the station. Within the same drainage basin,

a. Sand bar near Koops Island

b. Sand bar in the Six Mile Pool

Figure 15. Sand bars in Illinois

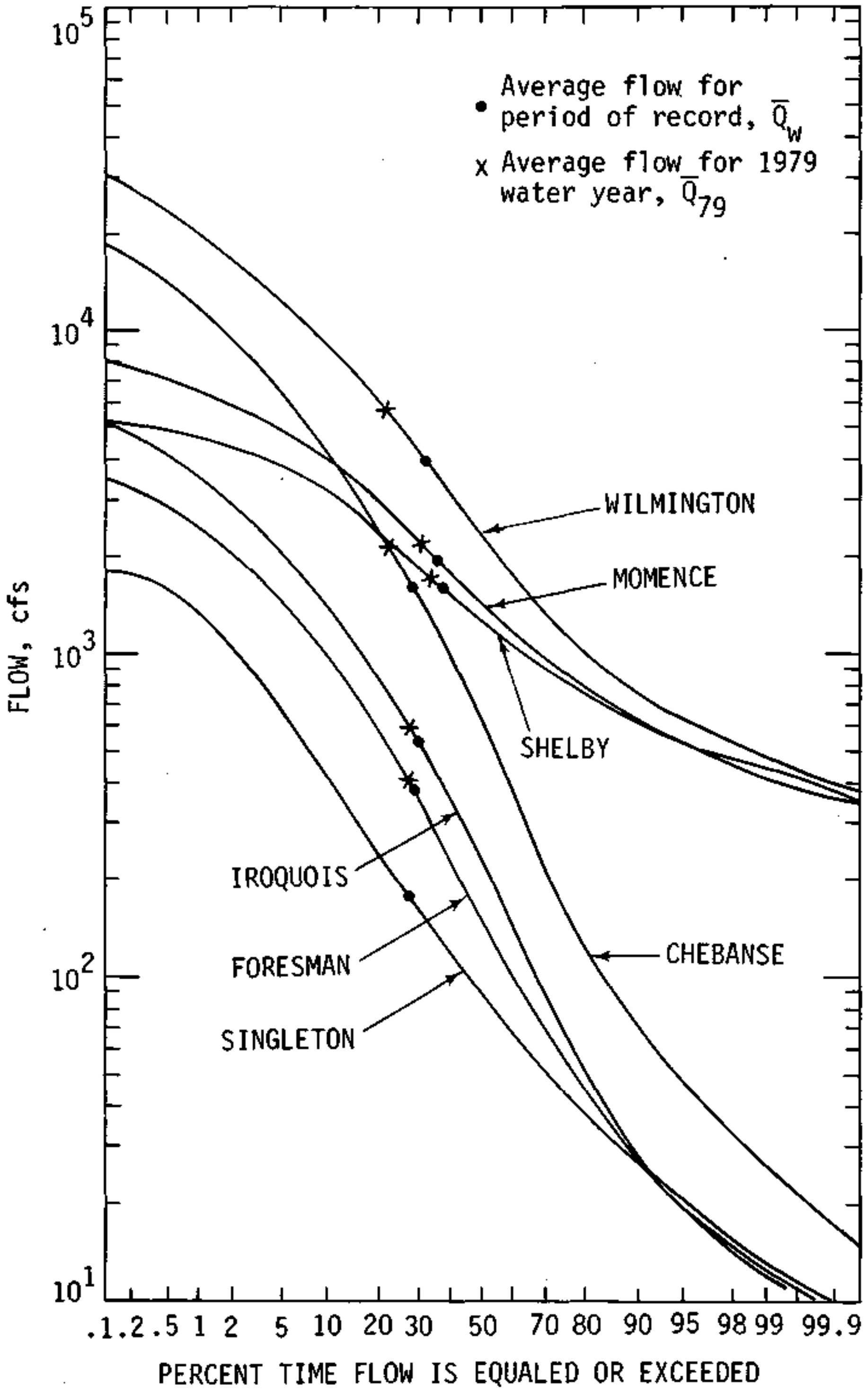


Figure 16. Flow-duration curves of mean daily flows at different gaging stations

with an increase in drainage area, the contributing flow at a station will increase. Low flows may not react exactly the same way. This is evidenced in figure 16. Seepage, storage in the floodplain, swamps, and other factors will change the low flow characteristics of the basin. In the Kankakee River System, although the drainage areas at Shelby, Momence, and Wilmington are completely different, the low flows at these stations are almost identical at about the 95 to 99 percent levels.

The average flows shown for the period of record for all the stations indicate that these are not too far from the median flow, defined as the flow that is exceeded only 50 percent of the time. When we consider the average discharges for the 1979 water year for all the stations (table 2), it is obvious that the 1979 water year can be considered an average year for Momence and Iroquois but a wet year for Chebanse and Wilmington.

Peak Flow

Before and during the present project, it was mentioned by local residents and others that the peak flows in the river basin have changed with time. The peak flow is defined as the instantaneous maximum flow that may occur in a stream at a certain section over a year; it is not the total quantity or volume of water that passes during a certain length of time such as a week or a month.

The peak flows at any gaging station can increase because of a number of manmade or natural factors. Increased precipitation in the basin, clearing of natural cover, heavy urban development, decrease in the natural infiltration rate, changes in the river regime, and other factors can change the peak flows in a natural stream. Some of the factors in the Kankakee River Basin that have affected peak flows are land use changes, agricultural usage, and channelization of the river in Indiana.

The annual peak flows for the period of record for Shelby, Momence, Iroquois, Chebanse, and Wilmington have been analyzed. Figure 17 shows the relationship between annual peak flows versus time for Shelby for the period 1923 to 1979. The 3-year moving average is also shown. To generate the 3-year moving average values, the peak flows from any 3 consecutive years are added, an arithmetic average value is computed, and this average value is taken to be the flow for the middle year. Then the flow from the following year is taken, the first year is dropped, and an average flow for these three years is computed. This process is continued until 3-year moving average values have been calculated for the period of record. The 3-year moving average method is a standard statistical technique used to smooth out sharp peaks and valleys in statistical data; it is also used to identify any trend in the historical data. If a trend is identified, it can be used for other statistical analyses.

An examination of figure 17 shows that a trend toward increasing average peak flows exists from about 1931 through 1979 but that the highest peaks over the period of record have shown a steady decrease. A regression line fitted to the data from 1931 through 1979 is shown in figure 17. The regression equation is given by equation 29.

$$Q_P = 3448 + 27.3T \tag{29}$$

where Q_P is the peak flow in cfs and T is the time in years. The value of T is zero for the year 1931 and 48 for the year 1979. When the regression line is fitted for the data for the period of record, the coefficient of T becomes 12.4 rather than 27.3 as shown

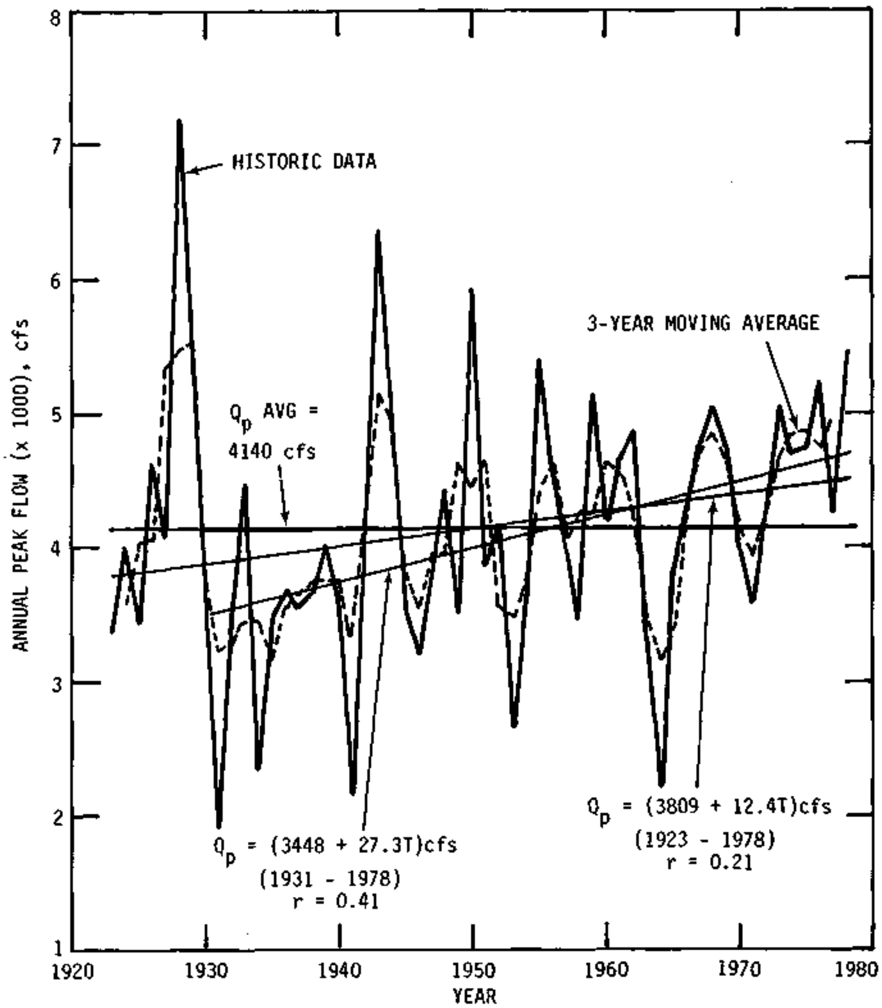


Figure 17. Annual peak flow versus time in years for Shelby, Indiana

in equation 29. Therefore, even if the data for the period of record are taken, there still exists an increasing trend in the peak flows at this location.

Figure 18 shows the relationship between peak flows and time in years for the gaging station at Momence. The peak flows from 1915 through 1930 varied between high peaks and low valleys without any noticeable trend. However, the data from 1931 through 1979 show a trend toward increasingly higher peaks, with the highest peak flow occurring in 1979. The 3-year moving averages smooth out the sharp peaks, but the trend is unmistakable. A regression line fitted to the data from 1931 through 1979 is shown in this figure. The regression equation is given by equation 30.

$$Q_p = 4224 + 89.9T \quad (30)$$

If the data from 1915 through 1979 are used to develop the regression line, then the coefficient T changes to 36.9. This indicates that even if the data from the period of record are considered, there still exists an upward trend of the peak flows at this location. The coefficient of T is the numerical value of the average annual increase in the

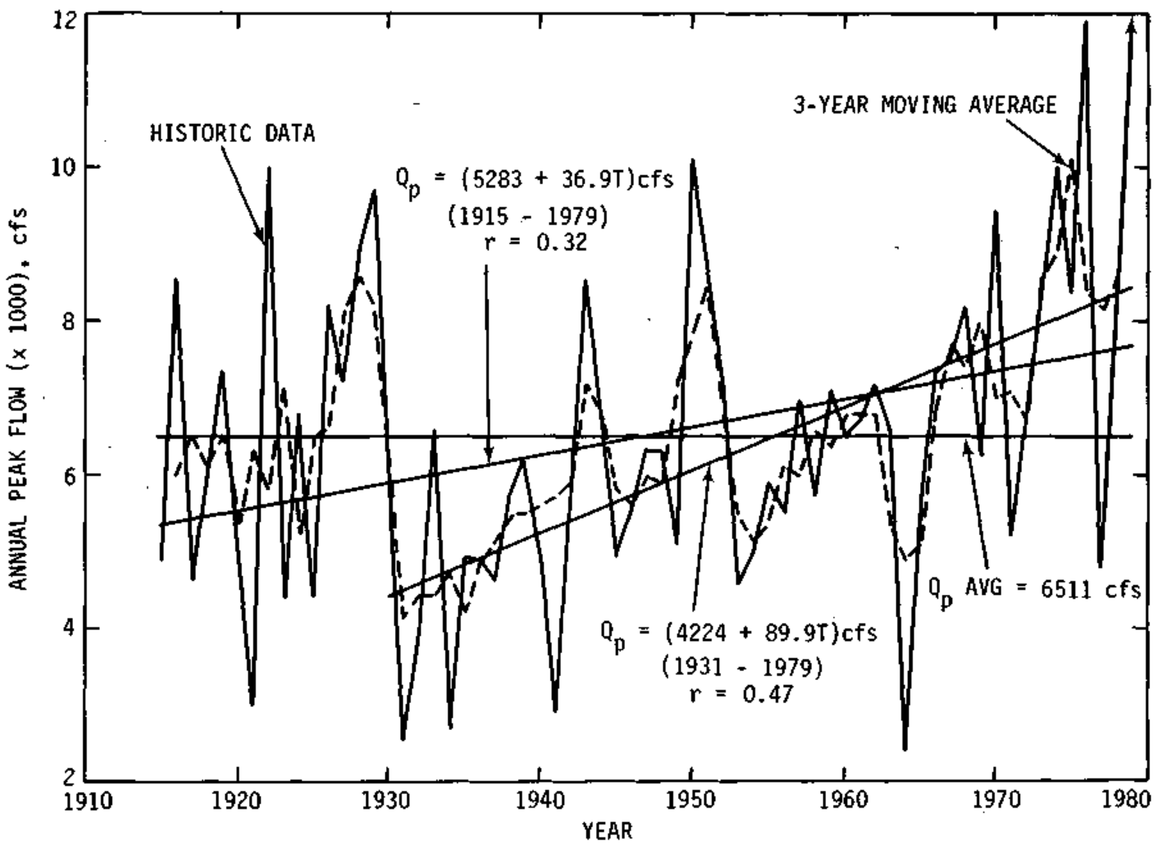


Figure 18. Annual peak flow versus time in years for the Kankakee River at Momence

peak flow at this station. The slope of the regression line is greater than zero, indicating an upward trend.

The physical constraint tells us that this trend cannot continue indefinitely. Either the peak flow will level off and follow a stochastic time series, or in some future time it will start a downward trend, indicating that presently we are observing a periodic series where the series may be at or near its highest peak. This observation may be proved or disproved by the data gathered in the next 30 to 40 years, but there is no doubt that right now there is an upward trend in the peak flows at the Momence gaging station.

Figure 19 shows the relationship between peak flows and time in years for the Iroquois gaging station on the Iroquois River. The period covered did not show any specific trend. Data analyzed from the gaging stations at Foresman, Chebanse, and Illinoi also indicated a similar variability without any upward or downward trend over the period of record.

An analysis was also made for the peak flows for the Wilmington gaging station. Data were available from 1915 to 1979. Figure 20 shows the relationship between peak flows and time in years. An examination of this illustration indicates that in all probability something happened in the early 1940s that changed the magnitudes of peak

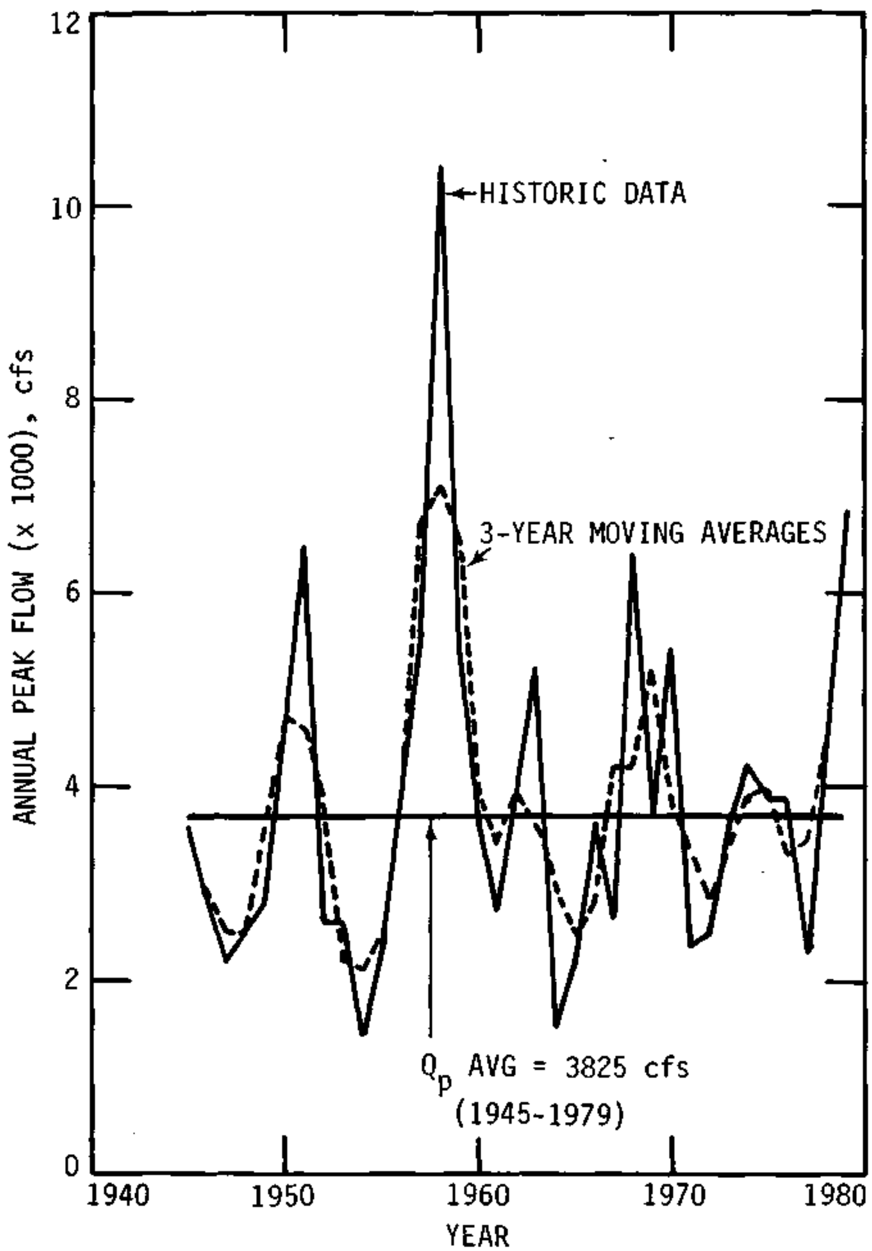


Figure 19. Annual peak flow versus time in years for the Iroqouis River at Iroquois

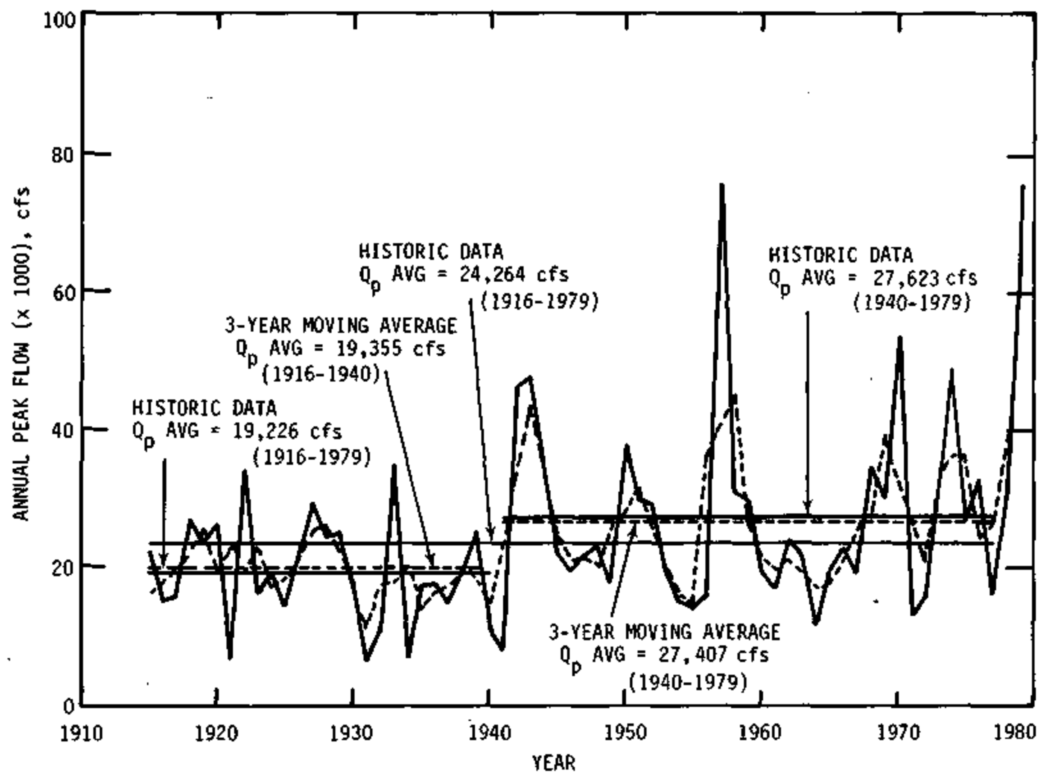


Figure 20. Annual peak flow versus time in years for the Kankakee River at Wilmington

flows at this location. A change in gaging station locations that occurred around this time might account for this change. It appears that there was a jump in the peak flows around 1941. If we subtract this jump from all the individual peak flows after 1941, the variation of the peak-flow plot from 1915 through 1979 indicates that this distribution is similar to a statistical distribution of long-term flows. The 3-year moving average and the average peak flows for various periods are also given in figure 20. Except for the jump in the early 1940s, no trend is visible from these data.

It has been shown that a trend exists at the Momence gaging station. The average peak flow at Momence is about 27 percent of the average peak flow at Wilmington. It appears that the peak flow trend present at Momence has a minimal effect, or no effect, on peak flows at the Wilmington gaging station. Apparently, by the time the peak flow from Momence travels to Wilmington, it is modified, truncated, and dampened by the flow from the Iroquois River and the pools behind the dams at Kankakee and Wilmington.

The above analyses indicate that there are certain trends in the peak flows at the Shelby and Momence gaging stations. For the other gaging stations, no discernible trends could be identified. To see whether or not similar trends are also present for the long term average flows and low flows, similar analyses have been performed; the results are given in the following paragraphs.

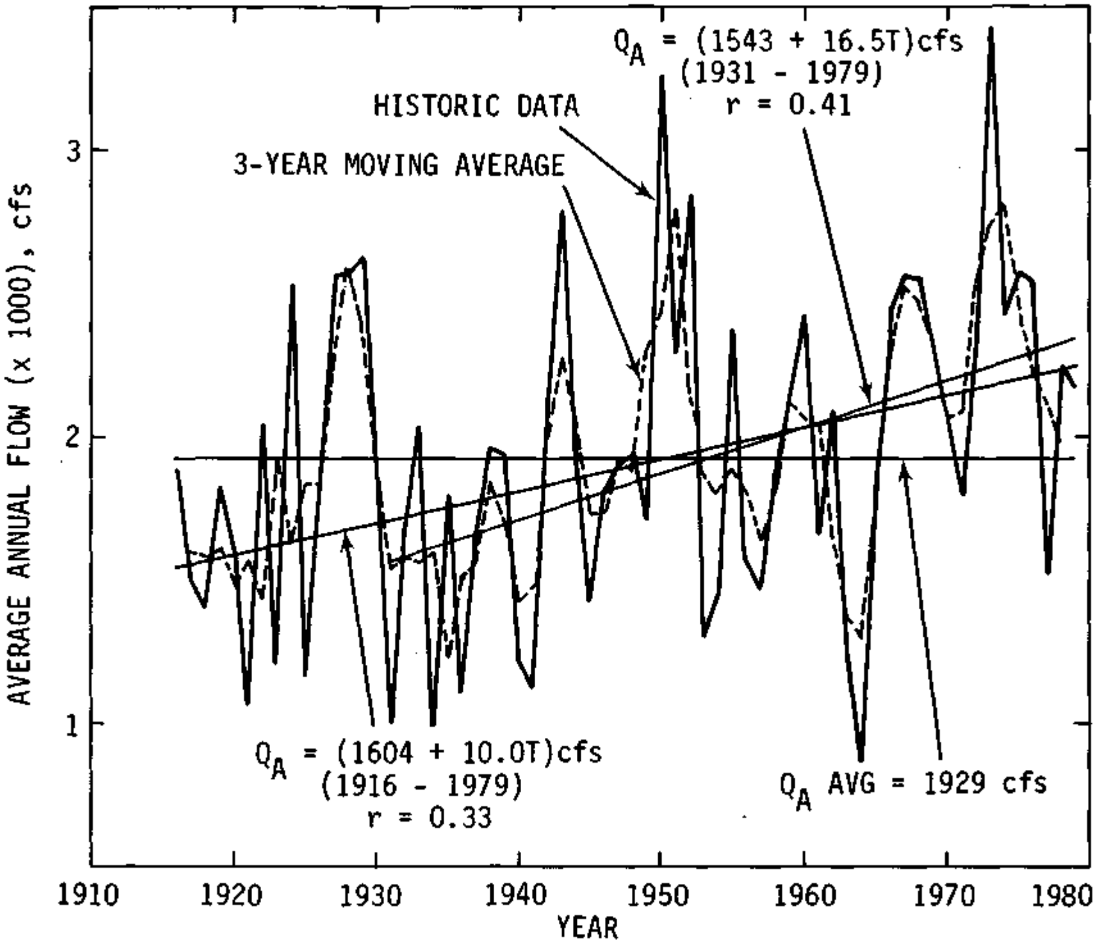


Figure 21. Average annual flow versus time in years for Momence

Average Discharge

Figure 21 shows the average annual flow versus time in years for the Momence gaging station for the period 1916 through 1979. The 3-year moving average is also shown in this figure. The regression line based on data from 1931 through 1979 indicates that there exists an upward trend in the average flows during this period. The regression line is given by equation 31.

$$Q_A = 1543 + 16.5T \quad (31)$$

where Q_A is the average annual flow and T is the time in years.

The trend shown here may have resulted from some long-term change in the watershed that may stabilize at some discharges in the near future or may even show a downward trend. Physical constraints may ultimately limit such an increasing trend. To resolve whether or not a trend is present for an indefinite period of time would require collecting data for the next 15 to 20 years.

Plots similar to figure 21 were also developed for the gaging stations at Shelby and Foresman in Indiana, and at Iroquois and Chebanse in Illinois. No trend was ap-

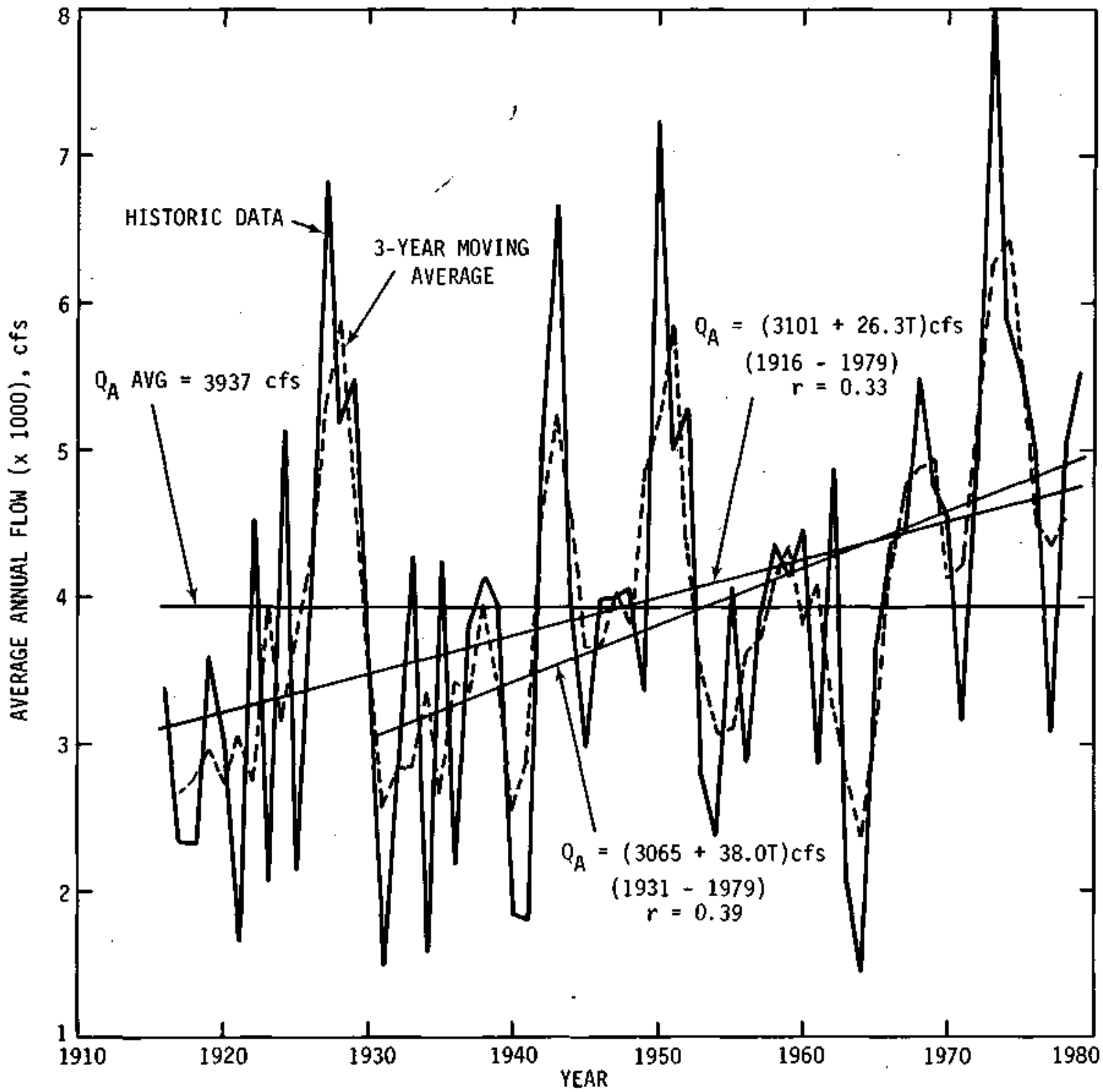


Figure 22. Average annual flow versus time in years for Wilmington

parent in any of the four plots. The average discharge appeared to be changing between low and high values but showed no upward or downward trend.

The relationship between average annual flow and time for the Wilmington gaging station is shown in figure 22. It is quite apparent that a definite trend of increasingly higher average flows started sometime in the 1930s and is still continuing. The regression line is represented by equation 32.

$$Q_A = 3065 + 38.0T \quad (32)$$

The slope of the trend line is positive and is equal to 38.0, showing that the average discharge at the Wilmington station had increased by 38.0 cfs every year since 1931. When the trend line is fitted for the data from 1916 through 1979, the coefficient of T becomes 26.3.

At this point it will be interesting and useful to make an analysis to see whether or not any similarities or dissimilarities exist in the trends of the peak and average flows at various locations. One of the simplest and easiest methods is to make all the coefi' cients of T in all the regression equations dimensionless by using a common base. The average peak discharge and the average of the average annual discharges are taken to be such common bases.

The general form of equations 29 and 30 can be taken as

$$Q_p = aT + b \tag{33}$$

where a and b are coefficients. Similarly, equations 31 and 32 can be replaced by equation 34.

$$Q_A = a_1 T + b_1 \tag{34}$$

where a_1 and b_1 are coefficients.

Table 5 shows the dimensionless ratio of $a/\bar{Q}_p$ and $a_1/\bar{Q}_A$, where $\bar{Q}_p$ is the average of peak flows and $\bar{Q}_A$ is the mean of average annual discharges. Data considered are from 1931 through 1979. It is obvious that for the average discharges for the Momence and Wilmington gaging stations, the trend $(a_1/\bar{Q}_A)$ is approximately identical. With regard to the peak flows at Shelby and Momence, the value of $a/\bar{Q}_p$ at Momence is higher than that at Shelby. This may indicate that the peak flows at Momence are increasing at a faster rate than those at Shelby. The significant amount of flow contributed by Singleton Ditch at the Momence station may account for this dissimilarity.

Low Flow

Identification of trends in the peak and average flows at Momence and Wilmington leads to further analyses of discharges at these and other gaging stations to determine whether any trends exist for low flows. Low flows are important for recreation, public water supplies, and maintenance of biological habitats. One of the standard terms for low flows that is used for stream flow analysis is the 7-day low flow at a location in a stream. The 7-day low flow in any year is the average low flow that exists in a consecutive 7-day period. Such flows were analyzed to investigate the existence or nonexistence of trends in low flows.

Figure 23 shows a plot of 7-day low flows for Momence from 1916 through 1979. The 3-year moving average is also shown. An examination of this illustration shows that no trend is present in the low flows at this location. The low flows have changed around a mean over the years, but neither an upward nor a downward trend is visible.

Table 5. Comparison of the Regression Coefficient in Equations $Q_p = aT + b$ and $Q_A = a_1 T + b_1$ for the Period 1931-1979

Gaging stations	*Peak flows* $a/\bar{Q}_p$	*Average flow* $a_1/\bar{Q}_A$
Shelby	0.0066	
Momence	0.011	0.0086
Wilmington		0.0096

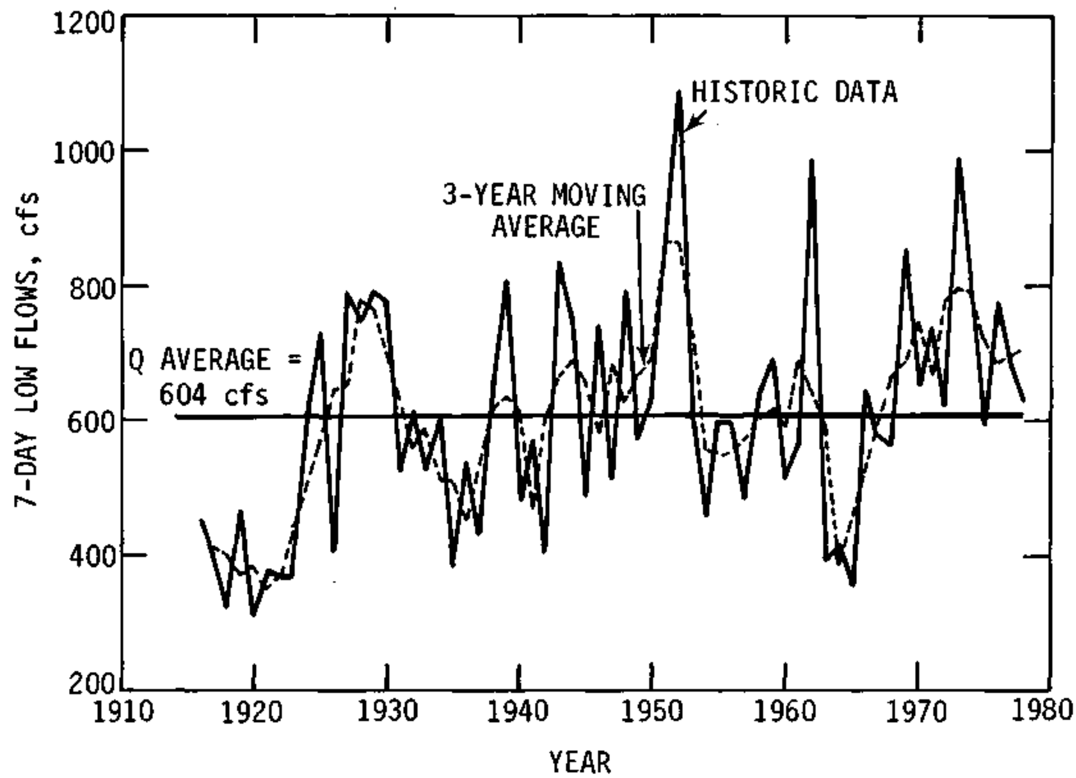


Figure 23. 7-day low flows for Momence

The 7-day low flows for Chebanse from 1925 through 1978 are shown in figure 24. Up to the late 1960s the low flows followed a somewhat random variation with no apparent trend. However, for a period of a few years from the late 1960s through the early 1970s, the 7-day low flows increased significantly. Similar variabilities were observed for the low flow data from the Foresman and Iroquois stations. These three stations are on the Iroquois River, suggesting that something happened on the Iroquois River during this period of time that contributed toward this sustained increase in low flows.

The sudden increase in low flows at Foresman, Iroquois, and Chebanse for the period of the late 1960s through the early 1970s did not persist downstream on the river at Wilmington. Figure 25 shows the variability of 7-day low flows for the Wilmington gaging station. Although there are some high peaks and low valleys, in general the low flows did not show an upward or a downward trend over the years.

The analyses presented so far indicate that there are trends in the peak flows at Shelby and Momence, and in average flows at Momence and Wilmington. On the average no trend is persistent for low flows at any station. The trends present at Momence for average and peak flows indicate that something must have happened in the watershed over the years that is responsible for this change in the flow regime. The change in the precipitation intensity, channelization of the stream, increased urban development,

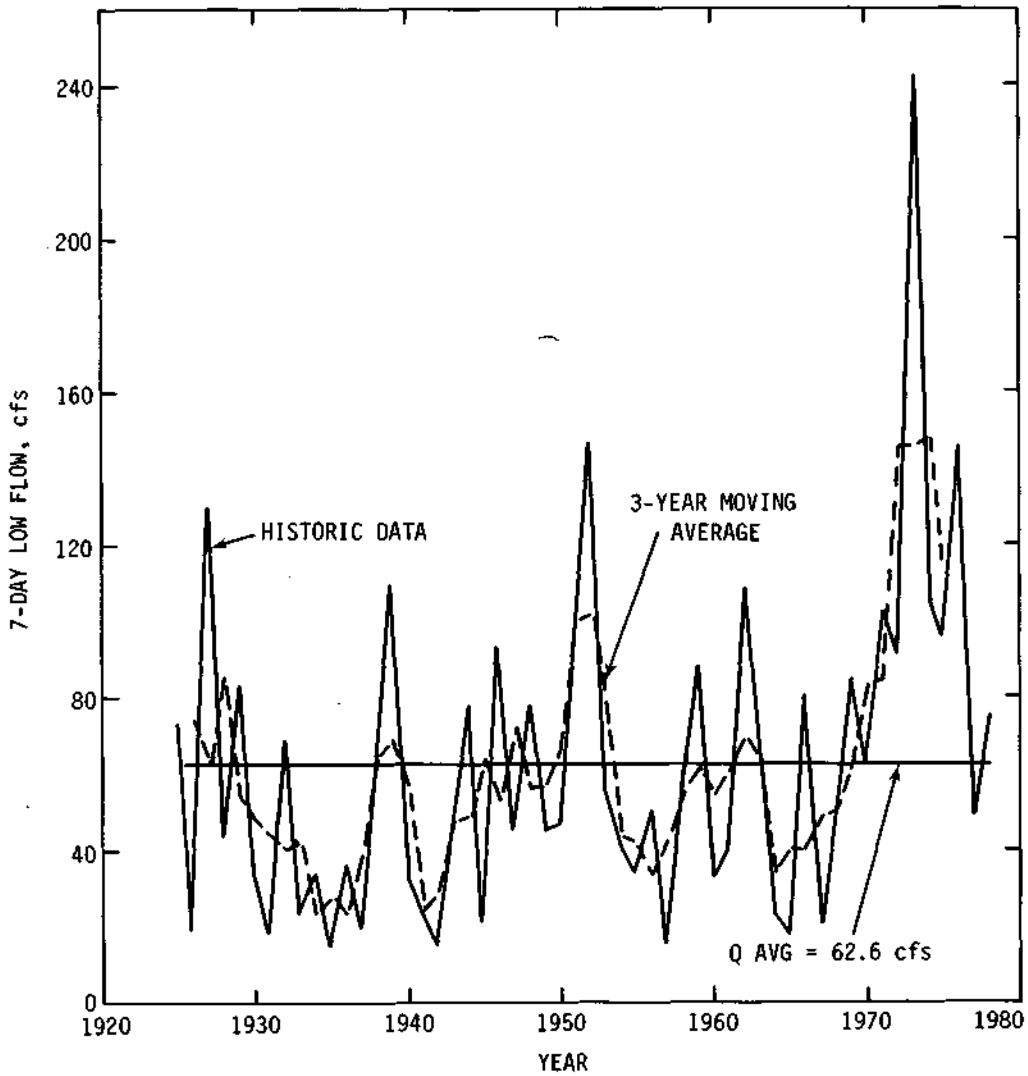


Figure 24. 7-day low flows for Chebanse

increased and efficient drainage from the watershed, change in agricultural patterns, and reduction in forest cover are some of the factors that may have contributed to this apparent increasing trend in average and peak flows at Momence. To see whether or not the total precipitation over the whole watershed has increased over the years, an analysis of the annual precipitation has been made.

Precipitation Analysis

It has been mentioned that one of the reasons flow at a location in a stream can show a general increasing trend is that precipitation has increased on the watershed. Since the Kankakee River extends over a large area both in Illinois and Indiana, an analysis was made of the long-term precipitation record over the watershed. One of the methods that can be used to estimate the precipitation over an area is called the isohyetal

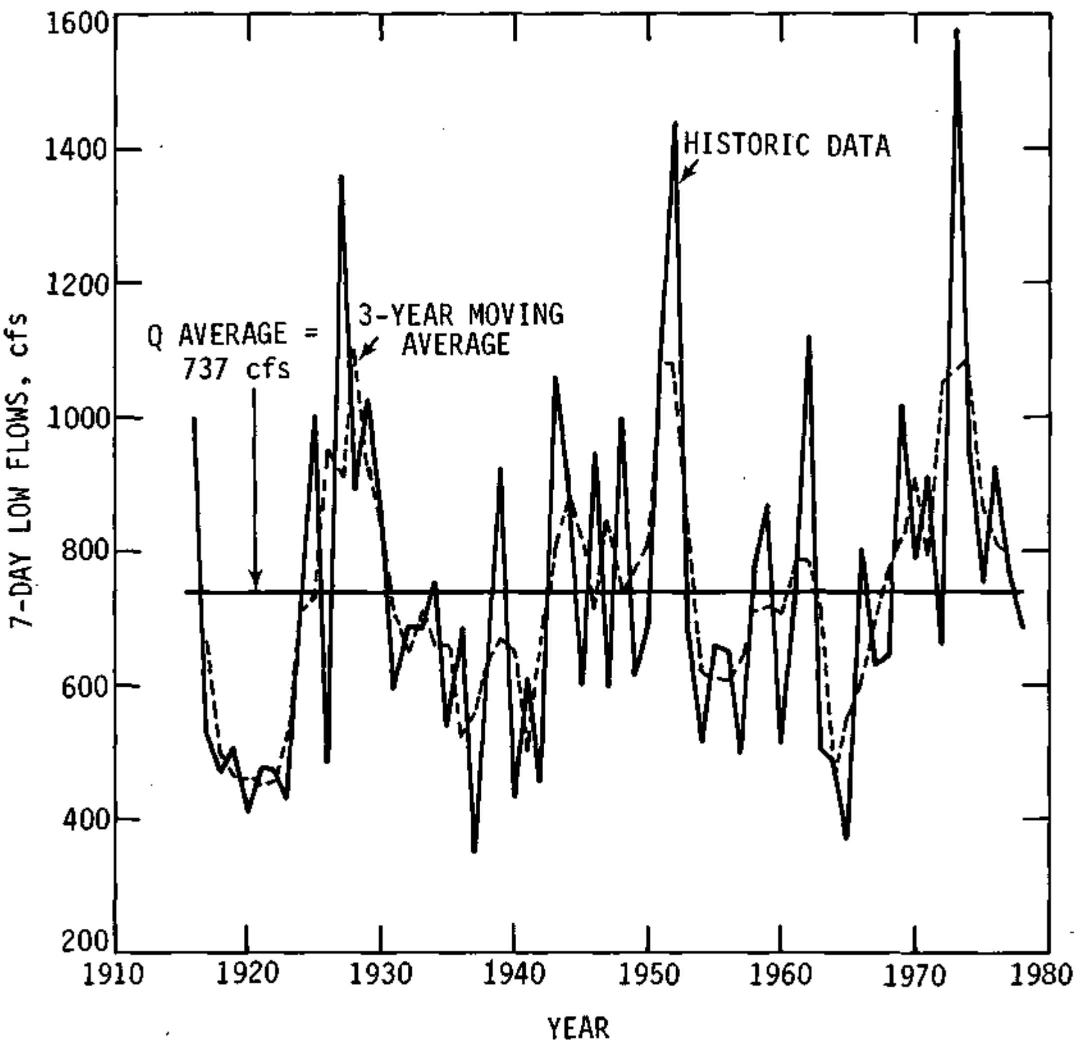


Figure 25. 7-day low flows for Wilmington

method. The precipitation at various locations over an area is plotted on a map, lines of equal average precipitation (isohyetal lines) are drawn, inclusive areas over all the isohyetal lines are measured, and an average weighted precipitation over the area is determined (Linsley et al., 1958).

Figure 26 shows an isohyetal map developed for the Kankakee River drainage basin for calendar year 1976, which indicates that the northeastern corner of the basin was subjected to higher precipitation than were other areas of the basin. The drainage area above the isohyetal line of 38 inches near the northeastern part of the drainage basin makes up approximately 25 percent of the drainage area at Momence.

Isohyetal maps developed for 1954 and 1967 also show a relatively higher concentration of precipitation near the northeastern part of the drainage basin. Thus for about 20 to 25 percent of the drainage area for the Momence gaging station, runoff from the watershed may be relatively higher than for the other areas.

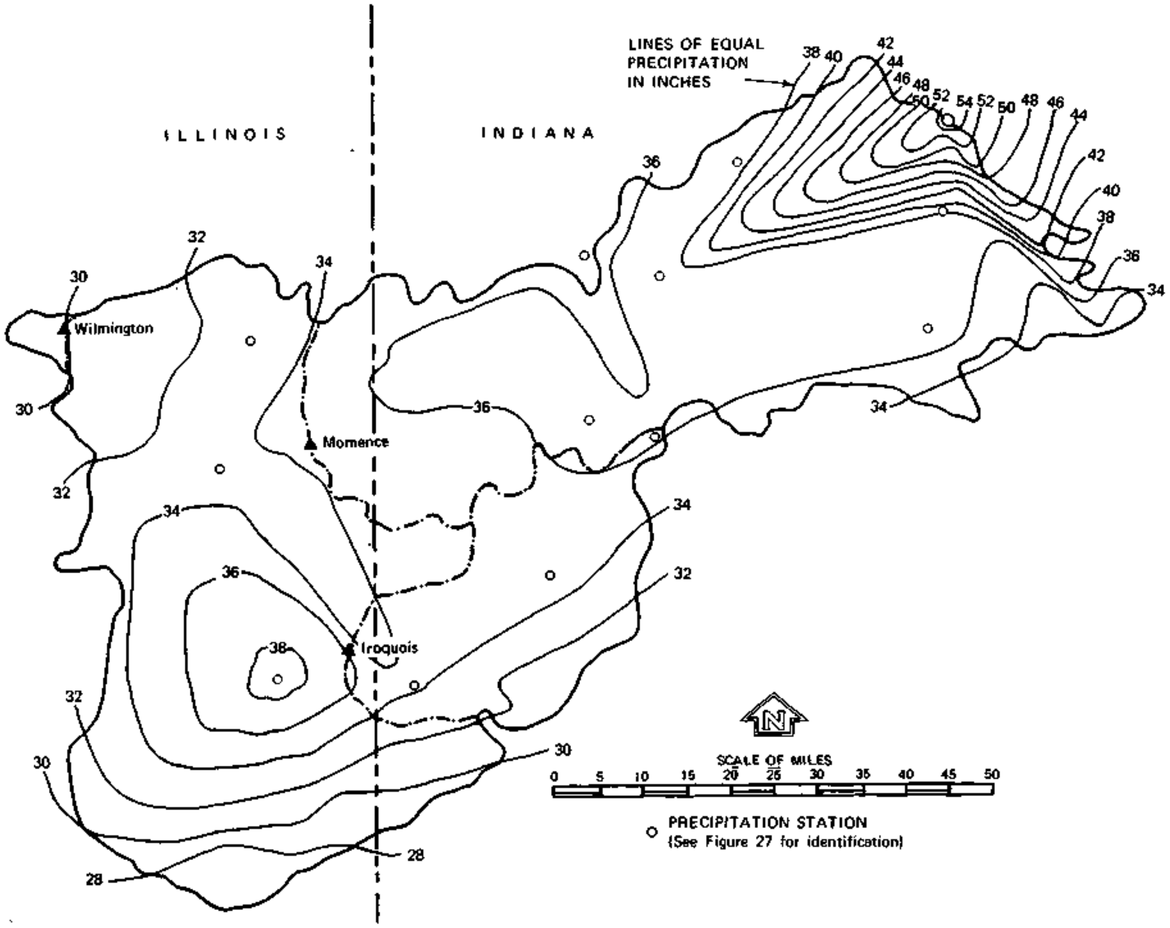


Figure 26. Isohyetal map for calendar year 1976

Average precipitation determined for a station based on isohyetal maps is relatively accurate provided the isohyetal lines are drawn based not only on the precipitation at a location but also on the relief features of the basin. Since this is a relatively difficult task to accomplish, a simpler method called the Thiessen Method is normally used to compute the average precipitation over an area (Linsley et al., 1958).

Figure 27 shows the Thiessen polygon for the Kankakee River Basin and indicates the stations for which precipitation data were collected. The precipitation for each of the stations was assumed to be the same for the polygonal area surrounding the specific station. The methodology given by Linsley et al. (1958) was used to compute average annual precipitation above two gaging stations — Momence and Iroquois. For the Wilmington station, the precipitation was computed for the drainage area between the Momence, Iroquois, and Wilmington stations. The average precipitation computed from isohyetal maps and that computed from the Thiessen polygon were compared. Table 6 shows such a comparison for three typical years. Since the average precipitation as estimated by the two methods did not differ significantly for these three specific years, it is reasonable to assume that the average precipitation computed by the Thiessen Method should yield a very reasonable estimate of the precipitation over the entire watershed.

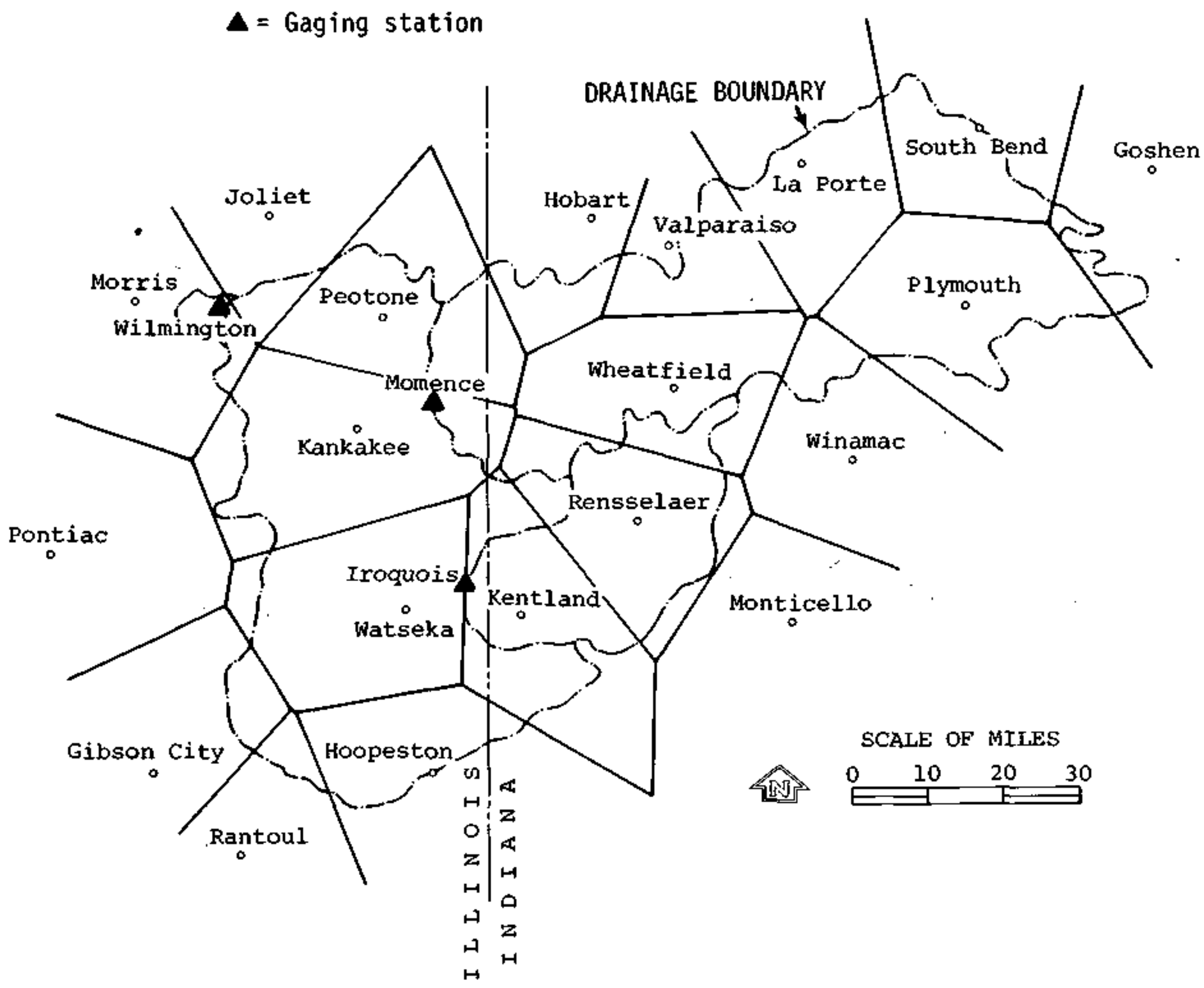


Figure 27. Thiessen polygon for the Kankakee River Basin

Table 6. Average Precipitation Estimated from Isohyetal Maps and Thiessen Polygon

Station	*Year*	*Average precipitation (inches)* *Isohyetal*	*Thiessen*
Momence	1954	49.21	50.66
Iroquois	1954	35.89	36.41
Wilmington	1954	36.70	34.92
Momence	1967	38.40	39.12
Iroquois	1967	39.90	40.11
Wilmington	1967	37.50	38.62
Momence	1976	37.65	37.91
Iroquois	1976	34.00	34.87
Wilmington	1976	33.02	33.73

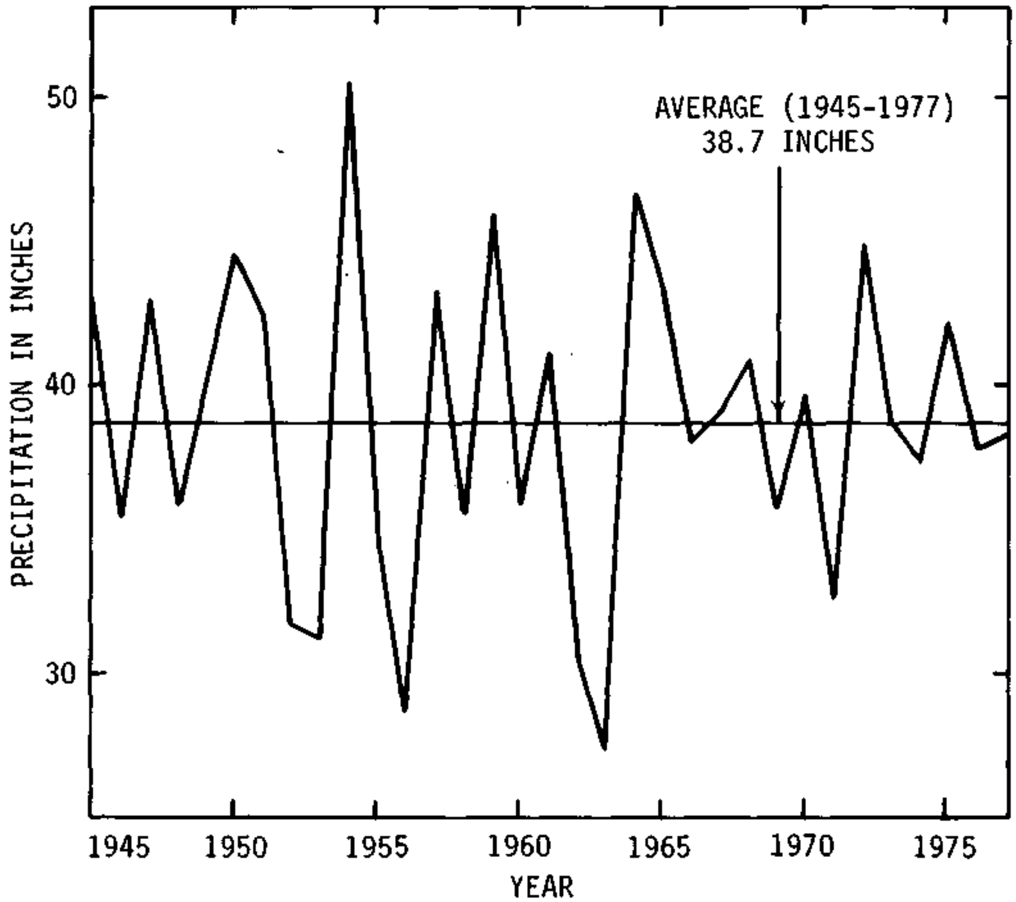


Figure 28. Variability of average precipitation upstream of the Momence gaging station

Figure 28 shows the relationship between the average annual precipitation and time in years for the watershed upstream of the Momence gaging station. It appears that the average annual precipitation did not show any increasing or decreasing trend. A similar correlation was observed for the area above the Iroquois gaging station.

Figure 29 shows the relationship between the average annual precipitation and time in years for the area upstream of the Wilmington gaging station. Here also, no significant trend in the precipitation is noticeable.

This analysis indicates that there are concentrations of increased precipitation in some local areas (figure 26) but that on the average and over the whole watershed this trend may not be significant.

Cross-Sectional Data

The Illinois Division of Water Resources (DOWR) collected and analyzed a set of cross-sectional data from the Kankakee River for 1966-1967 and 1977-1978, after which the raw data and the associated analyses were made available to the Water Survey. A further analysis of these data was made, and the results are presented here.

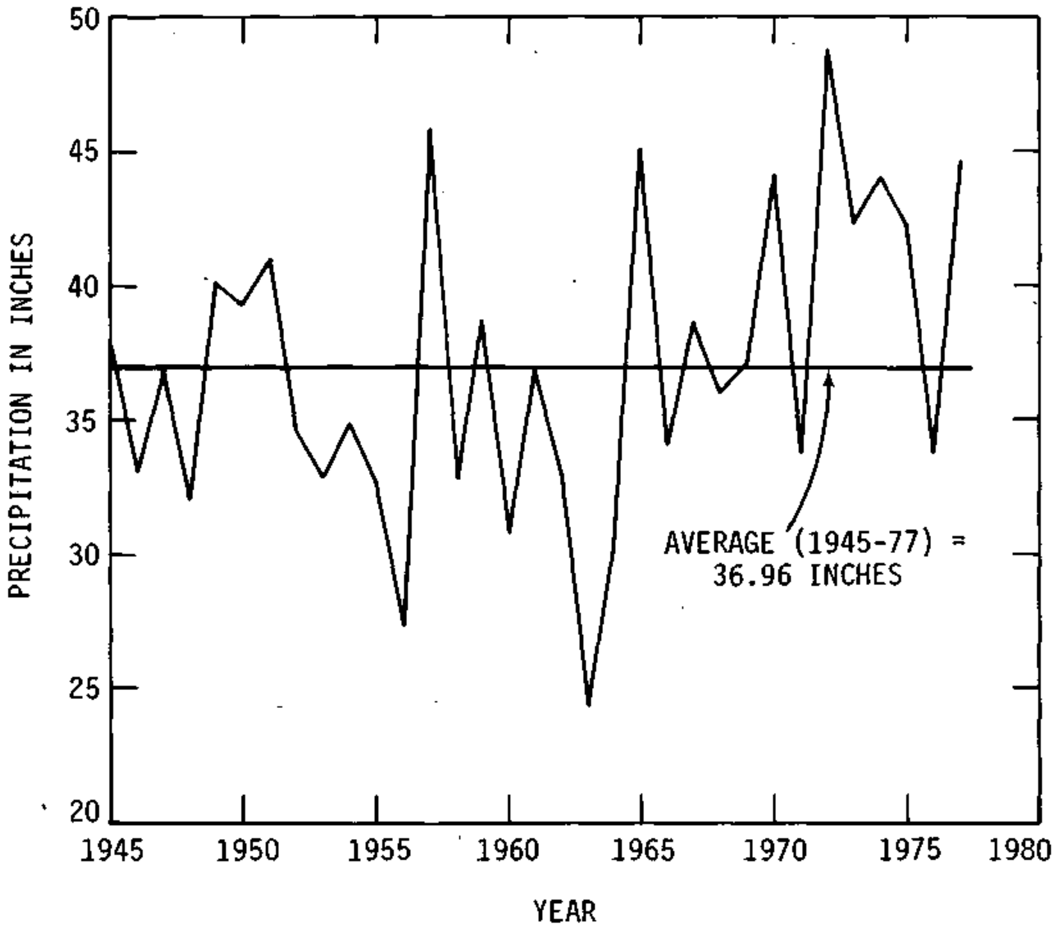


Figure 29. Variability of average precipitation upstream of the Wilmington gaging station

Figure 30 shows the locations of the cross sections where sounding data were collected by the DOWR. Data for both time periods were collected from the same specific cross sections. Sounding data were collected from about 90 cross sections and were analyzed to identify any variability in the cross-sectional areas and bottom elevations of the Kankakee and Iroquois Rivers.

Figure 31 shows the variability of bottom elevations of the Kankakee River from the Kankakee Dam to Momence. The 1959 data, for just upstream of the Kankakee Dam, were collected by the Chicago District Office of the U.S. Army Corps of Engineers. The discontinuity in slopes on the bottom-elevation lines indicates the locations where sounding data were collected. This analysis indicates that both erosion and deposition occurred over the 10 to 12 years between the periods sounding data were collected. For the analysis, the bottom elevations of the river between two adjacent cross sections for any specific set of data were joined by a straight line. It is assumed that the change in bed configurations between any two cross sections is determined by the data from those two cross sections. Although this is a standard analysis for these

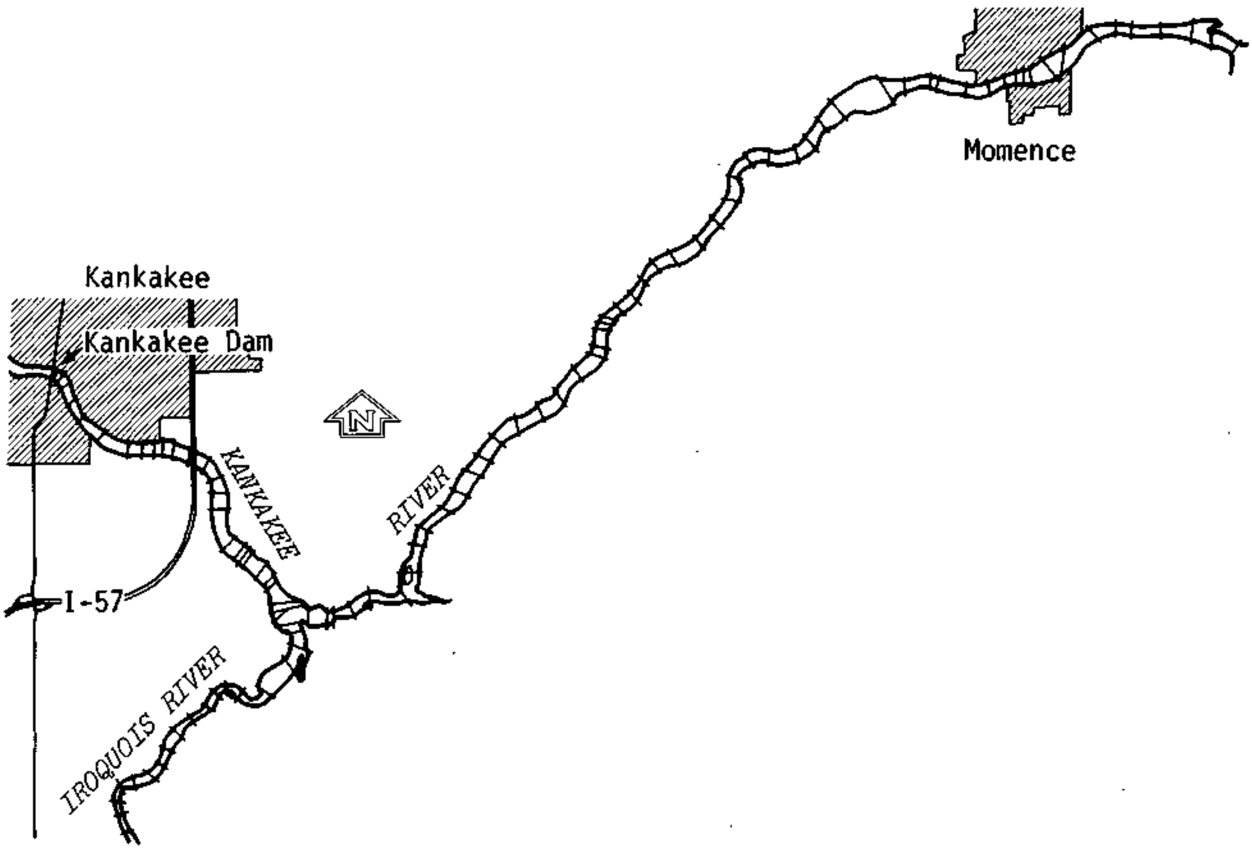


Figure 30. Locations of Kankakee River cross sections for sounding data collection (after DOWR)

types of data, errors may occur, since between any two cross sections, some changes that might have occurred during the intervening years are neglected.

Figure 32 shows the differences in cross-sectional areas below a water surface elevation of about 596 feet above mean sea level for the Iroquois River. Data are shown for 1958 and 1977. This illustration indicates that, within the last 20 years, an 0.75-mile segment of the Iroquois River, just upstream of its junction with the Kankakee River, has had some deposition of sediment. Upstream of this area, the river has been either eroding or depositing in an alternating pattern. The pattern of deposition of sediment near its mouth indicates that the river is behaving similarly to a stream whose velocity is suddenly reduced, forcing it to drop its sediment load, as if the stream is entering a man-made lake. This is the effect of the Six Mile Pool, which acts as a deterrent to the normal behavior of the natural stream at or near its confluence.

An analysis was performed to investigate the changes in cross-sectional areas of the Kankakee River between 1967-1968 and 1977-1978. These changes are shown as bar graphs in figure 33. For the first 6-7 miles upstream of the junction with the Iroquois River, the Kankakee River had both deposition and erosion along its path. However, for the next 6-7 miles, the river had more deposition than erosion.

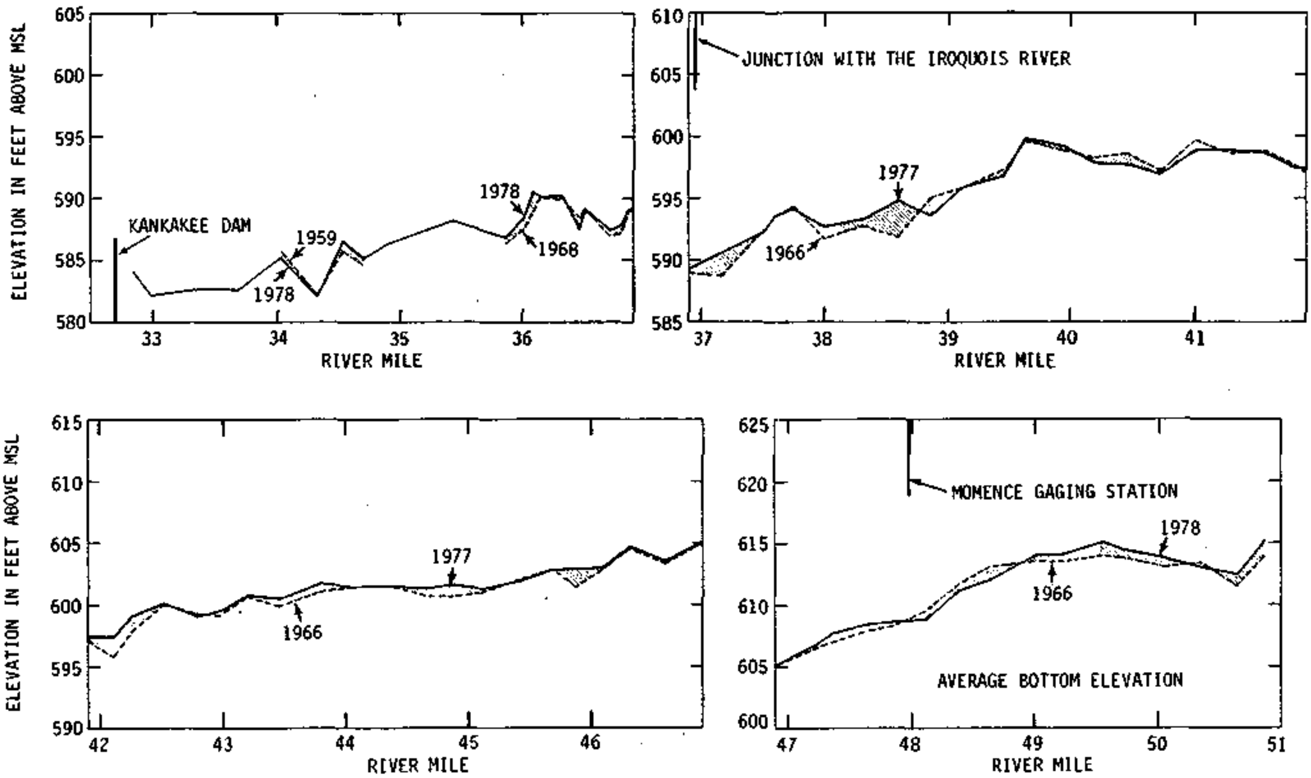


Figure 31. Variability of average bottom elevations of the Kankakee River from the Kankakee Dam to River Mile 51.0, based on DOWR data

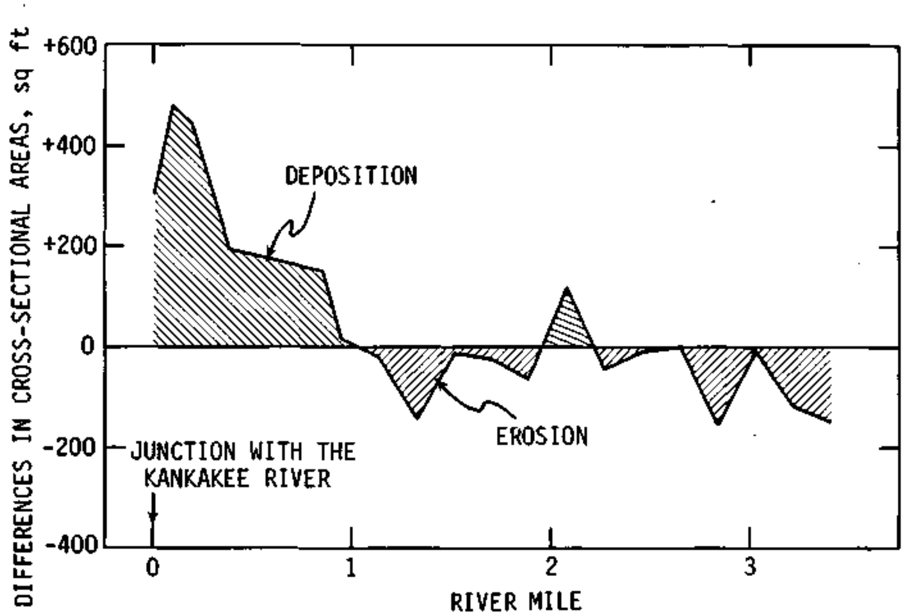


Figure 32. Differences in cross-sectional areas along the Iroquois River below 596 feet msl (data from DOWR)

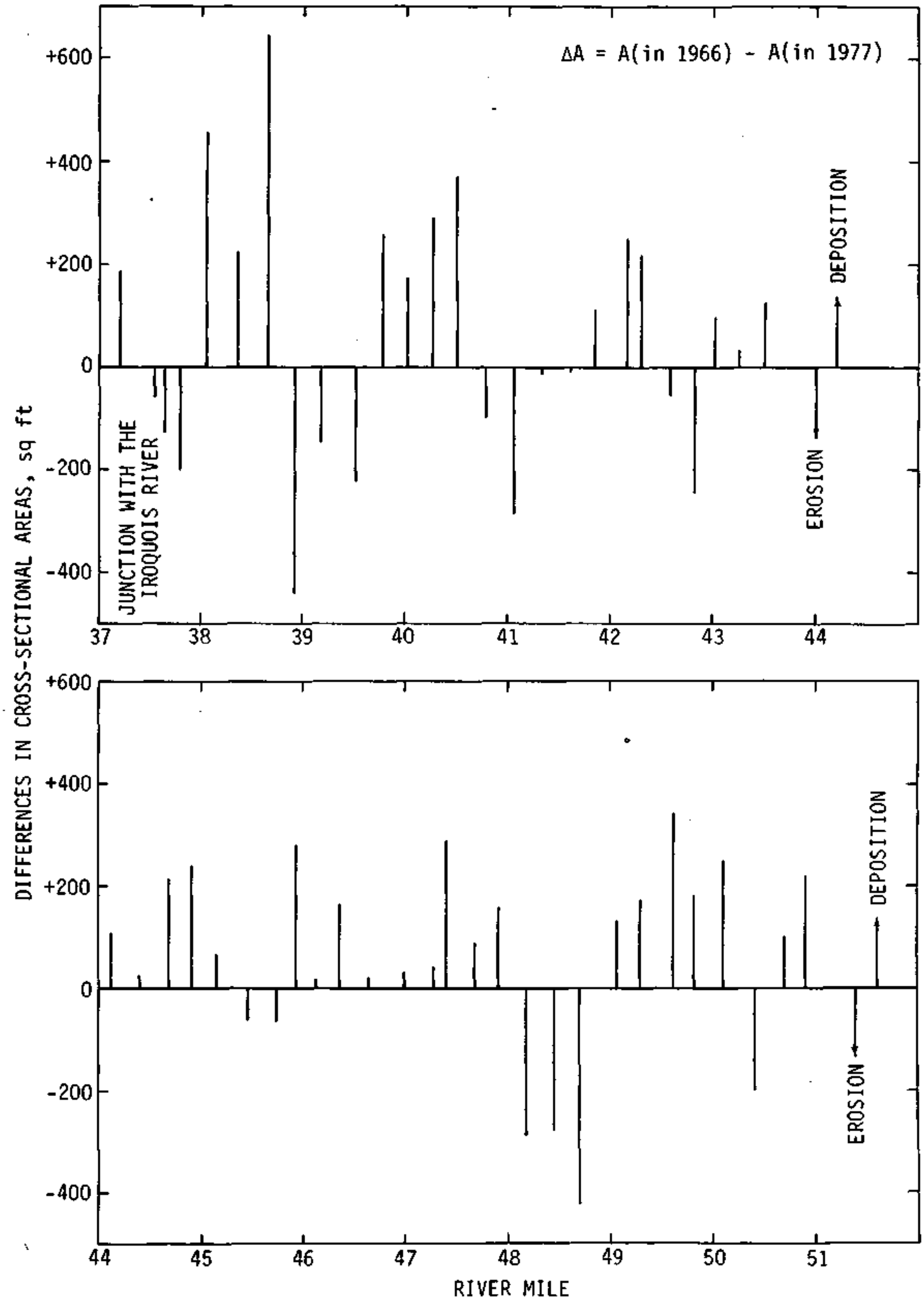


Figure 33. Differences in cross-sectional areas along the Kankakee River upstream of the junction with the Iroquois River (data from DOWR)

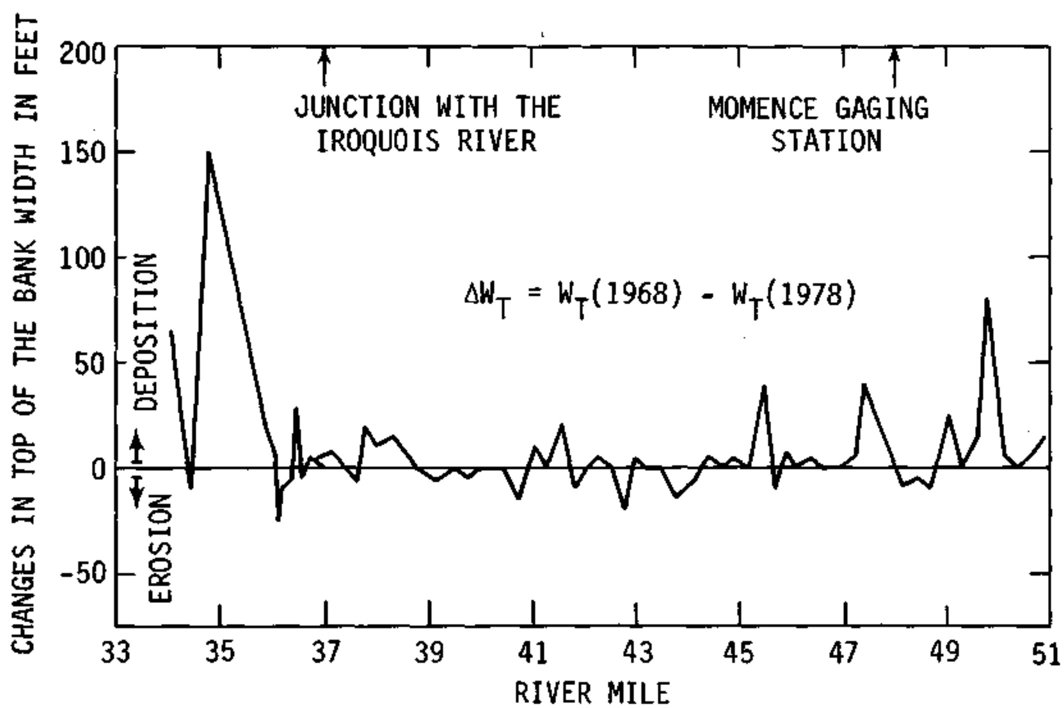


Figure 34. Changes in top width at the bankfull stage along the Kankakee River (data from DOWR)

The changes shown in figure 3 3 can occur either on the bed or on both the bed and banks of the river. If the banks are fairly stable, then the changes in cross-sectional areas can occur only on the bed of the river. Figure 34 shows a plot of the differences of the top widths of the river at the bankfull stage. ΔW_T is the change in top widths, and W_T (1968) and W_T (1978) are the top widths that were measured in 1968 and 1978, respectively. Except for a segment of the river within the Six Mile Pool, the changes in top widths of the Kankakee River over a period of about 10 years were minimal. Thus any changes in the cross-sectional areas of the Kankakee River must have occurred on the bed of the river.

The analysis presented so far indicates that the Kankakee River is a dynamic river. Changes on the bed of the river have been occurring and will continue to occur. In some areas the river will erode its bed of erodible materials and in other areas it will deposit. This pattern will possibly continue for the foreseeable future.

Present Data Analyses

Bed and Bank Materials

Approximately 375 bed and bank material samples were collected along the Kankakee River and were analyzed to characterize the particle size distribution of the bed materials and its effect on the sediment transport characteristics of the river. These samples were also analyzed to identify any changes or variability of the bed materials along the Kankakee River. All the samples were dried, and a standard sieve analysis was performed to determine their particle size distribution.

Appendix A shows the particle size characteristics of the bed materials collected from the Kankakee River. The terms d_{35}, d_{50}, d_{65} ,and d_{95} indicate the equivalent particle diameters for which 35, 50, 65, and 95 percent, respectively, of the particles are finer in diameter. The term σ is the standard deviation of the particle size distribution and is defined by equation 35.

$$\sigma = ½ [(d_{84.1}/d_{50}) + (d_{50}/d_{15.9})] \quad (35)$$

where $d_{84.1}$ and $d_{15.9}$ also indicate the equivalent particle diameters for which 84.1 and 15.9 percent, respectively, of the particles are finer in diameter. The term U in Appendix A represents the uniformity coefficient, which is computed by equation 36.

$$U = d_{60}/d_{10} \quad (36)$$

Here d_{60} and d_{10} have similar meanings to those of d_{35}, d_{50}, etc.

The values of σ and U indicate the presence or absence of uniformity in the particle size distribution. For uniform particles, the values of *a* and U should be close to unity, while for well-graded particles, the values of σ and U are higher than unity. Most of the bed materials along the Kankakee River are fairly uniform, as can be determined by inspection of the numerical values of σ and U in Appendix A.

A frequency analysis of the d_{50} sizes of the bed materials should show the variability of the bed materials along the Kankakee River. Figure 35 shows such an analysis of the bed materials, excluding those from the Six Mile Pool and sand bars. A total of 281 samples were analyzed. This illustration indicates that the median diameters of 136 of the samples are in the range of 0.3 to 0.4 mm, the median diameters of about 221 samples are between 0.2 and 0.4 mm, and almost all the bed materials have their median diameters in the range of 0.1 to 0.4. As will be seen in a subsequent illustration (figure 37), this range of median diameters places all these materials in the range of fine to medium sand. Thus, for all practical purposes, it can be assumed that the bed materials of the Kankakee River, except in areas of rocky bed, are composed of fine to medium sands. This point is further amplified in the next illustration.

The changing patterns of the d_{50} sizes of the bed materials along the centerline of the Kankakee River are shown in figure 36. As can be seen, the d_{50} sizes of the majority of the bed materials are close to 0.35 mm, and no increasing or decreasing trend is present. Therefore, based on this analysis, it appears that it would be very hard to identify the origin or location of any particular sand particle on the bed of the river.

Figure 37 shows the plots of particle size distributions of some of the selected bed material samples along the centerline of the Kankakee River from U.S. Highway 30 in Indiana to the Six Mile Pool in Illinois. These plots indicate that there is not much variability between the patterns of particle size distributions from Indiana to Illinois. The shapes of the plots are similar, and the particles are basically uniform, ranging in size from medium to fine sands. This is true for samples taken from the bed of the river (figure 37), from the Six Mile Pool (figure 38a and Appendix B), and from sand bars (figure 38b). This shows that the bed of the Kankakee River is composed of sand, except in some segments in Illinois where the bed is covered with rocky materials.

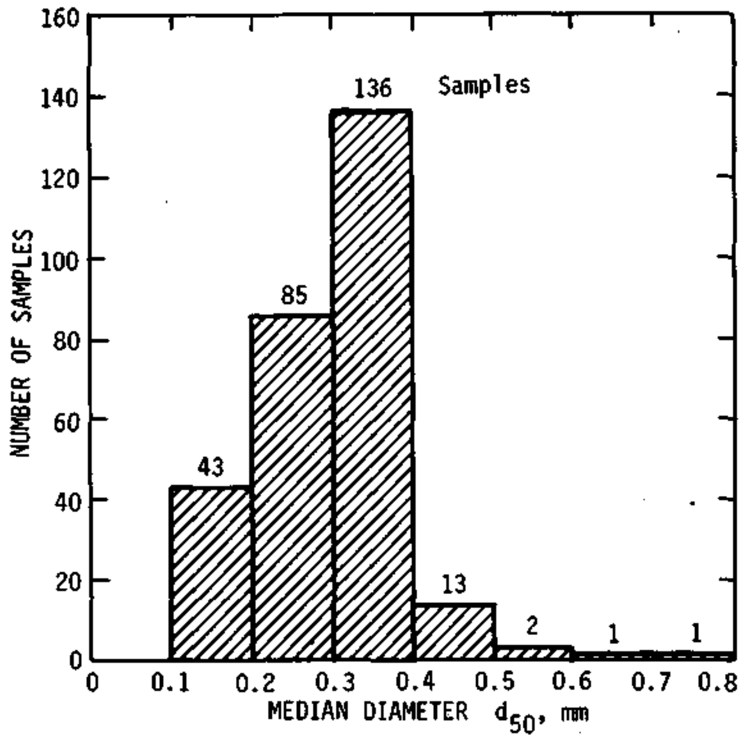


Figure 35. Frequency distribution of the d_{50} sizes of the bed materials

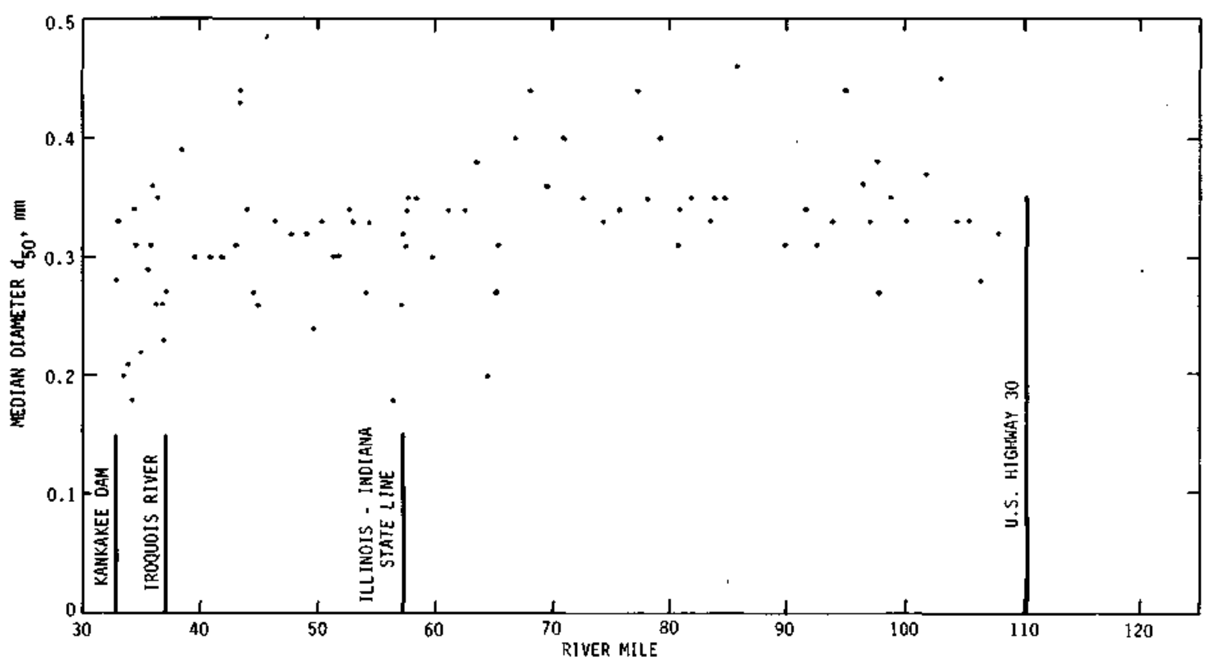


Figure 36. Median diameter d_{50} of the bed materials versus distance along the centerline of the Kankakee River

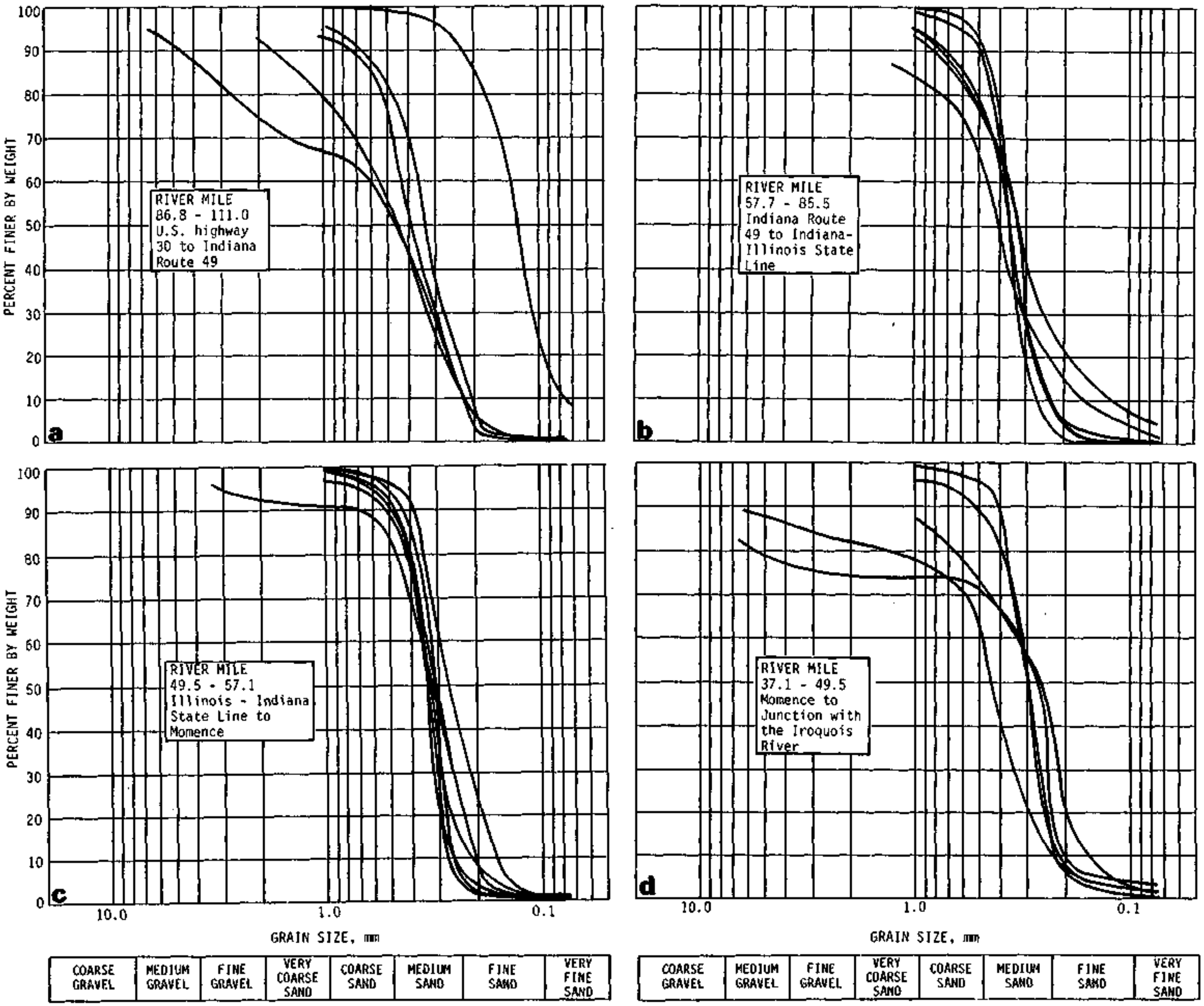


Figure 37. Particle size distributions of selected bed material samples for the Kankakee River from the junction with the Iroquois River to U.S. Highway 30

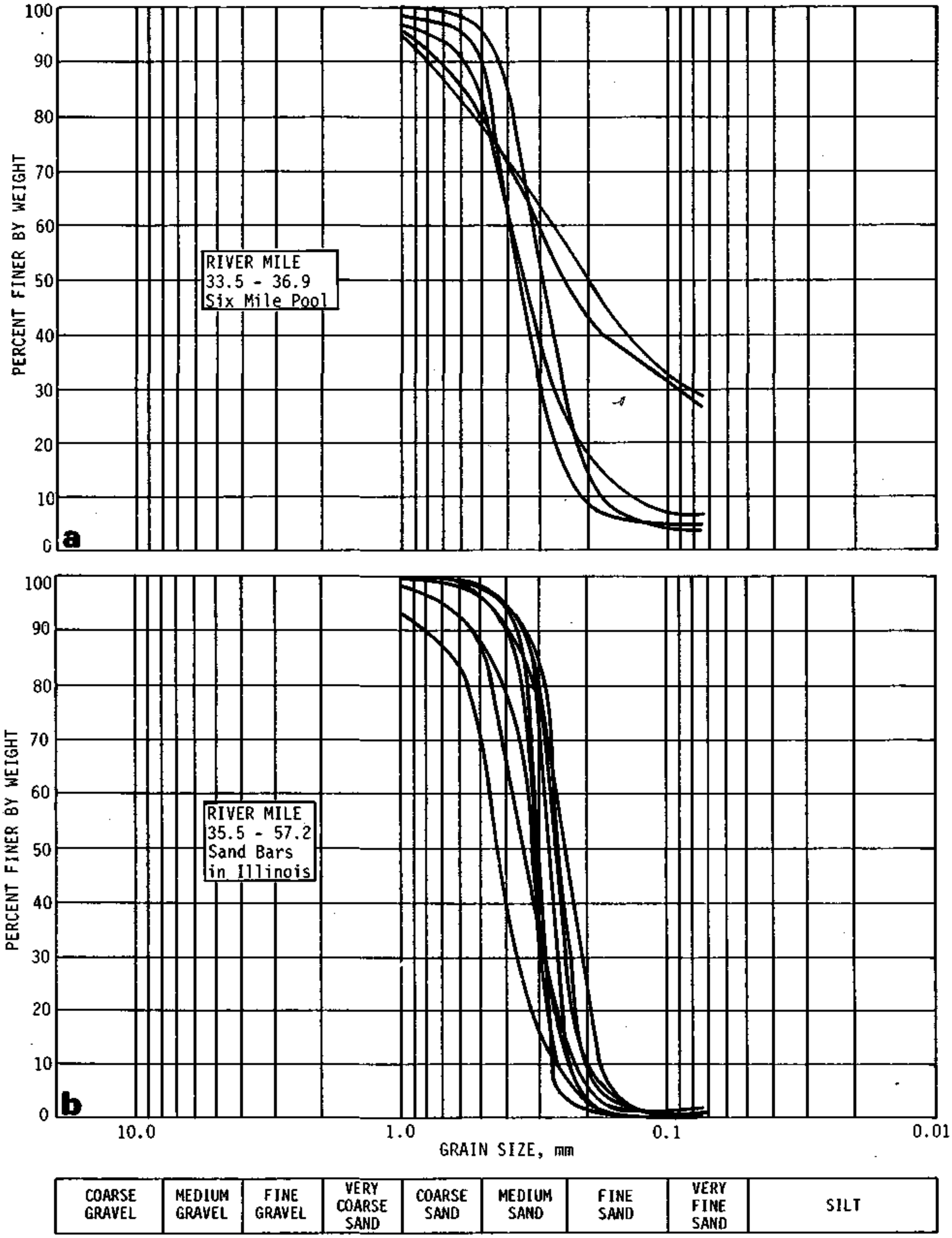


Figure 38. Particle size distributions of selected bed material samples

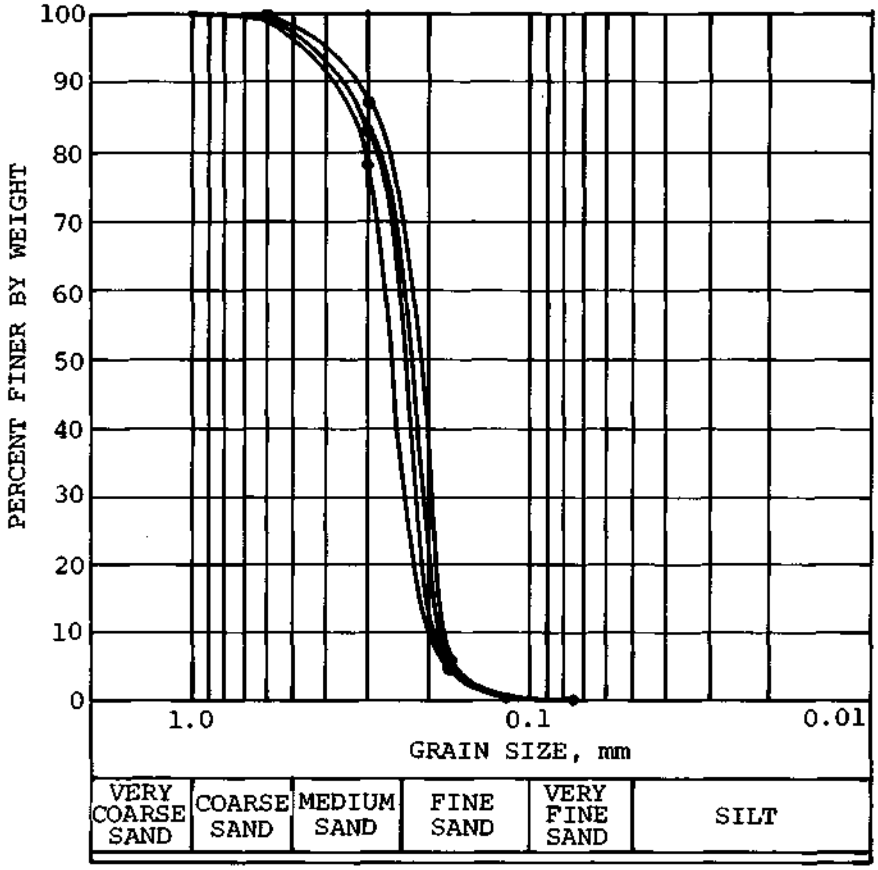


Figure 39. Particle size distributions of a sand deposit in the Six Mile Pool (depth of sampling: 0 to 2 feet)

An attempt was made to analyze the deposited sand from sand bars in Illinois for particle size distribution. Core samples extending up to 2 feet in length were collected. Particle size distributions of samples from different depths were made. Figure 39 shows the particle size distribution of four samples (0 to 0.5 ft, 0.5 to 1.0 ft, 1.0 to 1.5 feet, and 1.5 to 1.9 feet) from a sand bar in the Six Mile Pool. This illustration indicates that even with depth, the particle size distributions of the deposited sediments are nearly identical. Medium-sized sand constituted the bulk of the sand bars. Appendix C-I shows the particle size characteristics of these materials.

Similar core samples were collected from the centerline and near the left and right sides of the river at the sand bar near the state line. The particle size distributions of the materials are shown in figure 40. Here again, the sediment deposited in this sand bar consists of medium-sized sands. Appendix C-II shows the particle size characteristics of these materials. Appendix C-III shows the particle size characteristics of the bed materials of some of the other sand bars.

The analyses presented thus far indicate that the bed materials of the Kankakee River, for almost all of its length in Indiana (up to Highway 30) and most parts in Illinois (up to the Six Mile Pool), consist of medium sand with some fine and coarse sands.

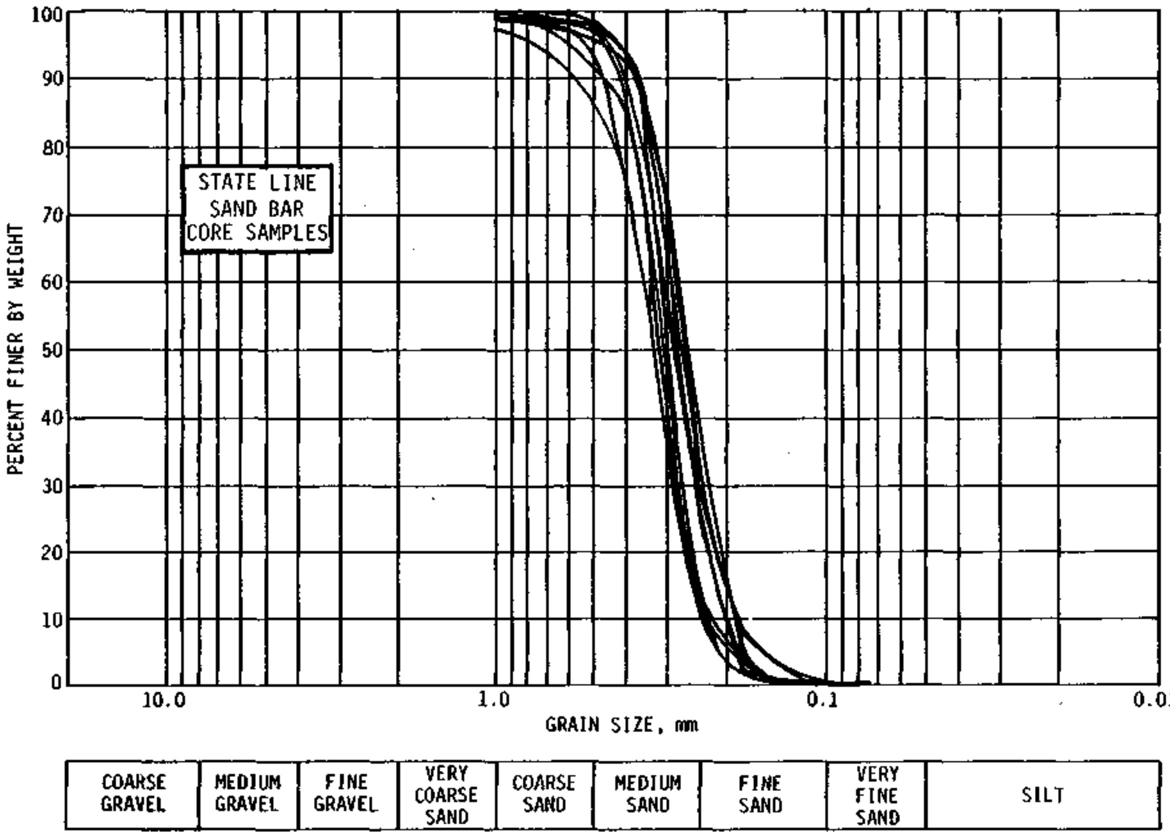


Figure 40. Particle size distributions of core samples from the sand bar near the state line

The river is obviously flowing on a sandy bed with the contributing tributaries also flowing on sandy beds. Even the bank materials are composed of sand. This is especially true in Indiana. Figure 41 shows some typical particle size distribution plots of bank materials collected in Indiana. These materials range in size from fine to coarse sands with medium sand predominating. Appendix D shows the particle size characteristics of the bank materials.

Bed material samples were collected from the State Line and Illinoi stations in 1978-1979. These materials were analyzed for particle size distributions. The locations, collection dates, particle size distributions, and main characteristics of these materials are given in Appendix E. The d_{50} sizes of all the materials range from about 0.2 to 0.35 mm.

Sampling of bed materials from the Iroquois River was not as extensive as for the Kankakee River. Most of the samples were collected from two gaging stations, Iroquois River at Iroquois and Iroquois River near Chebanse. Particle size distributions and other physical and descriptive parameters associated with these materials are given in Appendix F. Bed materials at both these gaging stations consist of coarser particles than those at the State Line and Illinoi stations. Apparently the Iroquois River flows

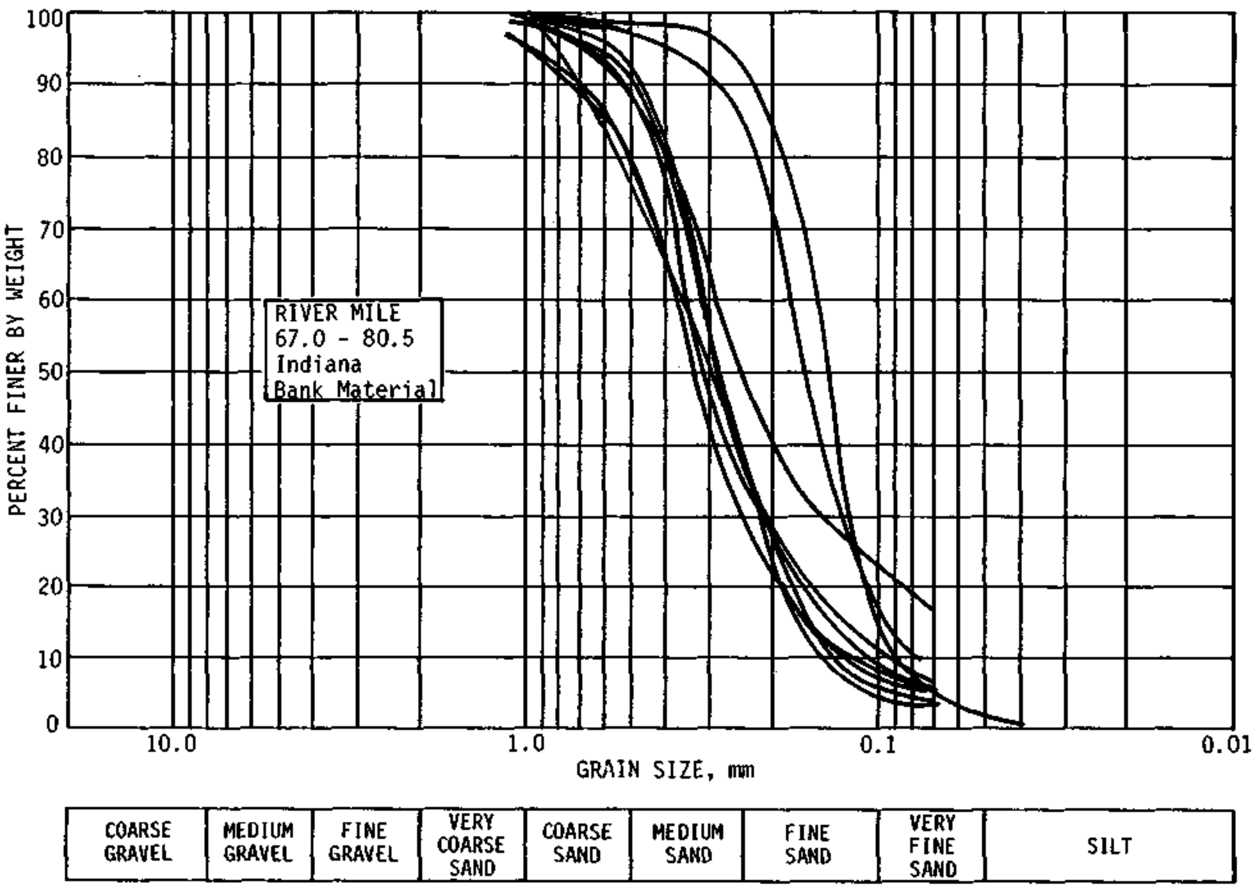


Figure 41. Particle size distributions of bank material samples

on gravel beds at a few locations. However, the bed materials in the Iroquois River near its confluence with the Kankakee River are basically sandy. Some of the sediment load carried by the Iroquois River must be depositing at this location because of the reduced flow velocity at the junction of the river and the Six Mile Pool.

Particle size characteristics of the bed load samples collected at the State Line and Chebanse stations are given in Appendix G. The d_{50} sizes of the bed load at the State Line station range from 0.3 to 0.4 mm. These median diameters appear to be a little larger than those of the bed materials at the State Line Bridge (Appendix E). This must have occurred because bed materials less than 0.25 mm in size have washed away through the 0.25 mm mesh opening of the Helley-Smith bed load sampler, resulting in the retention of bed load particles of relatively larger diameters.

That the Kankakee River flows in a sandy channel, especially in Indiana, is very important as far as the hydraulics of flow are concerned. The sand particles on a steep bank are unstable unless the banks are protected by artificial or natural protective works. Well-graded stones or rocks (called riprap) with properly designed filter blankets can be constructed to protect the banks in sandy channels. For a set of design criteria for riprap sizes and filter blankets, the reader is referred to the work done by Bhowmik

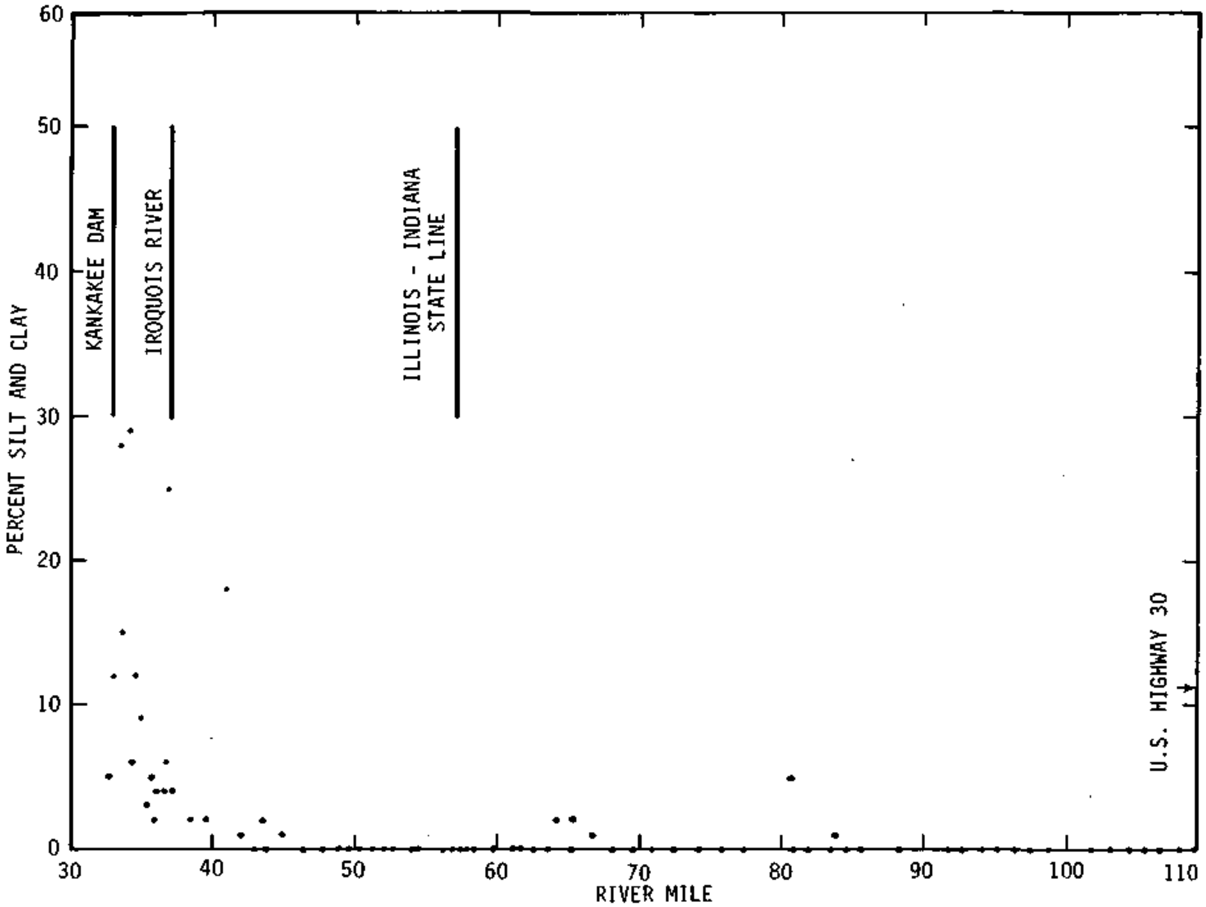


Figure 42. Percentage of silt and clay in the bed materials versus distance along the centerline of the Kankakee River

(1976). Natural cover such as tree roots, bushes, and vegetation can also protect a river bank composed of sandy materials.

That the bed materials of the Kankakee River, except those areas where it flows directly over bed rock in Illinois, consist of sandy materials can further be illustrated by figure 42. The percentage of silt and clay in the bed material samples collected from the centerline of the Kankakee River is shown in this illustration. Starting from Highway 30 in Indiana through the beginning of the Six Mile Pool near Kankakee, the percent of silt and clay in the bed materials is very small — less than 5 percent in most cases. The percentage of silt and clay in the bed materials increases to as much as 30 percent within the Six Mile Pool. This variability is natural since the Six Mile Pool acts to some extent as a detention basin on the Kankakee River, where some of the sediment load carried by the river is dropped out.

It should be pointed out that because of the uniformity of the bed materials collected from different locations along the Kankakee River, it is hard to determine the origin of the sands. The Kankakee River basically flows over sandy materials, so most of the bed materials must be originating either at upstream locations or from local areas by degradation.

Sediment Discharge

The total sediment load carried by a river consists of suspended load and bed load. The suspended load, which is the sediment load that moves in suspension within the water body, consists of the bed materials and the wash load. The wash load is composed of the materials that are washed from the watershed, usually consisting of silt and clay. The bed load, on the other hand, is composed of the materials that move near the bed either in suspension or with a sliding or rolling motion. The materials present on the bed of a river normally move as bed load.

Data related to the bed load and the suspended load that have either been collected by the Water Survey or gathered from other sources were analyzed, and the results are presented in this section.

Sediment data for the 1979 water year were collected from gaging stations at Wilmington, Chebanse, Iroquois, Momence, Illinoi, and the State Line Bridge (figure 8). As far as is known, these are the only sediment data that are available from the Kankakee River in Illinois. The U.S. Geological Survey at Indianapolis has been collecting suspended sediment load data from the Shelby gaging station since **1965** and from the Foresman gaging station since 1968. The frequency of **data** collection from the last two stations is about once a month. These data are **published** by **the** U.S. Geological Survey (1977) in their *Water Resources Data for Indiana* series.

Suspended Load. To investigate the long-term variability of the suspended sediment discharges from the gaging stations at Shelby and Foresman, an analysis was made of all available data. The reader must remember that since the data were collected only once a month they may or may not cover the storm episodes and flooding stages, and that the correlation described below may or may not truly represent the sediment discharge characteristics of these stations.

Figure 43 shows the relationship between suspended sediment load Q_s in tons per day versus water discharge Q_w in cubic feet per second (cfs) for the gaging station at Foresman. Data used were collected after July 1968. A regression line has been fitted to these data. The regression equation between Q_s and Q_w is given in figure 43. This relationship is a standard relationship that is used to determine the sediment load at a station based on water discharge. In many instances, the correlation coefficient between Q_w and Q_s may not be very high. Still, this type of relationship is useful for qualitatively estimating the sediment load in a stream. The correlation coefficient for the relationship shown in figure 43 is 0.83.

Sediment load carried by a stream is a function of a number of variables: 1) the characteristics of the watershed, such as soils, forest cover, and agricultural practices; 2) the meteorological conditions, such as rainfall and runoff characteristics, and snow and ice melt; 3) physical features, determined by land use and urbanization practices, the nature of the bed and bank materials, soil cover, bank cover, and characteristics of the tributaries or drainage ditches; 4) man-made constraints, such as river straightening and channelization, repair or maintenance of stream banks and levees, and construction

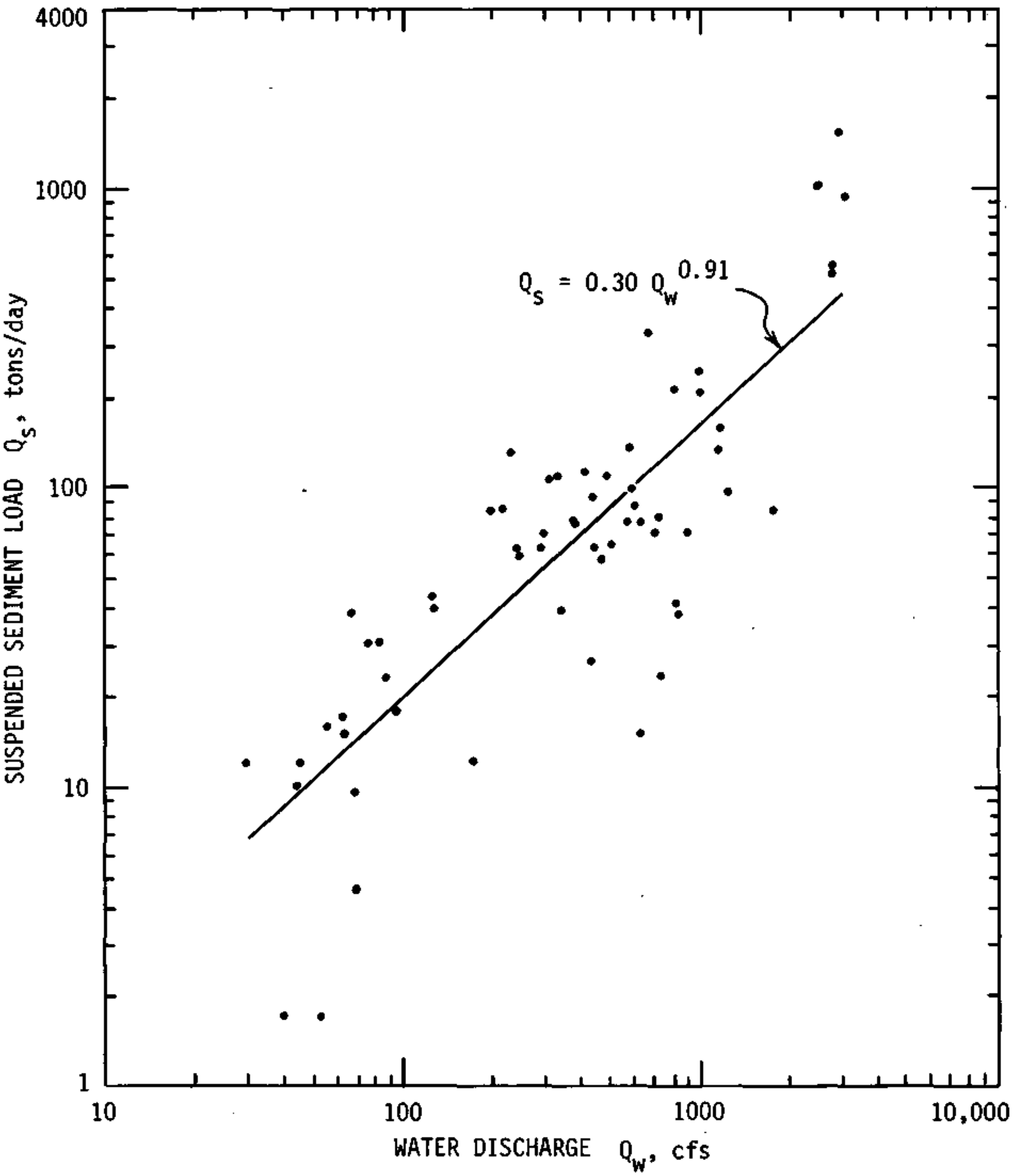


Figure 43. Relationship between suspended sediment load and water discharge for the Iroquois River near Foresman

of dams; and 5) a variety of other factors. These variables can interact and may modify or change the sediment load in a river although the discharge remains the same.

For midwestern streams, the constraints exerted on the watershed may have more influence on the sediment load than does the normal discharge of the stream. Thus, for the same discharge at two different times of year, such as early spring, when the watershed has been plowed, and fall, when a large part of the watershed is covered with residue from harvested corn or soybeans, the sediment load is completely different. This is a major reason why the correlation in figure 43 is poor and why it is hard to develop a perfect relationship between Q_s and Q_w for a stream at a specified location.

Figure 44 shows a similar relationship between Q_s and Q_w for the gaging station at Shelby. Data used for this station were collected by the U.S. Geological Survey beginning in October 1963. The correlation coefficient between Q_s and Q_w is 0.78, and a scattering of the data points is evident. The variabilities in the physical and meteorological parameters certainly affected the amount of the suspended sediment load carried by the river at different times of the year even though the discharge was the same. The regression line developed for these data is shown in figure 44.

Data analyzed for the Foresman and Shelby stations were collected over a number of years; thus these data are affected by variabilities in stream flow and by changing agricultural patterns on the watershed. The serious drawback to these data is the frequency at which they were collected. To be representative, sediment data should be collected daily or weekly over a period of time extending from 10 to 20 years.

Suspended sediment load data that were collected daily from Iroquois, Chebanse, Momence, and Wilmington, and biweekly (and more frequently during flooding) from the State Line Bridge and Illinoi stations were analyzed and are discussed next. Caution must be exercised in considering the representativeness of these data since they were collected for a period of only 12 months.

It is important to test whether the data collected in the 1979 water year represented data from a typical year. One way to test this is to compare the average long-term daily discharges from various gaging stations with those measured in the 1979 water year. Table 7 shows the long-term average 7-day low flows, average 7-day high flows, average peak flows, average discharges, and average discharges for the 1979 water year. An examination of this table shows that the 1979 average flows measured at Shelby, Momence, Foresman, and Iroquois are close to the long-term average discharges. However, for the Chebanse and Wilmington stations, the average discharges in the 1979 water year were much higher than the long-term average discharges. This points out the inadequacy of a sediment data base for which detailed data are available for only a single year.

Figure 45 shows the relationships between water discharge and sediment discharge versus time in days for the Kankakee River at the State Line station for the 1979 water year. During one period in the winter of 1978-1979, suspended sediment and water discharge data could not be collected because the river surface was covered with ice. It appears from figure 45 that with an increase in water discharge, the sediment discharge showed a corresponding increase. However, for a period of time from late March through early May 1979, the water discharge was relatively high while the sediment discharge was comparatively low. Obviously the suspended sediment load

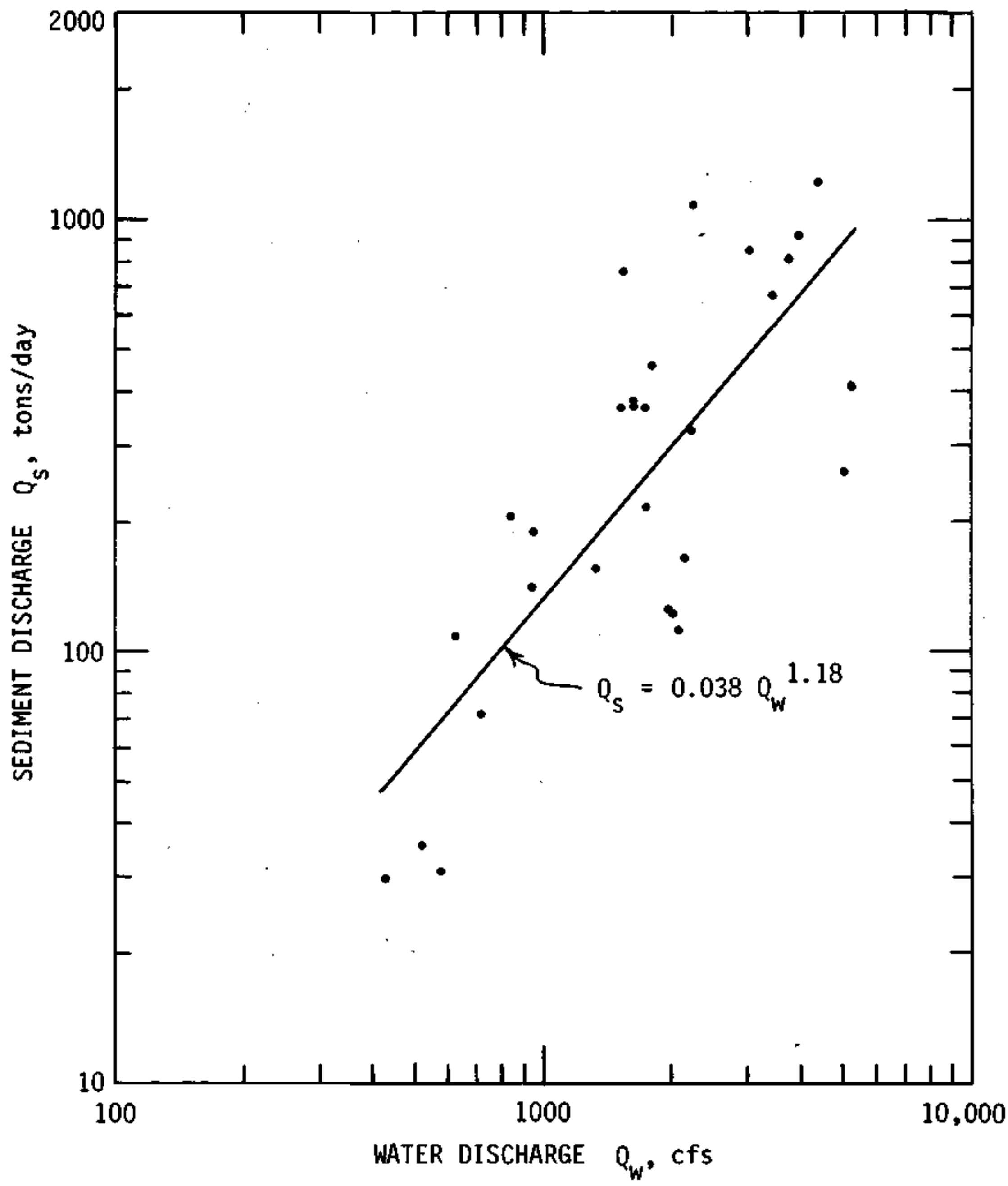


Figure 44. Relationship between suspended sediment load and water discharge for the Kankakee River at Shelby

Table 7. Discharge at Various Gaging Stations

Station	*Average 7-day low flow, $\bar{Q}_{7L}$ (cfs)*	*Average 7-day high flow, $\bar{Q}_{7H}$ (cfs)*	*Average peak flow, $\bar{Q}_p$ (cfs)*	*Average discharge, $\bar{Q}$ (cfs)*	*Average discharge 1979, $\bar{Q}_{79}$ (cfs)*
Shelby	577	3990	4130	1580	1700
Momence	604	5600	6280	1930	2170
Foresman	28	2260	2710	370	398
Iroquois	29	3280	3830	536	586
Chebanse	63	10400	12500	1610	2140
Wilmington	737	17900	24500	4090	5070

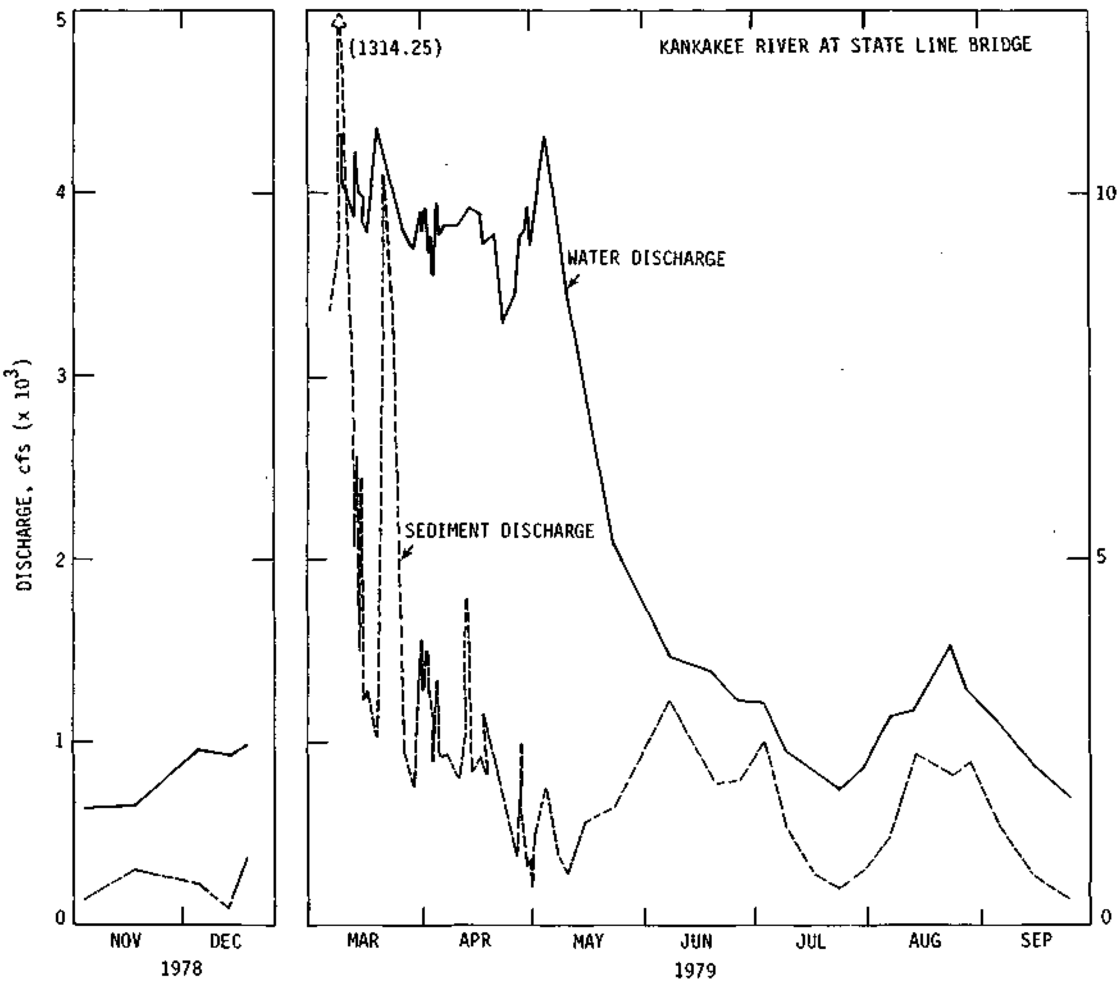


Figure 45. Suspended sediment load and water discharge versus time in days at the State Line Bridge

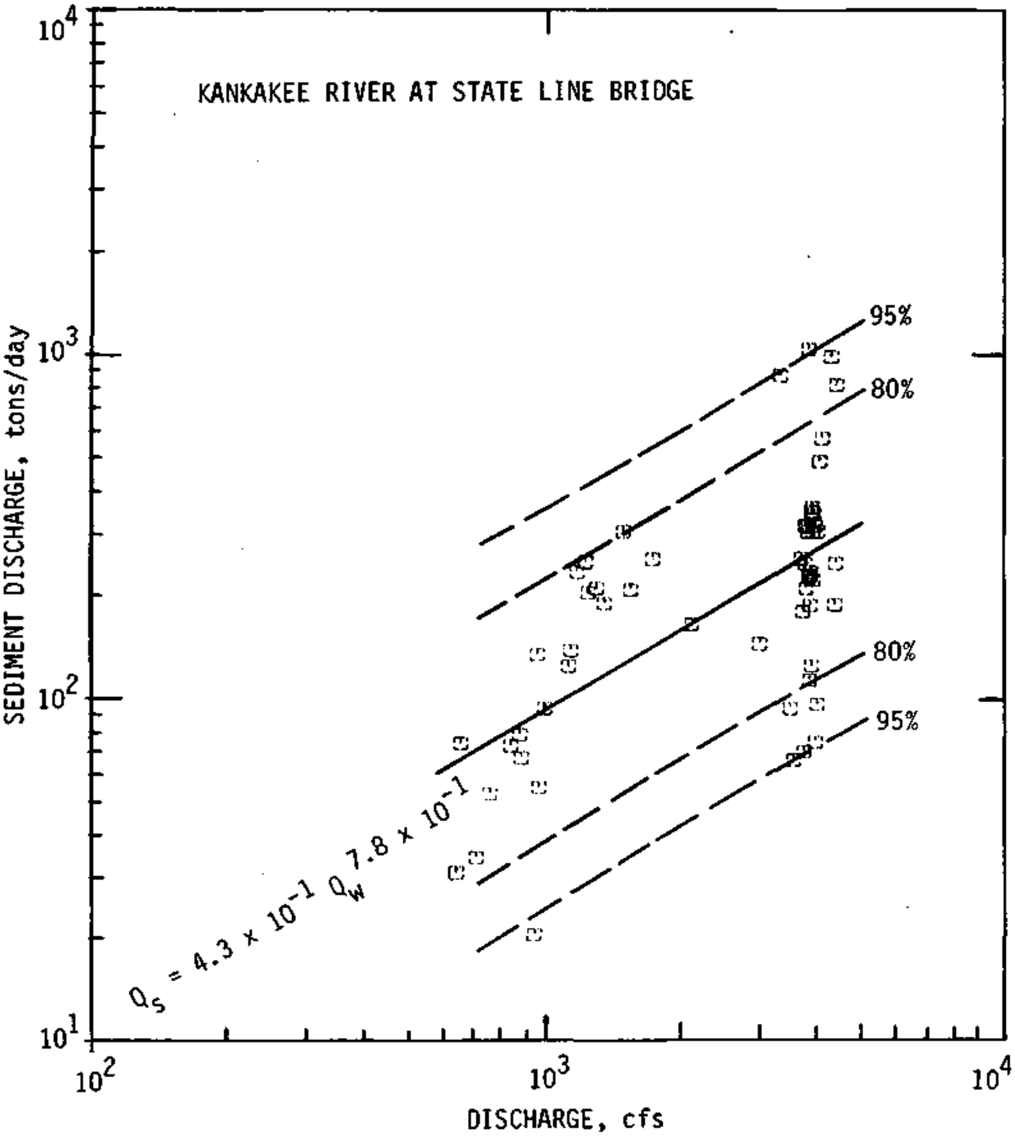


Figure 46. Relationship between suspended sediment load and water discharge for the Kankakee River at the State Line Bridge

carried by the river did not depend only on the water discharge but was also influenced by other factors. Despite these limitations, a regression equation between suspended sediment load Q_s in tons per day and water discharge Q_w in cfs was developed and is shown in figure 46. The scattering of the data from the least square fitted line attests to the variabilities shown in figure 45. The correlation coefficient is 0.61. The dotted lines above and below the regression line show the bands of confidence limits of 80 and 95 percent. The equation shown in figure 46 may be used to estimate an average suspended sediment load at the state line whenever the water discharge is known, although one must recognize the limitations of this relationship. Appendix H shows the data collected from the State Line station.

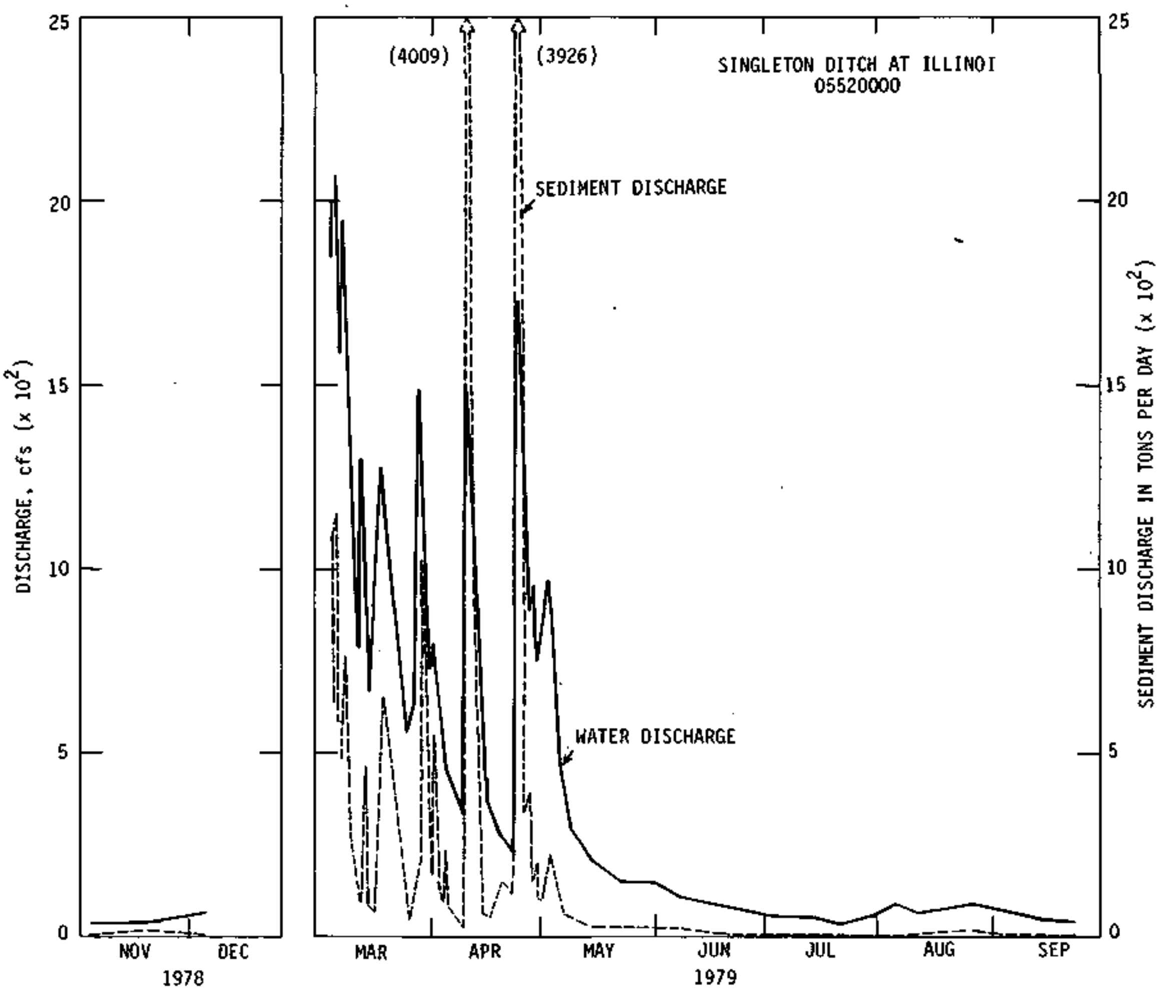


Figure 47. Suspended sediment load and water discharge versus time in days for the Singleton Ditch at Illinoi

The relationships between Q_s and Q_w versus time in days for the 1979 water year for the gaging station on the Singleton Ditch at Illinoi are shown in figure 47. The data gap during the winter of 1978-1979 is the result of ice cover. In this illustration it appears that the sediment discharge correlates well with the water discharge. This point is better illustrated in figure 48, where the relationship between Q_s in tons per day and Q_w in cfs is shown for the same station. The correlation coefficient of the regression line shown in figure 48 is 0.94. The upper and lower confidence limits of 80 and 95 percent are shown in the figure. Although there is some scattering of data points, the correlation is fairly good. Appendix I shows the data collected at this station.

Whereas the State Line and Illinoi stations were temporary gaging stations, the stations at Momence, Iroquois, Chebanse, and Wilmington are established U.S. Geological Survey gaging stations. Data collected from these stations were analyzed following a procedure similar to that shown in figures 45 through 48. Figure 49 shows the relationship between the suspended sediment load and water discharge versus time in days

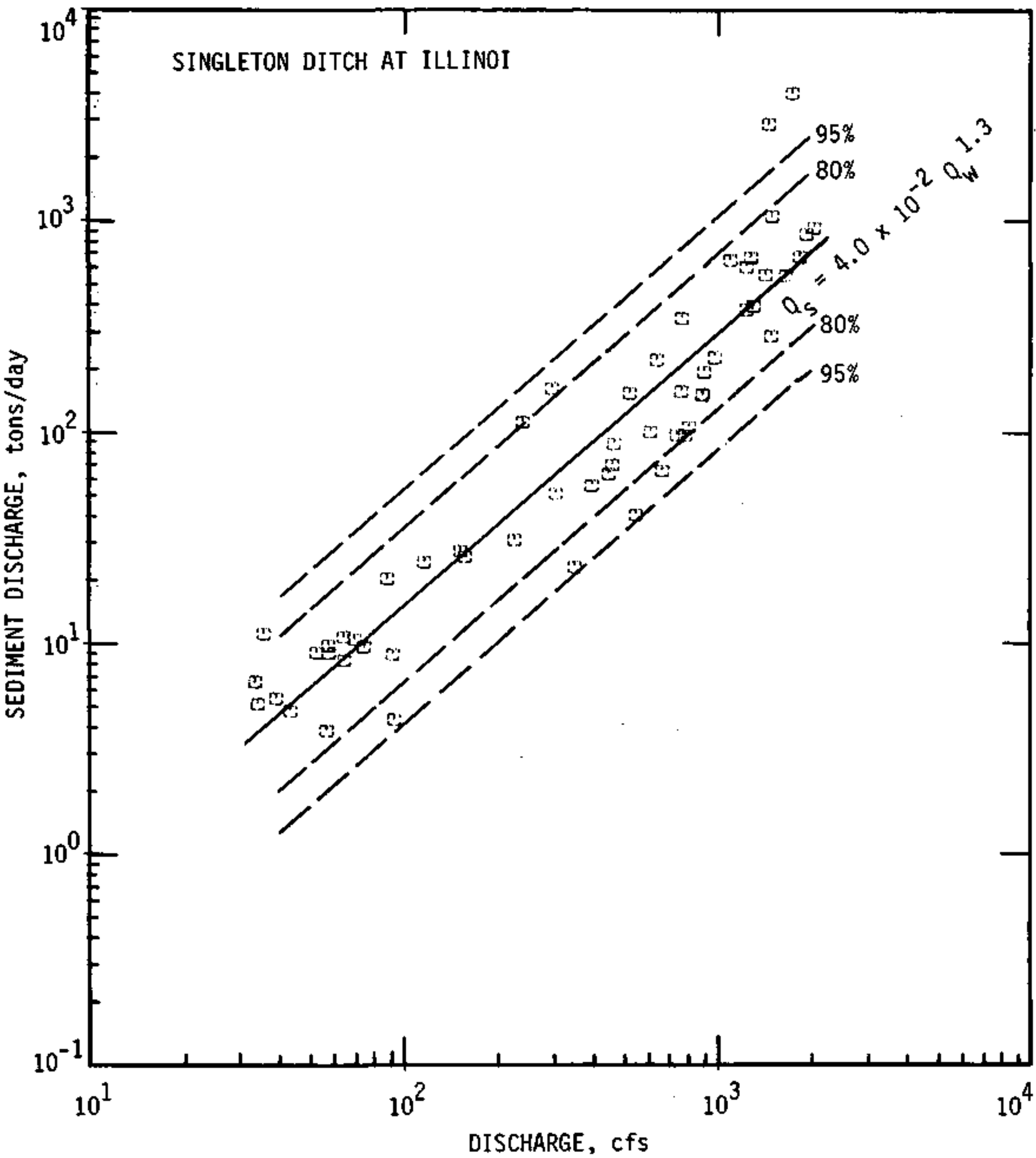


Figure 48. Relationship between suspended sediment load and water discharge for the Singleton Ditch at Illinoi

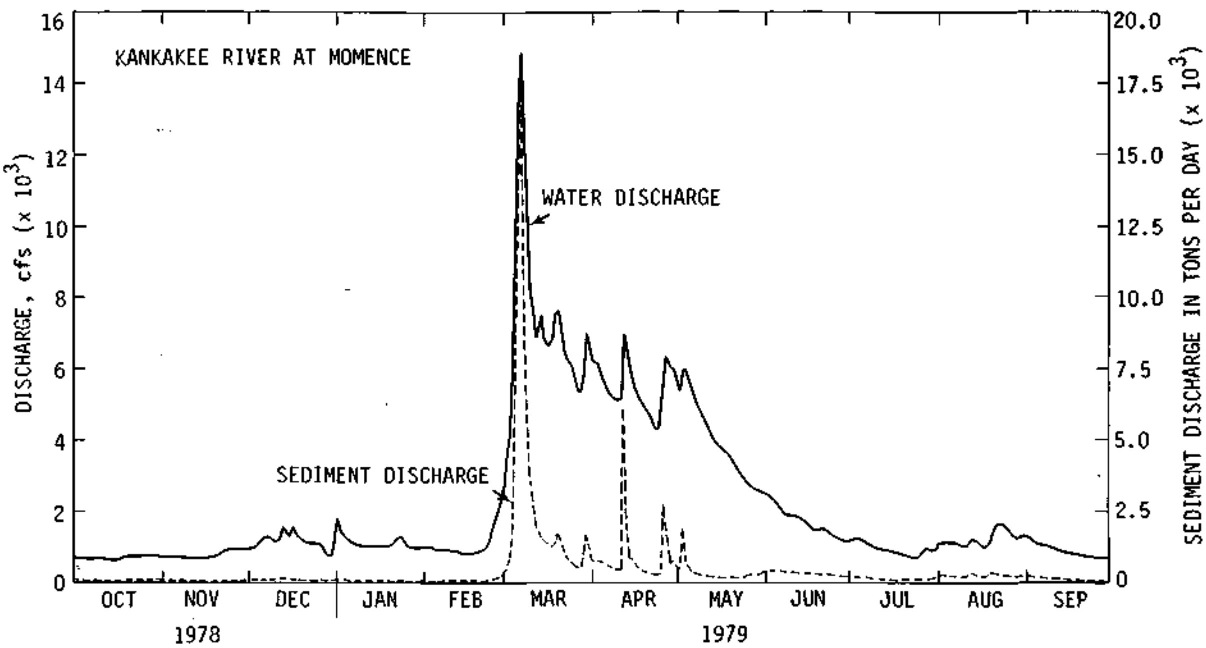


Figure 49. Suspended sediment load and water discharge versus time in days for the Kankakee River at Momence

for the 1979 water year for the Momence station. During early March 1979, the water discharge and sediment discharge at this station appear to correlate fairly well. However, from late March through April 1979, although the water discharge was fairly high, the sediment load was comparatively low. Only during the middle of April 1979, during a storm episode, did the sediment load show an increase.

The variability mentioned in connection with figure 49 can be explained further by the illustration in figure 50. The relationship between mean monthly sediment yield and water yield for the Momence station is shown. It is quite clear that for the same water yield, the sediment yield during winter months was much lower than that observed during the summer months. These variabilities might have been balanced if data had been available for a longer period of time. This is an important point to remember in analyzing the sediment data.

Figure 51 shows the relationship between Q_s and Q_w for the Kankakee River at Momenee. The correlation coefficient of the regression equation shown in figure 51 is 0.88. The variabilities between Q_s and Q_w are quite evident in this illustration. The upper and lower 80 and 95 percent confidence limits are also shown in the figure. The data collected from this station are given in Appendix J.

The particle size distributions of the suspended sediment carried by the Kankakee River at various times of the year and at different locations were determined. Figure 52 shows the particle sizes of four samples collected from the Momence station. A detailed analysis was done for the sample collected on March 9, 1979. For the other samples only the sand fractions and the silt and clay fractions were determined. The analysis of the

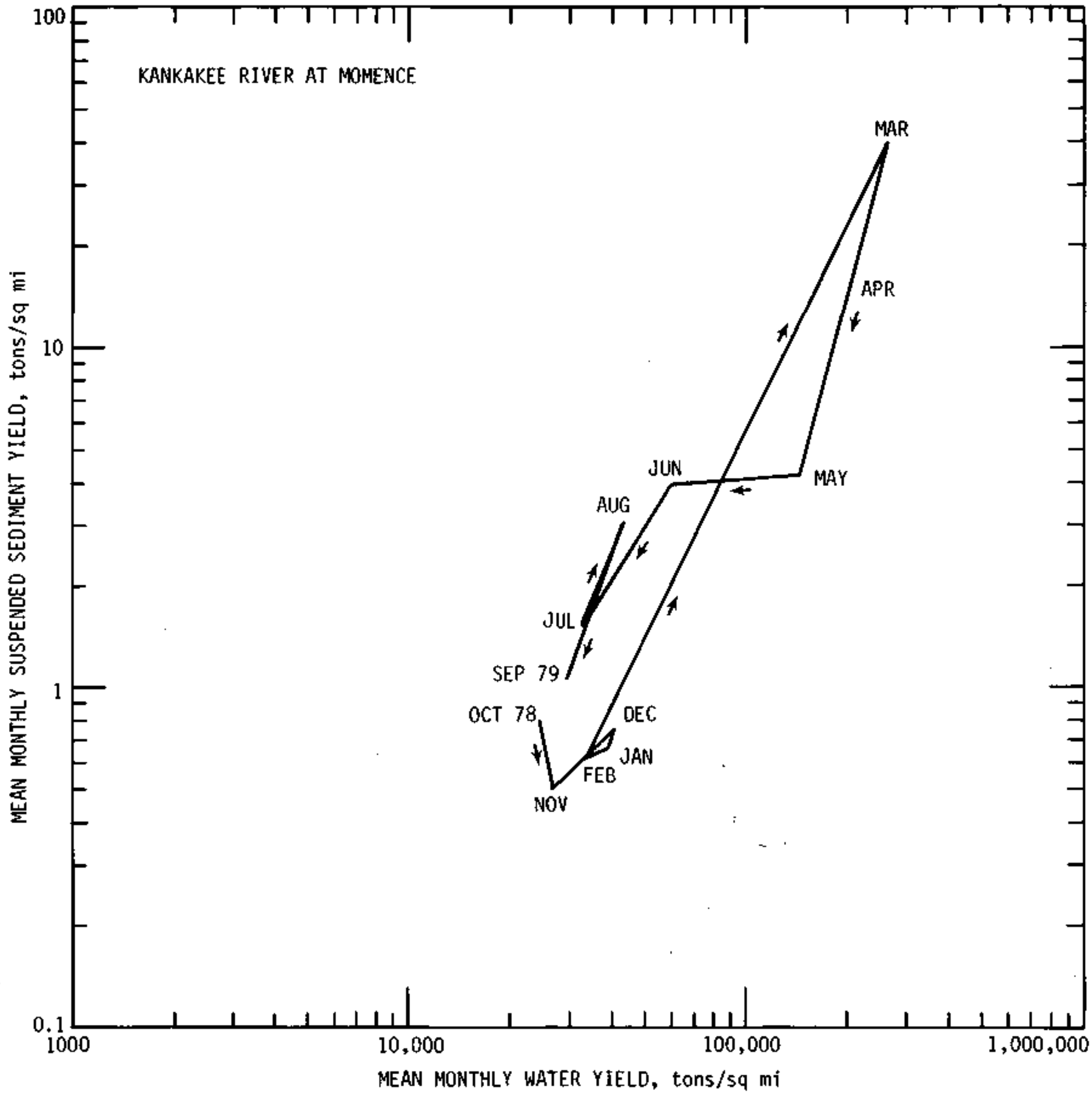


Figure 50. Relationship between mean monthly sediment yield and water yield for the Kankakee River at Momence

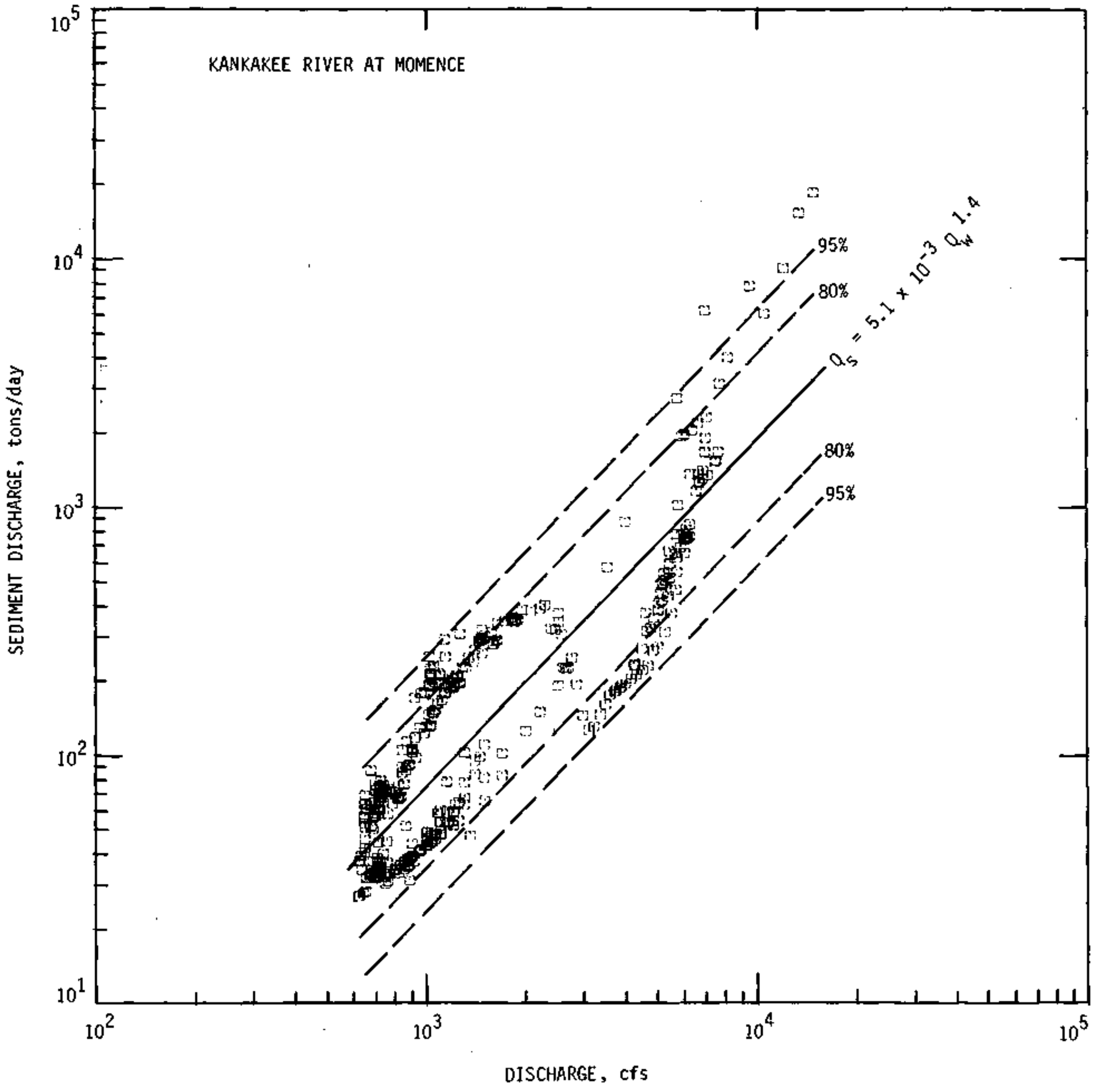


Figure 51. Relationship between suspended sediment load Q_s and water discharge Q_w for the Kankakee River at Momence

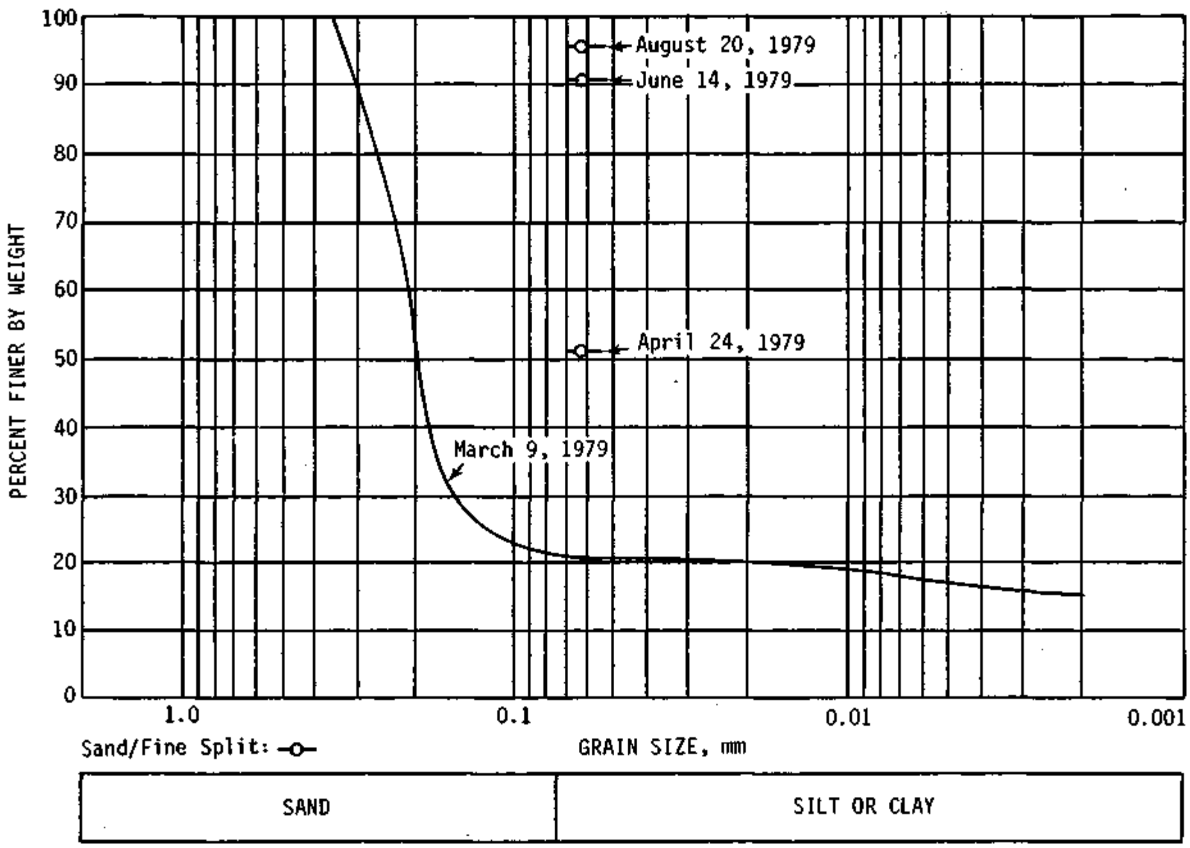


Figure 52. Particle size characteristics of suspended sediment at Momence

sample collected in March indicates that the suspended load carried by the river at Momence during flood stages was nearly 80 percent sand and about 20 percent silt and clay. During April 1979 the amount of sand was approximately equal to the amount of silt and clay, and in June and August, the suspended load consisted mainly of silt and clay. This observation has very important ramifications concerning the sediment transport characteristics of the river. It has already been shown that the bed materials of the Kankakee River basically consist of sand particles with median diameters of about 0.2 to 0.4 mm. It appears that during flood stages, when the velocity of water is relatively high and the water is very turbulent, most of the suspended sediment carried by the river consists of sandy materials.

Almost all the sediment load carried by the Kankakee River at the Momence station appears to be moving as suspended load. Data were collected from the Highway Bridge at Momence, where the bed of the river is rocky, the gradient of the river is relatively steep, and the water is therefore highly turbulent. This combination of hydraulic and geometric parameters effectively keeps the sediment load in the river in suspension at this location. Thus, the sediment rating curve shown in figure 51 may in all probability represent the total sediment load curve of the Kankakee River at the Momence gaging station.

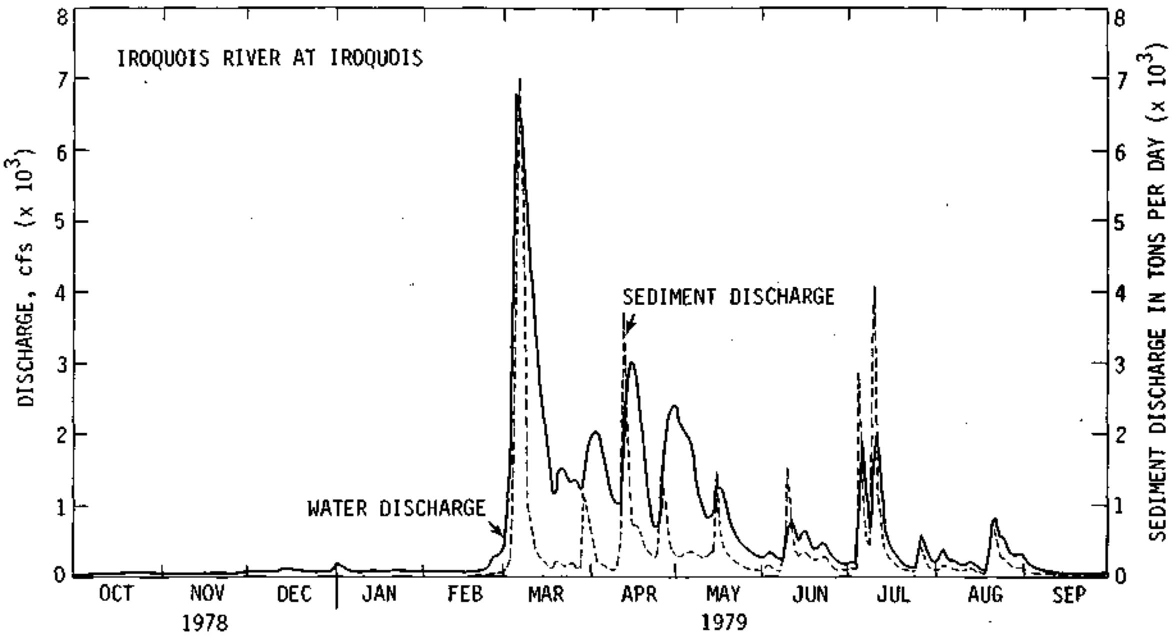


Figure 53. Suspended sediment load and water discharge versus time in days for the Iroquois River at Iroquois

The relationship between suspended sediment load and water discharge versus time in days for the Iroquois gaging station is shown in figure 53. The highest peak discharge and the highest sediment load were measured in March 1979, and three other relatively high sediment peaks occurred in April and July 1979. The water discharge for the storm episode in July was lower than that for the storm in April. On the other hand, the peak sediment load was higher in July than in April.

Obviously, the hydrological and other factors acting on the watershed contributed toward this variability between the sediment peaks and the flood peaks. That the same amount of flow can carry different amounts of sediment load is illustrated in figure 54, in which the mean monthly sediment yield in tons per square mile of basin has been plotted against the mean monthly water yield in tons per square mile. For the same water yield, the sediment load carried by the river during July through September was consistently higher than the sediment load carried by the river during December through May.

Despite the variabilities pointed out in figures 53 and 54, it is still possible to develop a rating curve between Q_s and Q_w (figure 55). An examination of this illustration will reveal that during low and high flows, there exist variabilities between Q_s and Q_w. However, for the medium ranges of Q_w there exists a linear relationship between Q_s and Q_w on this log-log plot. The regression line shown in figure 55 represents the least square fitted line to all the data. The 80 and 95 percent confidence limits are also shown. The regression equation given in figure 55 can be used to estimate the sediment load at this station once the water discharge is known. The correlation coefficient of the regression equation is 0.89. Appendix K shows the field data collected from this station.

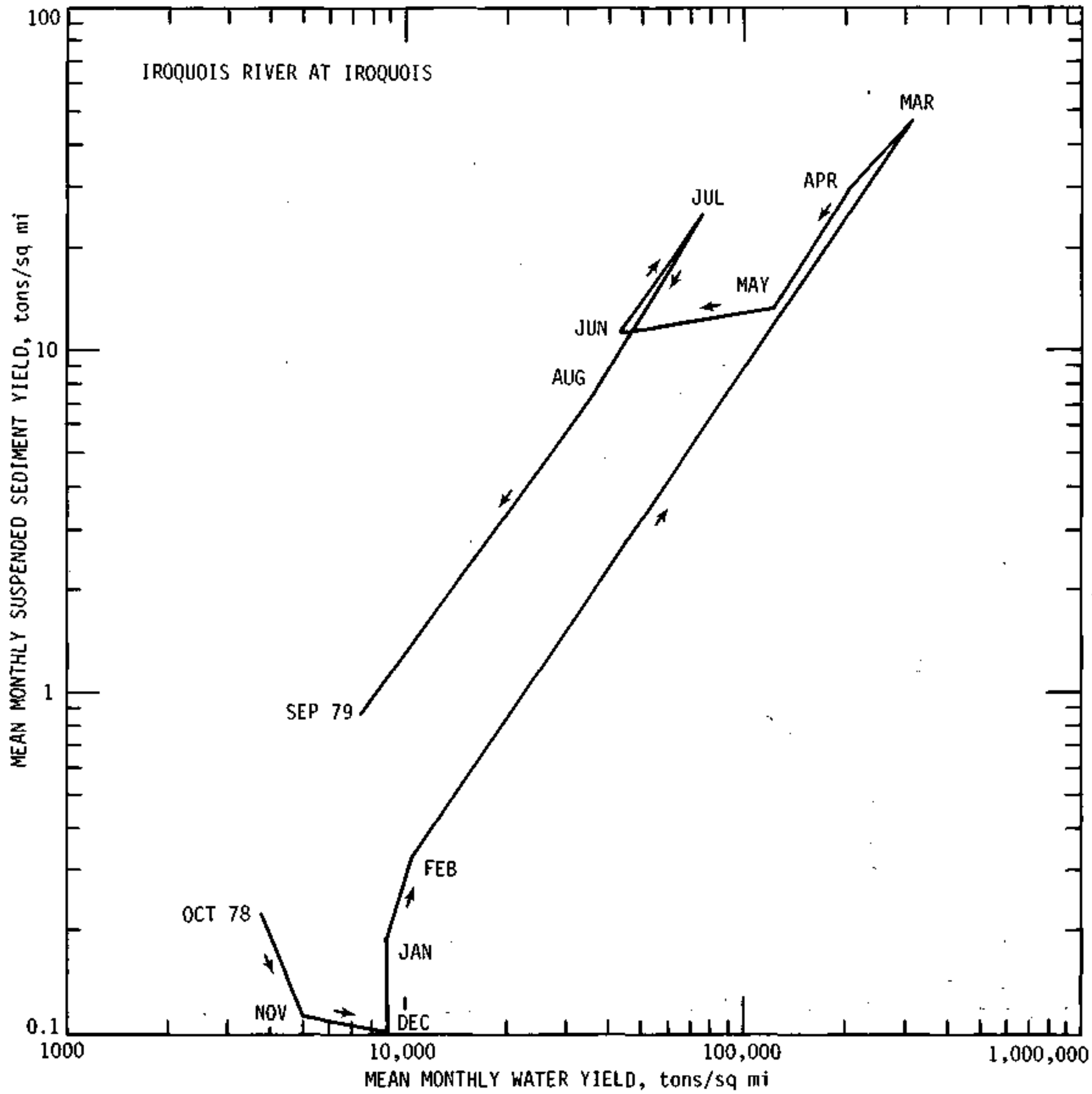


Figure 54. Relationship between mean monthly sediment yield and water yield for the Iroquois River at Iroquois

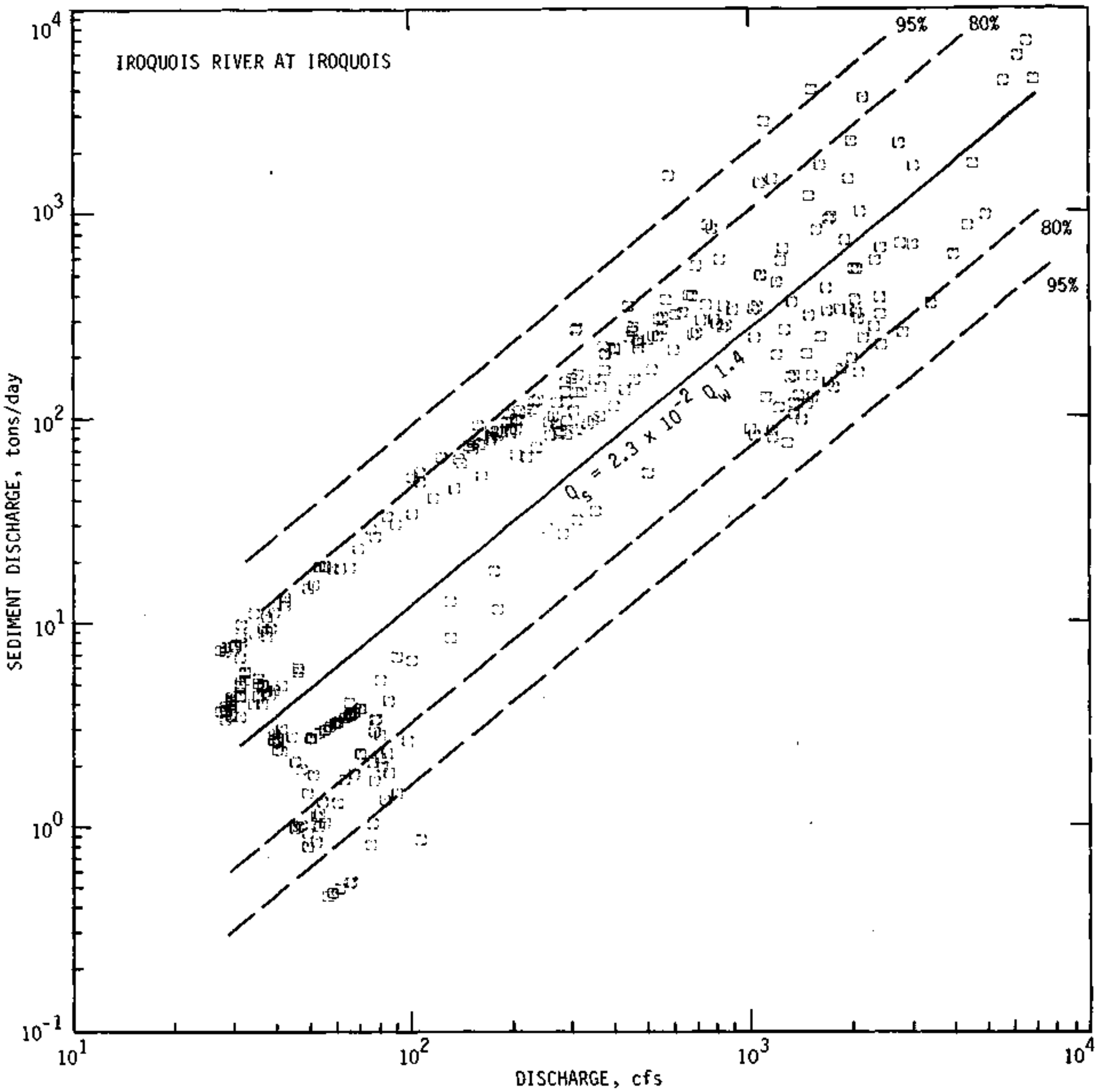


Figure 55. Relationship between suspended sediment load and water discharge for the Iroquois River at Iroquois

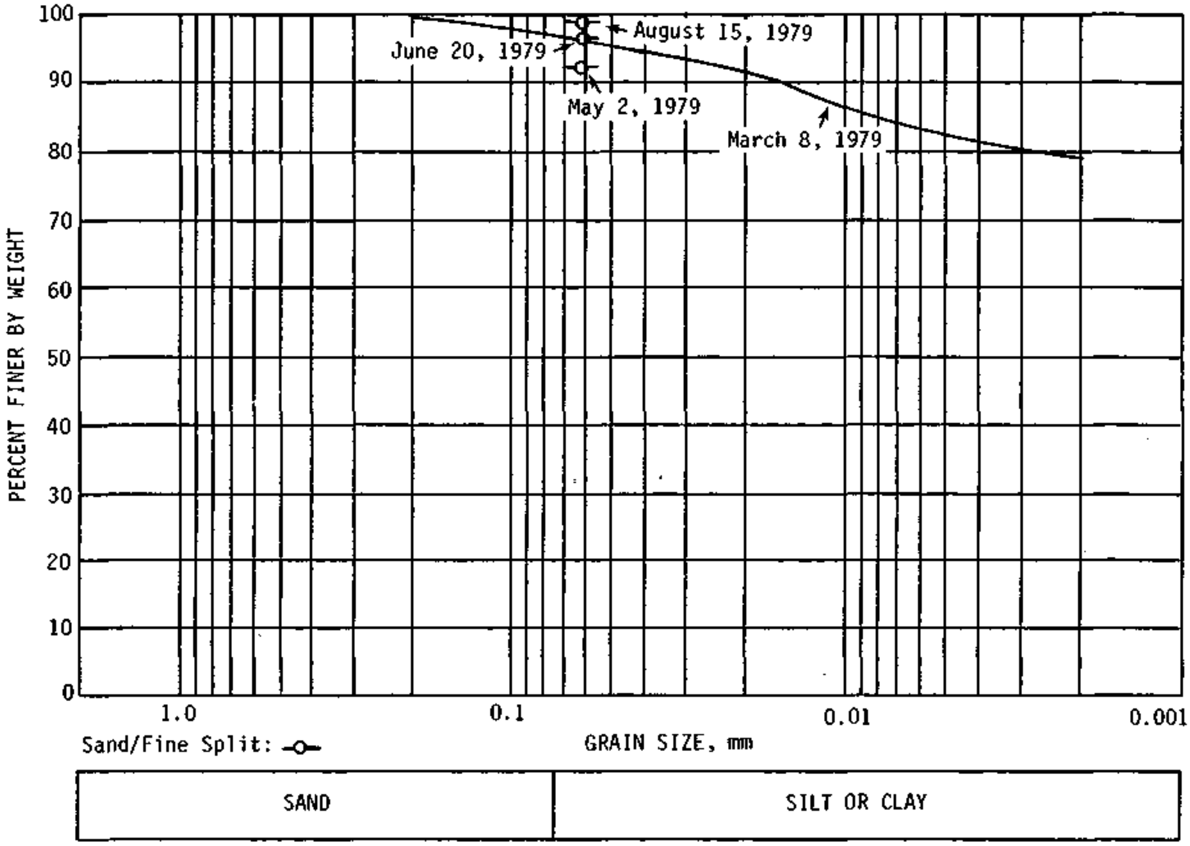


Figure 56. Particle size characteristics of suspended sediment at Iroquois

The characteristics of the particle sizes of the suspended load carried by the river at the Iroquois gaging station were also analyzed. Figure 56 shows the analyses of four sets of such samples. It is quite clear that the suspended sediment load carried by the Iroquois River at Iroquois consists almost wholly of silt and clay during spring, summer, and fall. This is in sharp contrast to the characteristics of the suspended load carried by the Kankakee River at Momence, where it was found that the major part of the suspended load during the spring was sand. Thus, in general, the Iroquois River at Iroquois, near the Indiana-Illinois state line, carries a relatively greater amount of fine materials as suspended load.

Figure 57 shows the variation of Q_s and Q_w with time in days for the Iroquois River near Chebanse. For this gaging station an excellent correlation exists between the sediment peaks and water discharges except in April 1979, when a higher sediment peak was observed for a relatively small storm episode. At all other times, whenever the water discharge was high, the sediment discharge was also relatively high. Figure 58 shows the relationships between the mean monthly sediment yield and water yield for the 1979 water year for this station. Here again, the mean monthly sediment yield per unit of watershed for the same water yield was higher during June through September than during November through May.

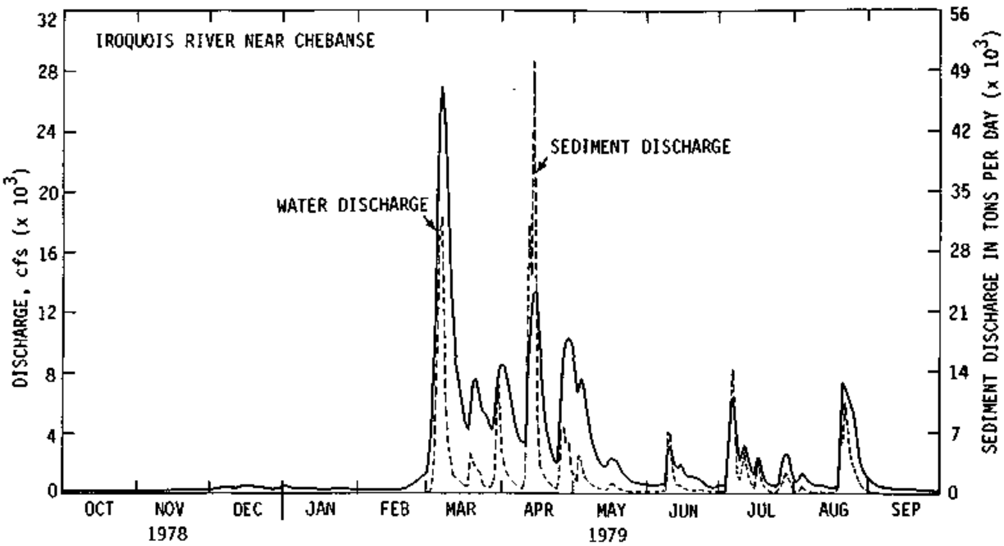


Figure 57. Suspended sediment load and water discharge versus time in days for the Iroquois River near Chebanse

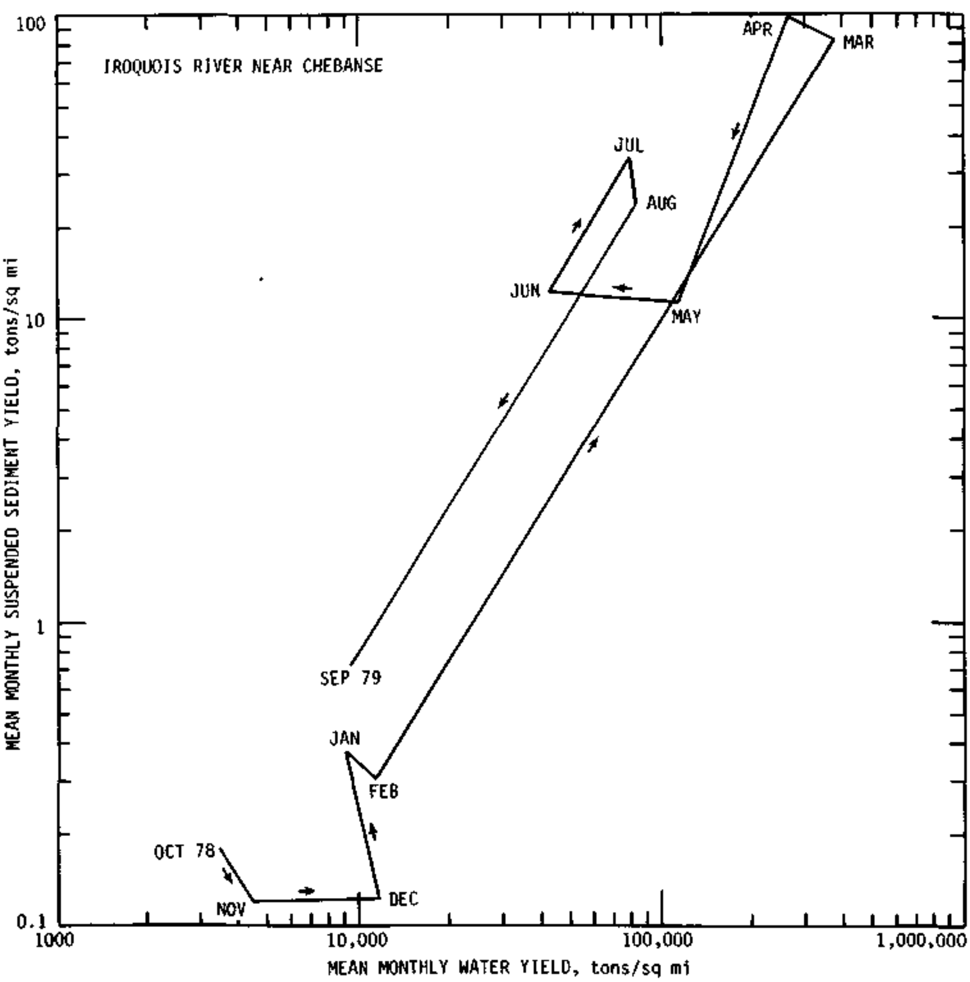


Figure 58. Relationship between mean monthly sediment yield and water yield for the Iroquois River near Chebanse

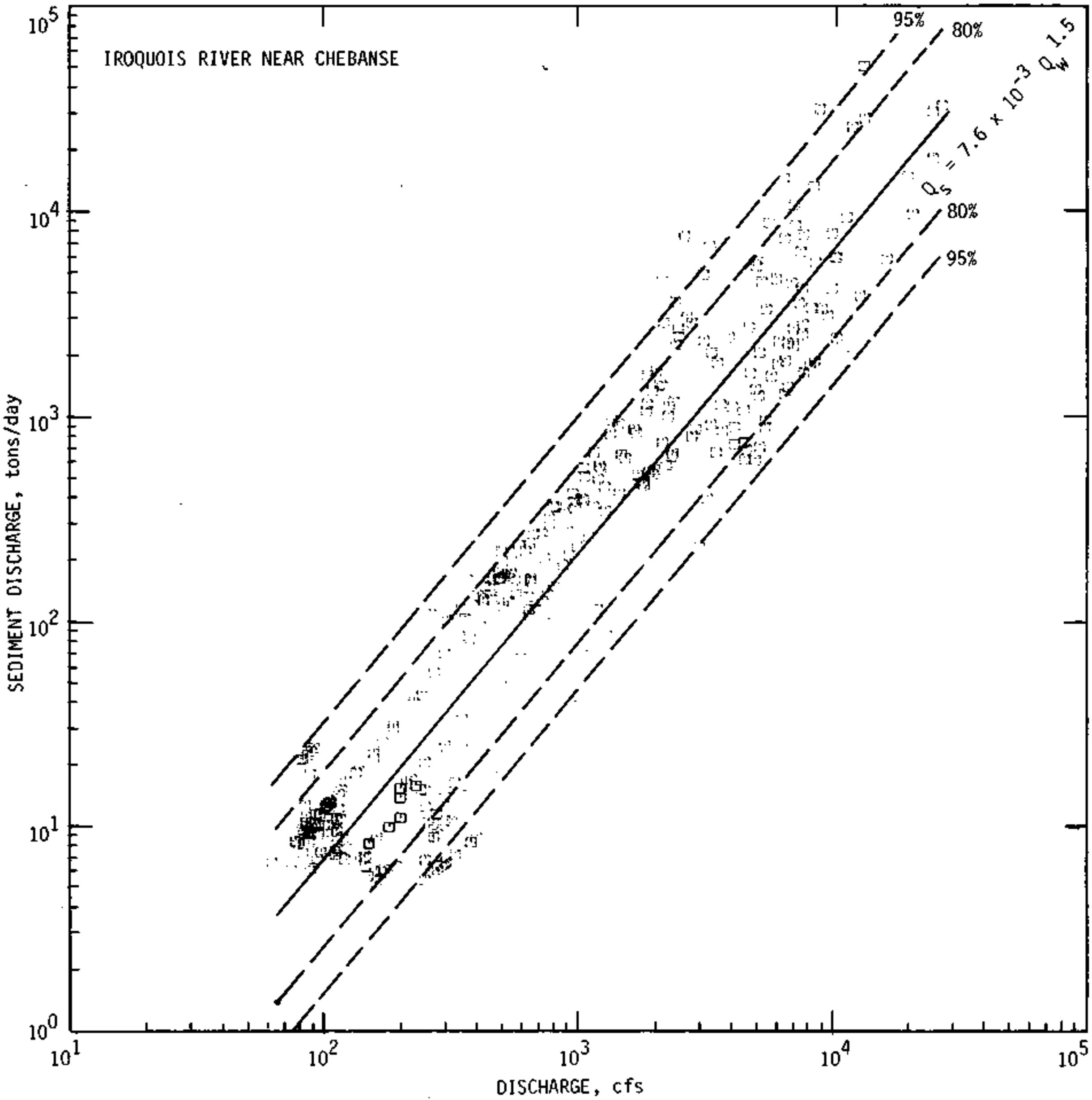


Figure 59. Relationship between suspended sediment load and water discharge for the Iroquois River near Chebanse

The relationship between Q_s and Q_w for the Chebanse station is given in figure 59. It appears that the dispersion of the plotted points about the fitted regression line is fairly uniform. For any sediment transport investigation the dispersion shown in figure 59 is quite common. In general, whenever a simplified relationship between Q_s and Q_w is developed, the correlation is not very good. The regression equation and the 80 and 95 percent confidence limits are also given in the figure. The correlation coefficient of the regression equation is 0.95. Appendix L shows the field data collected from this station.

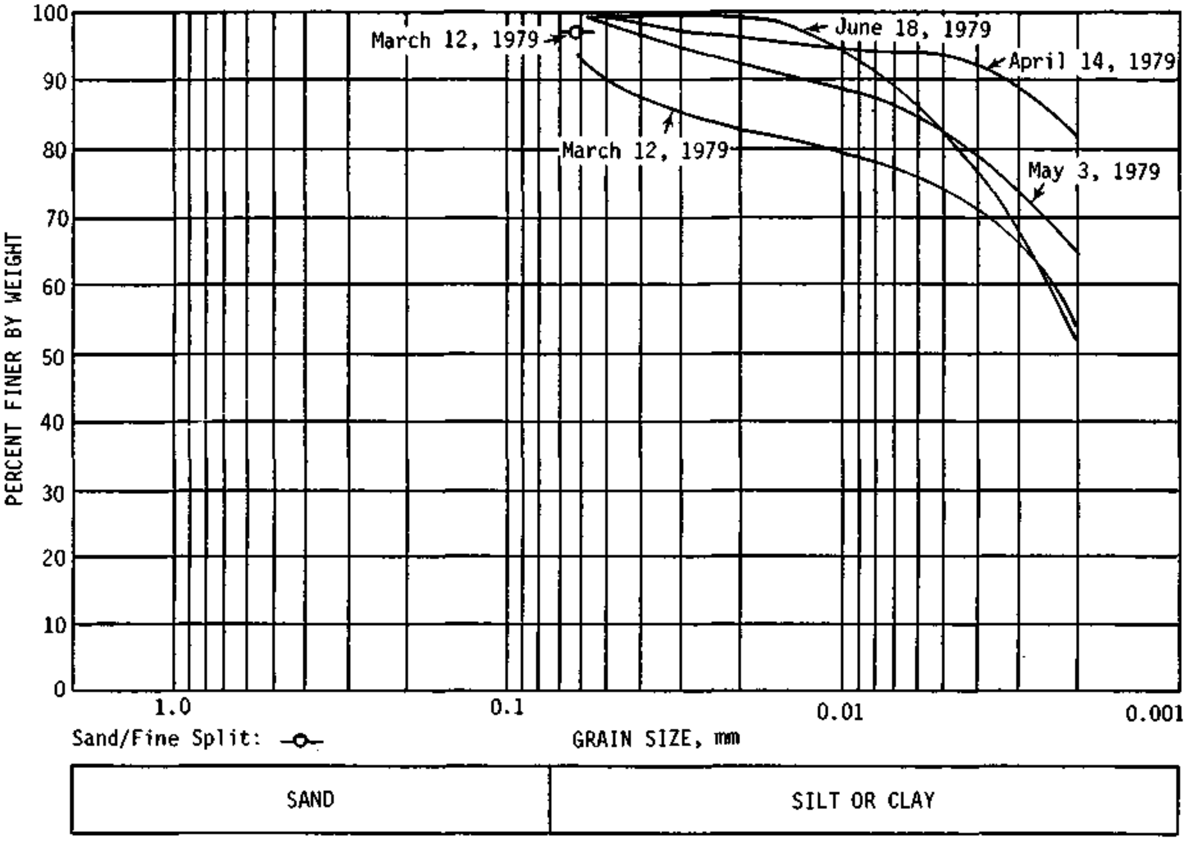


Figure 60. Particle size characteristics of suspended sediment at Chebanse

The particle size distributions of the suspended sediment load at the Chebanse station are shown in figure 60. It is clear that the suspended sediment load carried by the Iroquois River at the Chebanse station consists almost completely of silt and clay. In other words, the suspended load carried by the Iroquois River is composed basically of fine materials. This observation is very important to a consideration of the type of sediment load carried by the Iroquois and the Kankakee Rivers. The discoloration and the turbid nature of the water observed in the Six Mile Pool and downstream from Kankakee are obviously contributed by the Iroquois River. In all probability, these fine materials remain in suspension and are carried away by the Kankakee River to the Illinois River. On the other hand, the Kankakee River carries a substantial amount of sand as sediment load, which means that the sand deposits in the Kankakee River and in the Six Mile Pool are mainly contributed by the Kankakee River.

The last gaging station where suspended sediment load data were collected was the Wilmington station. This station is close to the Illinois River and should account for nearly all the sediment load that is carried by the Kankakee River and delivered to the Illinois River. Figure 61 shows the relationship between Q_w and Q_s versus time in days for this station. In all storm episodes, the suspended sediment load correlated well

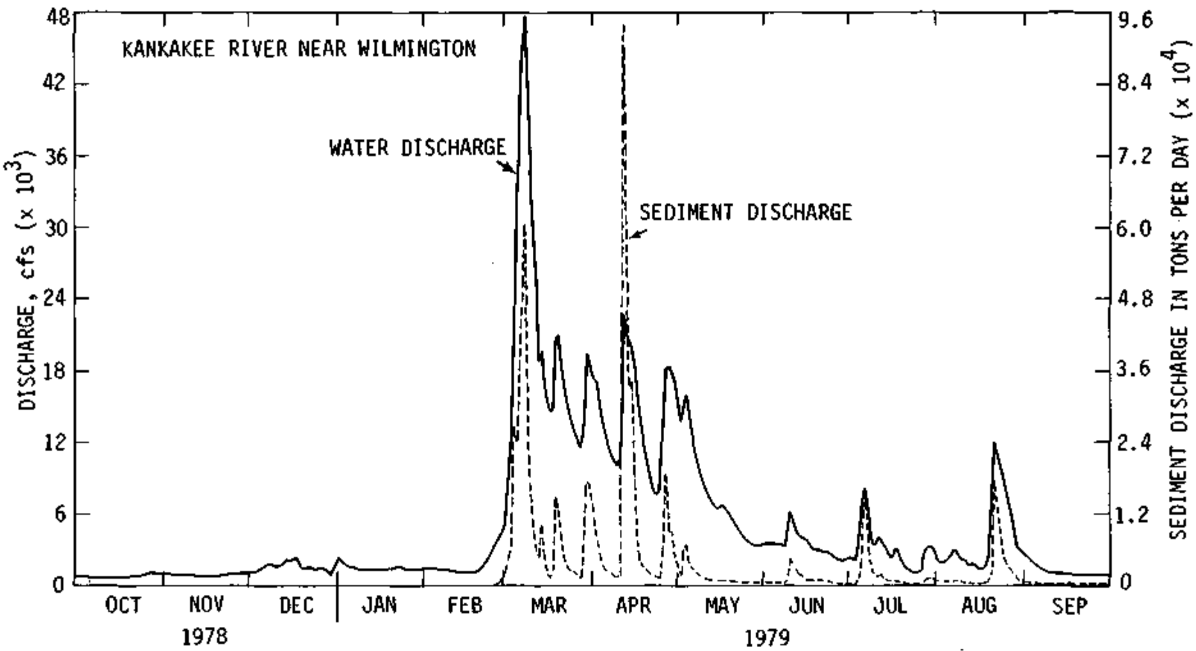


Figure 61. Suspended sediment load and water discharge versus time in days for the Kankakee River near Wilmington

with the water discharge except for the storm episode of April 1979. During this storm, the sediment load was much higher in relation to the water discharge.

Figure 62 shows the relationship between mean monthly sediment yield and water yield for this station. Here again, the sediment load carried by the river during the winter months was smaller than that carried for the same unit of water discharge during the summer months.

Relationships between Q_s and Q_w are shown in figure 63 for the Wilmington station. It appears that a few storm episodes exist where data related to Q_s and Q_w are clustered together. At other times, however, the correlation between Q_s and Q_w is fairly good. The regression line, the regression equation, and the 80 and 95 percent confidence limits are also shown in figure 63. The regression equation can be used to estimate suspended sediment load at this station from known water discharge. The correlation coefficient is 0.90. Appendix M shows the field data collected from this station.

Figure 64 shows the particle size characteristics of the suspended load at the Wilmington station. It appears that during spring 1979, about 50 percent of the suspended sediment load carried by the river at this location consisted of sandy materials, whereas during the summer most of the suspended sediment particles consisted

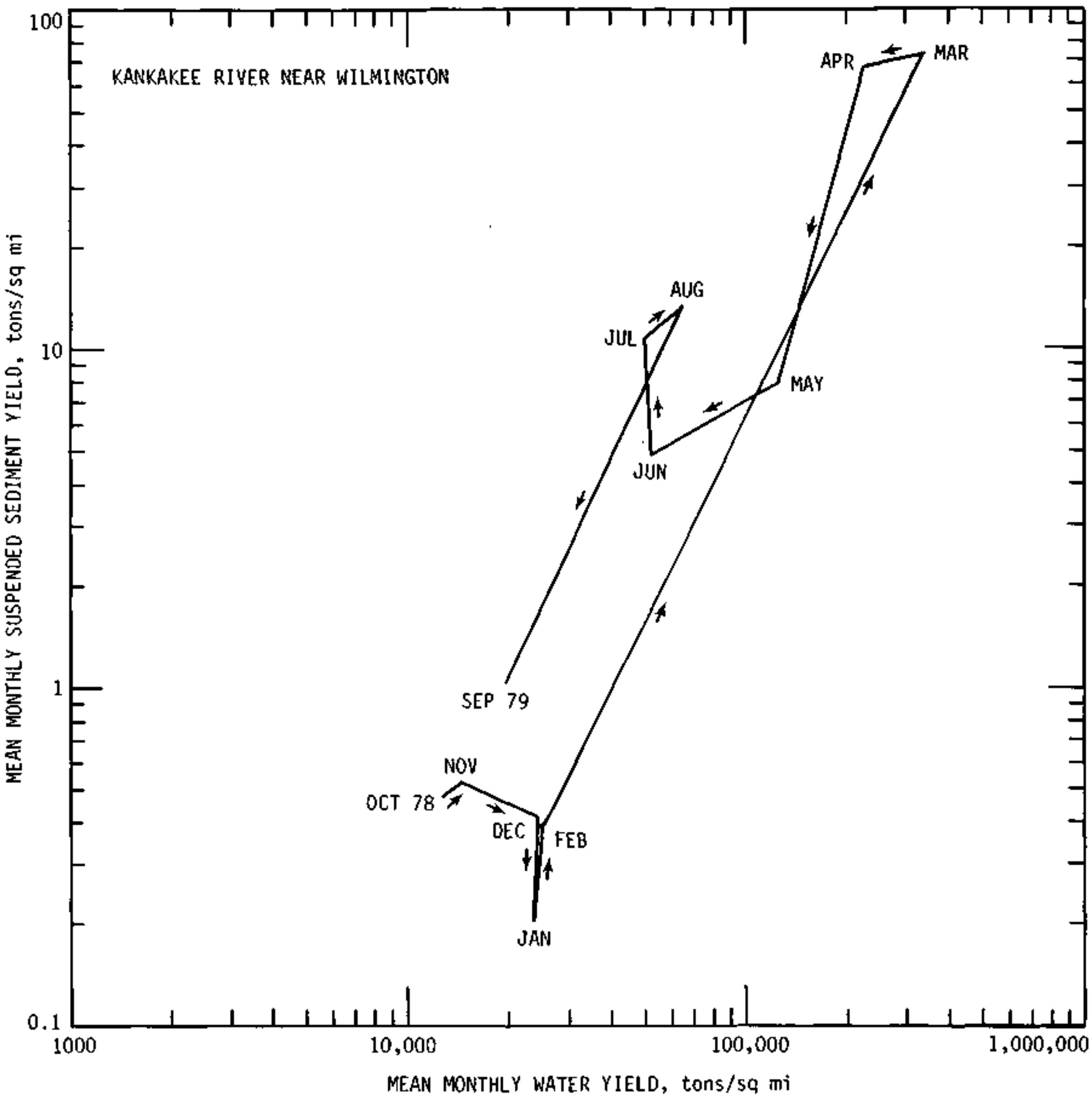


Figure 62. Relationship between mean monthly sediment yield and water yield for the Kankakee River near Wilmington

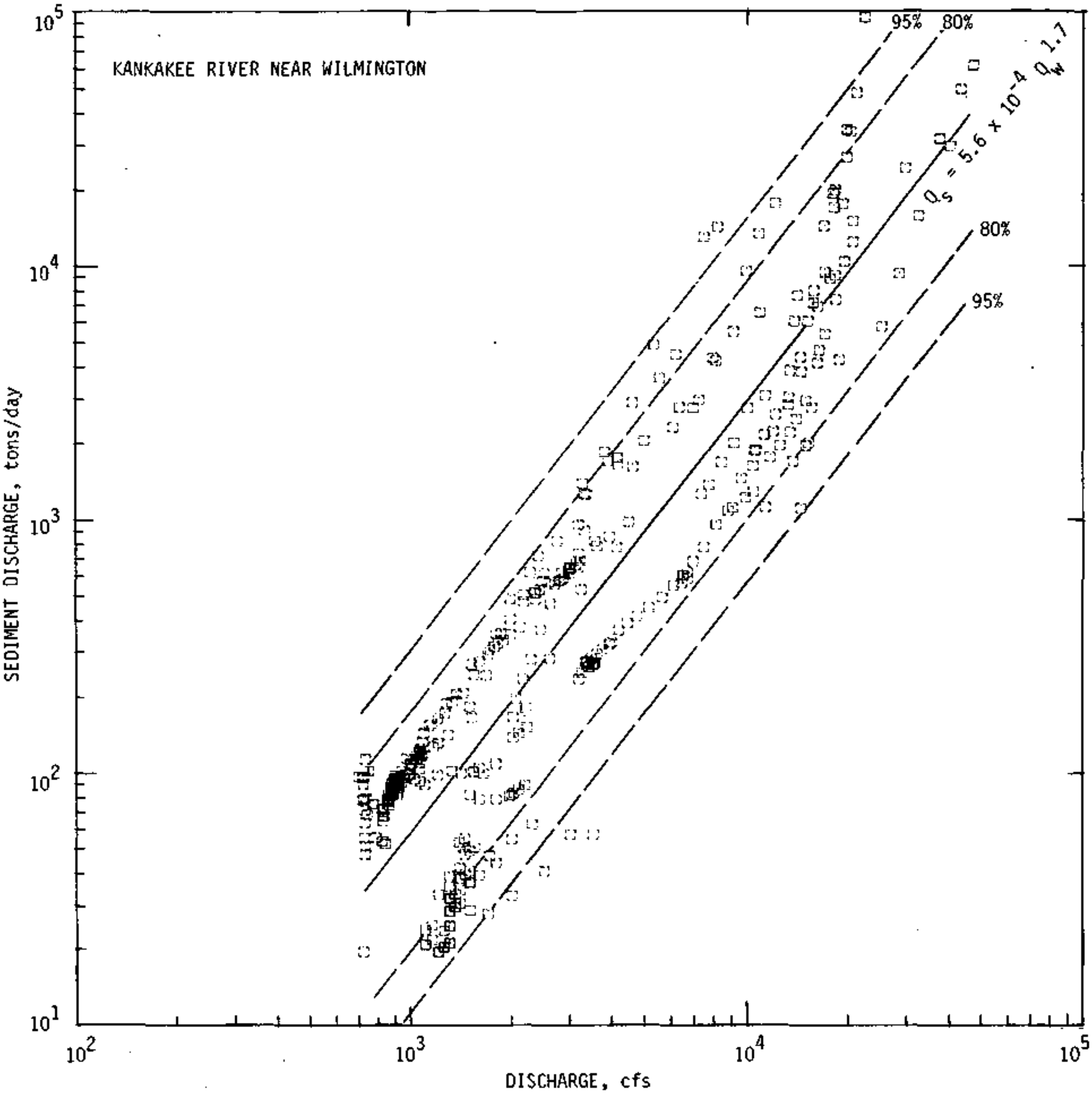


Figure 63. Relationship between suspended sediment load and water discharge for the Kankakee River near Wilmington

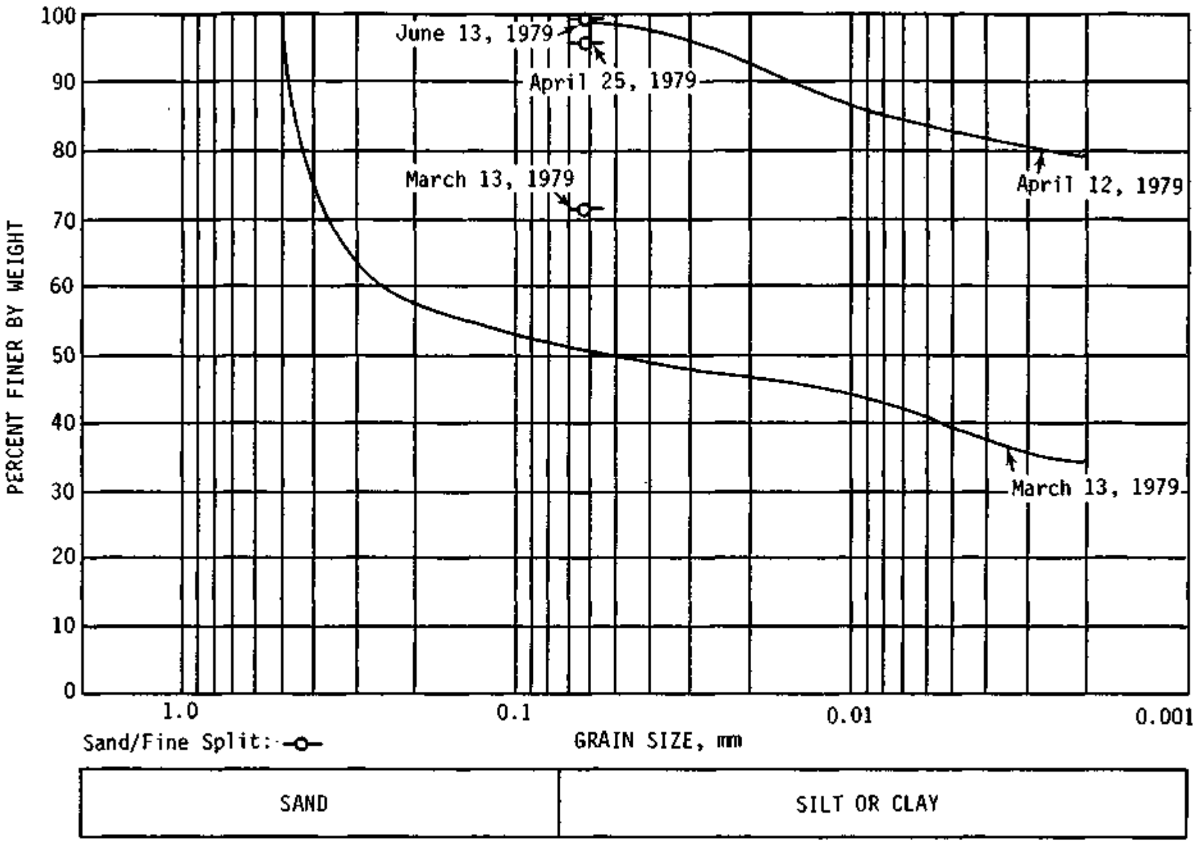


Figure 64. Particle size characteristics of suspended sediment at Wilmington

of silt and clay. This variability is similar to the variability of the particle size characteristics observed at the Momence station (figure 52). In a real sense, the characteristics of the particle size variability at Wilmington should reflect a heterogeneous combination of the particle size characteristics observed at the gaging stations at Momence and Chebanse. This appears to be a correct assumption. The bed materials of the Kankakee River near the Wilmington station consist basically of large boulders and rocks. During low flows, the river behaves as a riffle. The gradient of the river at this location is steep, the flow velocity is relatively high, and consequently the water is extremely turbulent. This remains true for both the low and high flows. Thus it is quite reasonable to assume that almost all the sediment load carried by the river at this location moves as suspended load. This point is reinforced when one considers the particle size distribution of the suspended load during early spring flows. The sizes of the sandy particles are similar to those observed on the bed of the Kankakee River above the Six Mile Pool.

This observation for the Wilmington station and those made for the Momence station have an important bearing on the present study. It appears that the suspended sediment loads measured at these two stations may, for all practical purposes, represent the total sediment load carried by the river at these two locations. Therefore, the sediment load estimated at Momence and Wilmington, based on the suspended load measured, should represent the total sediment load carried by the river at these locations.

Table 8. Percent Silt and Clay Values for Suspended Sediments

Date	*Percent finer than 0.062mm***	*Date*	*Percent finer than 0.062mm***
Iroquois River at Iroquois		*Kankakee River at Momence*	
3/8/79	96.50*	3/9/79	21.64*
5/2/79	92:64	4/24/79	52.26
6/20/79	97.00	6/14/79	91.45
8/15/79	98.35	8/20/79	96.29
Iroquois River near Chebanse		*Kankakee River near Wilmington*	
3/12/79	97.69	3/13/79	49.79*
3/12/79	93.34*	3/13/79	71.61
4/14/79	99.63*	4/12/79	98.69*
5/3/79	99.72*	4/25/79	95.45
6/18/79	98.72*	6/13/79	99.13

* *Pipet Analysis*

** *Particles less than 0.062mm are considered to be silt and clay*

Table 8 shows the percent of silt and clay values for the suspended sediment samples from all the stations.

Generalized Analysis — Suspended Load. It appears reasonable to make some general observations related to the suspended load carried by the river at the various locations.

Regression Equations. The regression equations developed between Q_s and Q_w for the various gaging stations are shown in figures 43, 44, 46, 48, 51, 55, 59, and 63. Equation 37 shows the general regression equation between Q_s and Q_w.

$$Q_s = mQ_w^n \tag{37}$$

where Q_s is in tons per day, Q_w is in cfs, and m and n are coefficients obtained from statistical analyses. Table 9 summarizes the values of m and n in equation 37 for all eight gaging stations for which sediment rating curves have been developed. These rating curves can be used to estimate suspended sediment load at these selected gaging stations. Table 10 shows some standard statistical parameters for these regression equations.

Table 9. Summary of Sediment Rating Curves

$$Q_s = mQ_w^n$$

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

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

Table 10. Standard Statistical Parameters for the Regression Equations

(1) Station	(2) Number of data points	(3) Intercept	(4) Regression coefficient	(5) Standard error of regression coefficient	(6) t-value	(7) Correlation coefficient	(8) Standard error of estimate	(9) Range of residuals	(10) Range/standard error of estimate
Foresman	62	−0.52	0.91	0.08	11.5	0.83	0.33	1.40	4.30
Shelby	29	−1.42	1.18	0.18	6.4	0.78	0.29	1.08	3.73
State Line	56	−0.37	0.78	0.14	5.7	0.61	0.29	1.24	4.24
Illinoi	56	−1.39	1.29	0.07	19.7	0.94	0.28	1.35	4.85
Iroquois	365	−1.64	1.37	0.04	37.6	0.89	0.45	2.25	5.01
Chebanse	365	−2.12	1.49	0.03	57.2	0.95	0.34	1.72	5.11
Wilmington	365	−3.25	1.67	0.04	40.4	0.90	0.36	1.86	5.13
Momence	365	−2.29	1.39	0.04	35.1	0.88	0.26	1.22	4.69

Cumulative Movement of Sediment Load. An examination of figures 45, 47, 49, 53, 57, and 61 shows that the bulk of the suspended load carried by the river at various locations is transported during flood stages. The river carries sediment load throughout the year, but the bulk of it is carried during a few storm episodes. An analysis was made to estimate the percentage of the total suspended sediment load transported by the river during a few selected storm episodes in a year. Since data from the State Line Bridge and Singleton Ditch at Illinoi were collected intermittently, these two stations were omitted from this analysis.

The amounts of suspended load carried by the river during storm episodes, as shown in figures 49, 53, 57, and 61 for gaging stations at Momence, Iroquois, Chebanse, and Wilmington, respectively, were added. A ratio of this cumulative load to the total yearly load was determined, and the results are shown in table 11. Since the storm episodes did not occur at exactly the same time at various locations, the total number of storm-days is not the same for all four stations. Also it must be remembered that the selection of the spans of the storm durations was somewhat arbitrary, and this resulted in variability in the number of storm-days at different stations.

Table 11 indicates that if data from these stations are collected for a period of about 60 to 80 days during the major storm events in a year, about 70 to 80 percent of the suspended sediment load carried by the river will be measured. This observation is

Table 11. Percent of Sediment Load Transported during Storm Episodes

Station	Total number of days	Cumulative percentage of suspended sediment load, from field data
Kankakee River at Momence	58	73
Iroquois River at Iroquois	77	69
Iroquois River near Chebanse	64	72
Kankakee River near Wilmington	60	80

Table 12. Total Water and Suspended Sediment Yield for Water Year 1979

(1) *Station*	(2) Q_w *(10^6 ft^3)*	(3) *Number of days data collected*	(4) Q_s *(tons)*
Momence	685	365	157,700
Iroquois	185	365	93,100
Chebanse	676	365	558,500
Wilmington	1600	365	932,800

** Based on field and regression curve*

very important in the development of a time schedule for collecting sediment data from a stream or river. It appears that if intensive data are collected for about 80 days in a year during storm episodes, and the remaining data are collected infrequently, it is quite reasonable to assume that up to 80 percent of the suspended sediment load will be measured. Therefore, it may not be necessary to collect data every day of the year from each gaging station. For streams in the midwest, where heavy storms occur in spring and early summer, the intensive or daily samples can be collected during this period of the year. For the remaining 8 to 9 months, weekly sampling should be sufficient to account for most of the sediment load carried by the river.

Suspended Sediment Load Budget. Suspended sediment data for the Kankakee and Iroquois Rivers were collected at six locations in Illinois. Table 12 summarizes the total suspended sediment load computations for four of the gaging stations. Data from the State Line Bridge and the Illinoi stations were omitted because of the discontinuity of the data at those locations.

The sediment load carried by the river at a downstream location represents not only the sediment that has passed an upstream gaging station, but also the sediment inflow between those two stations. Moreover, sediment load at a downstream station will reflect the erosional and depositional characteristics of the stream, as well as manmade activities between those two stations. A quick check will indicate that the sum of the sediment load in table 12, column 4, for the Chebanse and Momence stations is 716,200 tons for the 1979 water year. At Wilmington, the total suspended load for the 1979 water year is 932,800 tons. Obviously the watershed and the river between Momence, Chebanse, and Wilmington have contributed to the additional amount of suspended sediment load at Wilmington.

The sediment load data shown in table 12, column 4, are divided by the respective drainage area D_A at each location to transfer the sediment load data to a common base for comparison purposes. These data, along with data from the Foresman and Shelby stations, are plotted in figure 65. The suspended sediment load in tons per square mile for each station for the 1979 water year is plotted against the drainage areas at those locations. A curve can be drawn through the three points in figure 65 representing the Iroquois, Chebanse, and Foresman stations. It is clear that the drainage basin above the Momence and Shelby gaging stations is contributing the lesser amount of suspended sediment load per square mile of drainage area to the Kankakee River. The cumulative effect of the total drainage basin is shown by the data for the Wilmington station.

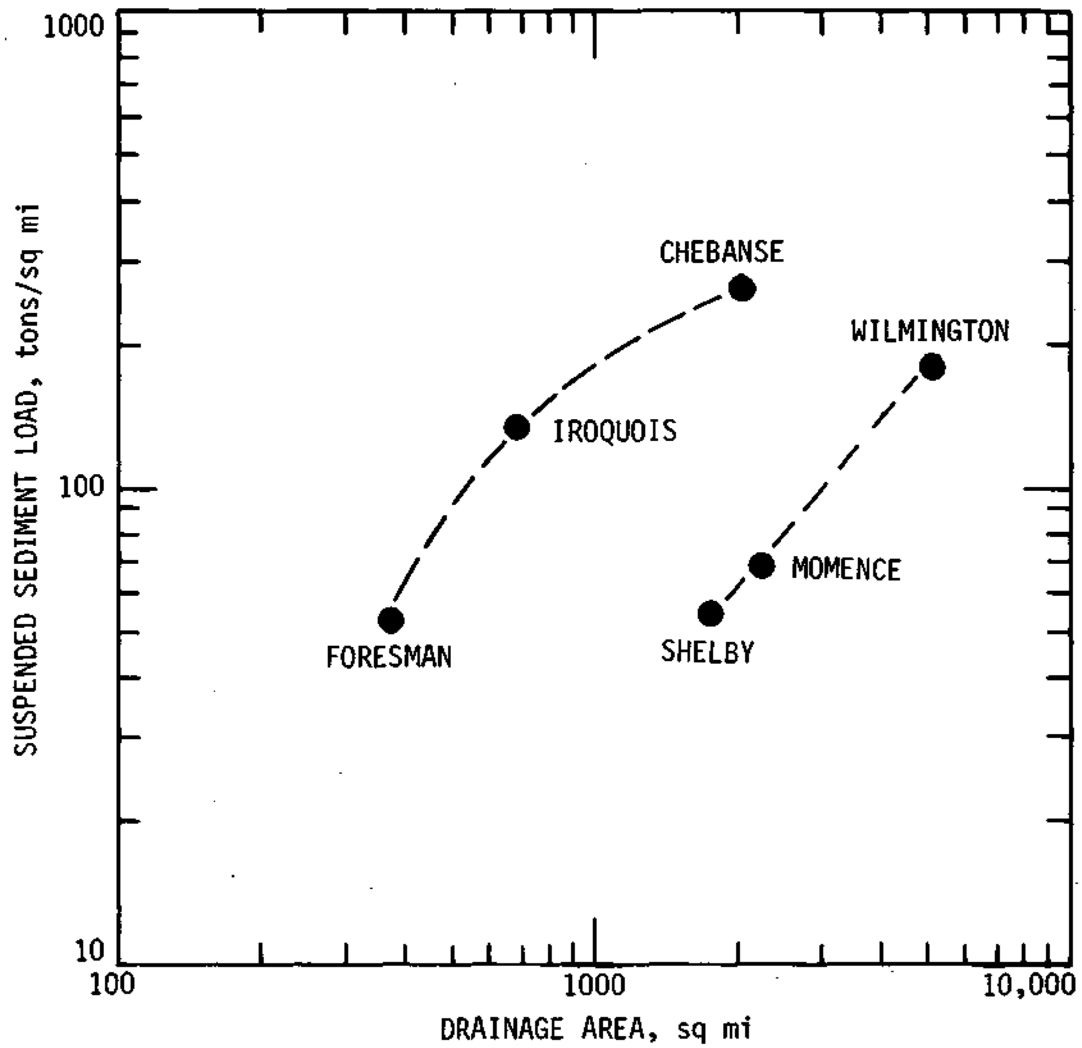


Figure 65. Relationship between total suspended load and drainage area for six gaging stations

It appears that two separate curves can be drawn to represent 1) the data from Foresman, Iroquois, and Chebanse on the Iroquois River, and 2) the data from Shelby, Momence, and Wilmington on the main stem of the Kankakee River. It must be pointed out that although the data for the gaging station at Wilmington represent the total effective sediment load of the main stem of the Kankakee River and the Iroquois River, on a per unit basis the Wilmington station aligns itself with the main stem of the river as far as the suspended sediment load is concerned.

The whole Kankakee River Basin could have been assumed to be homogenous as far as suspended sediment load is concerned if the Q_S/D_A values for the Shelby, Momence, and Wilmington stations were on the same hypothetical curve as that representing the data from the Foresman, Iroquois, and Chebanse stations. However, it appears that the basins above the stations at Foresman, Iroquois, and Chebanse contribute a comparatively larger share of suspended sediment load to the river than does the main stem of the Kankakee River. In summary, in the 1979 water year, the Iroquois River carried a larger quantity of suspended sediment load.

A computation can be made to estimate the total suspended sediment load for the State Line Bridge based on the data from the Momence gaging station. For the Momence station, the suspended load for 1979 was 68.7 tons per square mile. Thus, with a drainage area of 1920 square miles at the State Line Bridge, about 131,900 tons of suspended load should have passed this location in the 1979 water year.

It should be pointed out that the sediment load at Momence is contributed by the main stem of the Kankakee River and the Singleton Ditch. The drainage area of the Singleton Ditch is relatively small compared to the total drainage area of the river at Momence. Therefore, the net influence of the Singleton Ditch on the total suspended sediment load for the year at Momence may not be significant enough to change the computed value of sediment load at the State Line Bridge based on the measured sediment load at Momence.

Variation of Historical Suspended Sediment Load. Data related to the suspended sediment load were collected for the 1979 water year. Regression lines that were developed for each station are summarized in table 9. One of the methods that can be used to estimate the historical sediment load at any one of those stations is to use the regression curve for the specified station and then compute the sediment load based on the historical average water discharges for each year. However, in the case of the Kankakee River it will not be advisable to use the regression lines developed in this report to develop a historical account of the sediment load at various locations along the Kankakee River. The data base is too short to develop such a relationship.

Bed Load. It has already been mentioned that bed load data were collected from the stations at State Line Bridge, Iroquois, and near Chebanse. The Helley-Smith bed load sampler (figure 12) was used to collect these samples. While this sampler was designed for use with coarse materials ranging in size from 2 to 10 mm, the median diameters of the bed materials from the Kankakee River range in size from 0.2 to 0.4 mm. Although this sampler can be used for finer materials, its efficiency and effectiveness become doubtful when the bed materials are sandy in nature. On the other hand, this is the only sampler that is available at the present time to measure bed load in any open channel. With the understanding that the bed load data collected by the Helley-Smith sampler from a river with bed materials ranging in size from coarse to medium sands might not represent the true nature of the bed load movement, an attempt was made to collect data related to bed load movement in the river.

Many times throughout the year the sampler was allowed to rest on the bed of the river for 5, 10, 15, or 30 minutes at a time, but it primarily gathered leaves, twigs, and other organic materials. Only during high flows did it gather some bed load materials. At these times the flow velocity of the Kankakee River was relatively high, the bed materials consisted of soft sand, and sand was moving as dunes and ripples. A number of times when bed load material was gathered, it was suspected that possibly a dune front had just moved inside the sampler and been collected as bed load.

Another difficulty of collecting bed load samples with this sampler is the dead weight of the sampler. The sampler weighs about 65 pounds and there is a danger of scooping up some soft materials from the bed when the sampler is picked up from its resting position. The sinking of the sampler on the soft sand is also a disadvantage that must be remembered.

Even with all the limitations mentioned above, it is unmistakably clear that during flood flows extensive amounts of sand were moving near the bed of the Kankakee River either as bed load or as traveling dunes in the downstream direction. Substantial amounts of sample were collected several times even though the sampler was kept on the bed of the river for a period of only about 30 seconds to 2 minutes.

Appendix N shows the bed load data collected at the State Line Bridge. The bed load shown in grams is the amount of bed load that moved on a strip of bed only 3 inches wide. Most of these data were collected during storm episodes. Many times movement of bed load was found to be present at a few selected locations across the width of the river. The station numbers shown in Appendix N indicate the distances of the "verticals" in feet from the left abutment of the State Line Bridge. (The designations "left" and "right" in reference to the sides of a river are based on the point of view of an observer looking downstream from the middle of the river.) These data show that the main movement of bed load occurred near the left side of the river and within a distance of about 75 feet, from stations 50 to 125. Most of the time the samples were collected for a period of 2 minutes. However, on two occasions in April 1979 substantial amounts of samples were collected even for a period of 30 seconds.

Although the sampler was usually kept on the bed for 2 minutes, the dry weight of the bed load materials collected varied substantially, from a few grams to about 1000 grams. In general, an increase in the average velocities in the vertical resulted in a corresponding increase in the amount of bed load collected from the river. The specific gravity of these materials did not change significantly.

Figure 66 shows the particle size distribution of the bed load materials at the State Line Bridge. These materials are almost uniform in size, with most of the particles varying in size from 0.2 to 0.4 mm.

An attempt was made to estimate the bed load carried by the Kankakee River during flood flows. As was noted previously, a significant amount of the bed load movement occurred for about one-third of the width of the river. Thus, for April 10, 1979, the average bed load at three stations for 2 minutes was about 64.1 grams for a 3-inch width of the bed. The width of the river at this location is about 220 feet. Assuming that the bed load is moving on a strip of the bed about 50 feet wide at a rate of about 128 grams (dry weight) per minute per foot, the total bed load for a 24- hour period will be $[(128 \times 60 \times 24 \times 50)/(453.6 \times 2000)]$ or about 10.2 tons. This is small compared to the suspended load of 192 tons carried by the river on April 10, 1979 (Appendix H). Table 13 shows the computed bed load Q_b in tons per day for the State Line Bridge. The suspended sediment load is also shown in this table. In general, the bed load ranges from 1 to 45 percent of the total load.

It must be remembered that during floods, the Kankakee River floods the road leading to the bridge on both sides of the river, and a considerable amountof flow crosses the state line on top of the roadway. Since neither these flows nor the suspended

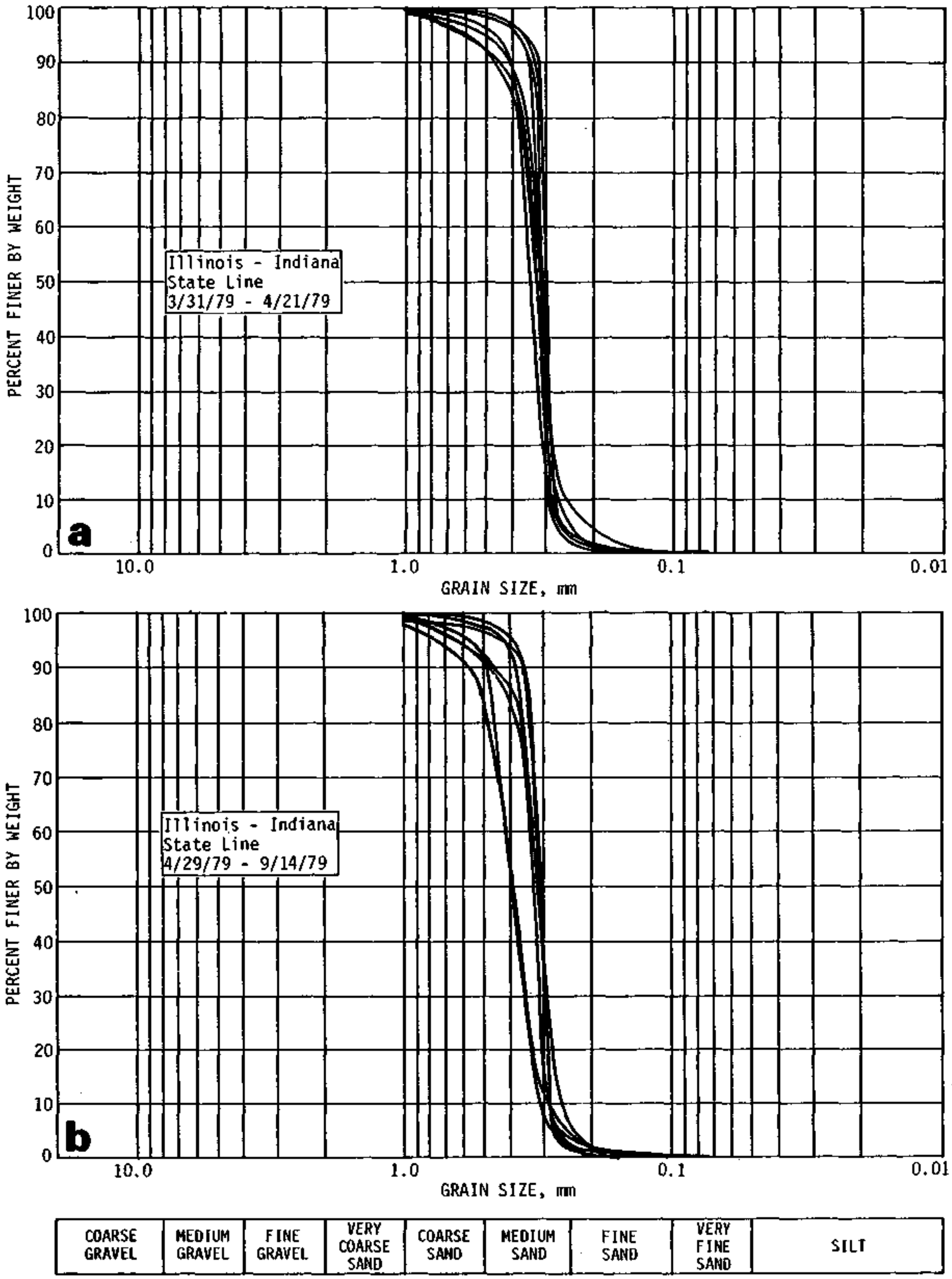


Figure 66. Particle size distribution of the bed load materials at the State Line Bridge

Table 13. Bed Load Computation for Kankakee River at State Line Bridge

Date	Bed load per unit width (grams/ft)	Effective width of river (ft)	Bed load Q_b (tons/day)	Suspended load Q_s (tons/day)	Q_b/Q_s X 100	$Q_b/(Q_s+Q_b)$ X 100
3/29/79	27.7	50	2.2	188.0	1.2	1.2
3/31/79	630.6	50	49.8	386.9	12.9	11.4
4/1/79	1153.8	50	91.4	343.9	26.6	21.0
4/2/79	631.2	50	49.9	331.3	15.1	13.1
4/3/79	604.1	50	47.9	256.1	18.7	15.8
4/4/79	229.4	50	18.4	309.7	5.9	5.6
4/5/79	164.6	50	13.0	236.4	5.5	5.2
4/6/79	306.9	50	24.3	234.5	10.4	9.4
4/10/79	128.2	50	10.1	192	5.3	5.0
4/12/79	187.5	50	14.9	306.9	4.9	4.6
4/13/79	359.3	50	28.4	323.9	8.8	8.1
4/16/79	888.8	50	70.4	225.6	31.2	23.8
4/17/79	230.3	50	18.2	247.7	7.3	6.8
4/20/79	330.4	50	26.2	1032.6	2.5	2.5
4/23/79	821.0	50	65.0	866.8	7.5	7.0
4/26/79	672.6	50	53.3	93.2	57.2	36.4
4/27/79	124.6	50	9.9	208.8	4.7	4.5
4/28/79	1032.5	50	81.8	112.9	72.5	42.0
4/29/79	671.6	50	53.2	74.4	71.5	41.7
4/30/79	747.0	50	59.2	70.2	84.3	45.7
5/1/79	247.0	50	19.6	124.3	15.8	13.6
5/4/79	809.4	50	64.1	187.2	34.2	25.5
5/7/79	780.8	50	61.8	96.3	64.2	39.1
5/10/79	292.0	50	23.2	66.2	35.0	26.0
5/15/79	201.0	50	15.6	143.3	10.9	9.8
5/23/79	80.4	50	6.4	163.6	3.9	3.8
9/14/79	216.7	50	17.2	66.7	25.8	20.5

load carried by these flows can be quantified, the suspended load measured and shown in Appendix H is less than what actually crossed the state line at this location. This additional suspended load can not be estimated. However, if the additional suspended load could be accounted for, the values of suspended sediment load given in Appendix H would be higher, resulting in a smaller ratio of Q_b/Q_s and $Q_b/(Q_S + Q_b)$in table 13.

If it is considered that, for a period of about 60 days, significant amounts of bed load movement occurred at the State Line Bridge, then the total quantity of bed load moved will be seen to be about 2210 tons. It already has been estimated that the total suspended load at the state line was 131,900 tons in the 1979 water year. Therefore, about 1.7 percent of the suspended load or 1.6 percent of the total load is estimated to be bed load. Again, it must be remembered that this is a gross estimate of the bed load movement at the State Line Bridge.

Attempts were also made to collect bed load material from the Iroquois gaging station on the Iroquois River. During a 12-month period, measurable amounts of bed load sample were obtained on only three occasions. These data are shown in Appendix O. No attempt was made to compute the bed load at this location for those three days.

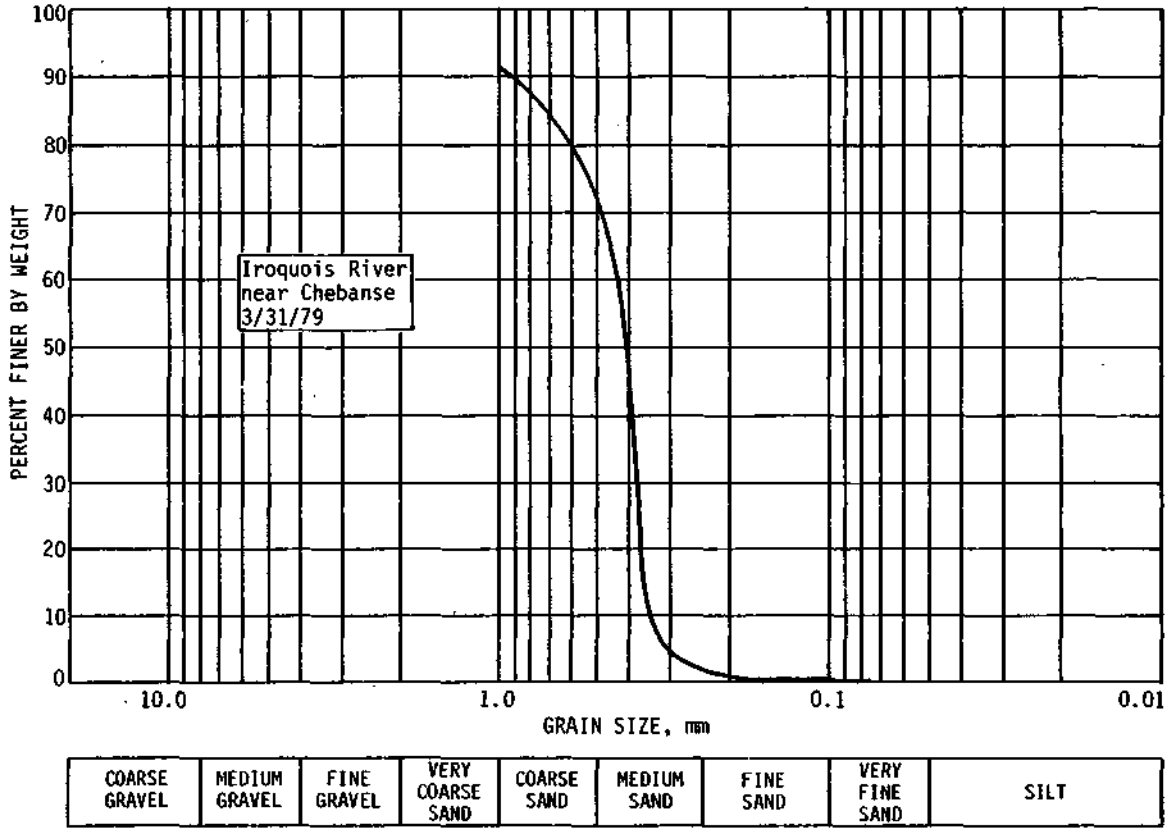


Figure 67. Particle size distribution of the bed load materials from the Chebanse station

The other station from which bed load material was collected was the Chebanse station on the Iroquois River. Here again attempts were made to collect bed load data throughout the year, but only in March and April 1979 were measurable quantities of bed load samples collected. The specific gravity of these materials appears to be lower than that of materials at the State Line Bridge (Appendix N). Figure 67 shows the particle size distribution of a bed load sample from the Chebanse station. The particle size distribution of the bed load materials is similar to that shown in figure 66 for the bed load materials at the State Line Bridge.

The bed load carried by the Iroquois River at the Chebanse station was computed following a procedure similar to that explained for the State Line station. It was assumed that bed load moved only near the center part of the river for an approximate width of about 100 feet. On the basis of these assumptions and the data given in Appendix P, computations were made to estimate the bed load at this location. These results are shown in table 14 and indicate that the bed load is about 1 percent or less of the suspended load. If it is assumed that significant amounts of bed load movement occurred for a period of about 60 days in 1979, then the total bed load at this station becomes 528 tons for the 1979 water year, while the total suspended load at this station for the 1979 water year is 558,500 tons (table 12, column 4). Therefore, only about

Table 14. Bed Load Computation for Iroquois River Near Chebanse

Date	Bed load per unit width (grams/min-ft)	Effective width of river (ft)	Bed load Q_b (tons/day)	Suspended load Q_s (tons/day)	Q_b/Q_s X 100	$Q_b/(Q_s+Q_b)$ X 100
3/5/79	3.2	100	0.5	14,600		
3/8/79	6.2	100	1.0	18,000	<0.1	<0.1
3/13/79	14.4	100	2.3	1,840	0.1	0.1
3/15/79	13.8	100	2.2	1,280	0.2	0.2
3/16/79	4.6	100	0.7	956	0.1	0.1
3/19/79	2.3	100	0.4	4,620	<0.1	<0.1
3/26/79	27.9	100	4.4	605	0.7	0.7
3/29/79	41.4	100	6.5	2,190	0.3	0.3
4/1/79	12.2	100	1.9	5,590	<0.1	<0.1
4/2/79	41.4	100	6.6	3,360	0.2	0.2
4/3/79	51.4	100	8.2	2,470	0.3	0.3
4/4/79	35.4	100	5.6	1,850	0.3	0.3
4/5/79	18.1	100	2.9	1,550	0.2	0.2
4/6/79	4.4	100	0.7	1,250	0.1	0.1
4/12/79	41.1	100	6.5	28,600	<0.1	<0.1
4/13/79	456.2	100	72.3	25,600	0.3	0.3
4/16/79	19.0	100	3.0	9,230	<0.1	<0.1
4/17/79	14.9	100	2.4	3,320	0.1	0.1
4/20/79	25.8	100	4.1	1,130	0.4	0.4
4/27/79	41.8	100	6.6	7,680	0.1	0.1
4/28/79	308.0	100	48.8	5,930	0.8	0.8
4/29/79	48.5	100	7.7	5,900	0.1	0.1
4/30/79	38.0	100	6.0	3,110	0.2	0.2

0.09 percent of the suspended load moved as bed load at this location. This percentage of bed load and the one shown for the State Line Bridge correspond with the percentages given by Simons and Senturk (1977) for bed load.

Attempts were not made to collect any bed load data from the gaging stations at Momence and Wilmington. Since bed materials at both of these stations are rock and boulder, it would have been extremely hard to lower and place the bed load sampler at these locations. Moreover, it had already been shown, in connection with the suspended sediment analysis, that in all probability the suspended sediment load measured at Momence and Wilmington did in fact measure the total load at those locations. This observation appears to be true if one considers the similarities of the particle size distribution of the bed materials (figure 35), the particle size distribution of the suspended materials (figures 52 and 64), and the particle size distribution of the bed load materials (figures 66 and 67). In all of these cases, the particle size distributions are almost identical. Therefore, it is almost certain that the gaging stations at Momence and Wilmington did in fact measure the total load as suspended load.

Sand Bar Monitoring

During the collection of field data and the boat travel on the river, it was noted that some fairly good-sized sand deposits existed in the Kankakee River. The front ends of some of these sand deposits or sand bars, as they will be called here, appeared to be moving even during low and medium flows. Detailed surveys of three of these sand bars were conducted to develop surface contour maps. It was hoped that in the future some of these sand bars could be resurveyed to develop new contour maps which could be compared with the 1979 maps to develop an understanding of the movement or progression of these bars.

Figure 14 showed the locations of major open river sand bars in Illinois.Sand bars 2, 3, and 4 and the one in Indiana near the State Line Bridge were surveyed, and surface contour maps were developed for them. The sand bar near the state line was surveyed twice during 1979.

Figure 68 shows the front of sand bar 3. This sand bar and sand bar 4 are more or less continuous and constitute a large sand deposit. No definite front of sand bars 3 and 4 exists.

Figure 69 provides a contour map of the sand bar near the state line as it was observed on July 25, 1979. The leading edge of the sand bar covers approximately the whole width of the Kankakee River. The bar is about 3 to 4 feet deep near its front and extends about 1600 feet upstream into Indiana. If the cross section of the bar is assumed to have a triangular shape, which appears to be true in this case, then the sand at this location weighs about 12,000 to 18,000 tons.

Figure 70 presents a contour map of the Kankakee River in Illinois just downstream of the State Line Bridge as observed on August 23, 1979. This map was developed for future reference and comparison purposes once the sand bar shown in figure 69 moved into Illinois.

The sand bar shown in figure 69 was again surveyed on November 5-6, 1979, at which time it was observed to have moved into Illinois. The contour map provided in figure 71 shows that the outline of the bar is now close to the edge of the river, with a deep channel near the northern shore at the State Line Bridge.

Figure 72 shows the location of the sand bar in Illinois on November 5-6, 1979. The sand bar is about 120 feet downstream of the State Line Bridge. The front of the bar has now been elongated compared to its shape in Indiana on July 25, 1979 (figure 69). This elongation is the result of the hydraulic characteristics and the plan form of the river.

Upstream of the State Line Bridge, the Kankakee River in Indiana is straight for almost 2 miles. The geometry of the river is fairly uniform and one would expect an almost uniform velocity distribution across the width of the river. In this area the river is devoid of any substantial amounts of snags, trees, or other obstructions and therefore should be an efficient conveyor of water and sediment load. This is why the front of the sand bar was fairly uniform and extended almost the whole width of the river in Indiana. The partially skewed shape of the sand bar just upstream of the State Line Bridge (figure 69) resulted from the effects of the deeper channel near the northern shore of the river at the state line.

The Kankakee River in Illinois is not straight, has not been channelized, and still maintains its natural meandering pattern. As a matter of fact, the main river takes a sharp left turn within a few hundred feet after entering Illinois (figures 10b, 70, and 72).

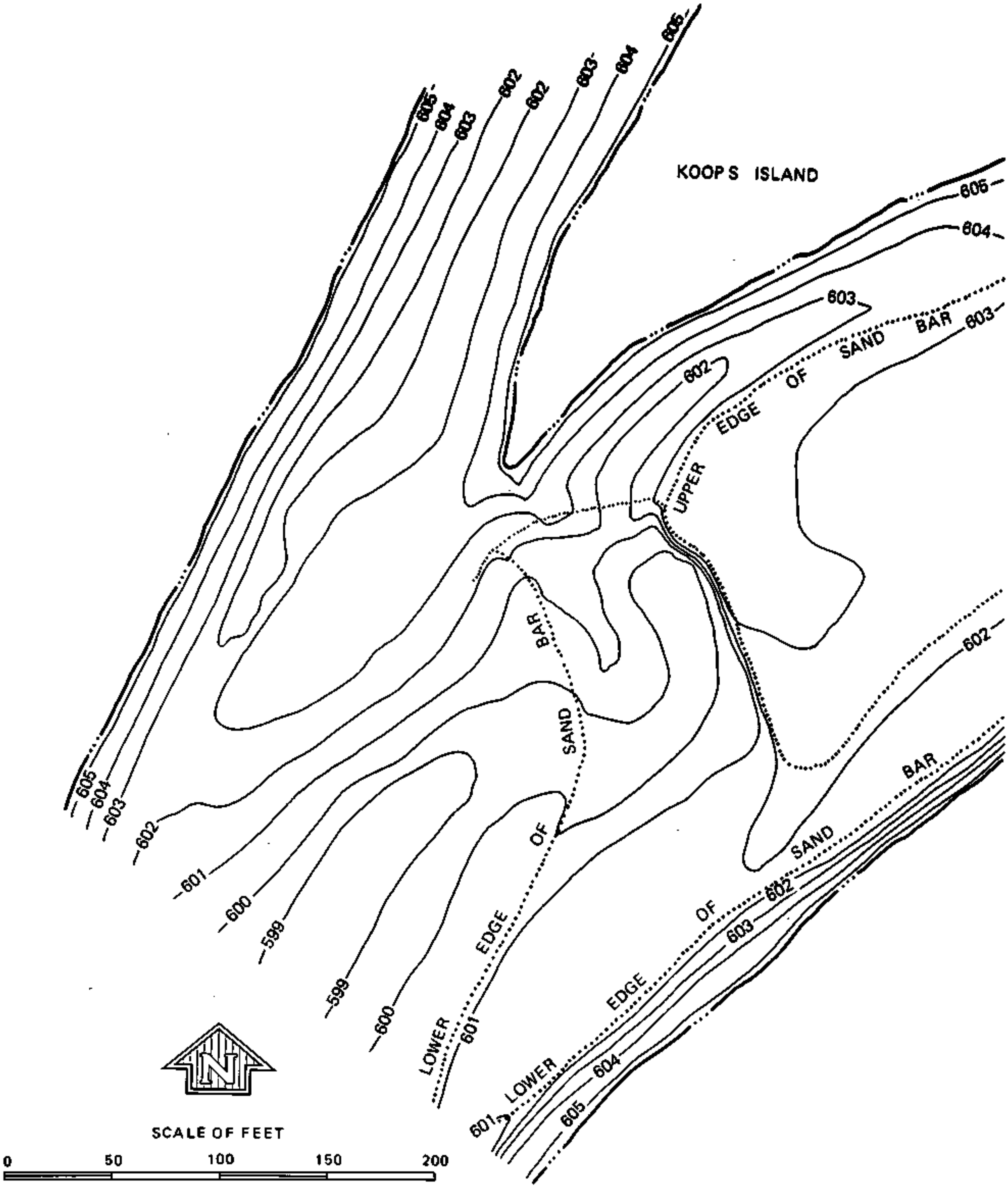


Figure 68. Front of sand bar 3

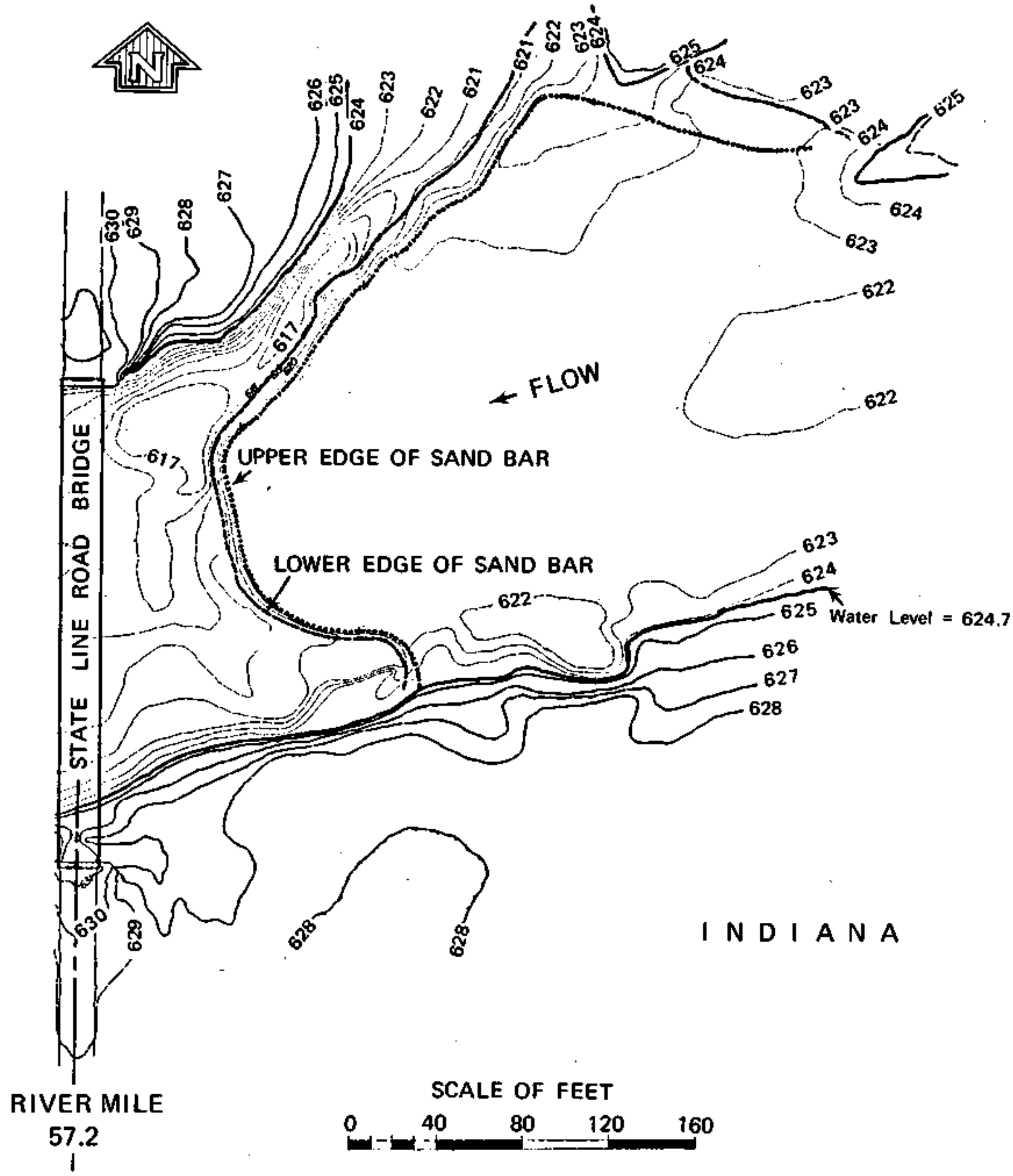


Figure 69. Contour map of the sand bar at the state line, Indiana, July 25, 1979

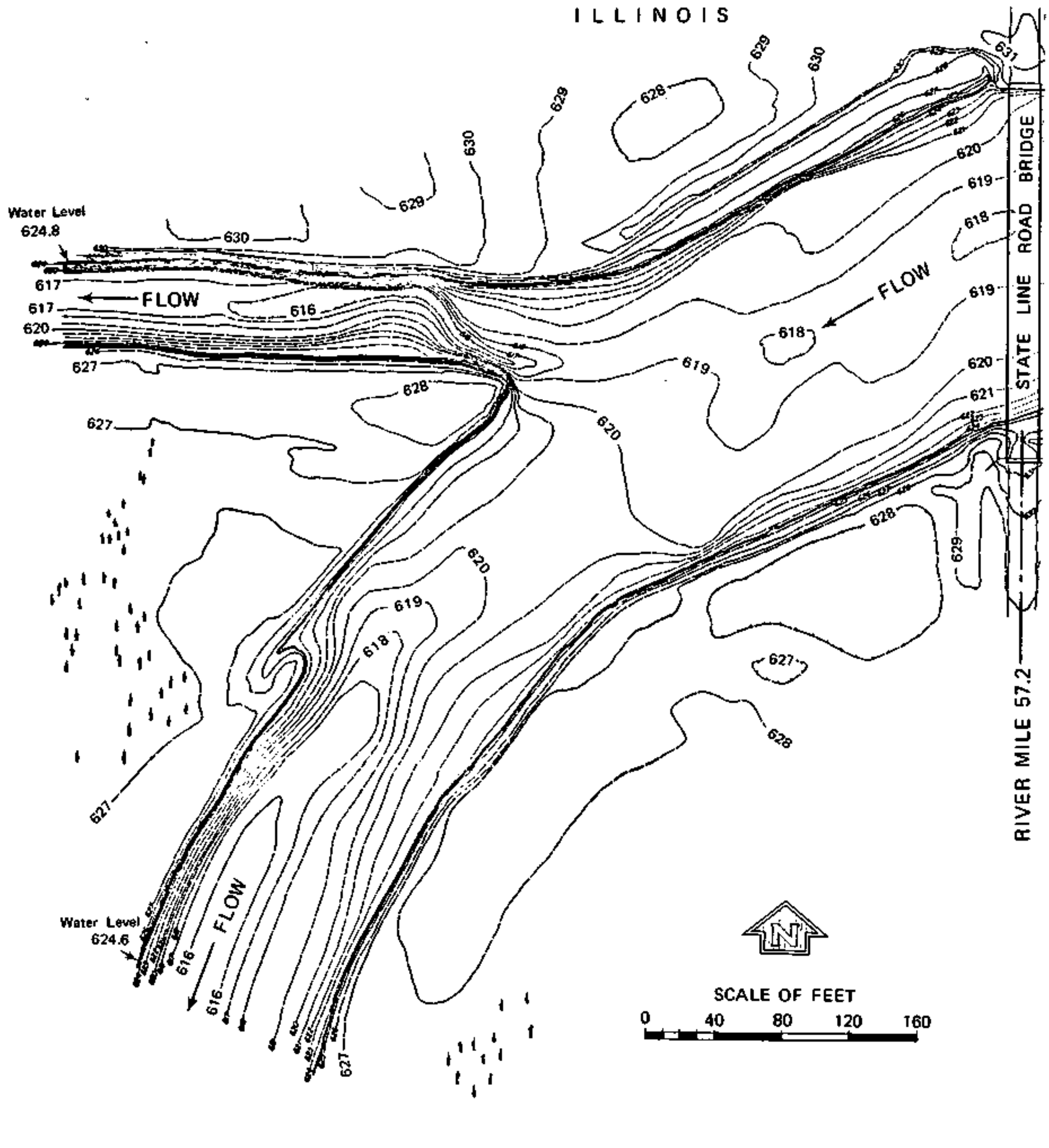


Figure 70. Contour map of the river at the state line, Illinois, August 23, 1979

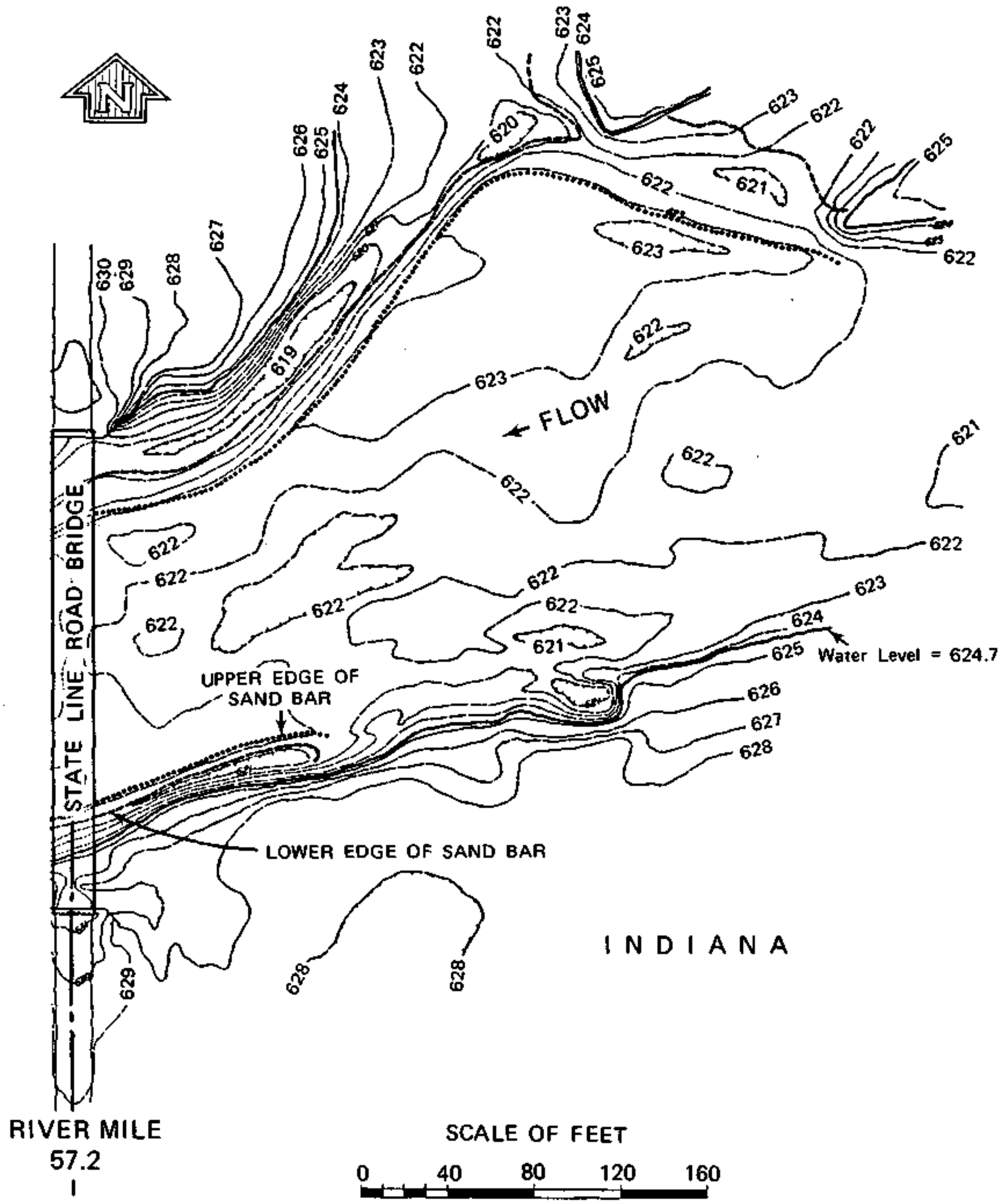


Figure 71. Contour map of the sand bar at the state line, Indiana, November 5-6, 1979

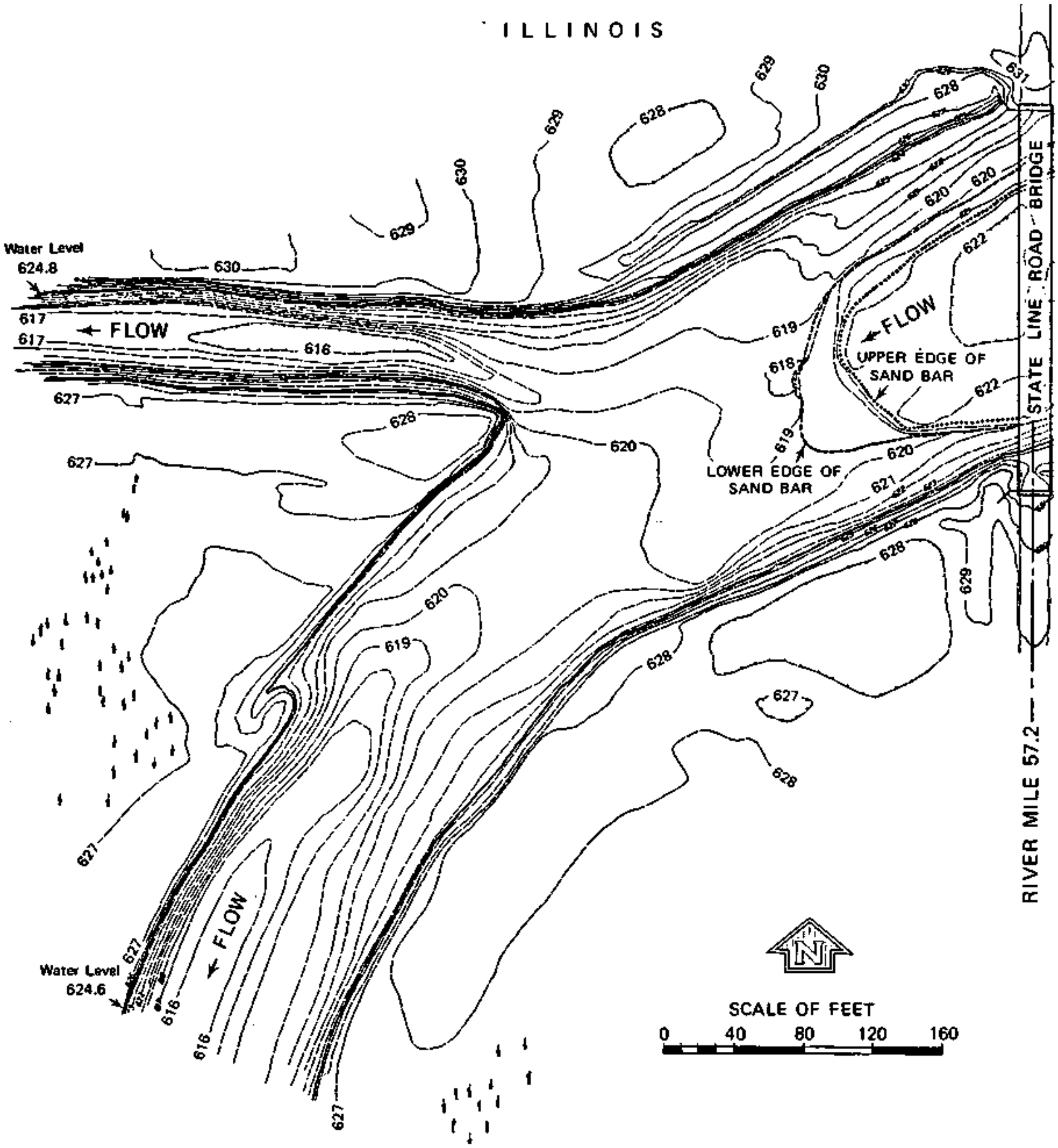


Figure 72. Contour map of the sand bar at the state line, Illinois, November 5-6, 1979

This meandering pattern of the river acts as a deterrent to the straight downstream flow of water from Indiana. Hydraulically, the meandering pattern at this location can be assumed to be acting as an obstruction similar to that of a low overflow dam. Moreover, in Illinois, flow splits in two parts with the major amount of discharge passing through the left main channel. All of these sudden restrictions affect not only the river at the State Line Bridge, but also the flow hydraulics upstream of the State Line Bridge. The river is a continuous system and any obstruction must be felt both upstream and downstream of the obstruction (Bhowmik, 1979).

With a simulated partial barrier at the state line, the pattern of lateral flow velocity changes, the higher velocity remains near the northern side of the river, the river is deeper in this part, and most of the sediment on the bed remains skewed to the southern shore. This is exactly what happened to the sand bar once it started to move into Illinois. The front edge of the bar started to disperse. Since it is no longer moving with a uniform front, it will possibly disperse much more within Illinois. The shape of the bar will be adjusted by the hydraulics of flow in the river. The effect of bends where high velocity flow stays close to the outside bank, the presence of fallen trees that can increase the flow velocity at one location and decrease it at other locations, and the deep and shallow parts of the river are just some of the physical and hydraulic constraints that will control the shape and the movement of the sand bar within Illinois. Some of the sand from this sand bar will eventually move into the Momence Wetlands.

The above observation appears to be true when the shape, position, and movement of the other sand deposits are considered. Most of the sand bars are irregular in shape, and no uniform movement of these bars was observed.

After the discovery of the sand bar near the state line in July 1979, it was monitored continuously until it started to disperse in Illinois. The location of the front of the bar was measured every week through the end of September 1979. The successive movement of the bar is shown in figure 73. The bar was moving about 18 to 24 inches per day during this period of time. It became skewed after crossing the State Line Bridge because of the changing flow patterns. It consisted wholly of sand particles (Appendix C-II) identical to those on the bed of the Kankakee River in Indiana.

During the monitoring of the sand bar at the state line, the question of whether or not the movement of the bar is a recurring phenomenon was discussed repeatedly. Since data were collected for only one year, it is not known if a sand bar moves near the state line every year. However, based on some data collected in late 1978, it appears that in all probability a sand bar or a bulk of sand moves into Illinois every few years, if not every year. This movement obviously depends on a number of factors, such as availability of sand, flow variability, peak and flood flows, management practices on the watershed, and other hydraulic parameters.

In late 1978, as a part of regular stream gaging work, cross-sectional data were collected from the Kankakee River at the State Line Bridge. The data collection program was continued through September 1979. Figure 74 shows the cross-sectional shape of the river at the State Line Bridge at various times in 1978 and 1979. A comparison of the data collected on November 3, 1978, and April 10, 1979, shows that the river has eroded its bed about 3 to 4 feet. On the other hand, it is probable that in November

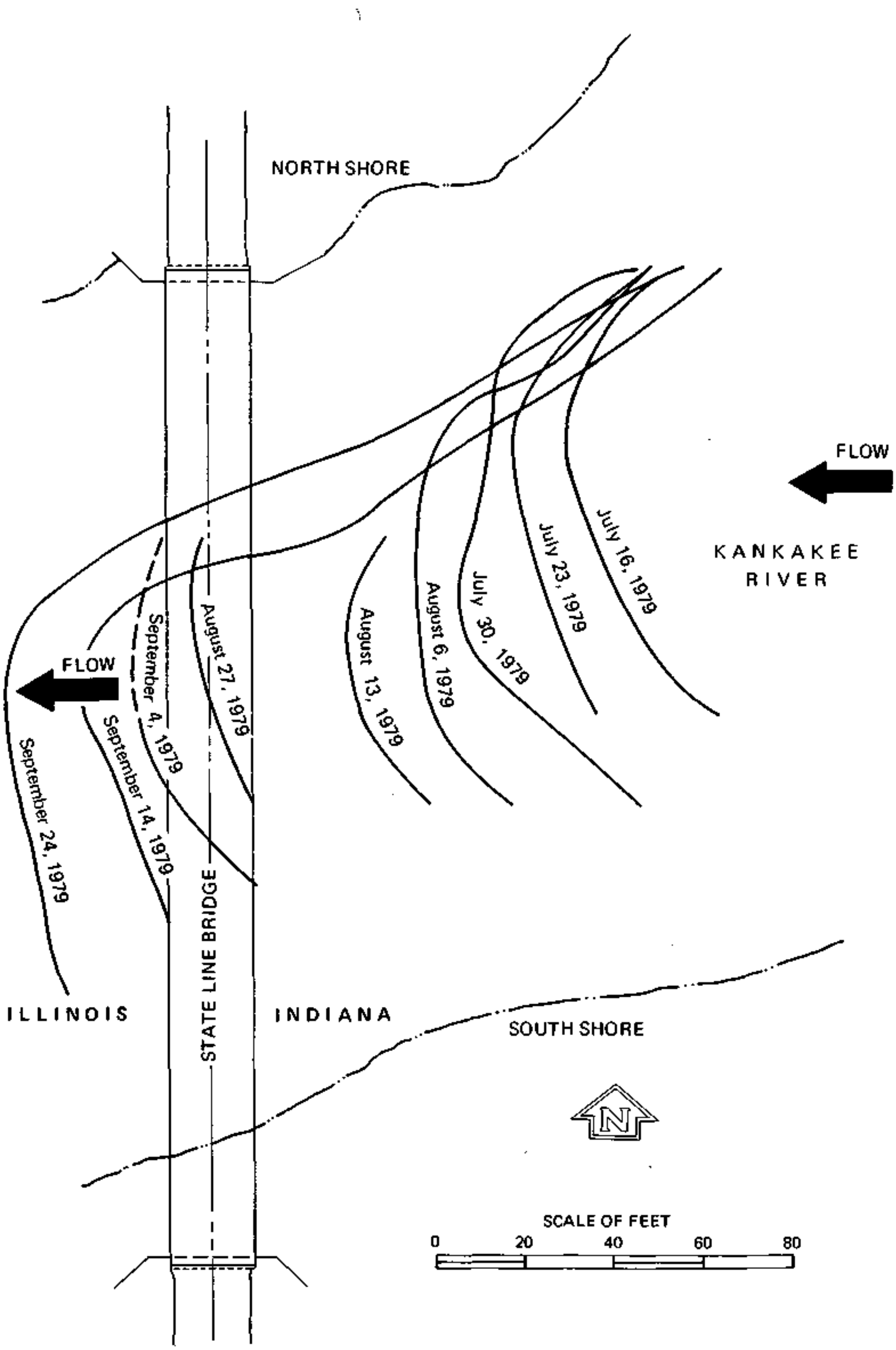


Figure 73. Successive movement of the sand bar at the state line

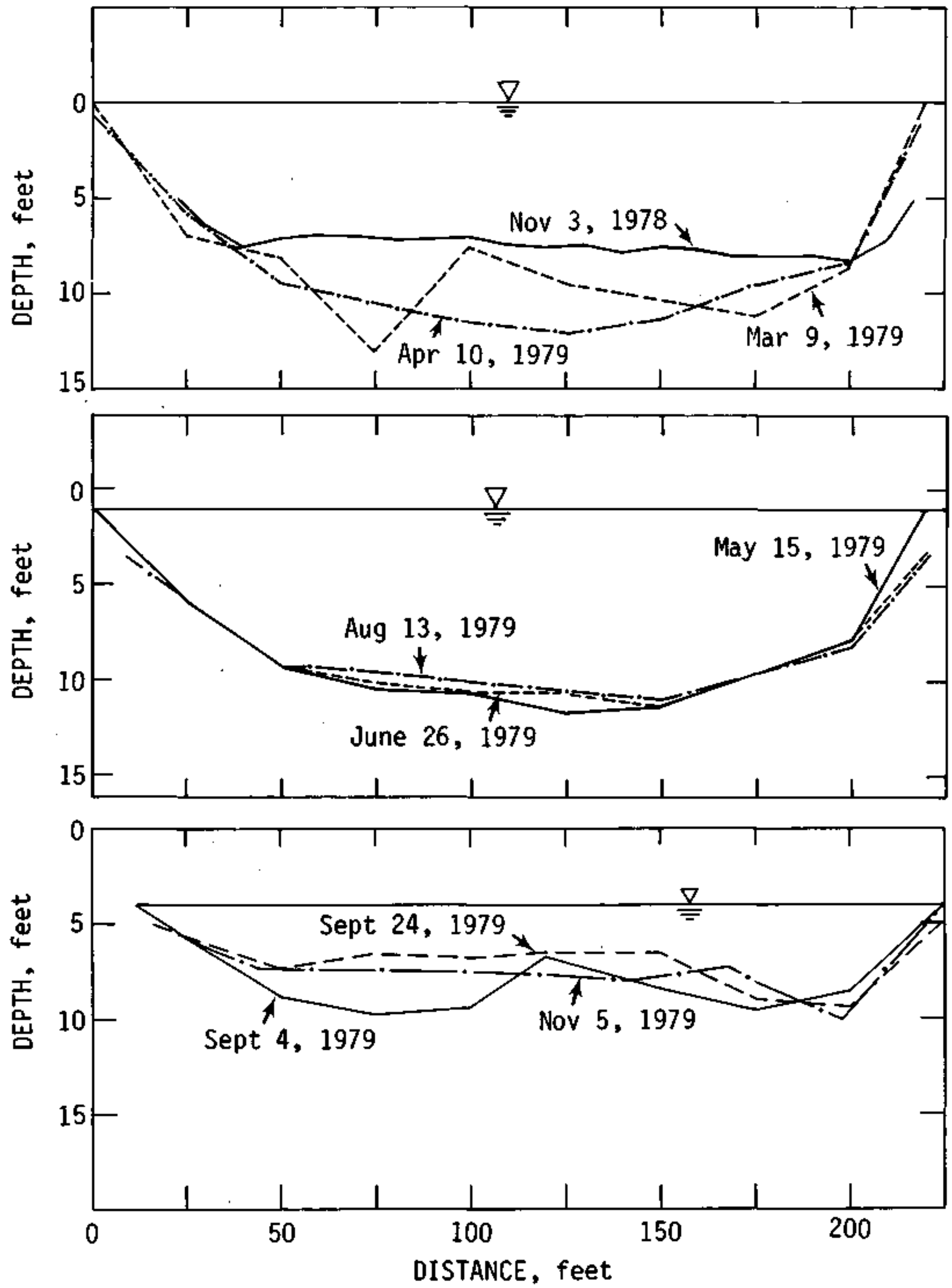


Figure 74. Cross-sectional views of the Kankakee River at the state line

1978, a sand bar was passing under the bridge at the state line. During the flood flow in early spring 1979, this bar was washed away or moved into Illinois, and the river returned to its lower bed elevation. Again, in summer 1979, when the next sand bar was passing under the bridge, the cross-sectional elevation of the river became almost identical to that shown for November 3, 1978. In all probability, during summer 1980, the cross-sectional shape of the river again looked like the cross section of April 10, 1979. Thus it is quite possible that a similar sand bar did pass through the state line in late 1978 and early 1979. This phenomenon may or may not repeat itself every year or every second or third year. Only detailed data collected for a period of 5 to 10 years would shed some light in this matter.

The sand bar at the state line is not carrying a tremendous amount of sand when compared to the total suspended load. However, it must be remembered that most of the suspended load moves downstream into the Illinois River. The movement and the presence of a sand bar that remains at a location for a long time, such as that near the state line, reduce the effective depth of water and thus the recreational use of the river at that location. Thus the total volume of sand moving as a sand bar may not be very large compared to the total sediment load of the river, but its effect on recreational use of the river may be very significant.

Some generalized hypotheses regarding the cause and formation of the sand bar at the state line are made in the next section.

Changes in River Regime

There are many different theories relating to what happens when a river regime is changed. One is that nature always tries to balance itself to its former appearance or to a new appearance or shape consistent with existing physical constraints. Throughout the world there are many examples of the effects of channelization on natural rivers. In almost all cases, the river tries to go back to its original shape and size. The river tries to expend a minimum amount of energy to move from one place to another; thus, when a stream is channelized, it will try to meander and in doing so may initiate erosion of its banks, scour of its bed, or both. If a river has no meandering tendencies, it must be concluded that its present shape and size are geometrically correct for the type of flow and other antecedent conditions present in the river.

For any stable stream, a balance exists between the water discharge, gradient, sediment load, type of bed material through which the river flows, and other physical and meteorological variables. However, if a simple approach is taken, the following balancing relationship of a river seems to work out fairly well.

$$Q_w S \sim Q_s d_s \qquad (38)$$

All the terms have already been defined. This relationship was originally postulated by Lane (1955). It can further be explained by the schematic diagram shown in figure 75, which indicates that a river will remain in balance as long as the product of Q_w and S is proportional to the product of Q_S and d_s. A change in any one of these parameters must be accompanied by a proportional change in other corresponding parameters. It has been shown that a functional relationship between Q_s and Q_w can be developed (figures 43, 44, etc.). However, no definitive relationship has yet been developed between S and d_s. Therefore, the proportional factor between both sides of the equation

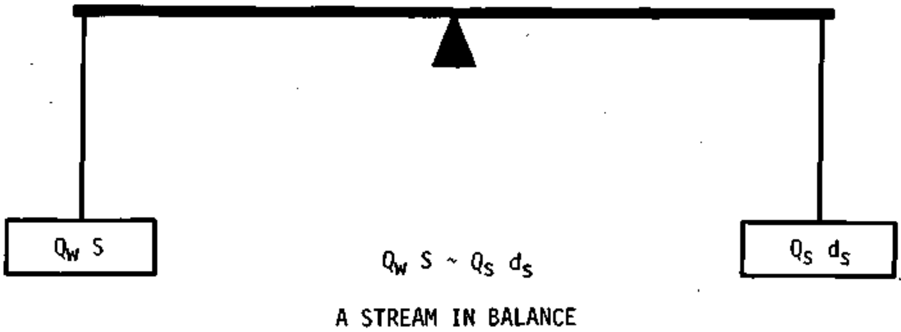


Figure 75. Schematic diagram of a river in balance

has not yet been fully defined. Equation 38 is still very useful for predicting the changes in a river that might occur because of man-made alterations. Some of these changes may not be noticeable immediately, and it may take years before the changes start to affect the river.

Two hypothetical cases may be used to show what can happen in a river if changes are made by the users of the river. Figure 76 shows the changes that a river may experience if the gradient of the river is increased, which might occur as the result of channelization. Channelization shortens the length of the river, but the bed elevations of the river at points upstream and downstream of the channelized reach remain at their natural elevations. Thus, the drop between those two points remains the same although the length of the river has been shortened. Therefore, the gradient S must be increased as a consequence of straightening the river.

If it is assumed that the materials through which the river flows do not change and the water discharge remains more or less the same, that is, Q_w and d_s are unchanged, then Q_s must increase to compensate for increased S in equation 38. In other words, the river will pick up relatively large quantities of sediment load from the channelized reaches and will deposit this extra load in the downstream, unchannelized, natural reaches of the river. These facts are shown schematically in figure 76.

The observation made in connection with figure 76 may be transposed to the conditions of the Kankakee River in Indiana and Illinois. It is true that the river was channelized in Indiana 65 to 70 years ago and that the river is extremely stable in its present condition; still, it is probable that a situation similar to the hypothetical case shown in figure 76 is present on the river. If it is assumed that the vertical dotted line in figure 76 is the boundary line between the two states, then the river should be picking up an additional load of sediment in Indiana and depositing the same load in Illinois. Before this hypothesis is carried too far, it must be cautioned that many other variables may be acting either to oppose or to support the situation shown in figure 76.

It has already been shown that the average annual flow at Momence has been increasing (figure 21), and this may serve to increase the sediment load from Indiana. Both the Q_w and S have been increased, and the particle size of the bed materials d_s remains almost unchanged in Indiana. Therefore, Q_s had to increase to balance the relationship between Q_w S and Q_s d_s shown in figure 75. It is therefore quite reasonable to

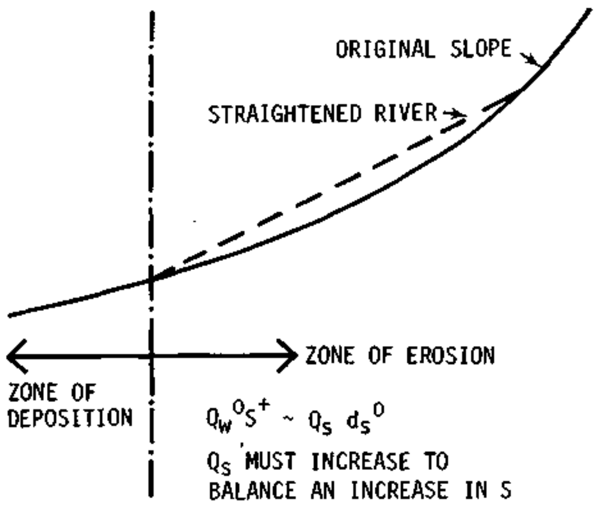


Figure 76. Effect of increased gradient in a river

expect that the Kankakee River will be carrying additional amounts of sediment load from its straightened reaches. Whether or not this is true is yet to be determined, and the hypothesis can not be fully substantiated based on only one year of data.

Another case to be considered is related to a main river and its tributary. The question is what happens to a tributary river when the base level on the main river is lowered by man-made changes, such as dredging. This case is illustrated schematically in figure 77. Before any changes in the main river occur, the bed elevation at the confluence of both the rivers is at the same elevation, and both the rivers are in equilibrium. If the base level in the main river is lowered, for example by dredging, then the tributary will try to adjust to this new base level and will start to erode its bed upstream of its mouth to bring its own bed gradient to conform to that of the main river. In doing

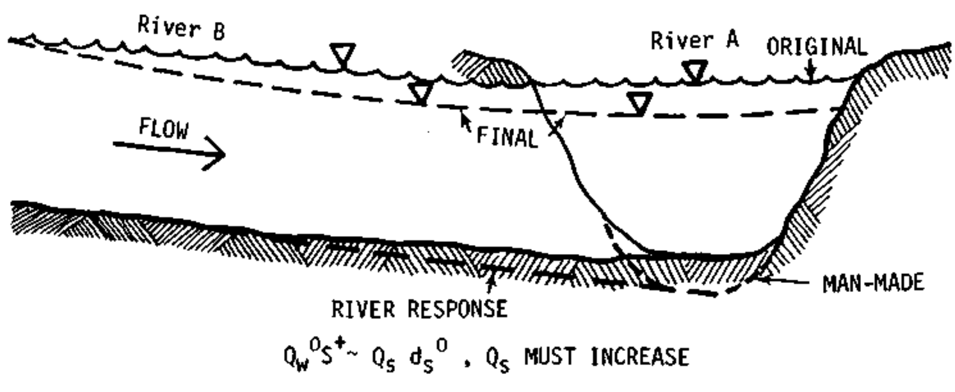


Figure 77. Effect of lowered base level in the main river on the tributary

so the tributary will increase its sediment load. However, the main river will be unable to transport the increased sediment load from the tributary and will in all probability deposit the sediment in the downstream reaches of the river. This deposition will result in the formation of sand bars and islands on the main river downstream of its confluence with the tributary. Thus, the whole process may be self-defeating and may result in an additional problem. Thereafter the dredging and clearing of the main river has to be continued as an annual maintenance program.

The situation described above may be applicable for conditions near the confluence of the Iroquois and Kankakee Rivers. If dredging is done on the Kankakee River, the dredged area will be filled in by the sediment load moving either from the Iroquois River or from the Kankakee River. This may result in the formation of an island in the Six Mile Pool. This point is also useful to a discussion of the sand bars on the main stem of the Kankakee River. If these sand bars are removed, in all probability they will again be filled in by the materials carried by the Kankakee River.

These hypothetical cases are only two of the cases that show some application of an empirical relationship for the present investigation. Many other cases could be considered and their implications analyzed.

One unique feature of the Kankakee River is the existence of almost uniform-sized bed materials along its length upstream of the Six Mile Pool. In its present form the river cannot expose large-sized particles such as gravel or stones by eroding its bed or banks, since these are not available, and thus it cannot develop an armor coat. Consequently it cannot increase the size of its bed materials d_s. Therefore with changes in S or Q_w, the river will change its sediment load Q_s.

Hydrographic Map of the Six Mile Pool

The Six Mile Pool, located on the Kankakee River near the City of Kankakee and upstream of the Kankakee Dam (figure 8), has been created by the Kankakee Dam. Although this pool is called the Six Mile Pool, it is actually only about 4.3 miles long.

It has already been mentioned that sounding data from this pool were collected by the Division of Water Resources (DOWR) of the State of Illinois in 1967-1968 and again in 1977-1978. Some additional sounding data were collected by DOWR and the crew of the Water Survey in 1979. All these latest sounding data were used to develop a hydrographic map of the pool.

During the data collection program for the present project, it was noted that some sand deposits occurred in the Six Mile Pool. Every year some rearrangement or shifting of sand deposits may occur within the confines of the pool. Thus, *any hydrographic map developed for the pool based on 1977-1978 data will reflect the conditions of the pool for 1977-1978 only.* Caution must be exercised in extrapolating these data for 1980 or the future. It is suspected, however, that in 80 to 90 percent of the area of the pool, the hydrographic map may not change significantly over the years.

Nine hydrographic maps covering the whole length of the pool from the Kankakee Dam through the confluence of the Iroquois and Kankakee Rivers have been developed. These maps are shown in Appendix Q. Additional copies of the maps are available from the State Water Survey.

The hydrographic maps shown in Appendix Q were used to determine the relationship between stage, storage capacity, and surface areas of the pool. Such a relationship for the Six Mile Pool is shown in figure 78.

The Six Mile Pool acts as a detention reservoir on the Kankakee River. It will be quite informative to find out the trapping capability of this reservoir compared to that of other man-made lakes around the country. One of the empirical methods that has been found to be applicable to this type of analysis is called Brune's method (Brune, 1953). The empirical relationship developed by Brune is shown in figure 79. Here the trap efficiency of the reservoir is related to its capacity-inflow ratio. The inflow in figure 79 is the total amount of flow that will pass through the reservoir in a single year. The third variable in figure 79 is the particle size of the bed materials. Thus, for the same capacity-inflow ratio, the trap efficiency will vary depending upon whether the bed materials of the stream consist of fine, medium, or coarse sediments. For the Kankakee River, the bed materials vary from fine to medium sands. For this type of materials, whenever the capacity-inflow ratio is equal to or less than 0.001, the trap efficiency becomes zero. Similarly, whenever the capacity-inflow ratio is 1 or more, the trap efficiency becomes almost 100 percent.

To use figure 79 for determining the trap efficiency of the Six Mile Pool, data related to the storage capacity and the average inflow to the pool must be known or computed. Figure 78 gives the capacity at various stages. However, since there is no gaging station within the Six Mile Pool area, some indirect method must be used to determine the inflow to the Six Mile Pool. One of the methods that can be used is a correlation between average flows and drainage areas for the river basin. Such a relationship for the Kankakee River Basin, based on data from 16 gaging stations, is shown in figure 80. The correlation between $\overline{Q}_w$ and D_A is excellent, with a correlation coefficient of 0.99.

The drainage area of the Kankakee River at the Kankakee Dam is 4650 square miles. With this drainage area, the inflow to the Six Mile Pool becomes 3722 cfs (from figure 80). Thus, the inflow for one year will be 1.17×10^{11} cubic feet, or 2.69×10^{6} acre-feet. The storage capacity of the Six Mile Pool at the normal pool elevation of 595 ft above msl is 2410 acre-feet (figure 78). Thus, the capacity-inflow ratio becomes 0.0009. With this capacity-inflow ratio, the trap efficiency from figure 79 is zero. Theoretically, and based on Brune's curve, the trapping efficiency of the Six Mile Pool is insignificant. This does not mean that some sand will not be deposited in some local areas, especially near the confluence of the Iroquois and Kankakee Rivers. As a matter of fact, some sand deposits have already occurred in this area (Appendix Q). The empirical relationship given by Brune is a useful approximate guide and, on the average, should be fairly accurate.

The above analysis shows that the size of the Six Mile Pool is very small compared to its drainage area. Obviously the self-cleaning action of the pool is keeping it free of any major sand deposits.

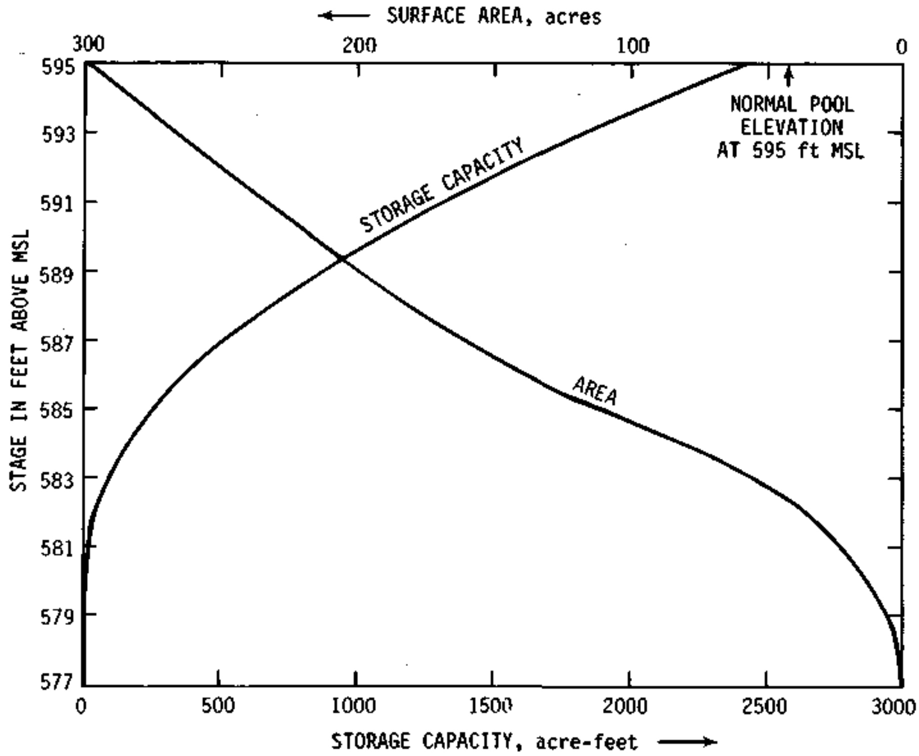


Figure 78. Stage versus storage capacity and surface area for the Six Mile Pool

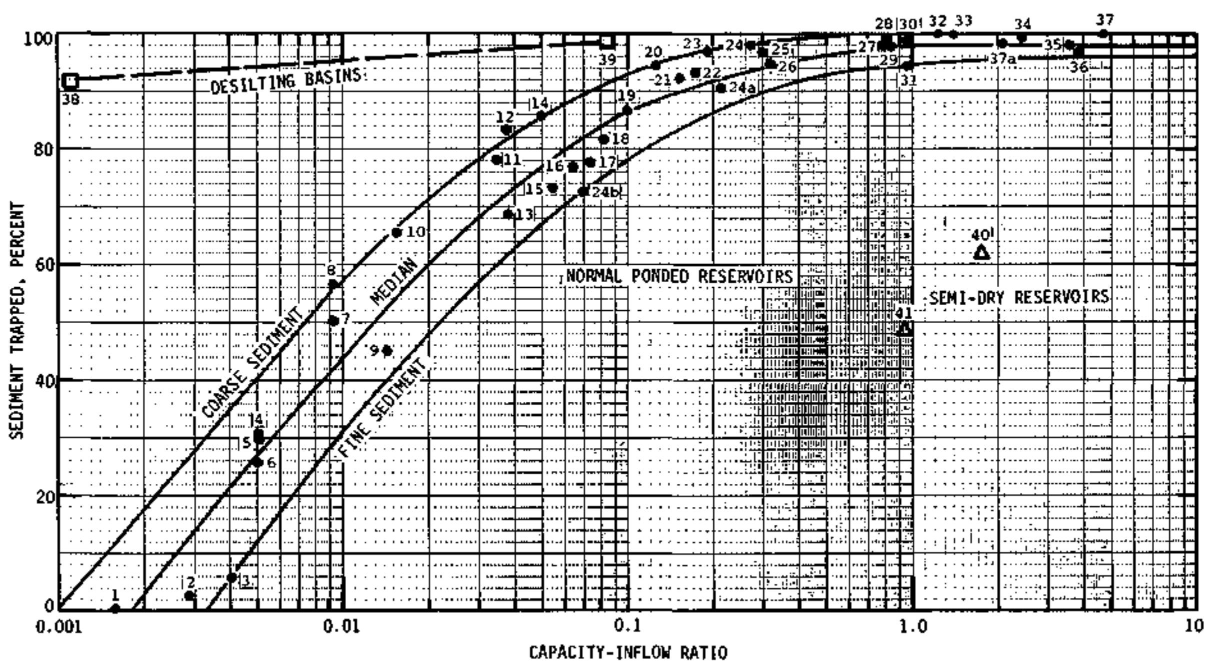


Figure 79. Trap efficiency of a man-made lake (after Brune, 1953)

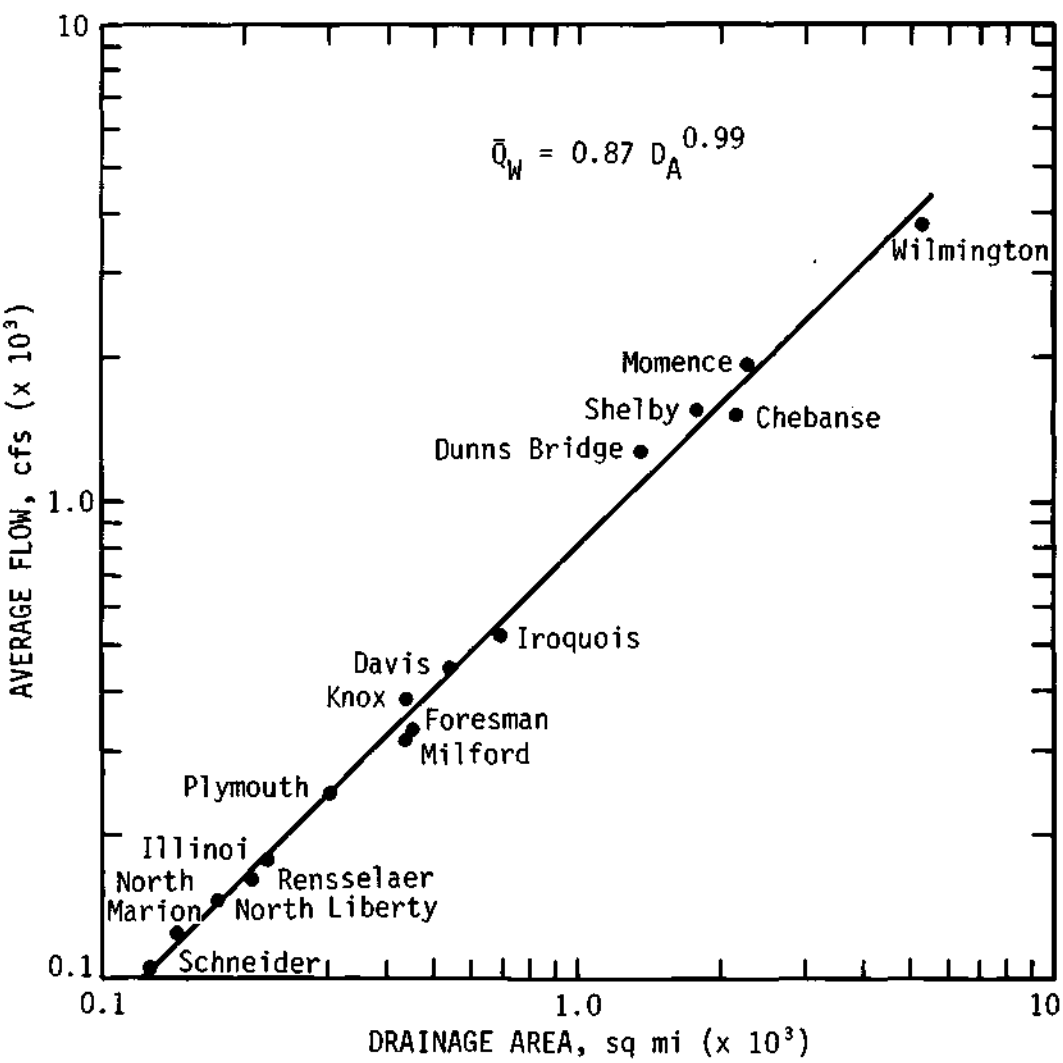


Figure 80. Relationship between average flow and drainage area for the Kankakee River

SUGGESTED PREVENTIVE AND REMEDIAL MEASURES

The preventive and remedial measures and other suggested actions presented here are based on the analyses and interpretations of the data collected in water year 1979. This is a very short data base, which should be remembered in interpreting the suggested measures. At present, this is the only data base available for the Kankakee River Basin, and conclusions, suggestions, and remedial measures must be postulated on the basis of the analyses of these data.

The preventive and remedial measures suggested here are based on the results of the present investigation, on an extensive literature review, and on inputs from various agencies and researchers. Researchers working in the field of sediment transport within state, federal, and local agencies, as well as those in universities, were contacted. Many of them were helpful in providing very valuable information.

The analyses of the data presented indicate that, in relative terms, the Iroquois River carries more suspended sediment load than the Kankakee River (see figure 65). The data suggest that most of the suspended load from the Iroquois River is carried by the Kankakee River to the Illinois River. Except near the confluence with the Kankakee River, sand deposits were not observed on the Iroquois River. On the other hand, even though the suspended load carried by the Kankakee River at Momence is small compared to that of the Iroquois River, its bed load may be significant, as was attested by the presence of sand bars in the Kankakee River. These sand deposits are very similar in nature to the bed materials. They are a major problem on the main stem of the Kankakee River in terms of their impacts on recreational uses, river access for riparian landowners, and the aquatic ecosystem.

For this study, these localized sand deposits were surveyed to develop hydrographic maps. The total volume of sand at the State Line sand bar was estimated to be about 9 to 14 percent of the total load at that location. Thus it is clear that a problem may exist with an excessive amount of sand moving on the Kankakee River. This problem may be alleviated by following some preventive and/or remedial measures.

The preventive and remedial measures that are presented here are just suggestions. No design criteria are presented or postulated. Implementation of the following measures or any other methods will require proper evaluation and engineering design. Some of the suggested measures are nothing but good engineering and management practices that should be followed whether or not a problem related to sand transport is present.

There are two ways to reduce the sediment load in a river: to take preventive measures, and to take remedial measures. If it is at all possible, it is better to use preventive measures rather than to have to solve an existing problem. The following six items are preventive measures that should be given serious consideration:

1) *Best Management Practices (BMPs) on the watershed.* These should in-include the whole watershed, both in Indiana and in Illinois. It is better to control the source of the sediment than it is to control it once it has reached the stream. The following BMPs may be suitable for the Kankakee Basin, especially in relation to agricultural land: access road protection; conservation cropping systems; conservation tillage systems, such as no

till, chisel plant, plow plant; contour farming; cover crop; crop residue use; debris basin; grade stabilization; field border and filter strips; strip cropping; terraces; grassed waterways; and others. The details of these methodologies are given by the Illinois Environmental Protection Agency (1979). These and other methods should help in reducing sheet, rill, and gully erosion from the watershed.

2) *Proper repair and maintenance of drainage ditches and levees.* This can prevent excessive sediment load in the river. Repair work in which dredged spoils are dumped on top of the bank (figure 11) should be avoided, since most of these materials will eventually erode back to the ditch and to the river. When such repair work is necessary, the exposed banks should be protected either by artificial means or by natural protection such as seeding.

3) *Minimal disturbance of the banks.* If at all possible, the banks of the main stem of the Kankakee River should not be disturbed. Bank materials of the river in Indiana are basically sand; roots and vegetation are protecting these banks. Examples of erosion of the exposed banks have been documented (figure 9b). If these banks are disturbed by clearing of the vegetation or trees, the exposed bank may erode and dump the sandy materials in the river, increasing its sediment load.

4) *Avoidance of structural disturbance of the river.* The main stem of the Kankakee River in Illinois and Indiana (up to Highway 30) is basically stable. Any man-made disturbance will alter this equilibrium and may initiate bed and bank erosion. The presence of a skewed railroad bridge upstream of Shelby is responsible for initiating bank erosion on the downstream left side and then on the right side of the river. This illustrates the adverse consequences of structural modification on the river.

5) *Reduction of sediment excesses arising from construction activities.* During construction activities, excessive amounts of sediment may be released from the watershed to the stream and its tributaries. There are various methods available to reduce the sediment load from such activities. Some of these methods are discussed by the Maryland Department of Water Resources et al. (1972).

6) *Artificial and natural means for preventing erosion.* Erosion from the watershed can be prevented by using near stream vegetation, grassed waterways, chemical treatment, soil stabilization, and mulching. For detailed descriptions of these methodologies, the reader is referred to the work done by Becker et al. (1974), Barfield et al. (1975), and Kerr and Schlosser (1977).

The methods described in items 1 through 6 are basically preventive measures and are preferable to remedial measures. Since sediment may be a problem in a limited area, some remedial measures that have been used by various researchers and administrators are described briefly below.

1) *Construction of detention reservoirs, sedimentation ponds, or settling basins.* Sediment carried by the stream can be removed by initially forcing

the sediment particles to settle out in a semi-stagnant pool and then removing these settled particles by physical means. Normally, detention reservoirs and settling basins are designed to remove sediment from watersheds of much smaller size that that of the Kankakee River. It is feasible to use settling basins for sub-watersheds within the Kankakee River Basin where erosion is a problem. For design, application, and methodology, the reader is referred to the research done by Ward (1979) and to the six reports done by Ward and other researchers in 1977, 1978, and 1979. For sediment control structures, the reader is referred to work done by the U.S. Waterways Experiment Station (1978), Ward et al. (1977b), the Maryland Department of Water Resources et al. (1972), and the American Society of Civil Engineers (1975), among others. Much work has been done on strip-mined areas and some of it has been described by Byerly et al. (1978), Curtis (1971a, 1971b, 1971c, 1974), and Vogel and Curtis (1978).

2) *Development of side channel flood retention basins.* Here the flood water is allowed to move into a side channel flood retention reservoir where the suspended sediment will settle out. During low flows, these basins are not affected by the flow from the main channel. Depending upon the size of the watershed and the size and location of the side channel detention basins, these basins can be very effective for settling sediment particles. Work done by Lee (1979) on Horseshoe Lake has shown the effectiveness of this type of basin.

3) *Removal of deposited sediment by dredging.* Removing the deposited sediment from the stream, lake, or reservoir by dredging is another remedial measure that can be undertaken.

The main purpose of describing the above preventive and remedial measures is to inform the reader about the various alternatives that are available. No comparison is made between these alternatives, and no suggestion is made as to the suitability of one over another. Before any remedial measures are adopted, they must be thoroughly investigated and all the benefits and adverse effects studied. It appears that the preventive measures are the ones that can be adopted and implemented with the least difficulty.

SUMMARY AND CONCLUSIONS

The hydraulics of flow and sediment transport in the Kankakee River in Illinois were investigated in a 2-year study partially funded by the Illinois Institute of Natural Resources. This study was initiated as a direct result of the recommendations made by the Kankakee River Basin Task Force in their 1978 report.

This report includes a background analysis, an historical perspective of the Kankakee River, descriptions of data collection measures, data analyses, and suggestions for preventive and remedial measures that can be initiated to reduce the sediment load in the river.

The present shape, size, and geometry of any river are the end products of the inflow characteristics, consistency of bed and bank materials, and man-made constraints. Historical analysis reveals the stabilities and instabilities of the river. Precise hydraulic data collected indicate the present condition of the river.

A detailed literature review was made to show the present state of knowledge of flow hydraulics and sediment transport in rivers. Items such as bed form and flow resistance, incipient motion of bed particles, and sediment load, including bed load and suspended load, were discussed from both a theoretical and a practical point of view. Instrumentation available to measure sediment load was discussed. It was pointed out that equipment is available for measuring suspended load from streams with midwestern characteristics, but that no satisfactory equipment is available to measure bed loads of sandy rivers, which are the common types of rivers in the Midwest.

The history of the Kankakee River from the late sixteenth century to the present was discussed. Discussions were limited to how the marshy areas in and around the Kankakee River Grand Marsh were changed, how the river was used for transportation, how locks and dams were built, how the marsh was used for recreation and hunting, how the early settlers tried to drain the marsh, and finally how the main marshy areas in Indiana were channelized in the early part of the nineteenth century. It was noted that as a result of the channelization of the Kankakee River and its tributary Yellow River in Indiana, the main stem of the Kankakee River was shortened from approximately 250 miles to 80 miles and the gradient was increased from approximately 5 inches per mile to about 10 inches per mile. Various attempts that were made to improve the drainage of the Kankakee basin through 1980 were also discussed.

Historical data available for the Kankakee River were analyzed. Flow duration curves were developed for all the main gaging stations in Illinois. Peak flows from various gaging stations were analyzed to identify trends. Annual peak flows at Shelby and Momence showed a trend toward increases from the 1930s through 1979, while peak flows at Iroquois and Chebanse did not show any trend. Peak flows at Wilmington showed a jump in the early 1940s that could have resulted from a change in gaging station locations. Trend analyses were also performed for the average annual and low flows from all the stations. Although the low flows did not show any trend, the average flows from the Momence and Wilmington stations did show a trend toward increases. The rates of increase of these average flows are almost identical.

Historical precipitation data over the basin were analyzed to test whether or not precipitation has been increasing. It appears that near the upper part of the basin, in an area that is about 25 percent of the drainage basin at Momence, the precipitation is much higher than that at any other place. However, no average trend was observed for the watershed as a whole.

Cross-sectional data collected in 1967-1968 and 1977-1978 for the river from the Kankakee Dam to the mouth of the Singleton Ditch were analyzed. The Kankakee River has experienced both erosion and deposition over this 10-year period. On the average, deposition exceeded erosion. The banks of the river remained very stable. The erosion and deposition that took place must have occurred on the bed of the river. The mouth of the Iroquois River showed substantial amounts of deposition, typical of a stream whose velocity has suddenly been reduced by the construction of a dam creating a pool.

Extensive bed and bank material samples were collected from the river in Indiana and Illinois. The characteristics of these materials are almost identical. The median diameters vary from 0.2 to 0.4 mm, and the particles are almost uniform in size. Particles deposited on the sand bars also showed similar characteristics. The bed materials from Highway 30 in Indiana to the Six Mile Pool were less than 5 percent silt and clay except within the Six Mile Pool, where values as high as 30 percent were observed. These high silt and clay contents in the pool are a normal characteristic of any pool where fine materials settle out due to reduced flow velocity.

Daily suspended sediment data were collected from the Momence, Iroquois, Chebanse, and Wilmington stations for the 1979 water year. Similar data were collected biweekly, and more frequently during flooding season, from the State Line and Illinoi stations. Bed load data were collected from the State Line, Iroquois, and Chebanse stations. Historical suspended sediment data from the stations at Shelby and Foresman were gathered from the files of the U.S. Geological Survey. These data were analyzed to determine rating curves at each station and also to estimate the suspended sediment load carried by the river at these stations.

A comparison of daily water discharge and sediment discharge indicated that the peak of sediment discharges does not always correspond to the peak of water discharges. For most stations, antecedent conditions in the watershed affected the peaks of flood and sediment discharges. At many stations, during various periods in a year the suspended sediment yield per square mile changed by 100 percent for the same water discharge. Thus, it is very difficult to develop a direct relationship between sediment discharge and water discharge for every gaging station.

Composition of the suspended sediment load carried by the river also changed from one station to another and from one season of the year to another. During low flows in the winter and late summer, the suspended sediment load consisted of silt and clay, but during high flows, the composition of the suspended load changed drastically, and sandy materials comprised 50 to 80 percent of the suspended load. The Iroquois and Chebanse stations were exceptions. For these two stations, the composition of the suspended sediment load remained silt and clay throughout the year.

The composition analyses of the suspended sediment load indicated that in all probability the suspended load measured at Momence and Wilmington is the total load carried by the river at those two stations. The Iroquois River carries finer materials as suspended load, and this gives a cloudy appearance to the water.

Analysis of the daily suspended load from the Illinois stations has shown that during flooding season and within a period of about 60 to 80 days, approximately 70 to 80 percent of the total yearly suspended load passed the four main stations in Illinois. Thus, extensive samples during flood stages and infrequent samples during other times of the year may account for about 80 percent of the total yearly suspended load in the river.

A simple suspended sediment load budget was performed for all the main stations in Illinois. These analyses have shown that the suspended sediment loads passing the stations at Momence, Iroquois, Chebanse, and Wilmington in water year 1979 were 157,700 tons, 93,100 tons, 558,500 tons and 932,800 tons, respectively. Suspended sediment load at the State Line station was estimated to be about 131,900 tons in wateryear 1979, based on the data from the Momence station.

The contribution of suspended sediment load by different drainage areas above the gaging stations of Momence, Iroquois, Chebanse, and Wilmington was different and indicated the nature and amount of sediment load carried by the river at various locations. This analysis has shown that for every square mile of drainage area, the Iroquois River has contributed much higher suspended load than the Kankakee River. For water year 1979, the suspended load at Momence was 68.7 tons per square mile and for Chebanse it was 267 tons per square mile. The drainage areas at these two stations are almost identical. Thus, the watershed of the Iroquois River is obviously contributing much more suspended load than the watershed of the main stem of the Kankakee River.

Bed load data were collected at the State Line, Iroquois, and Chebanse stations through use of a Helley-Smith sampler. This type of sampler was designed for collecting bed load samples from streams with coarse bed materials in the range of 2 to 10 mm in size, but the Kankakee River carries as bed load sandy materials in the range of 0.2 to 0.4 mm in size. Thus, the data collected by the Helley-Smith sampler may be of limited value.

Most of the bed load data collected at the State Line, Iroquois, and Chebanse stations were measured during flood stages. No significant amount of bed load was observed to move at other times. The particle size characteristics of the bed load materials at the State Line and Chebanse stations were almost identical to those of the bed materials. An approximate computation of the daily bed load at the State Line station has shown that the bed load at this location can occasionally be as high as 45 percent of the measured total load. However, the total estimated bed load at the State Line station for water year 1979 was approximately 2200 tons, or about 1.6 percent of the total load at this station. For the Chebanse station, the total bed load for water year 1979 was about 530 tons, or about 0.09 percent of the total load. No appreciable amount of bed load was measured at the Iroquois station.

Data were collected for a single year; however, basic data for any sediment transport data collection program must be collected for a period of 5 to 15 years before any definitive statements or analyses can be made. Moreover, any natural river such as the Kankakee River is a dynamic river. It may and will change its bed profile over a period of time when materials for scour and areas suitable for deposition are present.

A number of active sand bars on the Kankakee River were surveyed to develop detailed hydrographic maps. One sand bar near the State Line Bridge was monitored, and it was observed that in summer 1979, this sand bar moved about 18 to 24 inches a day. This bar was about 150 to 200 feet wide, approximately 1600 feet long, and about 3 to 4 feet high at the leading edge. Its total volume was estimated to be about 12,000 to 18,000 tons, which is about 9 to 14 percent of the total sediment load (suspended and bed load) at this location. It will take the sand moving as a bar a long time before it finally moves through the Kankakee River. Possibly the formation of the bar at the State Line is a recurring phenomenon.

A generalized analysis of changing flow regimes in a river has shown that increasing the gradient of a river having uniform bed materials and slightly increasing average flows results in an increase in the sediment load in the river. At the same time, dredging near the confluence of two rivers can increase the sediment load from the tributary and cause the formation of sand bars in the main river.

A detailed hydrographic map of the Six Mile Pool based on the sounding data collected in 1977-1978 has been developed. The Six Mile Pool stored about 2400 acre-feet of water at the spillway elevation of 595 feet above msl. Computations based on Brune's method were made to determine the trap efficiency of this pool, and it was determined that the trap efficiency is negligible. However, localized sand deposits are possible and field data that were collected suggested that such deposits have occurred.

Excessive sediment load in a river can be reduced by preventive and remedial measures. Preventive measures are preferable over remedial measures. Six preventive measures that have been identified are: 1) Best Management Practices on the watershed, 2) proper repair and maintenance of drainage ditches and levees, 3) minimal disturbance of the banks, 4) avoidance of structural disturbance of the river, 5) reduction of sediment excesses arising from construction activities, and 6) artificial and natural means for preventing erosion.

Three remedial measures have been identified: 1) construction of detention reservoirs, sedimentation ponds, or settling basins; 2) development of side channel flood retention basins, and 3) removal of deposited sediment by dredging. No comparison has been made between any of these measures. However, it appears that the preventive measures should be given first consideration.

All the basic data that were collected are included in the appendices to this report.

REFERENCES

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

Bagnold, R. A. 1966. *An approach to the sediment transport problem from general physics.* U.S. Geological Survey Professional Paper 422-J.

Barekyan, A. S. 1962. *Discharge of channel forming sediments and elements of sand waves.* Soviet Hydrology, American Geophysical Union, No. 2.

Barfield, B. J., and D. T. Y. Kao. 1975. *Analysis of the sediment filtering action of grassed media.* Research Report 90, University of Kentucky, Water Resources Research Institute, Lexington, Kentucky, United States Department of the Interior.

Barnes, H. H., Jr. 1967. *Roughness characteristics of natural channels.* U.S. Geological Survey, Water Supply Paper 1849, U.S. Government Printing Office, Washington, D.C.

Becker, B. C, M. A. Nawrocki, and G. M. Sitek. 1974. *An executive summary of three EPA demonstration programs in erosion and sediment control.* EPA - 660/2-74-073. Prepared for Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C.

Bhowmik, N. G. 1968. *The mechanics of flow and stability of alluvial channels formed in coarse materials.* Ph.D. dissertation, Colorado State University, Fort Collins, 207 p.

Bhowmik, N. G. 1976. *Development of criteria for shore protection against wind-generated waves for lakes and ponds in Illinois.* University of Illinois Water Resources Center, Urbana, Research Report 107.

Bhowmik, N. G. 1979. *Hydraulics of flow in the Kaskaskia River, Illinois.* Illinois State Water Survey, Report of Investigation 91.

Bishop, A. A., D. B. Simons, and E. V. Richardson. 1965. *Total bed-material transport.* Proceedings ASCE, Journal of the Hydraulics Division, v. 91 (HY2).

Brooks, N. H. 1963. *Calculation of suspended load discharge from velocity concentration parameters.* Proceedings Federal Interagency Sedimentation Conference, U.S. Department of Agriculture, Miscellaneous Publication 970.

Brown, C. B. 1950. *Sediment transportation. In* Engineering Hydraulics, H. Rouse, Ed., John Wiley and Sons, Inc., New York, pp. 789-792.

Brune, G. M. 1953. *Trap efficiency of reservoirs.* Transactions American Geophysical Union, v. 34:407-418.

Buchanan, T. J., and W. P. Somers. 1969. *Discharge measurement at gaging stations.* U.S. Geological Survey, Book 3, U.S. Government Printing Office, Washington, D.C., Chapter A8.

Byerly, D. W., J. B. Maddox, C. S. Fletcher, and D. T. Eagle. 1978. *Reclamation of mined land in the Piney Creek Watershed — an interim report. In* Surface Mining and Fish/Wildlife Needs in the Eastern United States - Proceedings of a Symposium. U.S. Government Printing Office, Washington, D.C.

Chang, F. M., D. B. Simons, and E. V. Richardson. 1967. *Total bed-material discharge in alluvial channels.* Proceedings of the 12th Congress of the IAHR, Fort Collins, Colorado.

Chang, Y. 1939. *Laboratory investigation of flume tractive and transportation.* Transactions ASCE, v. 104.

Chien, N. 1954. *The present status of research on sediment transport.* Proceedings ASCE, v. 80(565).

Chow, V. T. 1959. *Open-channel hydraulics.* McGraw-Hill Book Company, Inc., New York.

Colby, B. R. 1957. *Relationship of unmeasured sediment discbarge to mean velocity.* Transactions American Geophysical Union, v. 38(5).

Colby, B. R., and C. H. Hembree. 1955. *Computation of total sediment discbarge, Niobrara River near Cody, Nebraska.* U.S. Geological Survey, Water Supply Paper 1357.

Curtis, W. R. 1971a. *Strip-mining, erosion and sedimentation.* Transactions American Society of Agricultural Engineers (ASAE): v. 14(3):434-436.

Curtis, W. R. 1971b. *Terraces reduce runoff and erosion on surface-mine benches.* Journal of Soil and Water Conservation, v. 26(5).

Curtis, W. R. 1971c. *Vegetating strip-mine spoils for runoff and erosion control.* Proceedings Revegetation and Economic Use of Surface-Mined Land and Mine Reuse Symposium, Pipestem State Park, West Virginia, December 2-4.

Curtis, W. R. 1974. *Sediment yield from strip-mined watersheds in Eastern Kentucky.* Second Research and Applied Technology Symposium on Mined-Land Reclamation, National Coal Association, Louisville, Kentucky, October 22-24.

Division of Waterways. 1954. *Report on Illinois-Indiana interstate drainage, Yellowbead-Singleton Ditch system, June 1, 1954.* Illinois Department of Public Works and Buildings, prepared by authority of House Joint Resolution 50, 68th General Assembly.

Division of Waterways. 1967. *Kankakee River Basin Study.* Illinois Department of Public Works and Buildings, prepared by authority of House Bill 2227, 74th General Assembly.

Einstein, H. A. 1942. *Formulas for the transportation of bed load.* Transactions ASCE, v. 107.

Einstein, H. A. 1950. *The bed-load function for sediment transportation in open channel flows.* U.S. Department of Agriculture, Soil Conservation Service, Technical Bulletin 1026.

Einstein, H. A., and F. M. Abdel-Aal. 1972. *Einstein bed-load function at high sediment rates.* Proceedings ASCE, Journal of the Hydraulics Division, v. 98(HY1).

Einstein, H. A., and N. Chien. 1954. *Second approximation to the solution of the suspended-load theory.* University of California, Institute of Engineering Research, No. 3.

Forchheimer, P. 1914. *Hydraulik.* 1st ed. (2d ed., 1924, and 3d ed., 1930), Teubner, Leipzig-Berlin.

Gessler, J. 1971. *Beginning and ceasing of sediment motion. In* River Mechanics, H. W. Shen, Ed., Fort Collins, Colorado, v. 1, Chapter 7.

Gilbert, K. G. 1914. *The transportation of debris by running water.* U.S. Geological Survey, Professional Paper 433-B.

Graf, W. H. 1971. *Hydraulics of sediment transport.* McGraw-Hill Book Company, Inc., New York.

Grass, A. J. 1970. *Initial instability of fine bed sand.* Proceedings ASCE, Journal of the Hydraulics Division, v. 96(HY3):619-632.

Gross, D. L., and R. C. Berg. 1980. *Geology of the Kankakee River System in Kankakee County, IL.* Illinois State Geological Survey, Environmental Geology Notes 92.

Guy, H. P., and V. W. Norman. 1970. *Field methods for measurement of fluvial sediment.* U.S. Government Printing Office, Washington, D.C.

Healy, R. W. 1979. *River mileages and drainage areas for Illinois streams — volume 2, Illinois River Basin.* U.S. Geological Survey, Water Resources Investigations 79-111.

Helley, E. J., and W. Smith. 1971. *Development and calibration of a pressure-difference bed load sampler.* U.S. Geological Survey, Water Resources Division.

Houde, Mary Jean, and John Klasey. 1968. *Of the people, a popular history of Kankakee County.* The General Printing Company, Chicago, Illinois.

Hubbell, D. W. 1964. *Apparatus and techniques for measuring bedload.* U.S. Geological Survey, Water Supply Paper 1748, U.S. Government Printing Office, Washington, D.C.

Illinois Environmental Protection Agency. 1979. *Water quality management plan.* Volume III, Non-point Sources of Pollution, Grant No. P005311-01.

Indiana Department of Natural Resources. 1976. *Kankakee River Basin, Indiana.* In cooperation with the U.S. Department of Agriculture and the U.S. Department of Interior.

Jobson, H. E., and W. W. Sayre. 1970. *Vertical transfer in open channel flows.* Proceedings ASCE, Journal of the Hydraulics Division, v. 96(HY3).

Kalinske, A. A. 1947. *Movement of sediment as bed-load in rivers.* Transactions American Geophysical Union, v. 28(4).

Kankakee Company, The. 1871. *Prospectus of the Kankakee Company.* W. F. Brown and Company, Boston, Massachusetts.

Kankakee River Basin Task Force. 1978. *Final report to the Governor.* State of Illinois, Springfield, Illinois.

Kerr, J. R., and I. J. Schlosser. 1977. *Impact of nearstream vegetation and stream morphology on water quality and stream biota.* EPA - 600/3-77-097, Contract 68-01-3584.

Lane, E. W. 1955. *Design of stable channels.* Transactions ASCE, v. 120:1234-1260.

Lane, E. W., and A. A. Kalinske. 1939. *The relation of suspended to bed material in rivers.* Transactions American Geophysical Union, Part 4, pp. 637-641.

Lane, E. W., and A. A. Kalinske. 1941. *Engineering calculations of suspended sediment.* Transactions American Geophysical Union, v. 20.

Laursen, E. M. 1958. *The total sediment load of streams.* Proceedings ASCE, Journal of the Hydraulics Division, v. 84(HY1).

Lee, Ming T. 1979. *Inflow hydrology of Horseshoe Lake.* Contract Report prepared for Illinois Department of Conservation, Illinois State Water Survey.

Linsley, R. K., M. A. Kohler, and J. L. H. Paulhus. 1958. *Hydrology for engineers.* McGraw-Hill Publishing Co., 1st ed.

MacDougall, C. H. 1934. *Bed sediment transport in open channels.* Transactions American Geophysical Union.

Mahoney, Mike. 1978. *The Kankakee. In* Illinois Times, October 27-November 2, 1978, Illinois Times, Inc., Springfield, Illinois.

Maryland Department of Water Resources, B. C. Becker, and T. R. Mills. 1972. *Guidelines for erosion and sediment control planning and implementation.* Prepared for U.S. Environmental Protection Agency, EPA - R2-72-015.

Meyer, Alfred H. 1936. *The Kankakee "Marsh" of Northern Indiana and Illinois.* Papers of the Michigan Academy of Science, Arts and Letters, v. XXI.

Morrison, Elizabeth B. 1976. *Memories of Momence Township.* Project of the Kankakee Bicentennial Commission.

O'Brien, M. P. 193 3. *Review of the theory of turbulent flow and its relation to sediment transport.* Transactions American Geophysical Union.

O'Brien, M. P., and B. D. Rindlaub. 1934. *The transportation of bed load by streams.* Transactions American Geophysical Union.

Paddock, Daniel. 1883. *Atlas of Kankakee County, Illinois.* J. H. Beers and Company, Chicago, Illinois.

Reed, Earl H. 1920. *Tales of a vanishing river.* John Lane Company, New York, New York.

Rouse, H. 1937. *Modern concepts of the mechanics of turbulence.* Transactions ASCE, v. 102.

Schoklitsch, A. 1914. *Uber schleppkraft und geschiebebewegung.* Engelmann, Leipzig.

Searcy, J. K. 1959. *Flow duration curves.* U.S. Geological Survey, Water Supply Paper 1542-A, U.S. Government Printing Office, Washington, D.C.

Shen, H. W., and C. S. Hung. 1971. *An engineering approach to total bed material load by regression analysis.* Proceedings Sedimentation Symposium, Berkeley, California, June 17-19. Available fron P. O. Box 606, Fort Collins, Colorado 80521.

Shulits, S., and R. D. Hill. 1968. *Bed load formulas, part A — a selection of bed load formulas.* Pennsylvania State University, College of Engineering, University Park, Pennsylvania.

Simons, D. B., and E. V. Richardson. 1971. *Flow in alluvial sand channels. In* River Mechanics, H. W. Shen, Ed., Fort Collins, Colorado, v. 1, Chapter 9.

Simons, D. B., and F. Senturk. 1977. *Sediment transport technology.* Water Resources Publications, Fort Collins, Colorado.

Toffaleti, F. B. 1969. *Definitive computations of sand discharge in rivers.* Proceedings ASCE, Journal of the Hydraulics Division, v. 95(HY1).

U.S. Army Corps of Engineers. 1941. *Review report of the Kankakee River, Illinois and Indiana, for flood control.* Chicago District, July 1941.

U. S. Army Corps of Engineers. 1968. *Missouri River channel regime studies.* MRD Sediment Series 13 A, Omaha, Nebraska.

U. S. Army Corps of Engineers. 1979. *Kankakee River, Indiana, levee study.* Chicago District, December 1979.

U.S. Department of Agriculture. 1909. *A report upon the drainage of agricultural lands in the Kankakee River Valley, Indiana.* Office of Experiment Stations, Circular 80, Government Printing Office, Washington, D.C.

U.S. Geological Survey. 1977. *Water resources data for Indiana.* Water-Data Report In-77-1, Indianapolis, Indiana.

U.S. House of Representatives. 1879. *Kankakee River, letter from the Secretary of War.* 45th Congress, 3rd Session, Executive Document 73.

U.S. House of Representatives. 1916. *Kankakee River, Illinois and Indiana, letter from the Secretary of War.* 64th Congress, 1st Session, Document 931.

U.S. House of Representatives. 1931. *Kankakee River, Illinois and Indiana, letter from the Secretary of War.* 71st Congress, 3rd Session, Document 784.

U.S. Senate. 1880. *Survey of Kankakee River, in Indiana and Illinois, letter from the Secretary of War.* 46th Congress, 2nd Session, Executive Document 107.

U.S. Waterways Experiment Station. 1935. *Studies of river bed materials and their movement with special references to the lower Mississippi River.* Paper 17, USWES, Vicksburg, Mississippi.

U.S. Waterways Experiment Station. 1978. *Drainage and erosion-control structures for airfields and heliports.* TM5-820-3.

Vanoni, V., and G. Nomicos. 1960. *Resistance properties of sediment-laden streams.* Transactions ASCE, 125/I.

Vogel, W. G., and W. R. Curtis. 1978. *Reclamation research on coal surface-mined lands in the humid east.* Forest Service, USDA, Northeastern Forest Experiment Station, Berea, Kentucky.

Ward, A. D. 1979. *Model studies aid pond design.* Water and Wastes Engineering v. 16(5):36-40.

Ward, A. D., B. J. Barfield, and J. S. Tapp. 1979. *Sizing surface mine sediment control reservoirs for theoretical detention time.* Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, University of Kentucky, Lexington, Kentucky, December 4-7.

Ward, A. D., and C. T. Haan. 1978. *Evaluation of stripmine sediment detention basins in Kentucky.* Presented at the 1978 Winter Meeting, American Society of Agricultural Engineers, December.

Ward, A. D., C. T. Haan, and B. J. Barfield. 1977a. *Simulation of the sedimentology of sediment detention basins.* Research Report 103, University of Kentucky Water Resources Research Institute, Lexington, Kentucky.

Ward, A. D., C. T. Haan, and B. J. Barfield. 1977b. *The performance of sediment detention structures.* Agricultural Engineering Department, University of Kentucky, Lexington, Kentucky.

Ward, A. D., C. T. Haan, and B. J. Barfield. 1978. *The design of sediment basins.* University of Kentucky, Lexington, Kentucky.

Ward, A. D., D. L. Rausch, C. T. Haan, and H. G. Heinemann. 1979. *A verification study on a sediment basin model.* Presented at the 1979 Summer Meeting of ASAE and the Canadian Society of Agricultural Engineers (CSAE), June.

NOTATIONS

A_*B_*	=	Experimental constants
a	=	Thickness of bed layer or level above bed
a, b	=	Coefficients of Q_p regression line
a_1, b_1	=	Coefficients of Q_A regression line
$\underline{C}$	=	Concentration of sediment
$\overline{C}$	=	Average concentration
C_a	=	Concentration of sediment with fall velocity ω
C_L	=	Lift coefficient (dimensionless)
$\overline{C}_S$	=	Mean suspended sediment concentration
C_1	=	Chezy's roughness coefficient
C_μ	=	Coefficient of friction (du Boys)
D	=	Depth of water
D_A	=	Drainage area
d'	=	Sediment thickness
d_f	=	Fall diameter of the bed material
d_s	=	Representative size of bed particle
d_{35}, d_{50}, d_{65}, d_{95}	=	Equivalent particle diameters for which 35, 50, 65, and 95 percent, respectively, of particles are finer in diameter
F	=	Froude number = $V/(gD)^{1/2}$
F_D	=	Drag force
F_L	=	Lift force
F_R	=	Bed resistance force
F_W	=	Submerged weight of particle
f	=	Friction factor (Darcy-Weisbach)
fct	=	A general functional relationship
f_{ss}	=	Seepage force on the bed of the river
g	=	Gravitational constant
i_b	=	Fraction of bed sediment in a given grain size
i_s	=	Fraction of bed load in a given grain size
k	=	Empirical exponent used in bed load equation (equation 17)
k_1, k_2, k_3	=	Shape factors ($k_1 = k_2 = \pi/4$, $k_3 = \pi/6$ for spheres)
m	=	Number of sediment layers in du Boys' analysis
m, n	=	Coefficients used in the general regression equation (equation 37)
m_1	=	Empirical exponent used in bed load equation (equation 14)
n	=	Manning's roughness coefficient
P_L	=	Ratio of $\overline{C}$ to C near the bed
p	=	Probability of a particle eroding
Q_A	=	Average annual flow
$\overline{Q}_A$	=	Mean of average annual flows
Q_b	=	Computed bed load
Q_p	=	Peak flow in cfs
$\overline{Q}_p$	=	Average of peak flows
Q_s	=	Suspended sediment load
Q_w	=	Water discharge
$\overline{Q}_W$	=	Average flow for period of record
q	=	Water discharge per unit width

q_b	=	Bed load discharge per unit width
q_c	=	Water discharge at which material begins to move
q_s	=	Suspended load per unit width of channel
$\mathcal{R}$	=	Reynolds number
R	=	Hydraulic radius
R'_h	=	Hydraulic radius with respect to grains
S	=	River gradient
S_c	=	Shape factor of the cross section
S_e	=	Slope of energy grade line
S_p	=	Shape factor of the particles
S_R	=	Shape factor of the river reach
T	=	Time in years
U	=	Uniformity coefficient in particle size distribution
V	=	Velocity of water
$\overline{V}$	=	Average flow velocity
$\overline{V}_c$	=	Average critical velocity
V_s	=	Velocity increment between sediment layers
V_*	=	Shear velocity
W_T	=	Top width of river
y	=	Depth of water from the bed
z_1	=	Parameter defined in equation 25
β	=	Coefficient relating sediment diffusion coefficient to momentum diffusion coefficient
γ_s	=	Unit weight of sediment
γ_w	=	Unit weight of water
ΔA	=	Change in river cross-sectional area
ΔW_T	=	Change in top width of river
ϵ_m	=	Momentum diffusion coefficient
ϵ_s	=	Sediment diffusion coefficient
θ	=	Angle bed makes with horizontal
κ	=	von Karman constant
λ	=	Empirical constant used in Einstein's bed load function (equation 19)
μ	=	Dynamic viscosity of water-sediment mixture
ν	=	Kinematic viscosity of water
ρ	=	Density of water
ρ_f	=	Density of water-sediment mixture
ρ_s	=	Density of sediment
σ	=	Standard deviation of the particle sizes
τ_c	=	Critical shear stress
τ_o	=	Average shear stress
ϕ	=	Angle of repose
Φ	=	Einstein's intensity of bed load transport parameter
Φ_*	=	Einstein's intensity of bed load transport parameter for an individual grain size
χ, χ', χ''	=	Characteristic sediment coefficients
ψ	=	Einstein's flow intensity parameter (empirical)
ψ_*	=	Einstein's flow intensity parameter (analytical)
ω	=	Fall velocity of the bed materials

Appendix A. Particle Size Characteristics of the Bed Material from the Kankakee River

River mile	d_{35}, *mm*	d_{50}, *mm*	d_{65}, *mm*	d_{95}, *mm*	σ	*U*	*Percent silt & clay (<0.062 mm)*	*Remarks*
110.3	0.22	0.31	0.41	6.5	2.53	3.96	6	GRAVEL to SILT
110.3	0.12	0.13	0.15	0.28	1.48	1.84	5	Coarse SAND to SILT
110.3	0.30	0.34	0.38	0.52	1.39	1.71	-	Medium to fine SAND
109.3	0.10	0.13	0.18	0.60	-	-	10	Coarse SAND to SILT
109.3	0.27	0.32	0.37	0.78	1.52	1.89	-	Coarse to fine SAND
109.3	0.22	0.32	0.54	7.1	5.83	3.38	-	Coarse GRAVEL to fine SAND
107.7	0.10	0.14	0.15	0.80	1.98	-	<5	Coarse SAND to SILT
107.7	0.25	0.28	0.33	0.60	1.43	1.72	-	Coarse to fine SAND
107.7	0.31	0.40	0.53	10.0	4.80	2.94	<4	GRAVEL to fine SAND
106.7	0.26	0.33	0.40	-	1.98	3.92	<6	Very coarse to very fine SAND
106.7	0.29	0.33	0.37	0.59	1.34	1.64	-	Coarse to fine SAND
106.7	0.14	0.15	0.16	0.46	1.48	1.69	<5	Coarse to fine SAND
105.6	0.30	0.55	2.5	-	-	10.00	-	Coarse GRAVEL to fine SAND
105.6	0.29	0.33	0.37	0.90	1.42	1.59	-	Coarse to fine SAND
105.6	0.074	0.11	0.14	0.80	-	-	<30	Coarse SAND to SILT
104.4	0.18	0.23	0.30	1.5	2.02	3.11	<7	Very coarse to very fine SAND
104.4	0.35	0.45	0.63	2.3	2.34	2.39	-	GRAVEL to fine SAND
104.4	0.083	0.11	0.15	0.86	-	-	<25	Coarse SAND to SILT
103.1	0.089	0.13	0.18	0.82	-	-	<20	Coarse SAND to SILT
103.1	0.33	0.37	0.43	0.98	1.45	1.74	-	Coarse to fine SAND
103.1	0.24	0.29	0.34	1.5	1.72	2.62	4	Very coarse to very fine SAND

Appendix A. Continued

River mile	d_{35}, *mm*	d_{50}, *mm*	d_{65}, *mm*	d_{95}, *mm*	σ	*U*	*Percent silt & clay (<0.062 mm)*	*Remarks*
101.2	0.15	0.20	0.27	1.0	1.96	2.79	<5	Coarse SAND to SILT
101.2	0.28	0.33	0.38	0.58	1.40	1.71	-	Coarse to fine SAND
101.2	0.10	0.13	0.14	0.34	1.62	-	<13	Coarse SAND to SILT
100.0	0.20	0.24	0.30	0.60	1.82	3.15	7	Coarse SAND to SILT
100.0	0.31	0.35	0.38	1.0	1.43	1.54	-	Coarse to fine SAND
100.0	0.19	0.24	0.30	0.80	1.90	3.33	8	Coarse SAND to SILT
98.9	0.27	0.21	0.24	0.58	1.45	1.65	-	Coarse to fine SAND
98.8	0.33	0.42	0.65	-	-	3.53	2	Coarse GRAVEL to very fine SAND
98.8	0.31	0.38	0.43	-	1.54	1.83	-	Coarse to fine SAND
98.8	0.15	0.18	0.19	0.39	1.43	2.11	<4	Coarse SAND to SILT
97.4	0.28	0.37	0.76	-	9.54	3.13	<1	GRAVEL to fine SAND
97.4	0.33	0.36	0.38	0.80	1.32	1.48	-	Coarse to fine SAND
97.4	0.15	0.24	0.26	-	2.29	3.21	<6	Coarse to very fine SAND
96.2	0.34	0.46	2.0	-	-	4.38	-	GRAVEL to fine SAND
96.2	0.38	0.44	0.50	-	1.53	1.71	-	Very coarse to medium SAND
96.2	0.12	0.13	0.15	0.78	1.61	1.92	9	Coarse SAND to SILT
95.1	0.13	0.15	0.20	0.60	2.10	2.43	8	Coarse SAND to SILT
95.1	0.29	0.33	0.41	1.1	1.63	1.81	-	Coarse to fine SAND
95.1	0.24	0.33	0.40	0.70	1.81	3.08	4	Coarse to very fine SAND
93.6	0.13	0.15	0.17	0.54	1.70	-	10	Coarse SAND to SILT
93.6	0.26	0.31	0.34	0.70	1.85	3.00	-	Coarse to fine SAND
93.6	0.25	0.40	0.70	-	7.68	4.42	3	Coarse GRAVEL to very fine SAND

Appendix A. Continued

River mile	d_{35}, mm	d_{50}, mm	d_{65}, mm	d_{95}, mm	σ	U	Percent silt & clay (<0.062 mm)	Remarks
92.7	0.14	0.26	0.51	-	-	-	20	Very coarse SAND to SILT
92.7	0.29	0.34	0.39	0.94	1.49	1.74	-	Coarse to fine SAND
92.7	0.26	0.70	4.1	-	-	1.85	3	Coarse GRAVEL to very fine SAND
90.9	0.40	0.74	1.6	-	7.04	11.82	5	Coarse GRAVEL to very fine SAND
90.9	0.25	0.31	0.35	1.0	1.50	1.94	-	Coarse to fine SAND
90.9	0.13	0.16	0.21	0.67	-	-	15	Coarse SAND to SILT
89.0	0.15	0.21	0.24	0.53	1.88	2.64	-	Coarse to very fine SAND
89.0	-	-	-	-	-	-	-	Coarse GRAVEL to fine SAND
89.0	0.16	0.21	0.26	0.53	1.91	3.13	8	Coarse SAND to SILT
86.6	0.23	0.31	0.40	-	1.90	3.00	<3	Coarse to very fine SAND
86.6	0.35	0.46	0.79	6.5	4.40	2.73	-	GRAVEL to fine SAND
86.6	0.24	0.31	0.40	0.81	1.89	2.77	2	Coarse to fine SAND
85.4	0.20	0.23	0.26	0.47	1.56	1.92	3	Medium to very fine SAND
85.4	0.31	0.35	0.40	1.0	1.54	1.73	-	Coarse to fine SAND
85.4	0.14	0.16	0.21	0.87	1.82	2.00	5	Coarse to very fine SAND
84.5	0.31	0.34	0.41	0.57	1.22	1.74	-	Medium to fine SAND
84.5	0.31	0.35	0.40	0.80	1.44	1.65	1	Coarse to fine SAND
84.5	0.33	0.38	0.43	0.73	1.46	1.75	-	Coarse to fine SAND
84.3	0.24	0.33	0.44	-	2.70	3.08	2	Coarse GRAVEL to very fine SAND
84.3	0.28	0.33	0.40	4.6	1.58	0.17	-	Medium GRAVEL to fine SAND
84.3	0.13	0.14	0.17	0.71	1.73	2.03	8	Coarse SAND to SILT
82.7	0.18	0.22	0.24	0.50	1.51	1.77	2	Coarse to very fine SAND
82.7	0.32	0.35	0.41	1.0	1.48	1.60	-	Coarse to medium SAND
82.7	0.20	0.24	0.32	0.67	1.82	2.73	3	Coarse to very fine SAND

Appendix A. Continued

River mile	d_{35}, mm	d_{50}, mm	d_{65}, mm	d_{95}, mm	σ	U	Percent silt & clay (<0.062 mm)	Remarks
81.5	0.25	0.32	0.43	6.2	4.01	2.86	2	Medium GRAVEL to very fine SAND
81.5	0.31	0.34	0.38	0.85	1.40	1.57	-	Coarse to fine SAND
81.5	0.17	0.23	0.31	0.70	1.84	2.55	3	Coarse to very fine SAND
81.4	0.32	0.37	0.46	1.1	1.60	2.10	1	Coarse to fine SAND
81.4	0.26	0.31	0.38	1.0	1.94	2.92	5	Very coarse to very fine SAND
79.8	0.18	0.23	0.28	0.74	1.69	2.36	4	Coarse to very fine SAND
79.8	0.33	0.40	0.51	2.1	1.92	1.88	-	GRAVEL to fine SAND
79.8	0.26	0.35	0.46	4.4	2.89	3.07	2	GRAVEL to fine SAND
78.6	0.14	0.20	0.26	0.72	2.12	3.12	5	Coarse to very fine SAND
78.6	0.32	0.35	0.40	0.90	1.94	2.92	-	Coarse to fine SAND
78.6	0.25	0.30	0.35	0.61	1.48	2.20	2	Coarse to fine SAND
77.6	0.16	0.20	0.25	0.54	1.72	2.18	2	Coarse to very fine SAND
77.6	0.38	0.44	0.52	-	1.81	2.08	-	GRAVEL to medium SAND
76.0	0.21	0.35	0.50	-	5.54	4.09	1	GRAVEL to fine SAND
76.0	0.30	0.34	0.41	1.1	1.53	1.70	-	Coarse to fine SAND
74.4	0.22	0.26	0.33	0.55	1.69	2.14	3	Coarse to very fine SAND
74.4	0.30	0.33	0.40	-	1.63	1.68	-	Coarse to fine SAND
74.4	0.16	0.17	0.19	0.31	1.33	1.64	3	Medium to very fine SAND
72.6	0.11	0.13	0.16	0.60	-	-	17	Coarse SAND to SILT
72.6	0.31	0.35	0.41	1.1	1.57	1.50	-	Very coarse to fine SAND
72.6	0.11	0.14	0.16	0.51	-	-	19	Coarse SAND to SILT
70.9	0.19	0.24	0.30	0.74	1.79	2.55	3	Coarse to very fine SAND
70.9	0.35	0.40	0.45	1.0	1.39	1.72	-	Coarse to medium SAND
70.9	0.13	0.16	0.20	0.62	1.93	2.77	8	Coarse SAND to SILT

River mile	d_{35}, mm	d_{50}, mm	d_{65}, mm	d_{95}, mm	σ	U	Percent silt & clay (<0.062 mm)	Remarks
70.2	0.16	0.21	0.26	0.54	1.93	3.13	7	Coarse SAND to SILT
70.2	0.33	0.36	0.44	1.2	1.62	1.71	-	Very coarse to fine SAND
70.2	0.14	0.16	0.18	0.38	1.55	2.00	5	Medium to very fine SAND
68.7	0.21	0.28	0.36	2.8	1.96	2.69	3	GRAVEL to very fine SAND
68.7	0.38	0.44	0.53	1.4	1.76	1.79	-	Very coarse to medium SAND
68.7	0.11	0.14	0.16	0.35	1.66	-	10	Medium SAND to SILT
67.3	0.15	0.17	0.19	0.41	1.51	1.98	3	Medium to very fine SAND
67.3	0.33	0.40	0.50	-	2.25	2.88	1	GRAVEL to fine SAND
67.3	0.17	0.21	0.27	0.51	1.66	2.27	3	Medium to very fine SAND
65.3	0.21	0.27	0.32	0.67	2.04	3.88	7	Coarse SAND to SILT
65.3	0.25	0.27	0.34	-	2.11	1.55	-	GRAVEL to fine SAND
65.3	0.15	0.17	0.19	0.40	1.42	1.64	1	Medium to fine SAND
65.1	0.26	0.31	0.36	0.70	1.56	2.19	2	Coarse to fine SAND
64.1	0.18	0.20	0.21	0.34	1.27	1.54	2	Medium to fine SAND
63.3	0.16	0.16	0.18	0.26	1.23	1.55	-	Medium to very fine SAND
63.3	0.34	0.38	0.43	0.80	1.37	1.56	-	Coarse to medium SAND
63.3	0.20	0.34	0.40	0.55	1.93	3.25	1	Medium to fine SAND
62.6	0.092	0.11	0.14	0.90	-	-	27	Coarse SAND to SILT
62.6	0.31	0.34	0.38	0.53	1.34	1.61	-	Coarse to fine SAND
62.6	0.14	0.18	0.23	0.63	1.96	2.50	6	Coarse SAND to SILT
61.6	0.30	0.32	0.34	0.51	1.29	1.50	-	Coarse to fine SAND
61.6	0.20	0.25	0.31	0.90	1.75	2.42	4	Coarse to very fine SAND

River mile	d_{35}, mm	d_{50}, mm	d_{65}, mm	d_{95}, mm	σ	U	Percent silt & clay (<0.062 mm)	Remarks
61.1	0.24	0.31	0.38	0.90	1.84	2.69	4	Coarse to very fine SAND
61.1	0.31	0.34	0.36	0.46	1.23	1.40	-	Medium to fine SAND
61.1	0.14	0.16	0.18	0.40	1.48	1.79	5	Medium SAND to SILT
59.6	0.16	0.21	0.29	0.62	2.07	-	10	Coarse SAND to SILT
59.6	0.25	0.30	0.34	0.56	1.40	1.65	-	Coarse to fine SAND
59.6	0.21	0.25	0.30	0.55	1.60	2.15	4	Coarse to very fine SAND
58.2	0.14	0.15	0.17	0.24	1.38	1.84	3	Fine to very fine SAND
58.2	0.32	0.35	0.38	0.63	2.38	1.37	-	Coarse to medium SAND
58.2	0.20	0.23	0.27	0.46	1.48	1.86	-	Medium to fine SAND
57.6	0.20	0.25	0.31	0.57	1.69	2.31	2	Coarse to fine SAND
57.6	0.33	0.35	0.40	0.63	1.27	1.44	-	Coarse to medium SAND
57.6	0.20	0.25	0.31	0.50	1.61	2.50	2	Coarse to very fine SAND
57.4	0.21	0.24	0.29	0.70	1.61	2.08	2	Coarse to very fine SAND
57.4	0.31	0.34	0.37	0.50	1.29	1.50	-	Medium to fine SAND
57.4	0.25	0.30	0.36	-	1.63	2.19	-	Coarse to fine SAND
57.3	0.21	0.24	0.29	0.55	1.54	2.00	3	Coarse to very fine SAND
57.3	0.28	0.31	0.35	0.54	1.28	1.62	-	Coarse to fine SAND
57.3	0.25	0.31	0.36	1.1	1.90	3.18	6	GRAVEL to SILT
57.3	0.30	0.31	0.33	0.50	1.18	1.23	-	Coarse to fine SAND
57.3	0.30	0.32	0.36	0.60	1.30	1.46	-	Coarse to fine SAND
57.3	0.25	0.28	0.31	0.43	1.33	1.67	-	Medium to fine SAND
57.1	0.22	0.26	0.30	0.45	1.38	1.81	-	Coarse to very fine SAND

Appendix A. Continued

River mile	d_{35}, mm	d_{50}, mm	d_{65}, mm	d_{95}, mm	σ	U	Percent silt & clay (<0.062 mm)	Remarks
56.5	0.17	0.18	0.21	0.30	1.31	1.43	-	Coarse to very fine SAND
56.5	0.30	0.31	0.33	0.45	1.15	1.14	-	Coarse to fine SAND
56.5	0.15	0.16	0.17	0.24	1.17	1.42	1	Coarse to very fine SAND
55.5	0.15	0.16	0.18	0.25	1.29	1.70	2	Medium to very fine SAND
55.5	0.32	0.33	0.36	0.57	1.21	1.36	-	Coarse to fine SAND
55.5	0.16	0.18	0.20	0.24	1.28	1.58	2	Medium to very fine SAND
55.1	0.22	0.27	0.30	0.50	1.45	1.61	-	Coarse to fine SAND
54.8	0.30	0.33	0.35	0.73	1.28	1.31	-	Coarse to fine SAND
54.7	0.32	0.34	0.39	0.47	1.24	1.48	-	Coarse to fine SAND
53.8	0.31	0.34	0.37	0.51	1.28	1.64	-	Coarse to fine SAND
53.8	0.26	0.30	0.35	0.74	1.42	1.62	-	Coarse to fine SAND
53.8	0.30	0.33	0.35	0.45	1.22	1.36	-	Medium to fine SAND
53.2	0.37	0.30	0.34	0.47	1.32	3.00	-	Coarse to fine SAND
52.2	0.31	0.33	0.36	0.62	1.24	2.06	-	Coarse to fine SAND
51.5	0.22	0.25	0.28	0.49	1.41	1.69	-	Medium to fine SAND
50.9	0.27	0.32	0.38	3.0	1.52	1.90	-	Medium GRAVEL to very fine SAND
50.9	0.20	0.31	0.41	1.0	2.16	4.22	<7	Coarse SAND to SILT
50.8	0.35	0.45	0.70	-	4.27	3.00	1	Coarse GRAVEL to very fine SAND
50.8	0.31	0.37	0.43	0.90	1.67	2.56	4	Coarse to very fine SAND
50.8	0.22	0.28	0.40	5.0	2.97	2.27	2	Medium GRAVEL to very fine SAND
50.8	0.28	0.31	0.34	0.50	1.35	1.83	3	Medium to very fine SAND
50.8	0.31	0.35	0.41	0.90	1.59	2.17	4	Coarse to very fine SAND
50.8	0.23	0.29	0.34	0.78	1.65	2.29	-	Coarse to fine SAND

Appendix A. Continued

River mile	d_{35}, mm	d_{50}, mm	d_{65}, mm	d_{95}, mm	σ	U	Percent silt & clay (<0.062 mm)	Remarks
49.6	0.30	0.32	0.34	0.52	1.28	1.45	-	Coarse to very fine SAND
48.0	0.28	0.33	0.39	0.64	1.54	1.95	-	Coarse to fine SAND
46.4	0.22	0.26	0.39	-	-	2.06	<1	GRAVEL to very fine SAND
45.8	0.21	0.23	0.25	0.32	1.26	1.60	-	Coarse to fine SAND
44.6	0.36	0.43	0.51	-	4.32	2.33	2	Coarse GRAVEL to very fine SAND
44.2	0.28	0.30	0.32	0.60	1.23	1.29	-	Coarse to fine SAND
42.9	0.27	0.30	0.34	0.48	1.26	1.45	<1	Coarse to very fine SAND
41.6	0.22	0.30	0.39	0.90	-	-	<18	Coarse SAND to SILT
40.3	0.35	0.42	0.47	-	6.13	1.88	-	Coarse GRAVEL to fine SAND
40.3	0.27	0.30	0.33	0.74	1.34	1.45	<2	Coarse to very fine SAND
40.3	0.43	0.53	3.3	-	-	6.00	<2	GRAVEL to very fine SAND
38.5	0.31	0.32	0.34	0.60	1.27	1.94	6	Coarse SAND to SILT
38.5	0.27	0.39	0.46	-	2.05	3.14	<2	Coarse to very fine SAND
38.5	0.20	0.28	0.41	-	4.36	-	9	GRAVEL to SILT
37.1	0.35	0.42	0.48	1.5	1.78	2.88	-	GRAVEL to fine SAND
37.1	0.25	0.27	0.29	0.48	1.29	1.47	<4	Coarse to very fine SAND
37.1	0.29	0.35	0.42	1.0	2.00	4.21	7	Coarse SAND to SILT
23.5	1.5	2.8	6.2	-	-	11.11	-	GRAVEL to fine SAND
2.1	0.70	1.4	2.3	-	5.18	14.29	6	Coarse GRAVEL to SILT
2.1	0.23	0.28	0.34	0.56	1.56	2.46	6	Coarse SAND to SILT
2.1	0.35	0.44	0.51	-	2.05	4.90	7	Very coarse SAND to SILT
2.1	0.21	0.30	0.43	-	-	-	15	Very coarse SAND to SILT
2.1	0.30	0.43	0.50	-	3.44	-	12	Very coarse SAND to SILT
2.1	0.095	0.13	0.20	-	-	-	24	Very coarse SAND to SILT

Appendix A. Concluded

River mile	d_{35}, mm	d_{50}, mm	d_{65}, mm	d_{95}, mm	σ	U	Percent silt & clay (<0.062 mm)	Remarks
1.9	0.18	0.35	0.49	1.0	-	-	18	Very coarse SAND to SILT
1.8	0.31	0.37	0.43	-	1.69	3.73	7	Very coarse SAND to SILT
1.8	0.15	0.31	0.43	-	-	-	22	Very coarse SAND to SILT
1.7	0.15	0.31	0.44	0.98	-	-	22	Coarse SAND to SILT

Appendix B. Particle Size Characteristics of the Bed Material from the Six Mile Pool

River mile	d_{35}, *mm*	d_{50}, *mm*	d_{65}, *mm*	d_{95}, *mm*	σ	*U*	*Percent silt & clay (<0.062 mm)*	*Remarks*
36.8	0.18	0.30	0.39	-	2.36	-	11	Very coarse SAND to SILT
36.8	0.11	0.23	0.32	0.93	-	-	25	Coarse SAND to SILT
36.5	0.34	0.38	0.42	0.80	1.44	1.64	2	Coarse to fine SAND
36.5	0.33	0.35	0.40	0.67	1.30	1.50	5	Coarse to very fine SAND
36.5	0.22	0.26	0.31	0.46	1.50	2.23	6	Coarse SAND to SILT
36.5	-	0.10	0.16	1.0	-	-	<39	Coarse SAND to SILT
36.3	0.36	0.43	0.46	0.84	1.37	3.00	3	Coarse to very fine SAND
36.3	0.23	0.26	0.29	0.40	1.34	1.65	4	Medium to very fine SAND
36.3	0.13	0.15	0.17	0.75	1.49	1.98	4	Coarse to very fine SAND
36.2	0.38	0.47	0.63	-	-	5.89	6	GRAVEL to SILT
36.2	0.31	0.35	0.40	0.58	1.39	1.95	4	Coarse to very fine SAND
36.2	0.22	0.25	0.27	0.48	1.34	1.44	2	Medium to fine SAND
35.9	0.32	0.35	0.41	-	1.58	1.43	2	Very coarse to fine SAND
35.9	0.31	0.36	0.41	0.71	1.44	1.90	2	Coarse to very fine SAND
35.9	0.26	0.29	0.61	0.70	1.81	6.00	3	Coarse to very fine SAND
35.8	0.16	0.21	0.26	4.0	-	-	17	GRAVEL to SILT
35.8	0.27	0.31	0.35	0.60	1.38	1.89	5	Coarse SAND to SILT
35.6	0.30	0.34	0.40	0.90	1.46	3.80	6	Coarse SAND to SILT
35.6	0.30	0.34	0.38	0.57	1.36	1.76	4	Coarse to very fine SAND
35.4	0.35	0.54	1.9	6.8	5.82	6.67	2	Medium GRAVEL to very fine SAND
35.4	0.25	0.29	0.33	0.50	1.38	1.82	3	Medium to very fine SAND
35.4	0.23	0.25	0.28	0.41	1.89	1.59	-	Coarse to fine SAND

Appendix B. Concluded

River mile	d_{35}, mm	d_{50}, mm	d_{65}, mm	d_{95}, mm	σ	U	Percent silt & clay (<0.062 mm)	Remarks
34.9	0.21	0.24	0.26	0.84	-	-	18	Coarse SAND to SILT
34.9	0.21	0.22	0.23	0.40	1.33	2.30	9	Coarse SAND to SILT
34.9	0.34	0.50	1.9	-	-	8.46	6	GRAVEL to SILT
34.5	0.090	0.13	0.16	1.0	-	-	28	Very coarse SAND to SILT
34.5	0.22	0.31	0.41	-	3.08	-	12	GRAVEL to SILT
34.5	-	-	-	-	-	-	7	GRAVEL to SILT
34.3	0.082	0.13	0.21	1.1	-	-	33	Very coarse SAND to SILT
34.3	0.29	0.34	0.40	0.80	1.63	2.71	<6	Coarse SAND to SILT
34.3	0.26	0.40	0.81	-	-	6.78	6	GRAVEL to SILT
34.1	0.095	0.11	0.13	0.90	-	-	24	Coarse SAND to SILT
34.1	0.10	0.18	0.32	-	-	-	<29	Very coarse SAND to SILT
34.1	0.11	0.15	0.21	1.0	-	-	16	Coarse SAND to SILT
33.7	0.14	0.20	0.23	0.84	1.96	3.14	8	Coarse SAND to SILT
33.7	0.17	0.21	0.25	-	2.34	-	<15	Very coarse SAND to SILT
33.7	0.098	0.13	0.17	0.90	-	-	<23	Coarse SAND to SILT
33.4	0.11	0.21	0.37	1.1	-	-	20	Very coarse SAND to SILT
33.4	0.12	0.20	0.22	1.0	-	-	<28	Coarse SAND to SILT
33.4	0.22	0.42	0.93	-	8.81	8.44	9	Coarse GRAVEL to SILT
33.0	0.25	0.37	0.46	-	2.55	-	<12	Very coarse SAND to SILT
33.0	0.19	0.24	0.35	-	5.26	3.33	7	Coarse GRAVEL to SILT
32.8	0.15	0.22	0.33	-	2.63	-	<16	Coarse SAND to SILT
32.8	0.22	0.28	0.36	-	1.91	2.54	<5	Coarse SAND to SILT
32.8	0.70	1.50	3.0	-	-	10.91	<1	Medium GRAVEL to fine SAND

Appendix C-I. Particle Size Characteristics of the Core Samples
in the Six Mile Pool

River mile	*Depth of core (ft)*	d_{35}, *mm*	d_{50}, *mm*	d_{65}, *mm*	d_{95}, *mm*	σ	*U*	*Percent silt & clay (<0.062 mm)*	*Remarks*
35.3	0-0.5	0.23	0.25	0.27	0.40	1.17	1.30	-	Coarse to fine SAND
35.3	0.6-1.0	0.25	0.25	0.27	0.45	1.14	1.24	-	Coarse to fine SAND
35.3	1.1-1.5	0.24	0.25	0.27	0.40	1.21	1.30	-	Coarse to fine SAND
35.3	1.6-1.9	0.23	0.25	0.26	0.43	1.13	1.30	-	Coarse to fine SAND

Appendix C-II. Particle Size Characteristics of the Bed Material from the State Line Sand Bar

River mile	*Date*	*Distance from left bank* (ft)*	*Depth of core (ft)*	d_{35}, *mm*	d_{50}, *mm*	d_{65}, *mm*	d_{95}, *mm*	σ	*U*	*Percent silt & clay (<0.062 mm)*	*Remarks*
						Core Samples					
57.21	7/23/79	40	0.0-0.4	0.30	0.32	0.34	0.56	1.25	1.50	-	Coarse to fine SAND
57.21	7/23/79	40	0.5-0.9	0.25	0.27	0.30	0.44	1.27	1.45	-	Coarse to fine SAND
57.21	7/23/79	80	0.0-0.4	0.29	0.33	0.35	0.71	1.37	1.55	-	Coarse to fine SAND
57.21	7/23/79	80	0.5-0.8	0.24	0.27	0.30	0.42	1.30	1.61	-	Medium to fine SAND
57.21	7/23/79	80	0.9-1.1	0.23	0.25	0.28	0.40	1.31	1.42	-	Medium to fine SAND
57.21	7/23/79	80	1.2-1.5	0.24	0.27	0.29	0.43	1.29	1.56	-	Medium to fine SAND
57.21	7/23/79	80	1.6-1.7	0.24	0.26	0.28	0.40	1.27	1.59	-	Medium to fine SAND
57.21	7/23/79	130	0.0-0.5	0.28	0.31	0.34	0.48	1.27	1.50	-	Coarse to very fine SAND
57.21	7/23/79	130	0.6-1.0	0.27	0.30	0.32	0.40	1.21	1.41	-	Medium to fine SAND
57.21	7/23/79	130	1.1-1.5	0.25	0.28	0.31	0.43	1.33	1.50	-	Medium to fine SAND
57.21	7/23/79	130	1.6-2.0	0.29	0.32	0.35	0.52	1.34	1.55	-	Coarse to fine SAND
						Bed Material Samples					
57.21	7/23/79	40	-	0.30	0.31	0.33	0.44	1.12	1.19	-	Coarse to fine SAND
57.21	7/23/79	80	-	0.22	0.24	0.27	0.40	1.32	1.44	-	Coarse to fine SAND
57.21	7/23/79	80	-	0.29	0.31	0.33	0.40	1.10	1.19	-	Medium SAND
57.21	7/23/79	130	-	0.31	0.32	0.34	0.50	1.13	1.22	-	Coarse to medium SAND
57.20	8/15/79	25	-	0.16	0.19	0.22	0.41	1.48	2.56	8	Medium SAND to SILT
57.20	8/15/79	35	-	-	0.11	0.20	-	-	-	35	Coarse SAND to SILT
57.20	8/15/79	45	-	-	0.10	0.23	0.70	-	-	37	Coarse SAND to SILT

Appendix C-II. Continued

River mile	*Date*	*Distance from left bank* (ft)*	*Depth of core (ft)*	d_{35}, mm	d_{50}, mm	d_{65}, mm	d_{95}, mm	σ	*U*	*Percent silt & clay (<0.062 mm)*	*Remarks*
57.20	8/15/79	55	-	0.21	0.24	0.27	0.44	1.57	3.21	8	Coarse SAND to SILT
57.20	8/15/79	65	-	0.23	0.25	0.28	0.43	1.32	1.80	4	Coarse to very fine SAND
57.20	8/15/79	75	-	0.27	0.32	0.37	0.50	1.45	1.94	-	Coarse to fine SAND
57.20	8/15/79	85	-	0.27	0.29	0.31	0.40	1.17	1.43	-	Medium to fine SAND
57.20	8/15/79	95	-	0.27	0.29	0.30	0.40	1.17	1.43	-	Medium to fine SAND
57.20	8/15/79	105	-	0.22	0.25	0.29	0.42	1.93	1.42	-	Medium to fine SAND
57.20	8/15/79	115	-	0.29	0.31	0.32	0.48	1.14	1.24	-	Medium to fine SAND
57.20	8/15/79	125	-	0.28	0.31	0.35	0.51	1.30	1.48	-	Medium to fine SAND
57.20	8/15/79	135	-	0.28	0.31	0.33	0.45	1.16	1.33	-	Medium to fine SAND
57.20	8/15/79	145	-	0.27	0.30	0.34	0.48	1.29	1.57	-	Medium to fine SAND
57.20	8/15/79	155	-	0.26	0.27	0.29	0.41	1.18	2.80	-	Medium to fine SAND
57.20	8/15/79	165	-	0.24	0.26	0.30	0.72	1.41	1.81	1	Coarse to very fine SAND
57.20	8/15/79	170	-	0.28	0.31	0.34	0.45	1.27	1.43	-	Medium to fine SAND
57.20	8/15/79	180	-	0.30	0.33	0.38	5.0	1.61	3.60	-	Medium GRAVEL to fine SAND
57.20	8/15/79	190	-	0.21	0.24	0.28	0.44	1.41	1.69	-	Medium to fine SAND
57.26	8/15/79	125	-	0.30	0.34	0.39	0.59	1.34	1.68	-	Course to fine SAND
57.26	8/16/79	20	-	0.24	0.26	0.31	0.45	1.31	1.58	-	Coarse to fine SAND
57.26	8/16/79	30	-	0.28	0.30	0.32	0.48	1.18	1.29	-	Coarse to fine SAND
57.26	8/16/79	40	-	0.31	0.33	0.35	0.50	1.22	1.36	-	Coarse to fine SAND
57.26	8/16/79	60	-	0.30	0.33	0.36	0.50	1.23	1.40	-	Coarse to fine SAND
57.26	8/16/79	80	-	0.28	0.32	0.35	0.50	1.28	1.42	-	Coarse to fine SAND
57.26	8/16/79	100	-	0.26	0.29	0.32	0.41	1.21	1.35	-	Coarse to fine SAND
57.26	8/16/79	120	-	0.30	0.34	0.40	0.64	1.40	1.63	-	Coarse to fine SAND

Appendix C-II. Continued

River mile	*Date*	*Distance from left bank* (ft)*	*Depth of core (ft)*	d_{35}, *mm*	d_{50}, *mm*	d_{65}, *mm*	d_{95}, *mm*	σ	*U*	*Percent silt & clay (<0.062 mm)*	*Remarks*
57.26	8/16/79	140	-	0.31	0.32	0.35	0.64	1.21	1.36	-	Coarse to fine SAND
57.26	8/16/79	160	-	0.31	0.33	0.35	0.54	1.24	1.42	-	Coarse to fine SAND
57.26	8/16/79	180	-	0.31	0.34	0.36	0.48	1.23	1.40	-	Coarse to fine SAND
57.26	8/16/79	200	-	0.30	0.32	0.35	0.50	1.29	1.62	-	Coarse to very fine SAND
57.26	8/16/79	220	-	0.090	0.15	0.27	-	-	-	24	Very coarse SAND to SILT
57.26	8/16/79	230	-	0.16	0.21	0.30	1.0	2.57	-	10	Very coarse SAND to SILT
57.30	8/15/79	90	-	0.27	0.30	0.32	0.48	1.23	1.35	-	Coarse to fine SAND
57.30	8/16/79	10	-	0.31	0.34	0.38	0.54	1.28	1.54	-	Coarse to fine SAND
57.30	8/16/79	20	-	0.31	0.33	0.35	0.51	1.25	1.42	-	Coarse to fine SAND
57.30	8/16/79	40	-	0.28	0.31	0.34	0.51	1.27	1.50	-	Coarse to fine SAND
57.30	8/16/79	60	-	0.30	0.31	0.34	0.50	1.19	1.27	-	Coarse to fine SAND
57.30	8/16/79	80	-	0.30	0.31	0.34	0.52	1.27	1.38	-	Coarse to fine SAND
57.30	8/16/79	100	-	0.30	0.32	0.35	0.49	1.28	1.42	-	Coarse to fine SAND
57.30	8/16/79	120	-	0.34	0.39	0.40	0.56	1.27	1.67	-	Coarse to fine SAND
57.30	8/16/79	130	-	0.12	0.13	0.16	0.35	1.44	1.52	3	Medium to very fine SAND
57.40	8/15/19	90	-	0.31	0.33	0.36	0.54	1.55	2.06	-	Coarse to medium SAND
57.40	8/16/79	10	-	0.26	0.30	0.32	0.48	1.37	1.94	1	Coarse to very fine SAND
57.40	8/16/79	20	-	0.27	0.31	0.34	0.51	1.37	1.65	-	Coarse to fine SAND
57.40	8/16/79	30	-	0.31	0.32	0.34	0.60	1.17	1.22	-	Coarse to medium SAND
57.40	8/16/79	50	-	0.33	0.39	0.43	0.60	1.42	1.75	-	Coarse to fine SAND
57.40	8/16/79	70	-	0.31	0.33	0.36	0.60	1.33	1.52	-	Coarse to fine SAND
57.40	8/16/79	90	-	0.31	0.32	0.34	0.47	1.19	1.32	-	Coarse to medium SAND

Appendix C-II. Concluded

River mile	Date	Distance from left bank* (ft)	Depth of core (ft)	d_{35}, mm	d_{50}, mm	d_{65}, mm	d_{95}, mm	σ	U	Percent silt & clay (<0.062 mm)	Remarks
57.40	8/16/79	110	-	0.33	0.37	0.41	0.55	1.28	1.60	-	Coarse to medium SAND
57.40	8/16/79	120	-	0.29	0.31	0.33	0.50	1.30	1.60	-	Coarse to fine SAND
57.40	8/16/79	130	-	0.15	0.25	0.70	-	-	-	8	Coarse GRAVEL to SILT
57.60	8/15/79	90	-	0.31	0.32	0.34	0.48	1.13	1.18	-	Coarse to medium SAND
57.18	11/7/79	30	-	0.27	0.30	0.31	0.40	1.16	1.41	-	Medium to fine SAND
57.18	11/7/79	60	-	0.30	0.35	0.41	0.57	1.44	1.82	-	Coarse to fine SAND
57.18	11/7/79	90	-	0.28	0.30	0.32	0.41	1.11	1.19	-	Medium SAND
57.18	11/7/79	120	-	0.27	0.32	0.37	0.54	1.46	1.67	-	Coarse to fine SAND
57.18	11/7/79	150	-	0.32	0.34	0.36	0.70	1.23	1.21	-	Coarse to medium SAND
57.20	11/7/79	90	-	0.30	0.33	0.35	0.49	1.27	1.42	-	Coarse to fine SAND
57.26	11/7/79	125	-	0.23	0.26	0.30	0.50	1.39	1.47	-	Coarse to fine SAND
57.30	11/7/79	90	-	0.30	0.32	0.35	0.55	1.28	1.42	-	Coarse to fine SAND
57.40	11/7/79	90	-	0.28	0.30	0.31	0.44	1.18	1.35	-	Coarse to fine SAND
57.60	11/7/79	90	-	0.30	0.31	0.32	0.44	1.10	1.19	-	Medium SAND

*When looking downstream

Appendix C-III. Particle Size Characteristics of the Bed Material-Kankakee River

Sand Bars

River mile	Sand bar number	d_{35}, mm	d_{50}, mm	d_{65}, mm	d_{95}, mm	σ	U	Percent silt & clay (<0.062 mm)	Remarks
51.5	2	0.24	0.28	0.33	0.49	1.43	1.72	-	Medium to fine SAND
51.5	2	0.22	0.24	0.27	0.40	1.30	1.44	-	Coarse to fine SAND
45.8	3	0.26	0.27	0.29	0.39	1.14	1.22	-	Coarse to fine SAND
45.8	3	0.25	0.29	0.32	0.44	1.30	1.48	-	Coarse to fine SAND
45.8	3	0.25	0.27	0.29	0.47	1.24	1.40	-	Coarse to fine SAND
45.2	4	0.30	0.34	0.40	0.70	1.37	1.65	-	Coarse to fine SAND
44.7	5	0.38	0.44	0.49	-	1.46	1.81	-	Coarse to fine SAND
44.2	6	0.31	0.35	0.38	0.73	1.32	1.54	-	Coarse to fine SAND
44.2	6	0.29	0.31	0.34	0.74	1.37	1.57	-	Coarse to fine SAND

Appendix D. Particle Size Characteristics of the Bank Material from the Kankakee River in Indiana

River mile	d_{35}, *mm*	d_{50}, *mm*	d_{65}, *mm*	d_{95}, *mm*	σ	*U*	*Percent silt & clay (<0.062 mm)*	*Remarks*
79.8	0.26	0.33	0.40	1.0	1.88	3.08	4	Coarse to very fine SAND
78.6	0.13	0.14	0.15	0.26	1.38	1.81	4	Medium to very fine SAND
78.6	0.23	0.27	0.33	0.61	1.62	2.46	3	Coarse to very fine SAND
72.6	0.13	0.15	0.17	0.41	1.57	2.13	7	Medium SAND to SILT
72.6	0.16	0.24	0.31	0.64	2.63	-	14	Coarse SAND to SILT
72.6	0.091	0.13	0.17	0.54	-	-	15	Coarse SAND to SILT
70.2	0.24	0.31	0.35	0.67	1.85	3.40	6	Coarse to very fine SAND
70.2	0.26	0.31	0.35	0.77	1.65	2.62	4	Coarse to very fine SAND
67.3	0.23	0.30	0.40	0.80	1.90	2.57	3	Coarse to very fine SAND
67.3	0.23	0.28	0.33	0.60	1.18	3.87	5	Coarse to very fine SAND

Appendix E. Particle Size Characteristics of the Bed Material at State Line Bridge and Illinoi

River mile	*Date*	*Distance from left bank* (ft)*	d_{35}, *mm*	d_{50}, *mm*	d_{65}, *mm*	d_{95}, *mm*	σ	*U*	*Percent silt & clay (<0.062 mm)*	*Remarks*
					Kankakee River at State Line Bridge					
57.2	11/3/78	30	0.14	0.18	0.22	6.5	9.92	2.04	<5	Coarse gravel to SILT
57.2	11/3/78	60	0.29	0.31	0.33	0.53	1.15	1.17	-	Coarse to medium SAND
57.2	11/3/78	90	0.31	0.32	0.35	0.56	1.51	2.00	-	Coarse to medium SAND
57.2	11/3/78	120	0.31	0.33	0.35	0.54	1.18	1.21	-	Coarse to medium SAND
57.2	11/3/78	150	0.24	0.28	0.31	0.49	1.30	1.50	-	Coarse to fine SAND
57.2	11/3/78	180	0.29	0.32	0.34	0.57	1.27	1.32	-	Coarse to medium SAND
57.2	11/3/78	210	0.20	0.23	0.26	0.49	1.51	1.85	-	Coarse to very fine SAND
57.2	3/13/79	75	0.29	0.34	0.39	0.59	1.37	1.61	-	Coarse to fine SAND
57.2	3/13/79	175	0.31	0.33	0.35	0.60	1.24	1.26	-	Coarse to medium SAND
57.2	5/4/79	50	0.31	0.34	0.38	0.54	1.30	1.61	-	Coarse to fine SAND
57.2	5/4/79	100	0.29	0.31	0.33	0.52	1.19	1.28	-	Coarse to fine SAND
57.2	5/4/79	150	0.31	0.32	0.34	0.47	1.12	1.27	-	Coarse to medium SAND
57.2	6/1/79	100	0.23	0.25	0.29	0.47	1.33	1.65	-	Coarse to fine SAND
57.2	9/26/79	80	0.28	0.31	0.34	0.45	1.30	1.57	-	Medium to fine SAND
57.2	9/26/79	120	0.31	0.34	0.40	0.55	1.74	0.95	-	Coarse to fine SAND
57.2	9/26/79	160	0.28	0.30	0.31	0.50	1.53	2.07	-	Medium SAND
57.2	9/26/79	165	0.26	0.29	0.33	0.50	1.34	1.48	-	Medium to fine SAND
57.2	9/26/79	170	0.24	0.27	0.31	0.50	1.40	1.58	-	Medium to fine SAND
57.2	9/26/79	180	0.25	0.29	0.33	0.50	1.45	1.55	-	Coarse to fine SAND

Appendix E. Concluded

River mile	*Date*	*Distance from left bank* (ft)*	d_{35}, *mm*	d_{50}, *mm*	d_{65}, *mm*	d_{95}, *mm*	σ	*U*	*Percent silt & clay (<0.062 mm)*	*Remarks*
Singleton Ditch at Illinoi										
5.6	3/6/79	25	0.15	0.16	0.18	0.21	1.29	1.55	1	Fine to very fine SAND
5.6	3/13/79	20	0.22	0.28	0.35	-	1.80	2.46	4	Very coarse SAND to SILT
5.6	3/13/79	30	0.32	0.39	0.42	0.63	1.46	2.05	-	Coarse to fine SAND
5.6	3/13/79	35	0.26	0.31	0.34	0.80	1.54	2.54	5	Coarse SAND to SILT
5.6	3/13/79	50	0.27	0.35	0.47	-	-	3.23	5	Very coarse SAND to SILT

*When looking downstream

Appendix F. Particle Size Characteristics of the Bed Material from the Iroquois River

River mile	d_{35}, *mm*	d_{50}, *mm*	d_{65}, *mm*	d_{95}, *mm*	σ	*U*	*Percent silt & clay (<0.062 mm)*	*Remarks*
0.0	0.24	0.26	0.38	-	2.18	1.60	3	Very coarse to very fine SAND
0.0	0.18	0.23	0.27	1.0	2.20	3.71	9	Coarse SAND to SILT
0.1	0.20	0.22	0.25	0.67	1.53	2.00	6	Coarse SAND to SILT
				Iroquois River near Chebanse				
6.5	0.48	0.67	1.1	6.3	2.65	2.97	-	GRAVEL to fine SAND
6.5	1.2	1.9	2.8	-	4.22	8.33	-	GRAVEL to fine SAND
6.5	0.52	0.80	1.5	-	4.58	4.00	-	GRAVEL to very fine SAND
6.5	0.50	0.66	1.0	5.3	2.77	3.46	2	Coarse GRAVEL to very fine SAND
6.5	0.81	1.3	2.1	-	3.30	6.43	1	Coarse GRAVEL to very fine SAND
6.5	1.3	2.3	3.7	-	-	7.80	-	Coarse GRAVEL to fine SAND
6.5	0.97	1.6	2.7	-	-	9.17	2	GRAVEL to fine SAND
6.5	1.5	2.3	3.8	-	-	6.52	-	GRAVEL to very fine SAND
6.5	0.85	1.4	2.4	-	-	5.76	-	GRAVEL to very fine SAND
				Iroquois River at Iroquois				
50.4	0.21	0.47	1.4	-	7.99	-	15	Coarse GRAVEL to SILT
50.4	4.0	-	-	-	-	-	2	Coarse GRAVEL to very fine SAND
50.4	2.2	4.3	-	-	-	22.69	1	Coarse GRAVEL to very fine SAND
50.4	0.16	0.19	0.27	-	2.97	2.88	7	Very coarse SAND to SILT
50.4	1.2	2.8	5.7	-	-	45.00	9	Coarse GRAVEL to SILT

Appendix F. Concluded

River mile	d_{35}, *mm*	d_{50}, *mm*	d_{65}, *mm*	d_{95}, *mm*	σ	*U*	*Percent silt & clay (<0.062 mm)*	*Remarks*
50.4	1.4	3.3	6.0	-	-	22.73	1	Coarse GRAVEL to very fine SAND
50.4	0.13	0.14	0.16	6.0	4.32	1.92	6	Coarse GRAVEL to SILT
50.4	0.30	0.48	0.92	-	5.85	4.80	2	Coarse GRAVEL to very fine SAND

Appendix G. Particle Size Characteristics of the Bed Load

River mile	Date	Distance from left bank* (ft)	d_{35}, mm	d_{50}, mm	d_{65}, mm	d_{95}, mm	σ	U	Percent silt & clay (<0.062 mm)	Remarks
Kankakee River at State Line Bridge										
57.2	3/31/79	50	0.30	0.32	0.32	0.37	1.09	1.18	-	SAND
57.2	3/31/79	50	0.30	0.31	0.32	0.38	1.10	1.19	-	SAND
57.2	4/2/79	50	0.29	0.30	0.31	0.37	1.07	1.15	-	SAND
57.2	4/3/79	50	0.30	0.32	0.32	0.38	1.12	1.14	-	SAND
57.2	4/5/79	75	0.33	0.34	0.37	0.57	1.16	1.29	-	SAND
57.2	4/12/79	75	0.30	0.32	0.34	0.50	1.15	1.18	-	SAND
57.2	4/16/79	50	0.31	0.33	0.35	0.34	1.16	1.21	-	SAND
57.2	4/20/79	100	0.32	0.33	0.35	0.65	1.13	1.17	-	SAND
57.2	4/21/79	50	0.30	0.31	0.32	0.37	1.07	1.14	-	SAND
57.2	4/29/79	50	0.30	0.32	0.33	0.39	1.10	1.18	-	SAND
57.2	4/29/79	100	0.30	0.31	0.32	0.48	1.06	1.07	-	SAND
57.2	5/1/79	50	0.30	0.31	0.32	0.40	1.08	1.14	-	SAND
57.2	5/1/79	100	0.31	0.32	0.32	0.60	1.16	1.14	-	SAND
57.2	5/4/79	100	0.30	0.31	0.32	0.55	1.13	1.11	-	SAND
57.2	5/4/79	125	0.37	0.40	0.43	0.60	1.22	1.45	-	SAND
57.2	5/4/79	175	0.36	0.38	0.40	0.70	1.21	1.25	-	SAND
57.2	5/7/79	125	0.36	0.39	0.42	0.73	1.25	1.37	-	SAND
57.2	5/10/79	50	0.30	0.32	0.34	0.43	1.16	1.27	-	SAND
57.2	5/23/79	125	0.31	0.32	0.33	0.60	1.13	1.10	-	SAND
57.2	9/14/79	100	0.32	0.33	0.34	0.60	1.18	1.17	-	SAND
Iroquois River near Chebanse										
6.5	3/31/79	120	0.38	0.40	0.45	1.30	1.29	1.23	-	SAND

*When looking downstream

Appendix H. Kankakee River at State Line Bridge

Date	Time of day (hr)	$\overline{C_s}$ (ppm)	$\overline{V}$ (fps)	$\overline{D}$ (ft)	W_T (ft)	A (ft^2)	Q_w (cfs)	Q_s (tons/day)	Air Temp. (°C)	Water Temp. (°C)	G.H. above msl (ft)
11/3/78	1312	18	1.39	2.36	194	457.6	634.7	30.8	23.5	11.5	624.35
11/17/78	1133	42	1.41	2.34	196	459.5	649.9	74.0	8.0	6.5	624.44
12/5/78	1030	21	1.44	3.30	203	670.3	966.2	56.1	3.0	1.0	625.52
12/13/78	1357	8	1.44	3.25	201	653.2	939.6	21.3	3.0	0.5	625.51
12/18/78	1308	35	1.52	3.25	201	653.4	990.4	94.4	3.0	1.5	625.44
3/6/79	0915	67	NR	NR	NR	NR	NR	NR	NR	0.0	629.51
3/6/79	1811	71	NR	NR	NR	NR	4368.0	837.4	8.0	1.0	629.40
3/7/79	0825	81	NR	NR	NR	NR	NR	NR	2.0	0.5	629.42
3/7/79	1550	93	NR	NR	NR	NR	NR	NR	4.5	0.0	629.44
3/8/79	0844	63	NR	NR	NR	NR	NR	NR	-1.0	-1.0	629.63
3/8/79	1400	97	NR	NR	NR	NR	NR	NR	2.0	0.0	629.70
3/8/79	1648	119	NR	NR	NR	NR	NR	NR	NR	1.0	629.70
3/9/79	0728	78	2.35	8.48	219	1856.7	4368.9	926.0	-1.0	-0.5	629.41
3/9/79	1145	113	NR	NR	NR	NR	4300.0	1314.2	0.0	0.0	629.37
3/9/79	1535	66	2.36	7.92	219	1734.3	4093.9	538.3	0.0	0.0	629.32
3/10/79	0856	49	NR	NR	NR	NR	NR	NR	-9.0	-1.0	629.24
3/13/79	1109	48	2.11	8.42	219	1843.4	3882.1	510.5	6.0	1.0	629.04
3/13/79	1647	56	NR	NR	NR	NR	4236.0	640.5	9.5	2.0	629.01
3/14/79	0926	34	2.18	8.39	219	1837.8	4013.9	372.8	-3.0	0.0	629.00
3/14/79	1730	56	NR	NR	NR	NR	4014.0	613.4	-4.0	0.0	629.00
3/15/79	1023	36	2.20	8.26	219	1808.0	3974.4	388.5	-6.5	0.0	628.99
3/15/79	1717	29	NR	NR	NR	NR	3820.0	306.3	3.0	0.0	628.98
3/16/79	0906	31	2.10	8.21	219	1798.2	3776.9	324.3	NR	NR	628.99
3/19/79	1222	21	2.37	8.43	219	1845.5	4367.2	254.7	16.0	8.5	629.02
3/26/79	1215	22	2.15	8.07	219	1767.1	3797.2	232.7	-1.0	3.0	628.75
3/29/79	1021	18	2.10	8.01	219	1755.0	3685.0	188.0	11.5	6.5	628.63
3/30/79	1614	30	2.19	7.89	219	1727.2	3782.8	310.5	16.0	10.0	628.69
3/31/79	1005	36	2.23	8.00	219	1752.2	3904.2	386.9	4.5	8.0	628.73
3/31/79	1702	31	NR	NR	NR	NR	3797.0	322.9	4.0	9.0	628.74
4/1/79	0933	37	NR	NR	NR	NR	3797.0	379.3	5.0	8.0	628.75
4/1/79	1533	32	2.21	8.11	219	1776.8	3930.7	343.9	6.0	8.0	628.74
4/2/79	0905	33	2.06	8.10	219	1774.7	3662.9	331.3	4.0	7.0	628.74
4/2/79	1642	30	NR	NR	NR	NR	3797.0	313.7	3.0	7.0	628.75
4/3/79	0900	30	2.01	8.08	219	1769.1	3556.1	288.0	3.0	6.0	628.76
4/3/79	1715	22	NR	NR	NR	NR	3738.0	224.1	8.0	8.5	628.76
4/4/79	1014	26	2.23	8.13	219	1781.5	3968.6	280.7	3.0	6.0	628.77
4/4/79	1548	31	NR	NR	NR	NR	3968.0	338.6	5.5	7.0	628.77
4/5/79	0924	21	2.17	8.15	219	1784.0	3869.8	226.7	7.5	7.0	628.78
4/5/79	1650	24	NR	NR	NR	NR	3797.0	246.0	11.0	8.0	628.75
4/6/79	0955	22	2.16	8.08	219	1769.9	3826.3	234.5	-3.0	4.0	628.73
4/10/79	1208	18	2.12	8.22	219	1799.8	3823.0	192.0	7.0	5.0	628.66
4/12/79	1312	25	2.16	8.18	219	1792.5	3864.2	262.9	24.0	10.0	628.70
4/12/79	1719	33	NR	NR	NR	NR	3890.0	350.8	17.0	10.0	628.71
4/13/79	1012	42	2.16	8.29	219	1814.5	3920.8	447.8	11.0	10.0	628.76
4/13/79	1527	18	NR	NR	NR	NR	3920.0	200.0	13.0	11.0	628.76
4/16/79	1141	22	2.15	8.26	219	1809.7	3895.5	234.6	14.0	10.0	628.72
4/16/79	1647	20	NR	NR	NR	NR	3895.0	216.6	12.0	11.5	628.72

NR = Not Recorded, G.H. = Gage Height

Appendix H. Concluded

Date	Time of day (hr)	$\overline{C_s}$ (ppm)	$\overline{V}$ (fps)	$\tilde{D}$ (ft)	W_T (ft)	A (ft^2)	Q_w (cfs)	Q_s (tons/day)	Air Temp (°C)	Water Temp. (°C)	G.H. above msl (ft)
4/17/79	1037	20	2.08	8.15	219	1785.3	3722.0	204.0	14.0	10.0	628.70
4/17/79	1541	29	NR	NR	NR	NR	3722.0	291.4	16.0	12.0	628.70
4/20/79	1215	101	2.07	8.99	219	1775.9	3786.4	1032.6	14.0	12.0	628.59
4/23/79	1230	98	1.86	8.70	219	1714.0	3276.0	866.8	24.0	14.0	628.42
4/26/79	1150	10	1.96	8.61	219	1701.5	3450.4	93.2	10.5	14.0	628.45
4/27/79	1018	21	2.04	8.80	219	1738.4	3724.8	211.2	10.0	12.0	628.54
4/27/79	1150	25	NR	NR	NR	NR	3724.0	251.4	10.0	12.0	628.54
4/27/79	1543	16	NR	NR	NR	NR	3795.0	163.9	8.0	11.5	628.58
4/28/79	1015	11	2.13	8.83	219	1743.4	3801.0	112.9	6.0	10.0	628.64
4/29/79	1140	7	2.18	8.88	219	1753.4	3935.2	74.4	7.5	9.0	628.68
4/30/79	0951	9	2.08	8.81	219	1740.6	3711.0	90.2	7.0	8.0	628.68
4/30/79	1614	5	NR	NR	NR	NR	3711.0	50.1	8.0	8.5	628.68
5/1/79	1355	12	2.15	8.80	219	1738.4	3835.5	124.3	13.5	10.0	628.66
5/4/79	1255	16	2.42	8.91	219	1761.2	4334.6	187.2	13.0	12.0	628.70
5/7/79	1330	9	2.19	8.94	219	1766.5	3963.7	96.3	28.0	16.0	628.64
5/10/79	1355	7	1.98	8.73	219	1724.3	3501.8	66.2	31.0	21.0	628.49
5/15/79	1050	18	1.69	8.46	219	1672.4	2949.3	143.3	17.0	15.0	628.21
5/23/79	1335	29	1.31	7.70	219	1521.7	2090.1	163.6	18.0	16.0	627.67
6/1/79	1345	55	1.10	7.24	219	1421.5	1714.5	254.6	23.0	18.0	627.07
6/7/79	1225	77	1.15	6.81	219	1347.2	1472.4	306.1	22.0	21.0	626.70
6/19/79	1345	52	1.13	5.96	207	1233.8	1388.5	195.0	24.0	21.0	626.32
6/26/79	1250	61	1.08	5.55	206	1143.9	1232.7	203.0	27.0	20.0	625.84
7/3/79	1310	76	1.05	5.63	205	1153.9	1220.2	250.4	26.0	23.0	625.80
7/9/79	1320	52	0.92	5.03	205	1031.4	951.8	133.6	26.0	22.0	625.13
7/16/79	1140	32	0.87	4.72	205	967.3	837.8	72.4	27.0	25.0	624.81
7/23/79	1240	26	0.84	4.31	208	897.5	749.4	52.6	30.0	23.5	624.40
7/30/79	1310	33	0.90	4.63	210	972.3	874.2	77.9	28.0	25.0	624.79
8/6/79	1235	41	1.08	4.99	207	1033.9	1116.6	123.6	29.0	24.0	625.35
8/13/79	1150	74	1.08	5.20	208	1080.7	1168.7	233.5	23.0	21.0	625.60
8/23/79	1043	50	1.26	5.87	207	1215.7	1528.4	206.3	22.0	21.0	626.44
8/27/79	1335	60	1.17	5.29	208	1099.4	1286.4	222.3	24.0	21.0	625.78
9/4/79	1215	45	1.33	4.09	207	846.0	1128.7	137.1	24.0	22.0	625.35
9/14/79	1335	28	1.59	2.73	204	556.0	882.2	66.7	19.0	20.0	624.72
9/24/79	1505	18	1.64	2.12	202	427.8	699.6	34.0	22.0	16.0	624.36

NR= Not Recorded, G.H.= Gage Height

Appendix I. Singleton Ditch at Illinoi

Date	Time of day (hr)	$\overline{C_s}$ (ppm)	$\overline{V}$ (fps)	$\overline{D}$ (ft)	W_T (ft)	A (ft^2)	Q_w (cfs)	Q_s (tons/day)	Air temp (°C)	Water temp (°C)	G.H. above msl (ft)	S_w (ft/mile)
11/3/78	1100	71	0.23	2.46	46	113.0	33.7	6.5	19.5	11.5	NR	NR
11/17/78	1445	113	0.32	2.37	47	111.6	35.9	11.0	NR	NR	620.08	0.88
12/5/78	1455	47	0.54	2.50	48	120.2	64.6	8.2	3.5	1.0	619.51	0.86
3/6/79	1138	125	2.93	8.75	72	629.7	1846.0	622.0	4.5	0.5	629.61	NR
3/6/79	1750	202	NR	NR	NR	NR	2003.0	1095.1	9.0	1.0	629.78	NR
3/7/79	0858	206	3.14	9.20	72	662.1	2079.3	1159.3	2.0	1.0	629.36	NR
3/7/79	1618	126	3.34	8.30	72	597.5	1997.2	680.5	4.5	0.0	628.62	0.83
3/8/79	0914	129	3.15	7.50	72	540.0	1698.8	592.6	-1.0	-0.5	627.45	1.05
3/8/79	1433	113	3.07	7.23	72	520.4	1596.0	486.1	2.0	1.0	627.28	NR
3/9/79	0910	144	3.62	7.51	72	540.4	1954.9	760.1	-1.0	-0.5	627.36	NR
3/9/79	1430	123	3.31	7.28	72	523.9	1733.2	575.6	0.0	0.0	627.15	NR
3/10/79	1017	70	NR	NR	NR	NR	1477.0	280.8	-11.0	-1.0	626.22	NR
3/13/79	1247	34	2.17	5.06	72	364.2	789.5	71.8	9.0	2.0	624.48	0.51
3/13/79	1725	61	NR	NR	NR	NR	840.0	138.8	9.0	2.0	624.58	0.46
3/14/79	1053	133	NR	NR	NR	NR	1305.0	469.0	-3.0	0.0	625.71	NR
3/14/79	1748	92	NR	NR	NR	NR	1170.0	290.3	-4.0	-0.5	625.36	NR
3/15/79	1156	47	2.21	4.95	72	356.2	788.0	99.8	-8.0	-0.5	624.61	0.58
3/15/79	1740	42	NR	NR	NR	NR	793.0	89.7	NR	NR	624.45	NR
3/16/79	1032	36	2.02	4.73	70	331.0	668.8	64.5	NR	NR	624.15	0.51
3/19/79	1348	190	2.98	5.98	72	430.5	1282.2	656.0	15.0	7.0	625.52	NR
3/26/79	1030	27	1.87	4.46	66	294.4	550.9	39.9	-1.0	1.0	623.69	0.56
3/29/79	1212	126	NR	NR	NR	NR	642.0	218.9	13.5	7.0	624.01	0.57
3/30/79	1503	255	3.24	6.40	72	461.1	1492.2	1028.6	15.5	10.5	626.39	NR
3/31/79	0951	208	2.98	5.94	72	427.6	1272.8	714.5	4.0	8.0	625.72	NR
3/31/79	1725	147	NR	NR	NR	NR	1198.0	476.1	2.0	7.5	625.43	0.74
4/1/79	0912	83	NR	NR	NR	NR	962.0	214.8	5.0	6.0	624.86	0.69
4/1/79	1703	72	2.48	4.93	70	345.0	854.6	165.7	4.0	6.0	624.61	0.68
4/2/79	1107	76	2.19	4.79	70	335.1	735.3	151.9	4.0	6.0	624.26	0.57
4/2/79	1657	250	NR	NR	NR	NR	810.0	547.8	3.0	5.0	624.51	0.58
4/3/79	1700	74	NR	NR	NR	NR	769.0	153.4	10.0	8.0	624.38	0.64
4/4/79	0756	66	NR	NR	NR	NR	634.0	112.3	3.0	6.0	623.98	NR
4/4/79	1603	53	NR	NR	NR	NR	595.0	85.5	4.0	6.5	623.85	0.57
4/5/79	0900	45	NR	NR	NR	NR	534.0	64.7	7.5	6.5	623.60	0.54
4/5/79	1605	169	NR	NR	NR	NR	517.0	235.9	11.0	9.0	623.54	0.52
4/6/79	1124	69	1.76	4.07	65	264.7	467.1	87.0	-1.0	4.0	623.36	0.56
4/10/79	1104	24	1.52	3.78	61	230.5	350.5	22.5	7.5	5.5	622.60	0.45
4/12/79	1205	996	NR	6.75	69	465.9	1491.0	4009.2	23.0	11.0	626.27	NR
4/12/79	1808	427	NR	NR	NR	NR	1437.0	1655.2	21.0	12.0	626.08	NR
4/13/79	0917	214	2.90	5.69	69	392.5	1139.0	657.2	14.0	12.0	625.28	0.71
4/13/79	1510	216	NR	NR	NR	NR	1072.0	625.2	14.0	11.0	625.12	0.71
4/16/79	1056	51	1.74	4.02	66	265.5	462.2	64.1	14.5	9.0	623.24	0.52
4/16/79	1636	52	NR	NR	NR	NR	438.0	61.8	12.0	11.5	623.17	0.51
4/17/79	0930	51	1.67	3.98	62	247.0	413.0	57.2	15.0	10.0	622.91	0.49
4/17/79	1527	51	NR	NR	NR	NR	385.0	52.8	14.0	13.0	622.86	0.49
4/20/79	1115	200	1.39	3.56	60	213.5	296.7	160.2	12.5	11.0	622.30	0.43
4/23/79	1135	170	1.23	3.42	57	194.7	240.3	110.3	22.5	15.0	621.94	0.44
4/26/79	1310	838	3.49	6.91	72	497.5	1735.2	3926.1	9.0	12.0	626.61	NR
4/27/79	0915	190	3.27	6.38	72	459.0	1498.9	768.9	10.5	11.0	626.25	NR

NR = Not Recorded, G.H. = Gage Height

Appendix I. Concluded

Date	Time of day (hr)	$\overline{C_s}$ (ppm)	$\bar{V}$ (fps)	$\bar{D}$ (ft)	W_T (ft)	A (ft^2)	Q_w (cfs)	Q_s (tons/day)	Air temp (°C)	Water temp (°C)	G.H. above msl (ft)	S_w (ft/mile)
4/27/79	1528	93	NR	NR	NR	NR	1340.0	336.5	8.5	10.0	625.81	NR
4/28/79	0920	110	3.10	5.84	72	420.5	1303.1	387.0	5.0	8.5	625.58	0.78
4/29/79	1100	61	NR	NR	NR	NR	895.0	147.4	6.5	8.0	624.71	0.69
4/30/79	0855	74	2.65	5.02	72	361.3	959.2	191.6	8.5	7.0	624.58	0.64
4/30/79	1604	50	NR	NR	NR	NR	832.0	112.3	9.0	8.5	624.56	0.65
5/1/79	1245	48	2.29	4.61	70	323.0	740.6	96.0	13.0	12.0	624.02	0.60
5/4/79	1125	84	2.74	4.96	72	357.4	980.2	222.3	10.0	10.0	624.64	0.68
5/7/79	1225	55	1.78	3.95	66	260.7	463.4	68.8	25.0	16.0	623.03	0.50
5/10/79	1155	61	1.42	3.58	60	215.0	306.2	50.4	26.0	20.0	622.30	0.46
5/15/79	0945	50	1.19	3.36	56	188.4	224.8	30.4	15.0	13.0	621.81	0.53
5/23/79	1220	60	0.98	3.07	52	159.6	156.8	25.4	24.0	17.0	621.31	0.65
6/1/79	1145	66	0.96	3.04	52	158.1	151.4	27.0	16.5	17.5	621.23	0.80
6/7/79	1025	76	0.81	2.85	50	142.6	116.0	23.8	22.0	20.5	620.96	0.84
6/19/79	1206	35	0.68	2.75	49	134.8	91.7	8.7	22.5	19.0	620.81	0.90
6/26/79	1030	47	0.58	2.69	48	129.0	74.4	9.4	26.0	20.0	620.75	0.94
7/3/79	1045	62	0.47	2.56	48	123.0	57.3	9.6	29.0	22.0	620.66	0.96
7/9/79	1130	57	0.47	2.58	47	121.4	57.5	8.8	28.0	22.0	620.48	0.96
7/16/79	1415	63	0.44	2.48	48	119.2	52.6	9.0	29.0	27.0	620.32	0.95
7/23/79	1030	55	0.31	2.38	46	109.5	34.2	5.1	31.5	23.5	620.14	0.96
7/30/79	1120	25	0.48	2.48	47	116.4	56.4	3.8	25.0	23.0	620.31	0.94
8/6/79	1125	17	0.73	2.65	48	127.3	93.0	4.3	29.0	24.0	620.51	0.94
8/13/79	1400	61	0.53	2.51	48	120.7	64.3	10.6	24.0	21.0	620.39	0.88
8/23/79	1615	78	NR	NR	NR	NR	NR	NR	27.0	26.0	621.02	0.83
8/27/79	1435	83	0.67	2.74	48	131.6	88.4	19.8	26.0	24.0	620.62	0.86
9/4/79	1100	55	0.57	2.55	48	122.4	69.4	10.3	23.0	22.0	620.43	0.91
9/14/79	1535	40	0.38	2.41	47	113.2	43.5	4.7	18.0	19.0	620.30	0.96
9/24/79	1400	51	0.36	2.31	47	108.8	39.1	5.4	27.0	18.0	620.21	0.99

NR = Not Recorded, G.H. = Gage Height

Appendix J. Kankakee River at Momence 05520500

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY

STATION NUMBER 05520500 KANKAKEE RIVER AT MOMENCE, IL STREAM SOURCE AGENCY USGS
LATITUDE 410936 LONGITUDE 0874007 DRAINAGE AREA 2294.00 DATUM 609.18 STATE 17 COUNTY 091

SEDIMENT DISCHARGE, SUSPENDED (TONS/DAY), WATER YEAR OCTOBER 1978 TO SEPTEMBER 1979

DAY	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)
		OCTOBER			NOVEMBER			DECEMBER	
1	677	47	86	720	31	60	884	13	31
2	648	36	63	710	31	59	917	15	37
3	648	39	68	697	30	56	962	16	42
4	648	36	63	700	30	57	1020	16	44
5	646	32	56	687	30	56	1160	17	53
6	648	30	52	693	31	58	1210	18	59
7	643	29	51	712	23	44	1250	19	64
8	648	24	42	715	18	35	1220	19	63
9	648	23	40	706	17	32	1150	17	53
10	677	28	51	703	17	32	1100	20	59
11	687	27	50	718	17	33	1150	25	78
12	648	26	45	721	17	33	1300	29	102
13	631	23	39	710	19	36	1500	27	109
14	629	22	37	689	18	33	1400	25	94
15	625	22	37	698	17	32	1300	22	77
16	635	20	34	716	17	33	1400	22	83
17	655	18	32	727	18	35	1500	16	65
18	687	20	37	744	16	32	1250	16	54
19	717	31	60	747	15	30	1150	19	59
20	727	38	75	762	15	31	1080	20	58
21	727	40	79	765	16	33	1060	16	46
22	697	40	75	820	15	33	1040	16	45
23	697	38	72	873	15	35	1030	16	44
24	717	38	74	884	15	36	1030	17	47
25	737	36	72	873	16	38	1030	16	44
26	737	38	76	873	15	35	1000	18	49
27	717	36	70	884	15	36	900	18	44
28	721	36	70	884	16	38	757	18	37
29	732	35	69	852	16	37	707	20	38
30	726	35	68	852	15	35	862	22	51
31	713	34	65	---	---	---	1350	22	80
TOTAL	21894	---	1808	22835	---	1173	34669	---	1809
		JANUARY			FEBRUARY			MARCH	
1	1700	18	83	950	16	41	2500	28	189
2	1450	25	98	950	16	41	3500	60	567
3	1300	19	67	950	16	41	4000	80	864
4	1200	18	59	900	16	39	6000	120	1940
5	1100	18	53	900	16	39	9500	300	7690
6	1100	17	50	900	16	39	13400	415	15000
7	1050	17	48	900	16	39	14800	455	18200
8	1000	17	46	900	16	39	12000	280	9070
9	1000	16	43	900	16	39	10500	210	5950
10	1000	16	43	850	16	37	8130	180	3950
11	1000	16	43	850	16	37	7690	150	3110
12	1000	16	43	850	16	37	7040	120	2280
13	1000	16	43	800	16	35	6980	100	1880
14	1000	15	43	800	16	35	7470	75	1510
15	1000	16	43	800	16	35	6840	75	1390
16	1000	16	43	800	16	35	6610	75	1340
17	1000	16	43	800	16	35	6650	70	1260
18	1000	16	43	800	16	35	6810	70	1290
19	1000	16	43	800	16	35	7520	75	1520
20	1000	16	43	830	16	36	7640	80	1650
21	1100	16	48	870	16	38	7070	70	1340
22	1200	16	52	900	16	39	6540	65	1150
23	1200	16	52	1000	18	49	6220	50	840
24	1100	16	48	1300	18	63	6090	45	740
25	1000	16	43	1500	20	81	6040	45	734
26	950	16	41	1700	22	101	5700	35	539
27	950	16	41	2000	23	124	5420	35	512
28	950	16	41	2200	25	148	5290	35	500
29	950	16	41	---	---	---	5740	65	1010
30	950	16	41	---	---	---	6950	88	1650
31	950	16	41	---	---	---	6680	69	1240
TOTAL	33200	---	1508	28700	---	1392	223320	---	90905

Appendix J. Concluded

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY

STATION NUMBER 05520500 KANKAKEE RIVER AT MOMENCE, IL STREAM SOURCE AGENCY USGS
LATITUDE 410936 LONGITUDE 0874007 DRAINAGE AREA 2294.00 DATUM 609.18 STATE 17 COUNTY 091

SEDIMENT DISCHARGE, SUSPENDED (TONS/DAY), WATER YEAR OCTOBER 1978 TO SEPTEMBER 1979

DAY	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)
		APRIL			MAY			JUNE	
1	6220	45	756	5650	30	458	2500	55	371
2	6130	45	745	5350	30	433	2450	48	318
3	6110	45	742	5890	120	1910	2380	50	321
4	5850	43	679	5980	45	727	2280	65	400
5	5650	42	641	5700	40	616	2200	65	386
6	5420	40	585	5460	25	369	2070	68	380
7	5210	38	535	5230	22	311	1940	73	382
8	5120	35	484	5000	20	270	1890	68	347
9	5140	30	416	4840	20	261	1860	69	347
10	5040	30	408	4680	18	227	1860	68	341
11	5100	32	441	4500	18	219	1860	70	352
12	6930	327	6120	4320	18	210	1830	70	346
13	6610	121	2160	4150	18	202	1810	73	357
14	6070	49	803	3990	18	194	1730	74	346
15	5700	50	769	3880	18	189	1650	76	339
16	5400	45	656	3820	18	186	1580	73	311
17	5190	35	490	3720	18	181	1500	74	300
18	5020	28	380	3680	18	179	1460	74	292
19	4880	27	356	3570	18	174	1440	75	292
20	4760	25	321	3460	17	159	1450	73	286
21	4640	25	313	3350	16	145	1480	73	292
22	4480	22	266	3200	15	130	1470	73	290
23	4280	20	231	3090	15	125	1400	70	265
24	4240	20	229	2960	18	144	1340	68	246
25	4600	30	373	2840	25	192	1280	65	225
26	5700	176	2710	2750	33	245	1230	63	209
27	6330	118	2020	2680	31	224	1190	63	202
28	6240	80	1350	2640	31	221	1160	62	194
29	5980	40	646	2590	32	224	1130	58	177
30	5960	48	772	2560	44	304	1180	58	185
31	---	---	---	2520	50	340	---	---	---
TOTAL	164000	---	27397	124050	---	9769	50600	---	9099
		JULY			AUGUST			SEPTEMBER	
1	1180	58	185	1020	90	240	1260	57	194
2	1200	58	186	1030	75	209	1210	57	186
3	1210	58	189	1050	80	227	1140	57	175
4	1210	58	189	1050	80	227	1080	55	160
5	1110	55	165	1020	77	212	1050	52	147
6	1060	53	152	1030	76	211	1030	47	131
7	1040	53	149	1090	72	212	1020	47	129
8	1010	53	145	1060	68	195	1000	48	130
9	951	50	128	1020	69	190	982	46	122
10	920	47	117	981	67	177	923	39	97
11	906	43	105	1010	70	191	884	38	91
12	879	38	90	1130	95	290	862	37	86
13	852	33	76	1140	80	246	842	37	84
14	833	30	67	1100	70	208	819	34	75
15	823	30	67	1020	68	187	801	32	69
16	814	30	66	960	68	176	783	30	63
17	793	33	71	918	68	169	760	28	57
18	768	35	73	1040	67	188	753	22	45
19	747	35	71	1260	90	306	736	20	40
20	730	35	69	1470	80	318	719	19	37
21	695	34	64	1590	65	279	707	18	34
22	676	34	62	1620	65	284	700	18	34
23	657	34	60	1640	65	288	678	18	33
24	646	34	59	1600	64	276	669	18	33
25	727	34	67	1480	64	256	685	18	33
26	840	39	88	1390	63	236	689	17	32
27	899	42	102	1310	63	223	650	16	28
28	895	43	104	1240	61	204	624	16	27
29	840	46	104	1210	59	193	641	16	26
30	870	48	113	1240	58	194	618	16	27
31	1030	80	222	1260	57	194	---	---	---
TOTAL	27813	---	3407	36979	---	7014	25315	---	2427
YEAR	792575		157706						

Appendix K. Iroquois River at Iroquois 05525000

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY

STATION NUMBER 05525000 IROQUOIS RIVER AT IROQUOIS, IL STREAM SOURCE AGENCY USGS
LATITUDE 404925 LONGITUDE 0873455 DRAINAGE AREA 686.00 DATUM 614.34 STATE 17 COUNTY 075

SEDIMENT DISCHARGE, SUSPENDED (TONS/DAY), WATER YEAR OCTOBER 1978 TO SEPTEMBER 1979

DAY	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)
		OCTOBER			NOVEMBER			DECEMBER	
1	28	100	7.6	36	41	4.0	49	7	.93
2	27	100	7.3	35	46	4.3	49	6	.79
3	28	95	7.2	34	43	3.9	55	7	1.0
4	30	95	7.7	35	53	5.0	67	10	1.8
5	30	93	7.5	36	50	4.9	70	12	2.3
6	31	80	6.7	35	56	5.3	80	13	2.8
7	32	66	5.7	36	51	5.0	77	16	3.3
8	32	60	5.2	39	44	4.6	85	18	4.1
9	31	58	4.9	40	25	2.7	78	16	3.4
10	29	53	4.1	41	21	2.3	70	12	2.3
11	28	51	3.9	40	22	2.4	77	14	2.9
12	27	50	3.6	39	25	2.6	84	10	2.3
13	29	52	4.1	39	27	2.8	97	10	2.6
14	32	65	5.6	39	25	2.6	90	6	1.5
15	31	60	5.0	40	24	2.6	85	8	1.8
16	29	55	4.3	41	27	3.0	83	6	1.3
17	28	44	3.3	44	23	2.7	81	9	2.0
18	29	50	3.9	45	17	2.1	80	10	2.2
19	28	49	3.7	47	15	1.9	76	10	2.1
20	28	48	3.6	51	13	1.8	77	8	1.7
21	29	50	3.9	49	11	1.5	76	5	1.0
22	31	52	4.4	45	8	.97	75	4	.81
23	31	51	4.3	46	8	.99	66	3	.53
24	29	45	3.5	47	8	1.0	65	3	.53
25	29	44	3.4	49	6	.79	63	10	1.7
26	31	41	3.4	52	8	1.1	60	8	1.3
27	37	46	4.6	54	9	1.3	58	3	.47
28	46	48	6.0	53	8	1.1	56	3	.45
29	46	46	5.7	53	7	1.0	58	3	.47
30	41	44	4.9	52	6	.84	61	3	.49
31	38	43	4.4	---	---	---	106	3	.86
TOTAL	975	---	153.4	1292	---	77.09	2254	---	51.73
		JANUARY			FEBRUARY			MARCH	
1	180	24	12	59	20	3.2	500	40	54
2	130	24	8.4	59	20	3.2	1100	43	128
3	100	24	6.5	59	20	3.2	1600	58	251
4	80	24	5.2	59	20	3.2	4500	145	1760
5	70	20	3.8	57	20	3.1	6770	250	4570
6	67	20	3.6	55	20	3.0	6460	400	6980
7	65	20	3.5	53	20	2.9	6090	360	5920
8	65	20	3.5	50	20	2.7	5500	300	4450
9	65	20	3.5	50	20	2.7	4890	75	990
10	65	20	3.5	50	20	2.7	4330	75	877
11	65	20	3.5	50	20	2.7	3930	60	637
12	65	20	3.5	50	20	2.7	3370	40	364
13	65	20	3.5	50	20	2.7	2790	35	264
14	65	20	3.5	50	20	2.7	2420	35	229
15	66	20	3.6	50	20	2.7	2080	30	168
16	70	20	3.8	50	20	2.7	1750	30	142
17	70	20	3.8	50	20	2.7	1400	26	98
18	70	20	3.8	50	20	2.7	1150	26	81
19	67	20	3.6	50	20	2.7	1180	64	204
20	65	20	3.5	55	20	3.0	1450	53	207
21	65	20	3.5	65	23	4.0	1500	40	162
22	65	20	3.5	90	28	6.8	1460	30	118
23	65	20	3.5	130	36	13	1370	35	129
24	65	20	3.5	175	38	18	1300	45	158
25	65	20	3.5	250	43	29	1330	45	162
26	65	20	3.5	280	36	27	1330	33	119
27	63	20	3.4	310	38	32	1270	22	75
28	60	20	3.2	350	37	35	1200	35	113
29	60	20	3.2	---	---	---	1470	309	1230
30	60	20	3.2	---	---	---	1690	206	934
31	60	20	3.2	---	---	---	1680	147	746
TOTAL	2248	---	126.8	2706	---	222.0	79050	---	32320

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY

STATION NUMBER 05525000 IROQUOIS RIVER AT IROQUOIS, IL STREAM SOURCE AGENCY USGS
LATITUDE 404925 LONGITUDE 0873455 DRAINAGE AREA 686.00 DATUM 614.34 STATE 17 COUNTY 075

SEDIMENT DISCHARGE, SUSPENDED (TONS/DAY), WATER YEAR OCTOBER 1978 TO SEPTEMBER 1979

DAY	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)
		APRIL			MAY			JUNE	
1	2000	100	540	2300	45	279	276	115	86
2	2020	70	382	2140	43	248	308	160	133
3	1970	37	197	2070	55	307	317	157	134
4	1840	35	174	2030	60	329	286	125	97
5	1680	33	150	1930	65	339	255	120	83
6	1510	31	126	1810	70	342	232	115	72
7	1330	29	104	1660	75	336	217	110	64
8	1150	28	87	1470	80	318	307	333	276
9	1020	30	83	1250	80	270	569	996	1530
10	993	33	88	1020	90	248	739	441	880
11	1060	175	501	825	125	278	684	300	554
12	2130	643	3700	775	145	303	547	210	310
13	2720	303	2230	828	158	353	466	190	239
14	2990	212	1710	878	142	337	596	200	322
15	2970	88	706	1140	478	1470	626	194	328
16	2740	97	718	1230	203	674	534	210	303
17	2410	105	683	1180	145	462	439	210	249
18	2040	98	540	1030	127	353	371	205	205
19	1650	97	432	844	125	285	371	205	205
20	1310	105	371	689	140	260	396	205	219
21	1010	125	341	589	135	215	447	220	266
22	790	135	288	510	125	172	449	230	279
23	673	140	254	455	125	154	367	225	223
24	709	157	301	425	120	138	284	195	150
25	1050	497	1410	394	108	115	229	195	121
26	1580	406	1730	359	105	102	197	180	96
27	2090	183	1030	343	105	97	170	170	78
28	2310	95	593	331	105	94	151	185	75
29	2400	60	389	308	106	88	146	185	73
30	2400	50	324	285	108	83	156	220	93
31	---	---	---	271	115	84	---	---	---
TOTAL	52545	---	20182	31369	---	9133	11132	---	7743
		JULY			AUGUST			SEPTEMBER	
1	178	180	87	196	166	88	203	120	66
2	193	200	104	296	195	156	160	120	52
3	170	190	87	362	145	142	133	125	45
4	1080	974	2840	284	175	134	115	130	40
5	1920	286	1480	206	175	97	100	125	34
6	1550	200	837	227	180	110	89	125	30
7	1060	175	501	203	180	99	77	125	26
8	654	224	396	196	160	85	69	123	23
9	1490	1010	4060	171	175	81	65	105	18
10	1960	429	2270	157	175	74	61	110	18
11	1700	210	964	207	195	109	58	115	18
12	1210	180	588	216	180	105	55	125	19
13	734	180	357	179	170	82	55	125	19
14	546	185	273	137	170	63	53	130	19
15	465	185	232	105	170	48	51	110	15
16	396	200	214	84	145	33	49	110	15
17	309	195	163	75	140	28	42	115	13
18	234	195	123	150	175	71	42	105	12
19	191	185	95	434	300	352	42	110	12
20	162	190	83	762	410	844	39	105	11
21	139	160	60	802	275	595	37	105	10
22	122	195	64	666	220	396	36	95	9.2
23	105	190	54	530	175	250	38	90	9.2
24	100	190	51	515	180	250	37	90	9.0
25	304	330	271	465	175	220	37	85	8.5
26	562	250	379	346	165	154	34	95	8.7
27	500	180	243	286	155	120	31	94	7.9
28	371	170	170	260	145	102	31	100	8.4
29	266	165	119	253	140	96	31	115	9.6
30	203	160	88	300	135	109	34	120	11
31	185	170	85	266	130	93	---	---	---
TOTAL	19059	---	17338	9336	---	5186	1904	---	596.5
YEAR	213870		93129.52						

Appendix L. Iroquois River near Chebanse 05526000

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY

STATION NUMBER 05526000 IROQUOIS RIVER NEAR CHEBANSE, IL STREAM SOURCE AGENCY USGS
LATITUDE 410029 LONGITUDE 0874922 DRAINAGE AREA 2091.00 DATUM 597.99 STATE 17 COUNTY 091

SEDIMENT DISCHARGE, SUSPENDED (TONS/DAY), WATER YEAR OCTOBER 1978 TO SEPTEMBER 1979

DAY	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)
		OCTOBER			NOVEMBER			DECEMBER	
1	89	95	23	112	29	8.8	168	13	5.9
2	66	95	22	112	31	9.4	158	14	6.0
3	61	95	21	109	34	10	193	12	6.3
4	82	95	21	105	45	13	241	23	15
5	91	97	24	104	47	13	252	18	12
6	88	75	18	85	48	11	259	15	10
7	84	55	12	103	43	12	279	15	11
8	85	45	10	112	35	11	330	18	7.1
9	93	45	11	110	25	7.4	300	17	14
10	85	45	10	105	25	7.1	270	14	10
11	82	43	9.5	95	36	9.2	300	13	11
12	77	40	8.3	100	37	10	320	12	10
13	86	40	9.3	114	39	12	370	14	14
14	88	38	9.0	97	28	7.3	460	14	17
15	95	35	9.0	94	27	6.9	380	8	5.1
16	74	30	6.0	97	28	7.3	350	8	4.7
17	91	25	6.1	119	27	8.7	380	8	5.1
18	88	25	5.9	117	22	6.9	330	8	4.5
19	83	38	8.5	111	24	7.2	304	8	4.1
20	79	38	8.1	113	25	7.6	295	8	4.0
21	83	41	9.2	120	21	6.8	300	8	6.5
22	77	40	8.3	123	23	7.6	290	8	11
23	62	39	6.5	139	19	6.8	280	8	6.0
24	82	33	7.3	143	18	6.9	250	8	5.4
25	87	35	8.2	145	18	7.0	270	12	12
26	85	43	9.9	145	16	6.3	280	12	7.6
27	101	45	12	149	14	5.6	270	12	8.7
28	95	39	10	160	12	5.2	250	10	6.8
29	108	37	11	167	12	5.4	250	10	6.8
30	116	34	11	173	13	6.1	270	8	5.8
31	107	32	9.2	---	---	---	400	8	8.6
TOTAL	2710	---	354.3	3578	---	249.5	9049	---	262.0

DAY	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)
		JANUARY			FEBRUARY			MARCH	
1	500	160	216	180	20	9.7	1300	24	84
2	450	138	168	180	20	9.7	3000	28	227
3	350	35	33	180	20	9.7	4500	61	741
4	300	30	24	180	20	9.7	10000	154	4160
5	250	30	20	160	20	8.6	20000	271	14600
6	220	28	17	150	20	8.1	25000	450	30400
7	210	28	16	150	20	8.1	27000	442	32200
8	200	28	15	150	20	8.1	25000	266	18000
9	200	28	15	150	20	8.1	20900	170	9590
10	200	28	15	150	20	8.1	16500	130	5790
11	200	28	15	150	20	8.1	12900	110	3830
12	200	28	15	150	20	8.1	10400	85	2390
13	200	28	15	150	20	8.1	8510	80	1840
14	200	25	13	150	20	8.1	7710	78	1620
15	200	25	13	150	20	8.1	6490	73	1280
16	230	25	16	150	20	8.1	5450	65	956
17	230	25	16	150	20	8.1	4600	55	683
18	230	25	16	150	20	8.1	4110	79	877
19	200	25	13	150	20	8.1	5290	315	4620
20	200	25	13	200	20	11	7400	177	3440
21	200	25	13	250	22	15	7690	135	2800
22	200	20	11	350	25	24	7040	139	2640
23	200	20	11	500	35	47	6150	139	1910
24	200	20	11	600	40	65	5430	60	880
25	200	20	11	800	45	97	5200	50	702
26	200	20	11	950	15	38	4980	45	605
27	180	20	9.7	1050	24	68	4520	50	610
28	180	20	9.7	1200	35	113	4110	65	721
29	180	20	9.7	---	---	---	5190	144	2190
30	180	20	9.7	---	---	---	7180	438	8680
31	180	20	9.7	---	---	---	8470	570	12800
TOTAL	7070	---	800.5	8880	---	638.8	292020	---	171866

Appendix L. Concluded

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY

STATION NUMBER 05526000 IROQUOIS RIVER NEAR CHEBANSE, IL STREAM SOURCE AGENCY USGS
LATITUDE 410029 LONGITUDE 0874922 DRAINAGE AREA 2091.00 DATUM 597.99 STATE 17 COUNTY 091

SEDIMENT DISCHARGE, SUSPENDED (TONS/DAY), WATER YEAR OCTOBER 1978 TO SEPTEMBER 1979

DAY	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)
		APRIL			MAY			JUNE	
1	8630	240	5590	8160	80	1760	646	65	113
2	8290	150	3360	6670	77	1390	638	75	129
3	7630	120	2470	6900	238	4520	652	88	155
4	6530	105	1850	7650	204	4210	657	90	160
5	5740	100	1550	7050	115	2190	605	88	144
6	5150	90	1250	6090	108	1780	572	87	134
7	4500	87	1060	4980	100	1340	534	86	124
8	3700	85	849	4060	100	1100	584	148	321
9	3490	70	660	3340	100	902	2620	1060	6330
10	3220	45	391	2810	105	797	3290	760	6780
11	3350	225	2040	2360	103	656	2470	398	2770
12	8890	1300	28600	2010	100	543	1870	225	1140
13	12000	788	25600	1820	96	482	1670	190	857
14	13300	1400	50600	1780	97	466	1860	210	1050
15	13400	774	28200	1820	93	457	1700	180	826
16	11400	300	9230	2230	95	570	1490	160	644
17	9110	135	3320	2370	183	1170	1210	150	490
18	6690	125	2260	2260	162	983	1040	140	393
19	4770	125	1610	2150	127	733	1060	135	386
20	3640	115	1130	1730	110	514	982	132	350
21	2900	110	861	1460	106	418	963	160	416
22	2340	100	632	1290	96	341	969	145	379
23	1970	97	516	1110	85	255	888	140	336
24	1910	102	531	1000	85	229	777	130	273
25	3930	226	2440	928	83	208	648	128	224
26	7730	365	8270	879	78	185	547	115	170
27	10000	286	7680	806	67	146	469	113	143
28	10300	213	5930	762	65	134	423	110	126
29	10400	210	5900	728	63	124	427	108	125
30	9610	118	3110	685	61	113	538	110	160
31	---	---	---	643	61	106	---	---	---
TOTAL	204520	---	207490	88531	---	28822	32799	---	25648
		JULY			AUGUST			SEPTEMBER	
1	527	118	168	778	150	315	917	110	272
2	516	118	164	674	145	264	743	100	201
3	486	130	171	991	145	388	616	95	159
4	2140	784	5040	1370	255	943	510	85	117
5	5610	572	8740	1070	175	506	416	83	93
6	6410	828	14400	825	160	356	377	80	81
7	5090	408	5800	725	135	264	345	90	84
8	3130	274	2360	651	135	237	299	85	69
9	2100	251	1480	548	131	194	273	75	55
10	2800	375	2940	465	125	157	243	65	43
11	3100	581	4910	435	125	147	226	65	40
12	2680	415	3000	494	120	160	187	60	30
13	2030	300	1640	455	120	147	187	58	29
14	1450	235	920	406	120	132	170	55	25
15	1240	165	552	349	120	113	157	53	22
16	2180	483	3060	308	120	100	157	50	21
17	2410	555	3620	264	150	107	137	50	18
18	1880	310	1570	368	160	159	133	50	18
19	1170	210	663	1060	194	555	121	50	16
20	802	165	357	5000	397	5360	117	47	15
21	623	130	219	7500	311	6300	114	46	14
22	496	120	161	7090	553	10600	106	45	13
23	414	115	129	6500	415	7280	102	45	12
24	360	104	101	6020	285	4630	106	45	13
25	460	101	125	5510	220	3270	102	45	12
26	1350	222	915	4710	212	2700	96	44	11
27	2150	240	1370	3520	190	1810	96	43	11
28	2500	358	2440	2280	180	1110	92	41	10
29	2420	340	2240	1540	150	624	89	40	9.6
30	1960	250	1320	1280	130	449	89	40	9.6
31	1220	172	567	1160	115	360	---	---	---
TOTAL	61704	---	71142	64346	---	49737	7325	---	1523.2
YEAR	782532		558533.3						

Appendix M. Kankakee River near Wilmington 05527500

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY

STATION NUMBER 05527500 KANKAKEE RIVER NEAR WILMINGTON, IL STREAM SOURCE AGENCY USGS
LATITUDE 412048 LONGITUDE 0881111 DRAINAGE AREA 5150.00 DATUM 510.86 STATE 17 COUNTY 197

SEDIMENT DISCHARGE, SUSPENDED (TONS/DAY), WATER YEAR OCTOBER 1978 TO SEPTEMBER 1979

DAY	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)
		OCTOBER			NOVEMBER			DECEMBER	
1	746	50	101	878	35	83	1060	32	92
2	728	40	79	888	36	86	1100	30	89
3	728	57	112	878	34	81	1200	30	97
4	695	51	96	854	33	76	1330	28	101
5	712	49	94	853	33	76	1410	26	99
6	721	49	95	868	35	82	1540	24	100
7	717	46	89	873	36	85	1650	22	98
8	715	40	77	882	36	86	1800	22	107
9	719	40	78	866	35	82	1600	24	104
10	725	36	70	852	34	78	1500	20	81
11	767	36	75	822	32	71	1600	18	78
12	765	36	74	843	34	77	1800	16	78
13	736	34	68	869	39	89	2000	15	81
14	724	32	63	868	37	87	2100	15	85
15	721	28	55	819	30	66	1970	15	80
16	728	26	51	822	30	67	2030	15	82
17	728	24	47	897	40	97	2190	15	89
18	781	26	55	883	39	93	1440	14	54
19	817	24	53	884	38	91	1390	14	53
20	817	24	53	891	38	91	1430	13	50
21	835	23	52	910	38	93	1550	12	50
22	835	23	52	913	38	94	1500	12	49
23	854	32	74	995	40	107	1450	12	47
24	817	29	64	1060	42	120	1300	11	39
25	891	39	94	1050	42	119	1400	11	42
26	970	43	113	1040	40	112	1500	10	40
27	930	40	100	1080	40	117	1400	10	38
28	891	39	94	1060	38	109	1300	10	35
29	891	39	94	1060	36	103	717	10	19
30	911	38	93	1020	34	94	1210	10	33
31	894	39	94	---	---	---	1720	10	46
TOTAL	24509	---	2409	27478	---	2712	47187	---	2136
		JANUARY			FEBRUARY			MARCH	
1	2300	10	62	1300	6	21	5000	150	2030
2	2000	10	54	1300	6	21	8000	200	4320
3	1800	9	44	1300	6	21	11000	219	6500
4	1600	9	39	1250	6	20	20000	491	26500
5	1500	9	36	1250	7	24	30000	297	24100
6	1450	10	39	1250	6	20	38000	305	31300
7	1400	10	38	1250	6	20	44000	412	48900
8	1350	9	33	1250	6	20	48000	468	60700
9	1300	9	32	1250	6	20	41000	263	29100
10	1300	9	32	1200	6	19	33000	175	15600
11	1300	9	32	1200	6	19	28700	119	9220
12	1300	8	28	1200	6	19	25400	83	5690
13	1300	8	28	1150	7	22	19000	82	4210
14	1300	8	28	1100	7	21	19600	195	10300
15	1300	9	32	1100	7	21	16300	93	4090
16	1350	8	29	1100	7	21	15300	48	1980
17	1350	8	29	1100	7	21	14500	28	1100
18	1350	8	29	1100	8	24	15000	48	1940
19	1300	8	28	1150	8	25	20900	263	14800
20	1300	9	32	1300	7	25	20900	218	12300
21	1400	6	30	1500	7	28	18500	146	7290
22	1500	9	36	1700	6	28	16500	103	4590
23	1500	9	36	2000	6	32	15000	72	2920
24	1400	9	34	2500	6	40	14100	65	2470
25	1300	9	32	3000	7	57	13500	60	2190
26	1300	9	32	3500	6	57	12600	57	1940
27	1300	8	28	4000	30	324	11800	55	1750
28	1300	8	28	4500	80	972	11400	36	1110
29	1300	8	28	---	---	---	14200	198	7590
30	1300	7	25	---	---	---	19500	330	17400
31	1300	7	25	---	---	---	19300	340	16800
TOTAL	44050	---	1038	46800	---	1962	639000	---	380730

Appendix M. Concluded

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY

STATION NUMBER 05527500 KANKAKEE RIVER NEAR WILMINGTON, IL STREAM SOURCE AGENCY USGS
LATITUDE 412048 LONGITUDE 0881111 DRAINAGE AREA 5150.00 DATUM 510.86 STATE 17 COUNTY 197

SEDIMENT DISCHARGE, SUSPENDED (TONS/DAY), WATER YEAR OCTOBER 1978 TO SEPTEMBER 1979

DAY	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)	MEAN DISCHARGE (CFS)	MEAN CONCEN-TRATION (MG/L)	SEDIMENT DISCHARGE (TONS/DAY)
		APRIL			MAY			JUNE	
1	17100	308	14200	15600	65	2740	3500	28	265
2	17200	201	9330	13800	45	1680	3520	28	266
3	16300	155	6820	15200	146	5990	3500	28	265
4	14500	110	4310	15800	166	7080	3540	28	268
5	13400	83	3000	14600	96	3780	3520	28	266
6	12200	78	2570	13300	78	2800	3410	28	258
7	11300	70	2140	12000	68	2200	3410	28	258
8	10600	65	1860	10700	64	1850	3240	28	245
9	10500	45	1280	9690	55	1440	4130	69	769
10	9960	45	1210	8840	45	1070	6200	265	4440
11	10500	57	1620	8150	43	946	5540	240	3590
12	22600	1540	94000	7470	38	766	4610	230	2860
13	21400	818	47300	6950	36	676	4160	145	1630
14	20500	601	33300	6690	32	578	4150	155	1740
15	20000	627	33900	6440	32	556	3920	80	847
16	18400	394	19600	6480	34	595	3600	80	778
17	15900	184	7900	6670	34	612	3220	78	678
18	13500	105	3830	6500	34	597	3010	78	634
19	11400	99	3050	6100	33	544	3120	78	657
20	10100	100	2730	5650	32	488	2980	78	628
21	9190	80	1990	5150	32	445	2830	80	611
22	8450	73	1670	4740	32	410	2880	75	583
23	7750	65	1360	4440	32	384	2790	75	565
24	7370	63	1250	4190	32	362	2620	65	460
25	9090	45	1100	3930	30	318	2440	55	362
26	13900	160	6000	3740	30	303	2280	45	277
27	18200	388	19100	3600	30	292	2150	40	232
28	18400	183	9090	3460	30	280	2050	35	194
29	17800	183	8790	3370	30	273	2020	30	164
30	17200	115	5340	3350	30	271	2200	30	178
31	---	---	---	3350	30	271	---	---	---
TOTAL	424710	---	349640	239950	---	40597	100540	---	24968
		JULY			AUGUST			SEPTEMBER	
1	2220	25	150	2400	110	713	2600	80	562
2	2100	25	142	1980	90	481	2350	80	508
3	2020	25	136	1980	75	401	2120	65	372
4	3170	27	231	1980	65	347	1890	65	332
5	6350	161	2760	2430	80	525	1720	65	302
6	8230	636	14100	2500	90	607	1600	63	272
7	7490	638	12900	3170	85	728	1510	65	265
8	5340	335	4830	2710	75	549	1430	53	205
9	3790	179	1830	2170	85	498	1130	50	153
10	3280	155	1370	2170	80	469	1320	53	189
11	4160	155	1740	1860	70	352	1260	50	170
12	3900	160	1680	1770	65	311	1200	50	162
13	3320	140	1250	1820	65	319	1150	50	155
14	2740	110	814	1700	63	289	1090	48	141
15	2270	100	613	1540	58	241	1080	45	131
16	2360	80	510	1360	55	202	1060	43	123
17	3170	75	642	1270	54	185	1030	42	117
18	2990	75	605	1680	53	240	1010	41	112
19	2360	75	478	2470	85	567	1000	40	108
20	1800	72	350	6980	145	2730	980	37	98
21	1490	45	181	12200	530	17500	969	37	97
22	1290	40	139	10900	450	13200	946	37	95
23	1160	40	125	10000	350	9450	932	36	91
24	1070	40	116	9180	220	5450	907	33	81
25	1200	40	130	8150	190	4180	902	34	83
26	1520	40	164	7230	150	2930	907	35	86
27	2600	40	281	6070	140	2300	913	36	89
28	3240	60	525	4630	128	1600	848	35	80
29	3360	137	1240	3550	85	815	814	32	70
30	3320	100	896	2990	79	638	821	30	67
31	3170	110	941	2830	75	573	---	---	---
TOTAL	96480	---	51869	123670	---	69390	37489	---	5316
YEAR	1851863		932767						

Appendix N. Kankakee River at State Line Bridge: Bed Load Data

Date	Station	Time (hr)	Time interval (min)	Dry weight (g)	Specific gravity	$\overline{V}$, in vertical (fps)
3/29/79	100	1040	5	34.6		2.58
3/31/79	50,100,150	1030	5*	-		2.44†
3/31/79	50	1030	5	890.7		2.67
3/31/79	50	1030	2	-		2.67
3/31/79	50	1030	3	277.2		2.67
3/31/79	50	1030	4	809.7		2.67
4/1/79	50	1640	2	576.9		2.44
4/2/79	50	1020	2	-		2.43
4/2/79	50	1020	0.5	78.9	2.67	2.43
4/3/79	50	1120	0.5	206.2		2.14
4/3/79	50	1120	1	40.7		2.14
4/3/79	50	1120	1.5	-		2.14
4/3/79	50	1120	2	438.0	2.61	2.14
4/3/79	50	1120	2.5	33.4		2.14
4/3/79	50	1120	3	209.0		2.14
4/4/79	50	1112	2	114.7		2.52
4/5/79	50	1045	2	103.9	2.39	2.61
4/5/79	75	1045	2	-		2.84
4/5/79	100	1045	2	60.7	2.60	2.52
4/6/79	50	NR	2	102.7		2.73
4/6/79	75	NR	2	204.2		3.03
4/8/79	50	1040	2	-		NR
4/8/79	75	1040	2	-		NR
4/10/79	50	1300	2	125.5	2.62	2.34
4/10/79	75	1300	2	50.5		2.85
4/10/79	100	1300	2	16.3		2.49
4/12/79	50	1420	2	76.1		2.32
4/12/79	75	1420	2	-		2.92
4/12/79	100	1420	2	111.4		2.49
4/13/79	50	1100	2	19.2		2.51
4/13/79	75	1100	2	453.7		3.06
4/13/79	100	1100	2	66.0	2.66	2.45
4/16/79	50	1230	2	-		2.64
4/16/79	75	1230	2	327.3		2.81
4/16/79	100	1230	2	561.5		2.50
4/17/79	50	1130	2	122.5		2.46
4/17/79	75	1130	2	78.1		2.78
4/17/79	100	1130	2	144.9	2.62	2.42
4/20/79	50	1300	2	-		2.60
4/20/79	75	1300	2	165.2		2.89
4/20/79	100	1300	2	-	2.65	2.59
4/23/79	50	1315	2	-		2.17
4/23/79	75	1315	2	410.5	2.59	2.59
4/23/79	100	1315	2	-		2.43
4/26/79	75	1230	2	336.3		2.93
4/27/79	75	1145	2	62.3		2.84
4/28/79	50	1100	2	932.5		2.77
4/28/79	75	1100	2	236.6		2.98
4/28/79	100	1100	2	379.6	2.58	2.67
4/29/79	50	1230	2	-		2.67
4/29/79	75	1230	2	335.8		3.00
4/29/79	100	1230	2	-		2.74
4/30/79	50	1040	2	31.3		2.76
4/30/79	75	1040	2	718.1		3.00
4/30/79	100	1040	2	371.2	2.58	2.39
5/1/79	50	1450	2	-		2.68
5/1/79	75	1450	2	123.5		2.88
5/1/79	100	1450	2	-		2.61
5/4/79	50	NR	2	367.3		2.87
5/4/79	75	NR	2	342.6		3.01
5/4/79	100	NR	2	1020.7	2.56	3.38
5/4/79	125	NR	2	137.4		2.52
5/4/79	175	NR	2	155.6		2.36
5/7/79	125	1400	2	390.4	2.61	2.65
5/10/79	50	1420	2	-		2.32
5/10/79	75	1420	2	196.5		2.75
5/10/79	100,125	1420	2*	95.5	2.57	2.40†
5/15/79	75,100	1130	2*	100.5	2.51	2.48†
5/23/79	75	1415	2	-		2.09
5/23/79	100	1415	2	40.2		1.95
5/23/79	125	1415	2	-		2.14
9/14/79	75,80	1340	2*	17.3		1.83
9/14/79	100	1340	2	87.7	2.66	1.95
9/14/79	100	1340	2	-		1.95
9/14/79	120	1340	2	42.2		1.95
9/14/79	120	1340	2	114.1		1.95
9/14/79	150	1340	2	9.6		1.78

† Mean value

* Time interval at each station

NR = Not recorded

Appendix 0. Iroquois River at Iroquois: Bed Load Data

Date	*Station*	*Time (hr)*	*Time interval (min)*	*Dry weight (g)*
10/26/78	60	1320	2	-
10/26/78	70	1320	2	-
10/26/78	75	1320	2	-
10/26/78	75	1320	10	-
10/26/78	80	1320	2	-
10/26/78	85	1320	2	-
10/26/78	90	1320	2	-
10/26/78	95	1320	1	-
11/10/78	65	1400	15	-
11/27/78	65	1300	15	-
12/11/78	65	1345	15	-
3/6/79	90	1500	5	-
3/7/79	65	1330	5	0.7
3/7/79	90	1330	30	1.0
3/14/79	65	1245	5	-
3/19/79	65	1640	5	-
3/26/79	65	1645	5	-
3/29/79	90	1535	5	-
3/31/79	65	NR	5	-
4/1/79	65	1420	5	-
4/2/79	65	1530	5	-
4/3/79	65	1500	5	-
4/4/79	65	1540	5	-
4/5/79	65	1200	5	-
4/10/79	65	1505	5	-
4/12/79	65	1530	5	-
4/13/79	65	1225	5	11.6
4/16/79	65	1345	5	-
4/17/79	65	1240	5	-
4/20/79	65	1430	5	-
4/23/79	65	1500	5	-
4/26/79	65	1430	5	-
4/27/79	65	1250	5	-
4/28/79	65	1205	5	-
4/30/79	65	1430	5	-
5/7/79	65	1530	5	-
5/23/79	65	1525	5	-
6/19/79	65	1520	5	-
7/23/79	65	1620	5	-
9/4/79	65	1340	5	-

NR = Not recorded

Appendix P. Iroquois River near Chebanse: Bed Load Data

Date	Station	Time (hr)	Time interval (min)	Dry weight (g)	Specific gravity
10/26/78	48	945	1	-	
10/26/78	70	945	1	-	
10/26/78	90	945	1	-	
10/26/78	110	945	1	-	
10/26/78	130	945	1	-	
10/26/78	148	945	1	-	
10/26/78	200	945	1	-	
10/26/78	210	945	1	-	
10/26/78	220	945	1	-	
10/26/78	230	945	1	-	
10/26/78	240	945	1	-	
10/26/78	250	945	1	-	
10/26/78	261	945	1	-	
10/26/78	270	945	1	-	
10/26/78	280	945	1	-	
10/26/78	290	945	1	-	
10/26/78	300	945	1	-	
10/26/78	310	945	1	-	
10/26/78	320	945	1	-	
11/10/78	140	1030	15	-	
11/27/78	140	1020	15	-	
12/11/78	235	1000	15	-	
3/5/79	170	1635	5	4.0	
3/8/79	290	1215	5	7.7	
3/13/79	120,210,290	1545	5*	18.0	
3/15/79	120,210,290	1335	5*	17.2	
3/16/79	120,210,290	1240	5*	5.7	
3/19/79	120,210,290	1530	5*	2.9	
3/26/79	120,210,290	1500	5*	34.9	
3/29/79	120,210,290	1430	5*	51.7	2.39
3/31/79	120,210,290	1400	5*	-	
4/1/79	120	1100	5	35.8	
4/1/79	210	1100	5	3.1	
4/1/79	290	1100	5	6.8	
4/2/79	120,210,290	1415	5*	51.8	
4/3/79	120,210,290	1300	5*	64.3	
4/4/79	120,210,290	1230	5*	44.3	
4/5/79	120,210,290	1415	5*	22.6	
4/6/79	120,210,290	1415	5*	5.5	
4/10/79	120,210,290	1010	5*	-	
4/12/79	120,210,290	1700	5*	51.4	2.43
4/13/79	120	1400	5	570.3	
4/13/79	210,290	1400	5*	-	
4/16/79	120,210,290	1530	5*	23.7	
4/17/79	120,210,290	NR	5*	18.6	
4/20/79	120,210,290	1000	5*	32.3	
4/23/79	120,210,290	1015	5*	-	
4/26/79	120,210,290	940	5*	-	
4/27/79	120,210,290	1420	5*	52.3	
4/28/79	120,210,290	1330	5*	385.0	
4/29/79	120,210,290	1430	5*	60.6	2.53
4/30/79	120,210,290	1315	5*	47.5	
5/1/79	120,210,290	1030	5*	-	
5/7/79	120,210,290	1020	5*	-	
5/10/79	120,210,290	1000	5*	-	
5/15/79	120,210,290	1315	5*	-	
5/23/79	120,210,290	1030	5*	-	
6/1/79	120,210,290	1015	5*	-	
6/19/79	120,210,290	1000	5*	-	
7/23/79	120,210,290	900	5*	-	

*Time interval at each station

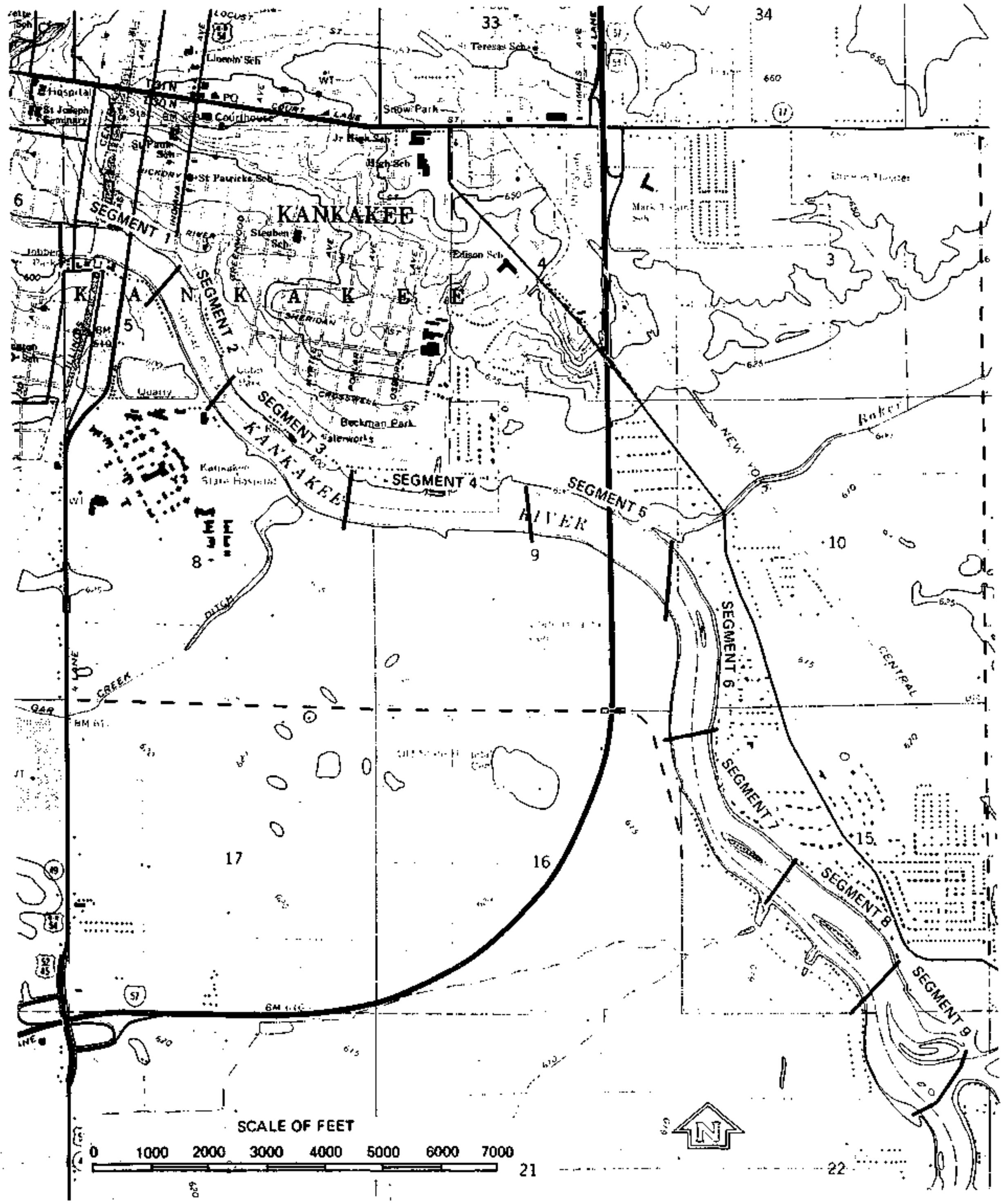
NR = Not recorded

Appendix Q. Hydrographic Map of the Six Mile Pool

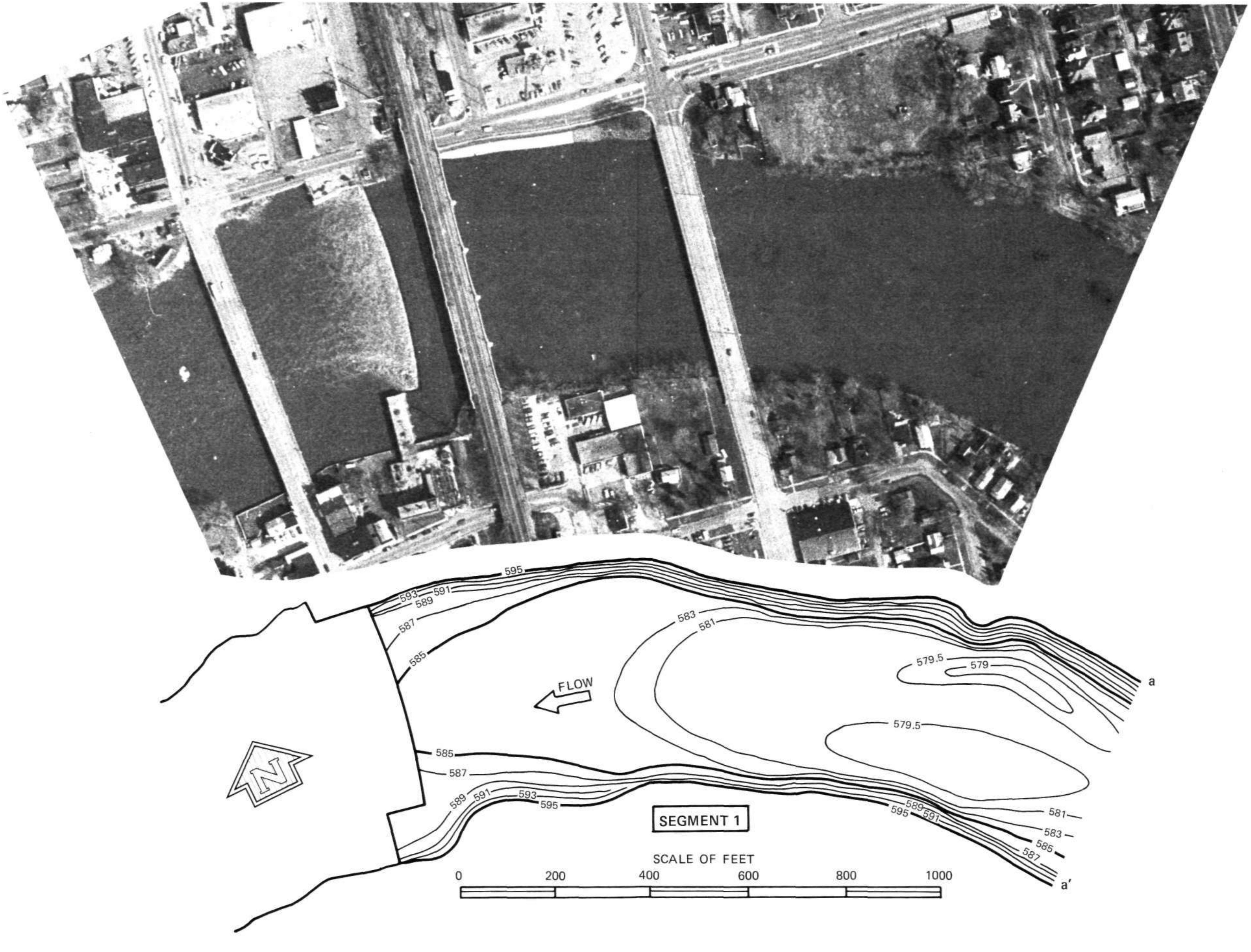
Developed from data collected by the Illinois Department of Transportation, Division of Water Resources, in 1977 and 1978

For copies of these maps, contact:

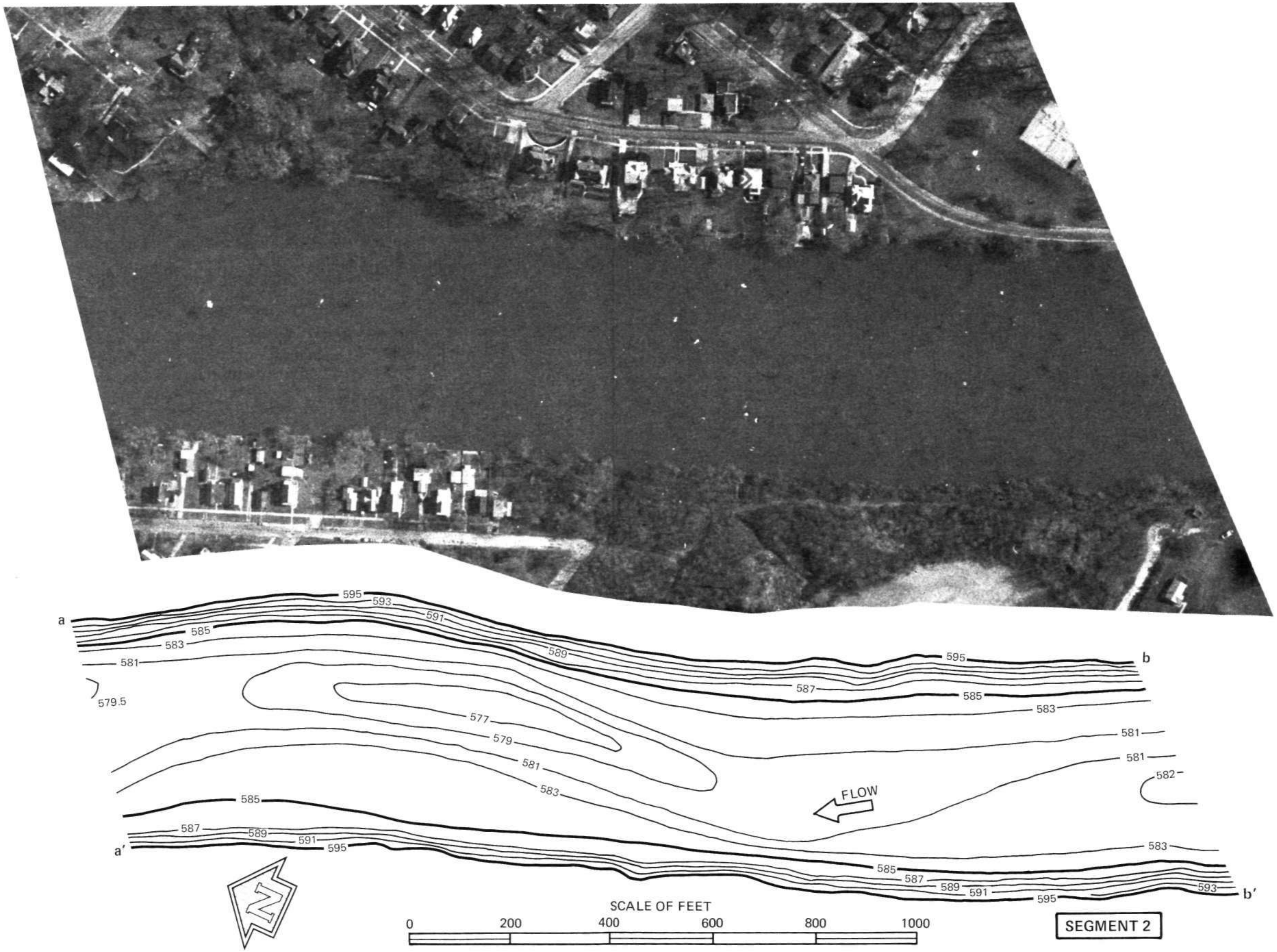
Illinois State Water Survey P.O. Box 5050, Station A Champaign, IL 61820 Attention: Nani Bhowmik	or	Illinois Institute of Natural Resources 309 West Washington Street Chicago, IL 60606 Attention: David Jones



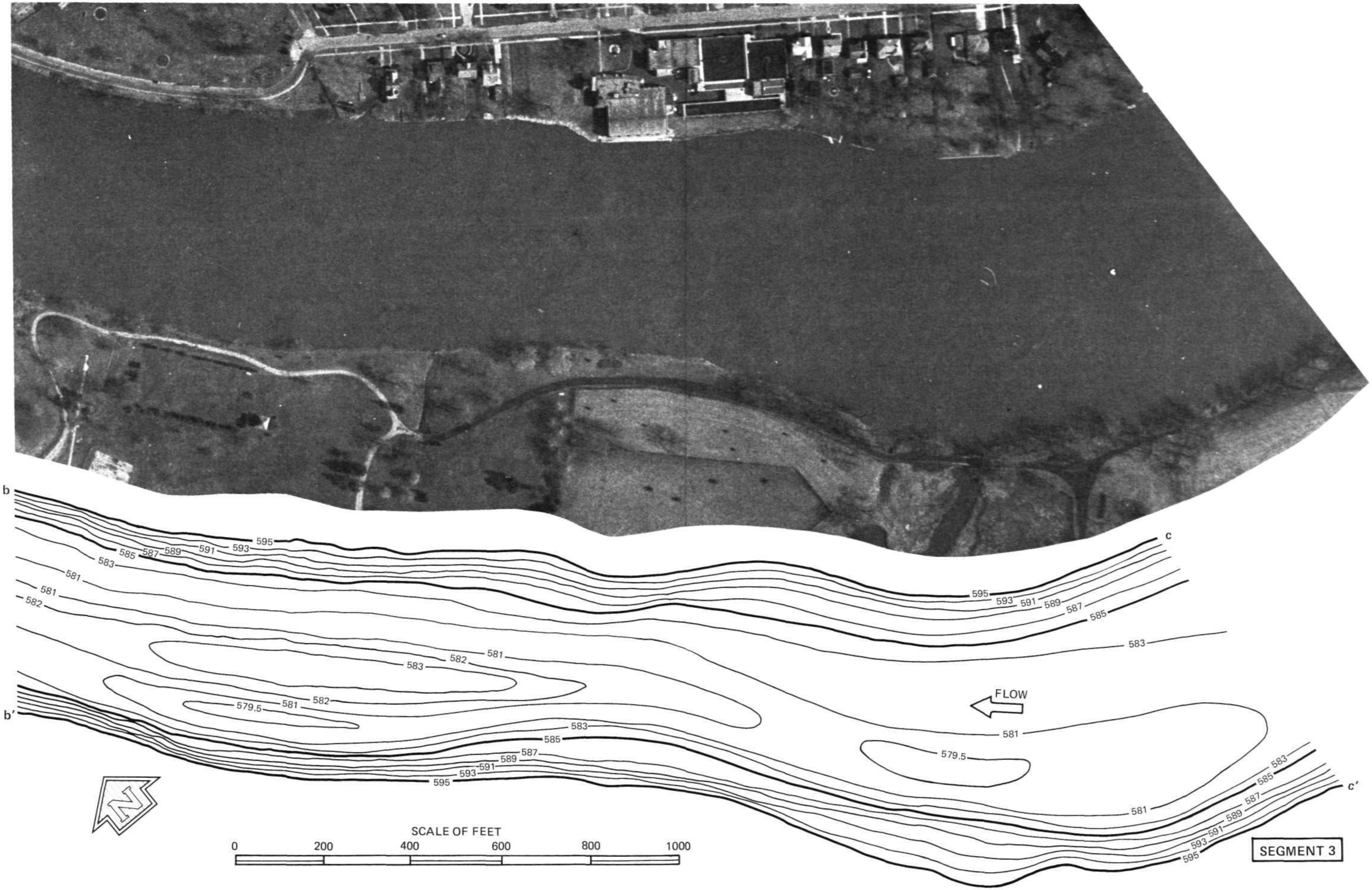
Index map of the Six Mile Pool

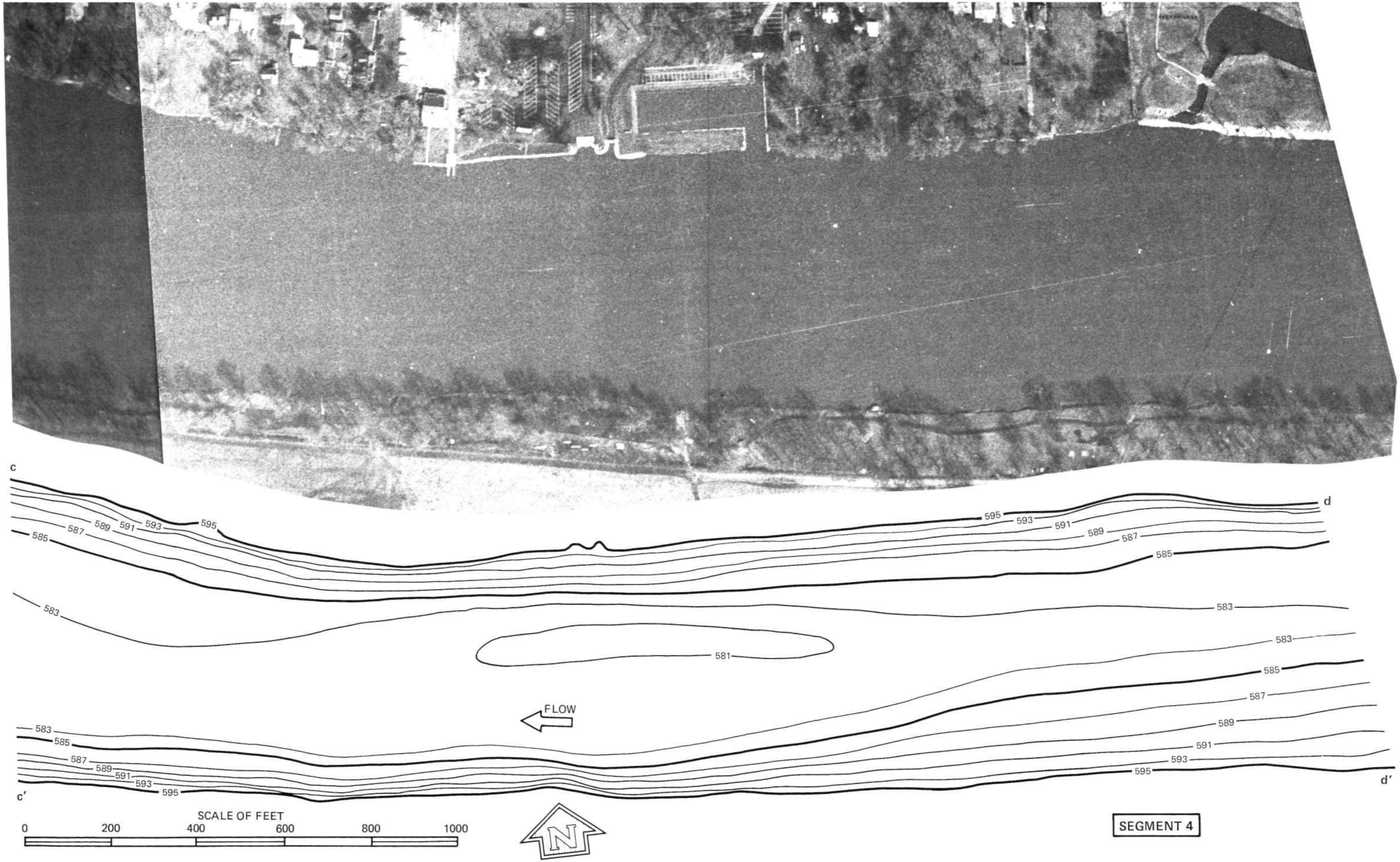


595
593
591
589
587
585
583
581
579.5
579
579.5
FLOW
a
585
587
589
591
593
595
589
595
591
581
583
585
587
a'
SEGMENT 1
SCALE OF FEET
0
200
400
600
800
1000

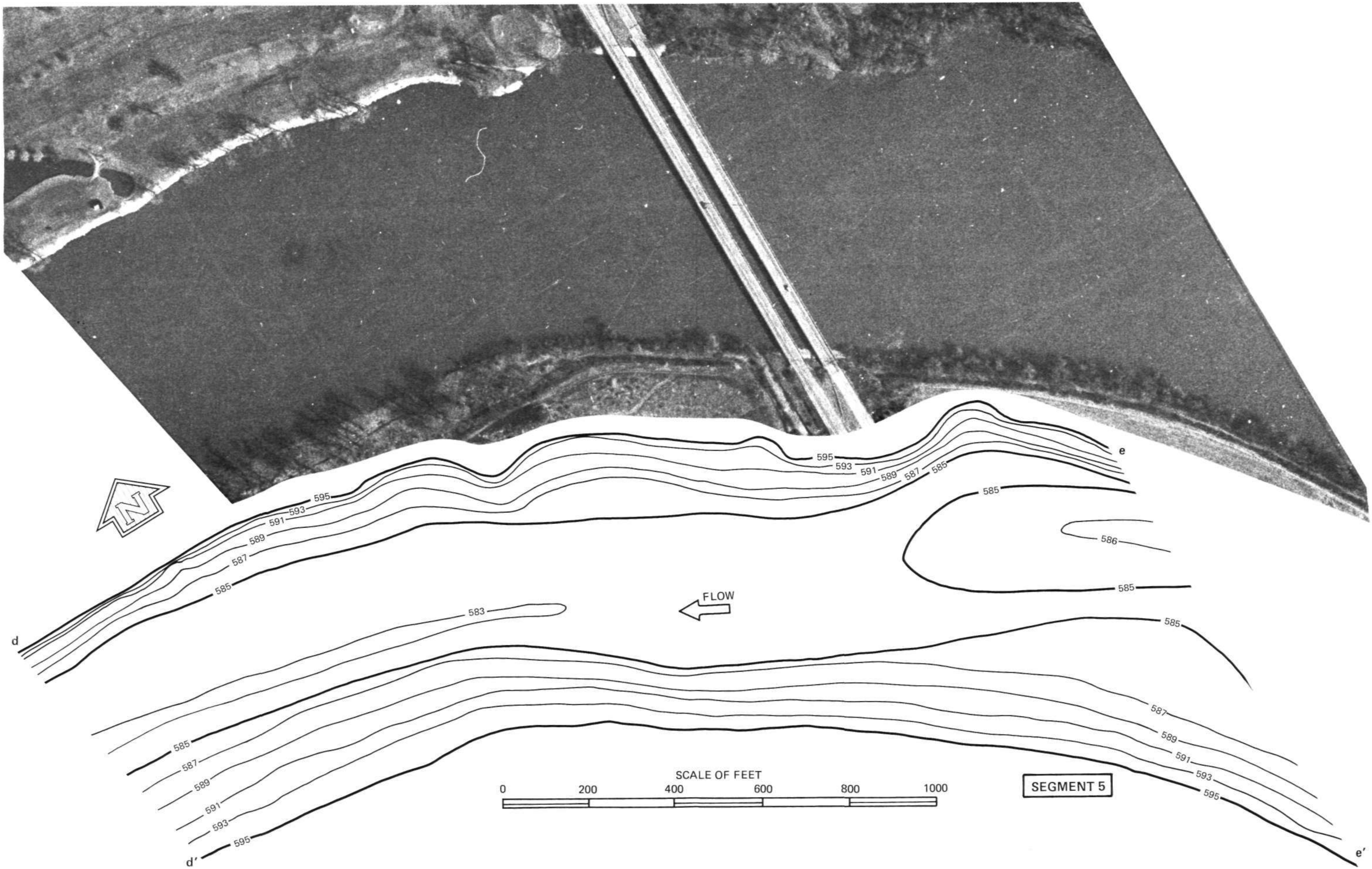


a
b
a′
b′
595
593
591
589
587
585
583
582
581
579.5
579
577
FLOW
N
SCALE OF FEET
0
200
400
600
800
1000
SEGMENT 2

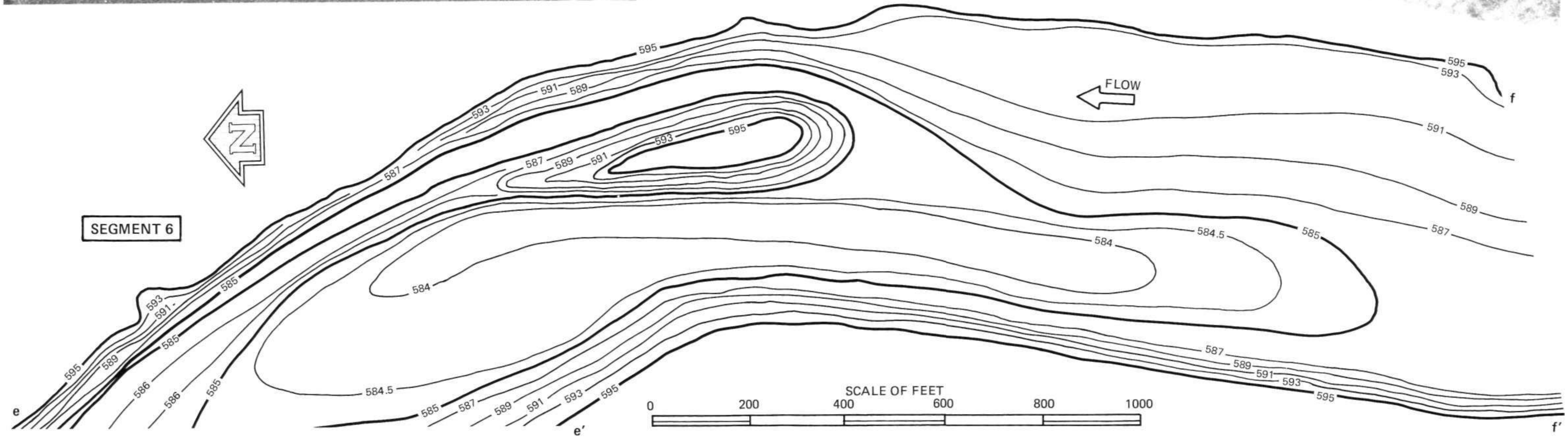

b
c
b′
c′
595
593
591
589
587
585
583
582
581
579.5
FLOW
SCALE OF FEET
0
200
400
600
800
1000
SEGMENT 3

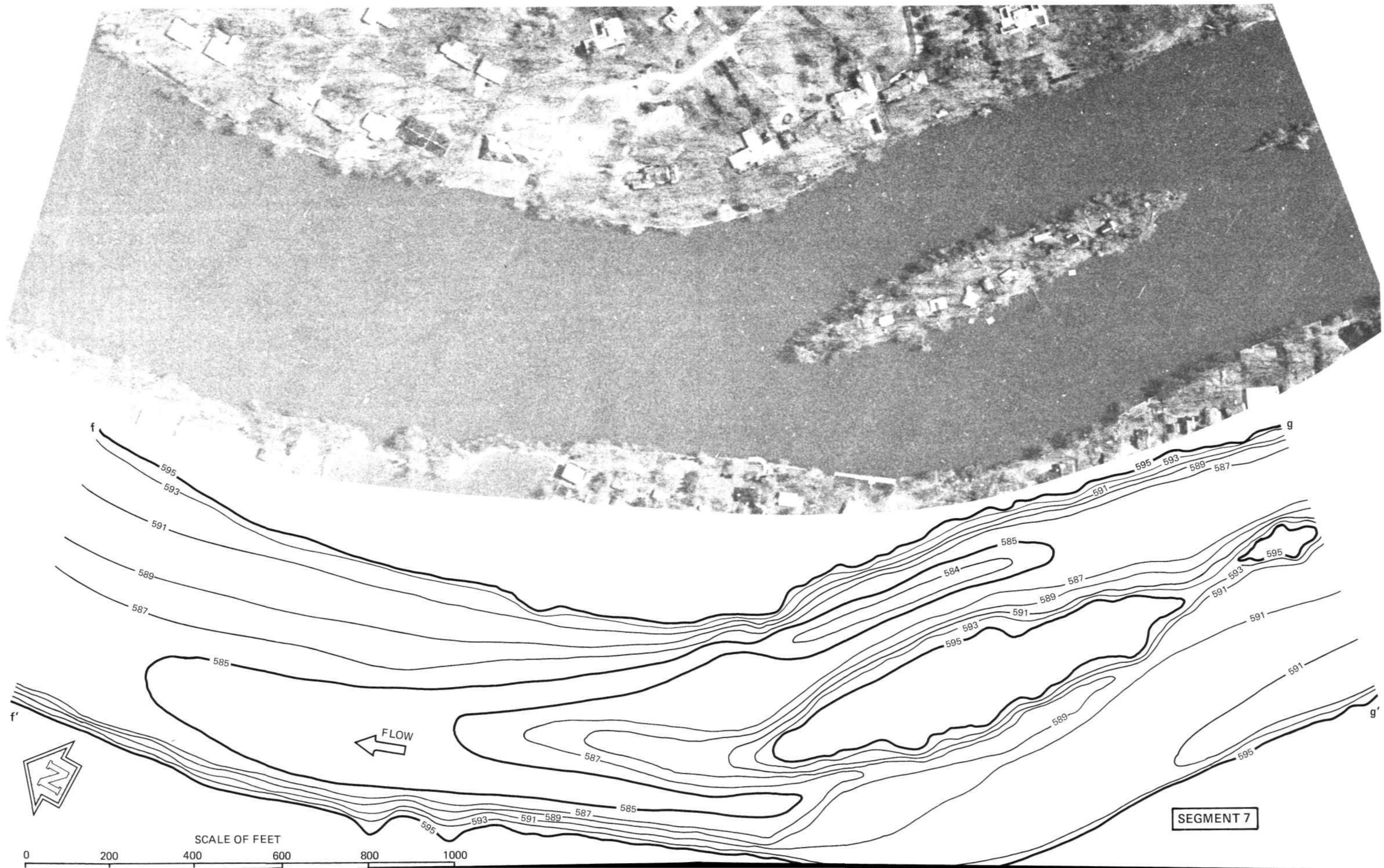

c
d
595
593
591
589
587
585
583
581
FLOW
c′
d′
SCALE OF FEET
0
200
400
600
800
1000
N

SEGMENT 4



N
FLOW
d
d′
e
e′
595
593
591
589
587
585
586
583
SCALE OF FEET
0
200
400
600
800
1000
SEGMENT 5


SEGMENT 6
FLOW
SCALE OF FEET
0 200 400 600 800 1000
595
593
591
589
587
585
586
584.5
584
e
e′
f
f′



f
g
595
593
591
589
587
585
584
595
f'
g'
FLOW
SEGMENT 7
SCALE OF FEET
0
200
400
600
800
1000


SEGMENT 8
N
FLOW
SCALE OF FEET
0
200
400
600
800
g
g′
h
h′
595
593
591
589
587
585.5
585
583
582

h′
h
SEGMENT 9
FLOW
N
SCALE OF FEET
0
200
400
600
800
581.5
582
583
585
587
589
591
593
595