Illinois State Water Survey Division

SURFACE WATER SECTION

SWS Contract Report 484

CACHE RIVER BASIN: HYDROLOGY, HYDRAULICS, AND SEDIMENT TRANSPORT

VOLUME 1: BACKGROUND, DATA COLLECTION, AND ANALYSIS

by Misganaw Demissie, Ta Wei Soong, Richard Allgire,
Laura Keefer, and Paul Makowski

Prepared for the
Illinois Department of Conservation

Champaign, Illinois
January 1990

Illinois Department of Energy and Natural Resources

CACHE RIVER BASIN: HYDROLOGY, HYDRAULICS, AND SEDIMENT TRANSPORT

VOLUME 1: BACKGROUND, DATA COLLECTION, AND ANALYSIS

by Misganaw Demissie, Ta Wei Soong, Richard Allgire,
Laura Keefer, and Paul Makowski

Illinois State Water Survey
2204 Griffith Drive
Champaign, IL 61820- 7495

Prepared for the
Illinois Department of Conservation

Champaign, Illinois
January 1990

CONTENTS

Concluded on next page

Page

CACHE RIVER BASIN: HYDROLOGY, HYDRAULICS, AND SEDIMENT TRANSPORT
VOLUME 1: BACKGROUND, DATA COLLECTION, AND ANALYSIS

by
Misganaw Demissie, Ta Wei Soong, Richard Allgire,
Laura Keefer, and Paul Makowski

INTRODUCTION

Location

The Cache River basin is located in the extreme southern part of Illinois, just north of the confluence of the Ohio and Mississippi Rivers, as shown in figure 1. The basin covers parts of the six southern Illinois counties of Union, Johnson, Alexander, Pulaski, Massac, and Pope. The total drainage area of the watershed is 737 square miles. Since the construction of the Post Creek Cutoff in 1915, the Cache River basin has been divided into two subwatersheds: the Upper Cache and Lower Cache River watersheds, as shown in figure 2. The Upper Cache watershed consists of the eastern part of the Cache River basin with a drainage area of 368 square miles; it drains directly to the Ohio River at River Mile 957.8 through the Post Creek Cutoff. The Lower Cache River watershed consists of the western part of the Cache River basin with a drainage area of 358 square miles; it drains to the Mississippi River at River Mile 13.2 through the diversion channel at the downstream end of the river. Eleven square miles of the Lower Cache River watershed continue to drain into the Ohio River at River Mile 974.7 through the original channel.

Need for Collection of Hydrologic, Hydraulic, and Sediment Data.

In 1984, only one continuous streamgaging and sediment station (Cache River at Forman) in the Cache River watershed was being monitored. The gaging station was operated by the U.S. Geological Survey (USGS), and the sediment data were collected by the Illinois State Water Survey as part of the Instream Suspended Sediment Monitoring Network. Because of the complex nature of the Cache River, data from more than one station are required to define the dynamics of the river. Furthermore, the construction of the Post Creek Cutoff has drastically altered the flow pattern in the Lower Cache River. For instance, the Cache River in the Buttonland Swamp area flows east towards the Post Creek Cutoff or west towards the Lower Cache River depending on the water-surface elevations in the Lower Cache River and on tributary inflows. There have been no documented data about water discharge in the Lower Cache River that show the changes in the flow regimes of the Lower Cache River. The water discharge from the Upper Cache River was measured at the gaging station at

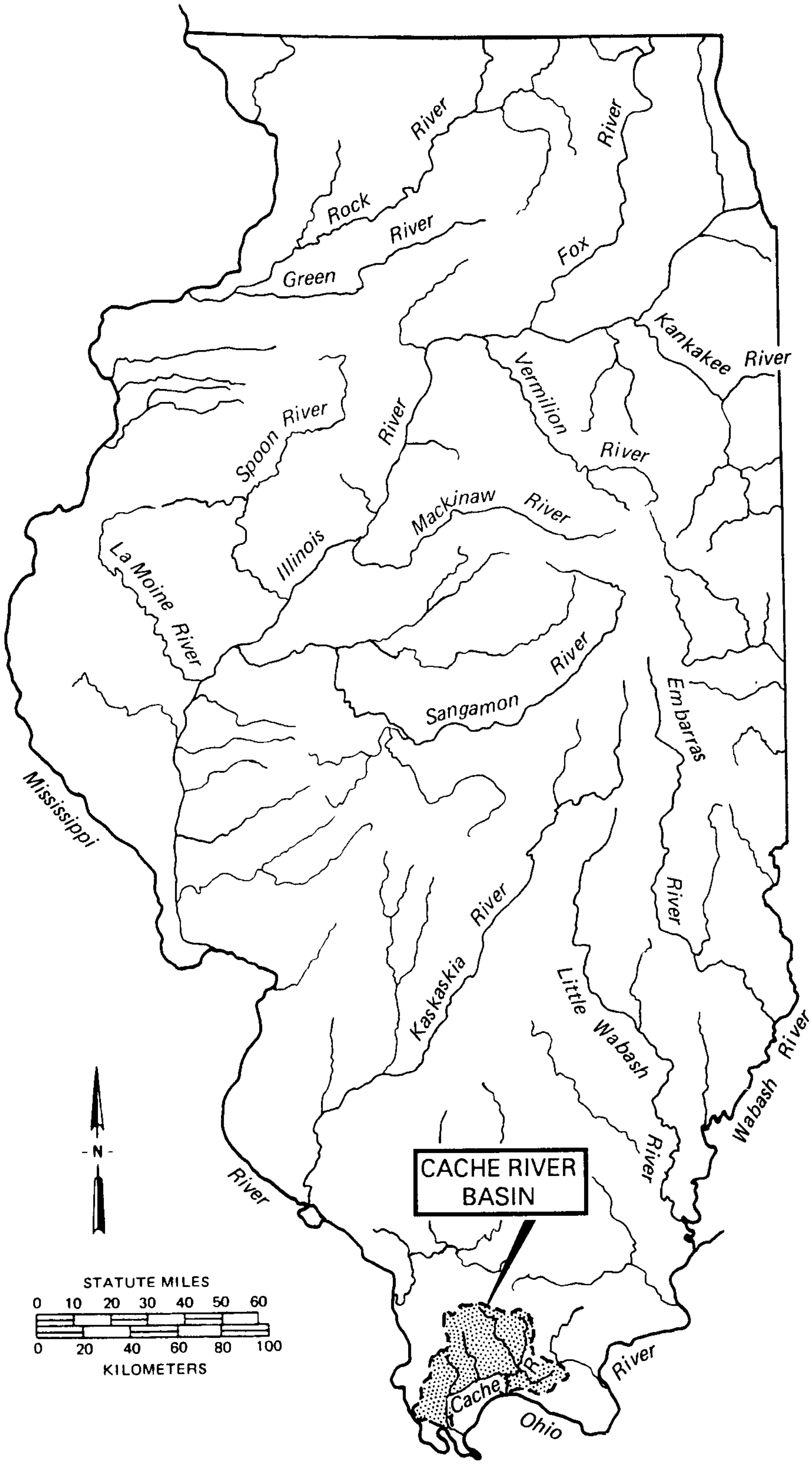


Figure 1. Location of the Cache River basin in Illinois

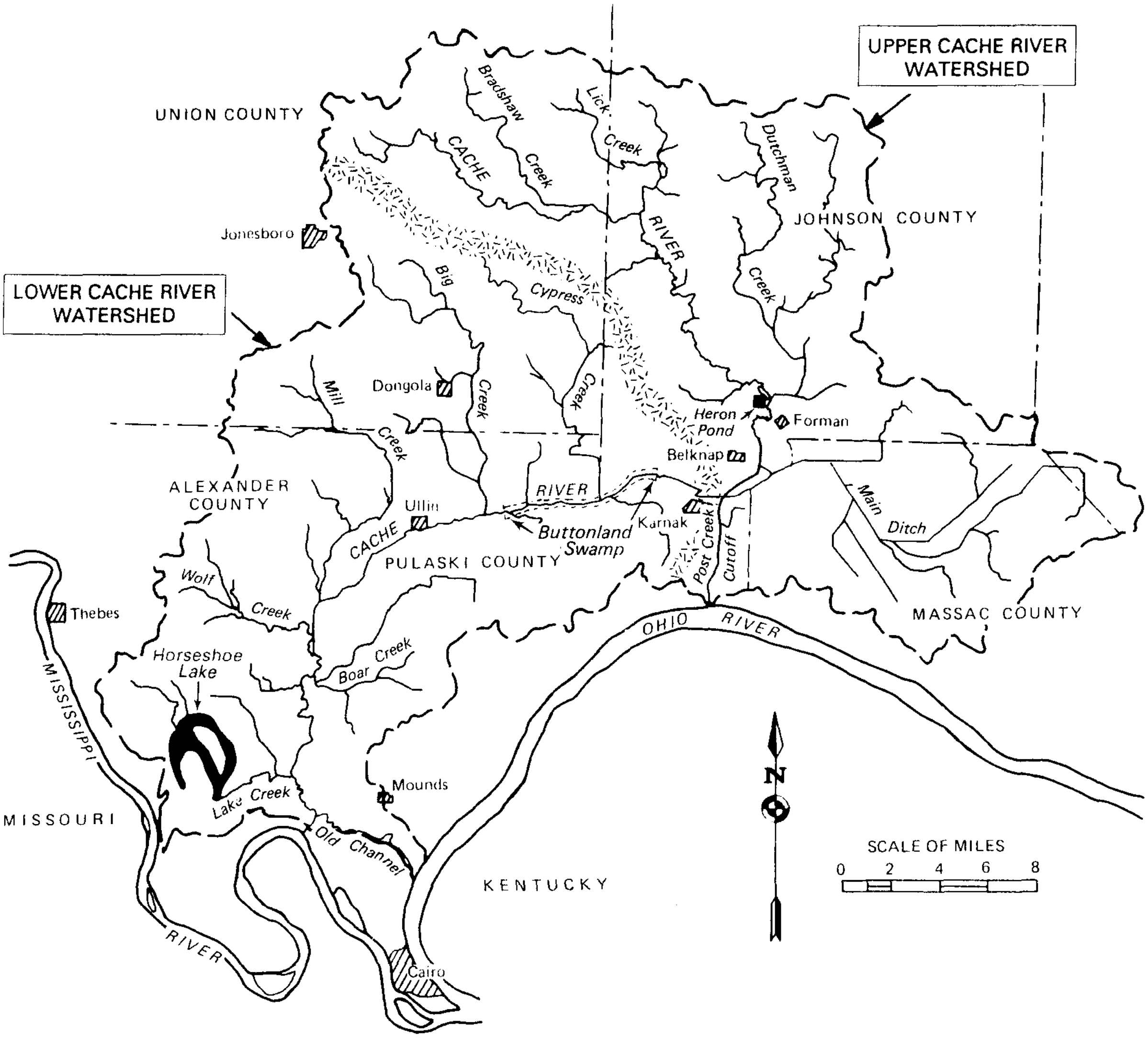


Figure 2. The Upper and Lower Cache River

Forman. Thus the flow record at Cache River near Forman does not show the impact of the Cutoff.

The construction of the Post Creek Cutoff not only altered the flow conditions in the Lower Cache River but also changed the sediment transport dynamics in the Lower Cache River and in Buttonland Swamp. Sediment transported by tributary streams that used to be flushed by the annual flood in the Cache River is now deposited at a higher rate in Buttonland Swamp and around the mouth of the tributary streams. Also, tributary streams such as Cypress Creek, Big Creek, Mill Creek, and many other smaller creeks have been channelized and re-routed several times in the past. Thus the present flow conditions and sediment transport characteristics of the Cache River basin are drastically different from the natural conditions which existed before human manipulation of the stream channel.

To understand and document these complex hydraulic problems and to develop and evaluate the best alternative solutions to the problems, the Illinois State Water Survey designed the Cache River project. The project, which was initiated in 1985, had the following four main tasks:

1) Review and analyze existing data, reports, and other relevant information about the basin.
2) Design and install streamgaging and sediment monitoring stations in the basin to understand and document the complex hydrologic and hydraulic characteristics of the Cache River.
3) Develop hydrologic and hydraulic models for the river to generalize the data being collected and to evaluate different conditions not encountered during the data collection period.
4) Develop a list of alternative solutions for the many problems in the basin and evaluate each alternative as to its effectiveness.

Of the four main tasks, the installation and maintenance of streamgaging and sediment stations and the data collection and analyses that were required consumed the most project time and financial resources. This report, which deals with the first two major tasks mentioned above, presents the bulk of the results of the Cache River project.

Report Organization

Since 1985, the Water Survey has been collecting hydrologic, hydraulic, and sediment data in the Cache River basin. This report is volume 1 of the first comprehensive report prepared by the Water Survey on the Cache River and the Cache River project. A brief report published in 1985 (Demissie and Bhowmik, 1985) described the nature of the problems in the basin and outlined the Cache River project. In addition, one brief progress report (Demissie et al., 1987) summarized the data being collected and the progress in the analysis of the data.

The final results for the Cache River study have been organized into two volumes. This volume deals with background information, data collection, and analysis. The second volume presents the results of mathematical modeling for the project. In addition to these two volumes, a report has been prepared that outlines problems, alternative solutions, and recommendations.

The "Background" section of this report reviews existing information on watershed characteristics and historical developments. The following section describes the hydrology and hydraulics of the basin, including the influence of the Ohio and Mississippi Rivers on the Cache River. Discussions of erosion and sedimentation and of water quality in the Cache River basin are presented next, followed by a summary of the report. The appendices, which include all the data collected for the project, are printed in a separate volume along with the appendix for volume 2.

Acknowledgments

This work was accomplished as part of the regular work of the Illinois State Water Survey under the administrative guidance of Richard G. Semonin, Chief; Richard J. Schicht, former Assistant Chief; Michael L. Terstriep, Head of the Surface Water Section; and Nani G. Bhowmik, Assistant Head of the Surface Water Section.

The work upon which this report is based was supported in part by funds provided by the Illinois Department of Conservation (IDOC). Marvin Hubbell is the project manager for IDOC and provided valuable guidance for the project. Several Surface Water Section staff members assisted during different phases of the project from installation of the gaging stations to data collection. We would like to acknowledge the assistance of Kevin Davie, William P. Fitzpatrick, Mark Grinter, and Don Blakley. Assistance in data analysis was provided by Renjie Xia, a graduate student in civil engineering at the University of Illinois; Ann Marie Riggert, an undergraduate student in biology at the University of Illinois; and Walter F. Reichelt, an undergraduate student in computational mathematics at Eastern Illinois University. Kathleen Brown and Becky Howard typed the report, Gail Taylor edited it, and Linda Riggin prepared the illustrations.

BACKGROUND

The Cache River basin is unique in Illinois because of its location and physical characteristics. It is located between and just upstream of the junction of the two largest rivers in the region, the Mississippi and the Ohio Rivers. Major floods in these two rivers have controlled and continue to control the drainage and flooding in the Lower Cache River. The unique physical features and land-use patterns of this area stem from the fact that this is the only major watershed in Illinois that has not been glaciated. Because of its unique physical characteristics and location, flooding and drainage have not been favorable to agricultural development in the lower part of the basin. Many drainage and flood control projects have been undertaken to improve the situation since the late 1800s. Some of these projects have had a lasting impact on the character and nature of the river.

Before any comprehensive management plans are developed, it is important that the past developments in the river basin be documented and properly understood. This part of the report first outlines the physical characteristics of the watershed and then discusses the historical developments and manipulations.

Watershed Characteristics

A knowledge of the physical characteristics of the watershed is vital to an understanding of basin dynamics. These characteristics provide important information that assists in understanding the quantity of runoff and sediment yield from the watershed. The quantity of water that results in runoff is dependent not only on precipitation but also on many physical factors such as the slope of the watershed and stream channels, soil type, vegetative cover, and catchment area. The watershed characteristics can also be used to quantify the amount of soil that has the potential to be eroded and to identify the locations of severe erosion and the areas in which sediment deposition is expected. The following subsections discuss watershed characteristics pertaining to geology, physiology, topography, soils, and drainage. The discussions are brief, but important reference materials are identified for those interested in more detailed information.

Geology

Much of the surficial geology of Illinois is a result of the glaciers that covered the state at various times during the great ice age. About 90% of Illinois has been glaciated at least once. The glaciers that covered Illinois are the same glaciers that covered most of North America during the Pleistocene epoch of the Quaternary period. Even though all four major glacial stages in North America (Nebraskan [earliest], Kansan, Illinoian, and Wisconsinan [latest]) are believed to have involved some parts of Illinois, the two most recent ones, the Illinoian and the

Wisconsinan, had the most significant impact on the surficial geology of Illinois. This is illustrated by figure 3, where the areas covered by the drifts left by the different glaciers are shown. The surficial geology of northeast and east-central Illinois is the result of the Wisconsinan drift. The rest of the state is covered with Illinoian drift, with the exception of the driftless areas in southern and northwest Illinois and the area in western Illinois just upstream of the junction of the Illinois with the Mississippi River, which consists of Kansan drift and a small driftless area.

As shown in figure 3, the southern limit of glacial drift does not reach extreme southern Illinois, where the Cache River is located. Therefore the land surfaces of the Cache River uplands are driftless and pre-glacial. However, the low-lying areas and the river valleys were impacted by drift carried by glacial rivers, especially the Ohio River. The low-lying areas and river valleys in extreme southern Illinois are covered with lake deposits from the Wisconsinan stage and with more recent (Holocene) alluvium. The alluvium is mainly from deposits of the Cache, Ohio, and Mississippi Rivers. The lake deposits are believed to be from a glacial lake named Cache Lake, which was created when outwash sediments carried by the melting waters from the Wisconsinan glacier in the Ohio River were deposited at tributary mouths, blocking drainage from tributary streams into the Ohio River. These blockages in essence created dams that held back water draining from tributary streams, thus creating the lake. The lake deposit in the Cache River valley is believed to have been sediment deposited in Cache Lake. On top of much of the glacial lake deposits, alluvial deposits from the Cache, Ohio, and Mississippi Rivers are found.

The bedrock, which is at the ground surface or beneath the glacial materials and loess (glacial sediments of windblown silt and clay), consists of beds of sedimentary shales, sandstone, limestone, dolomite, and chert (a cryptocrystalline variety of quartz), arranged one upon the other. The bedrock systems are layered, with the younger systems closer to the land surface, as may be seen in figure 4 for a south-north cross section through southern Illinois. These systems from the top to the bottom are Pennsylvanian, Mississippian, Devonian, Silurian, Ordovician, and Cambrian. The surficial bedrock within the Cache River basin (which is the bedrock on top) is shown in figure 5. Most of this bedrock is covered by varying layers of material. The bedrock strata rest on a basement of ancient crystalline rocks composed mainly of granite. These beds were originally deposited as sediments in shallow seas or borders and later were buried and hardened into solid rock. The rock systems were later warped and in some places fractured, so that they are no longer horizontal (Pryor, 1956).

The warpage of the bedrock now results in the western side dipping eastward and the southern part dipping northward. The deepest part of this bedrock lies in White County northeast of the watershed, where it is buried at a depth of several thousand feet below the

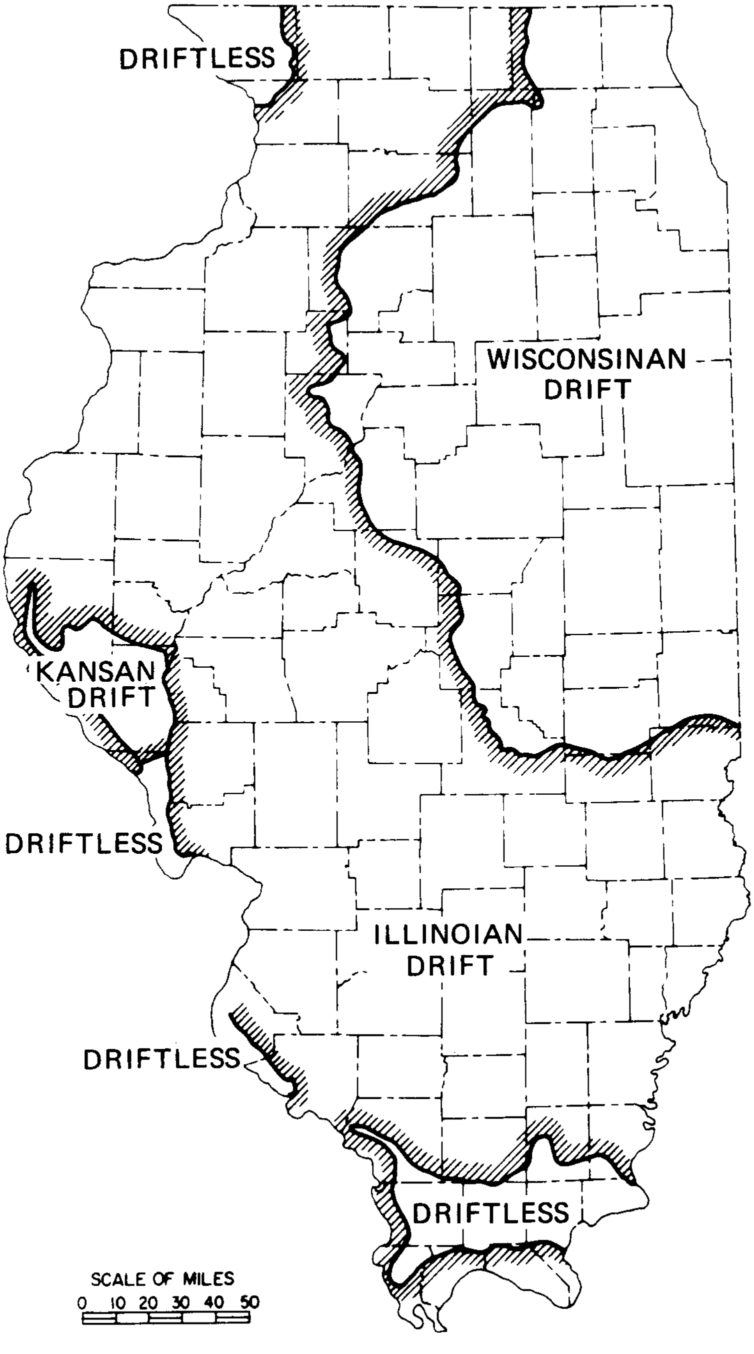


Figure 3. Glacial drifts in Illinois

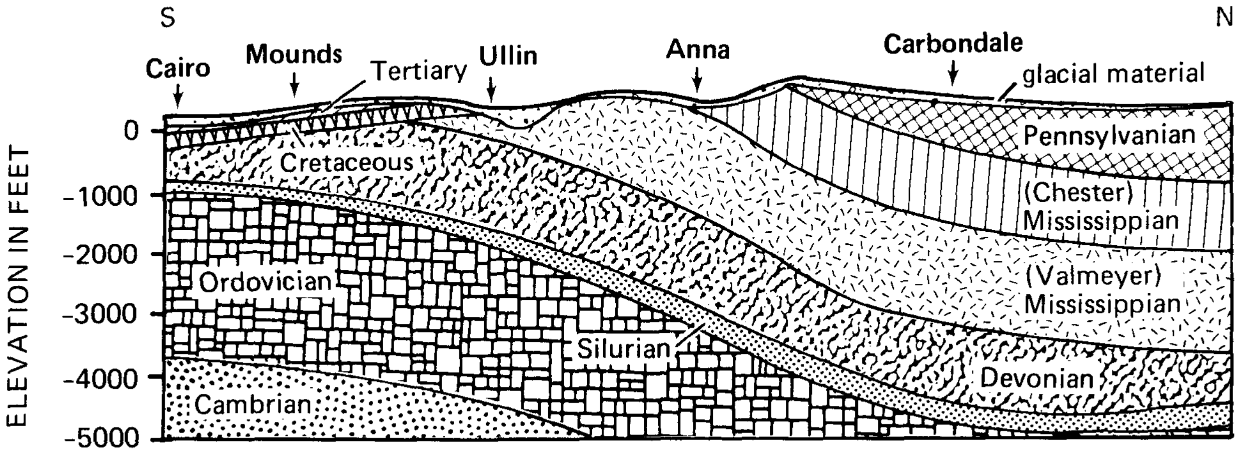


Figure 4. Cross section of bedrock in southern Illinois

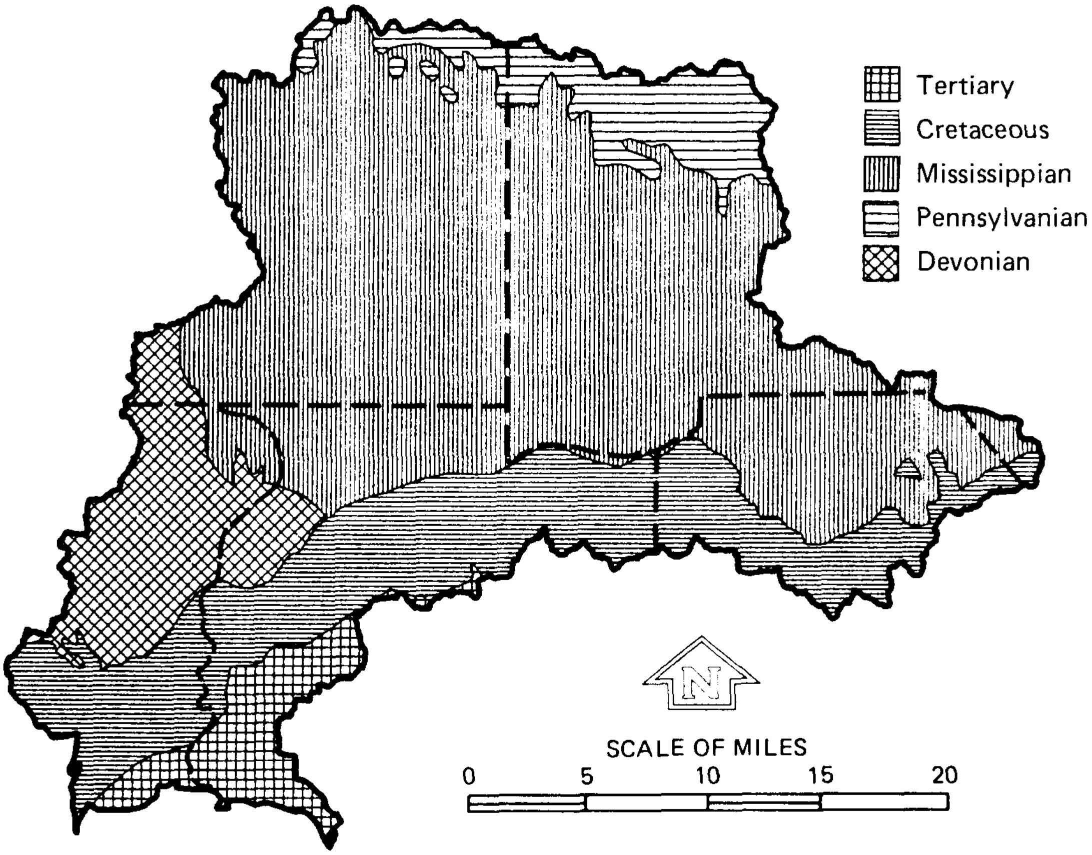


Figure 5. Surficial bedrock below glacial drift in Cache River basin

surface, while the same rock formation is exposed along the Mississippi River north of Cairo. Along with being tilted and folded, the bedrock strata have been fractured along fault systems. Movement along the fault zone has resulted in rocks being displaced by as much as 3500 feet (Pryor, 1956).

Physiology

A physiographic province is a region in which all the parts are similar in geologic structure and which has a unified geomorphic history. The physiographic differences between various parts of Illinois are due to the “topography of the bedrock surface, extent of glaciation, differences in the ages of the uppermost drift, height of the glacial plain above main lines of drainage, glaciofluvial aggradation of basin areas, and glaciolacustrine action” (Leighton, Ekblaw, and Horberg, 1948).

The entire Cache River basin lies outside the glacial advances. The upper nine-tenths of the state of Illinois lies within the Central Lowland Province and has experienced glaciation at least one time (except for the Wisconsin Driftless Section in northwestern Illinois). The higher uplands of southern Illinois prevented the further southward advance of the glaciers.

The Cache River basin lies within three different physiographic provinces: the Ozark Plateaus Province (Salem Plateau Section), the Interior Low Plateaus Province (Shawnee Hills Section), and the Coastal Plain Province. In addition, the Central Lowland Province (Till Plains Section, Mount Vernon Hill Country) is immediately north of the basin (Leighton, Ekblaw, and Horberg, 1948). The physiographic divisions in southern Illinois are shown in figure 6. A brief discussion of the characteristics of the physiographic divisions in southern Illinois follows.

The Ozark Plateaus Province forms a discontinuous upland along the southwest margin of the state and represents the eastern edge of an extensive upland in southern Missouri and northern Arkansas. The Salem Plateau Section of the Ozark Plateaus Province is underlain by Devonian chert and cherty limestone which, in the southern unglaciated segment, are overlapped by coastal Plain sediments. A clearly defined physiographic boundary separates the Salem Plateau Section of the Ozark Plateaus Province from the Shawnee Hills Section of the Interior Low Plateaus Province to the east and north, with more rugged hills, closer drainage texture, absence of structural control, and higher elevations found in the plateau section. Most of the plateau is maturely dissected by intricate dendritic drainage (irregular branching tributaries joining the main stream at all angles), although small remnants of a flat upland surface remain. A central divide separates the Mississippi and Cache River valleys. Most of the larger tributary valleys are deeply alluviated (deposited by river sediments), and only the

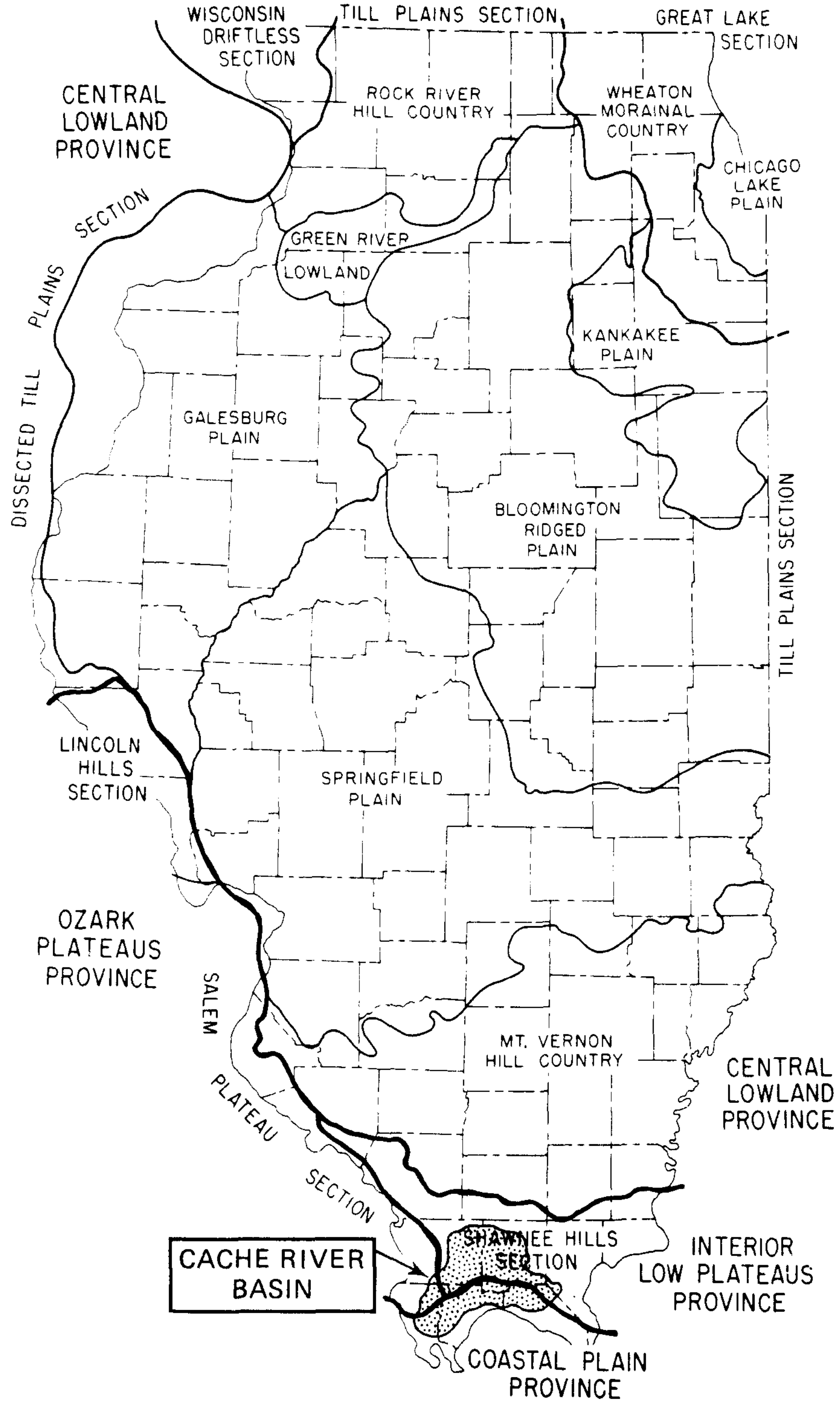


Figure 6. Physiographic divisions of Illinois

secondary tributaries are youthful. The topography was modified during the glacial period by the alluviation of the major valleys (Leighton, Ekblaw, and Horberg, 1948).

The Shawnee Hills of the Interior Low Plateaus Province are popularly referred to as the "Illinois Ozarks." The Pennsylvanian cuesta (a sloping plain terminated on one side by a steep slope) forms a continuous ridge extending across the state. In most places the ridge is maturely dissected (cut by erosion into hills and valleys) by youthful valleys, but remnants of the flat upland are locally preserved on narrow ridge crests throughout the length of the escarpment (a steep face abruptly terminating high lands). The plateau on Mississippian rocks to the south is maturely dissected, and the larger valleys are alluviated. These alluviated valleys reflect the local structure of the bedrock. The erosional history of the region is similar to that of the Ozark Plateaus previously discussed (Leighton, Ekblaw, and Horberg, 1948).

The Coastal Plain Province forms the most southern part of the state. The alluvial plains of the Coastal Plain Province are characterized by terraces and recent floodplain features. The hills are maturely eroded into a low upland of gently sloping knolls and ridges. Outwash and alluvium extended far up tributary valleys, so that the upland is partially buried and certain segments are essentially isolated. Prior to glaciation, the Cache River valley was occupied by the Ohio River, and the present Ohio River valley was occupied by the Cumberland and Tennessee Rivers. During the glacial period, the valleys were aggraded to the level of the divide between the Ohio and Cumberland Rivers, and the lower course of the Ohio River was opened. Both courses were used during floods as the Ohio River water passed through the Cache River valley, and it was in recent times that the southern channel became the permanent course of the Ohio River (Leighton, Ekblaw, and Horberg, 1948).

Topography

The elevations in the Cache River watershed range from 890 feet mean sea level (msl) in the northernmost portion of the watershed to a low of 280 feet msl at the Mississippi River. There are many areas in the watershed where the local relief is several hundred feet. The steepest slopes occur in the upper portion of the watershed adjacent to the river valleys; the valley and bottomland areas, in contrast, offer little relief. Typically, runoff from the upland areas moves very quickly into the river valleys and bottomland areas. The bottomland areas slow the floodwaters that run off the steep areas and then release them downstream very slowly.

Soils

Soil surveys of the Cache River basin have been conducted by the Soil Conservation Service (SCS) in cooperation with the Illinois Agricultural Experiment Station, and the results have been published in the form of reports and maps (Parks and Fehrenbacher, 1968;

Fehrenbacher et al., 1984). The soil associations for the watershed as generated by the Geographic Information System (GIS) at the Water Survey are shown in figure 7. The GIS data are based on the General Soil Map of Illinois developed by the Agricultural Experiment Station in cooperation with the SCS (Fehrenbacher et al., 1984). The soil association map provides a general picture of soil types in the area. The Cache River area includes six different soil associations. The upland areas with steep slopes have Alford-Goss-Baxter, Hosmer-Zanesville-Berks, and Grantsburg-Zanesville-Wellston associations. The Alford-Goss-Baxter soil association is found in the uplands in the western and southern parts of the watershed. The soil is found only in southern Illinois and is formed in deciduous forests on steep and strongly dissected upland areas. The soil is generally well drained. The problems associated with this type of soil include susceptibility to erosion, low organic matter in the surface layer, and low available-water storage capacity.

The Hosmer-Zanesville-Berks soil association is found in the uplands in the Cache River watershed. It occurs only in extreme southern Illinois in the Ozark uplift region and has never been affected by continental glaciation. It is found on rough, sloping, and dissected uplands where outcrops of bedrock, rock escarpments, and boulders are common. Streams and tributaries provide good drainage. The problems associated with this type of soil are similar to those of the Alford-Goss-Baxter association and include susceptibility to erosion, low organic matter in the surface layer, low fertility, and low available-water holding capacity.

The Grantsburg-Zanesville-Wellston soil association is found in the northeastern comer of the Cache River watershed. In general, it occurs only in extreme southern and southeastern Illinois and has not been influenced by continental glaciation. It is located on dissected and sloping uplands that are covered by thin to 7-foot-thick loess. The sloping topography and the streams and tributaries provide good drainage to this well-drained soil. The problems associated with this type of soil are similar to those of the upland soils in the Cache River watershed and include susceptibility to erosion, low organic matter in the surface layer, low fertility, and low available-water holding capacity.

The river valleys and floodplains consist of the Lawson-Sawmill-Darwin, Martinsville-Sciotoville, Oakville-Lamont-Alvin, and Haymond-Petrolia-Karnak soil associations. These soils are generally described as being found in bottomlands and stream terraces. A large part of the Cache River valley is covered by Haymond-Petrolia-Karnak and Martinsville-Sciotoville soil associations. The Oakville-Lamont-Alvin and Lawson-Sawmill-Darwin associations are found only on the western end of the Cache River valley around Horseshoe Lake. The major floodplain soil association is the Haymond-Petrolia-Rarnak. It covers most of the Cache River floodplain, including the floodplain of most of the tributary streams; occurs in small and large floodplains; and has a light color, with low to medium organic content. It is formed in stratified

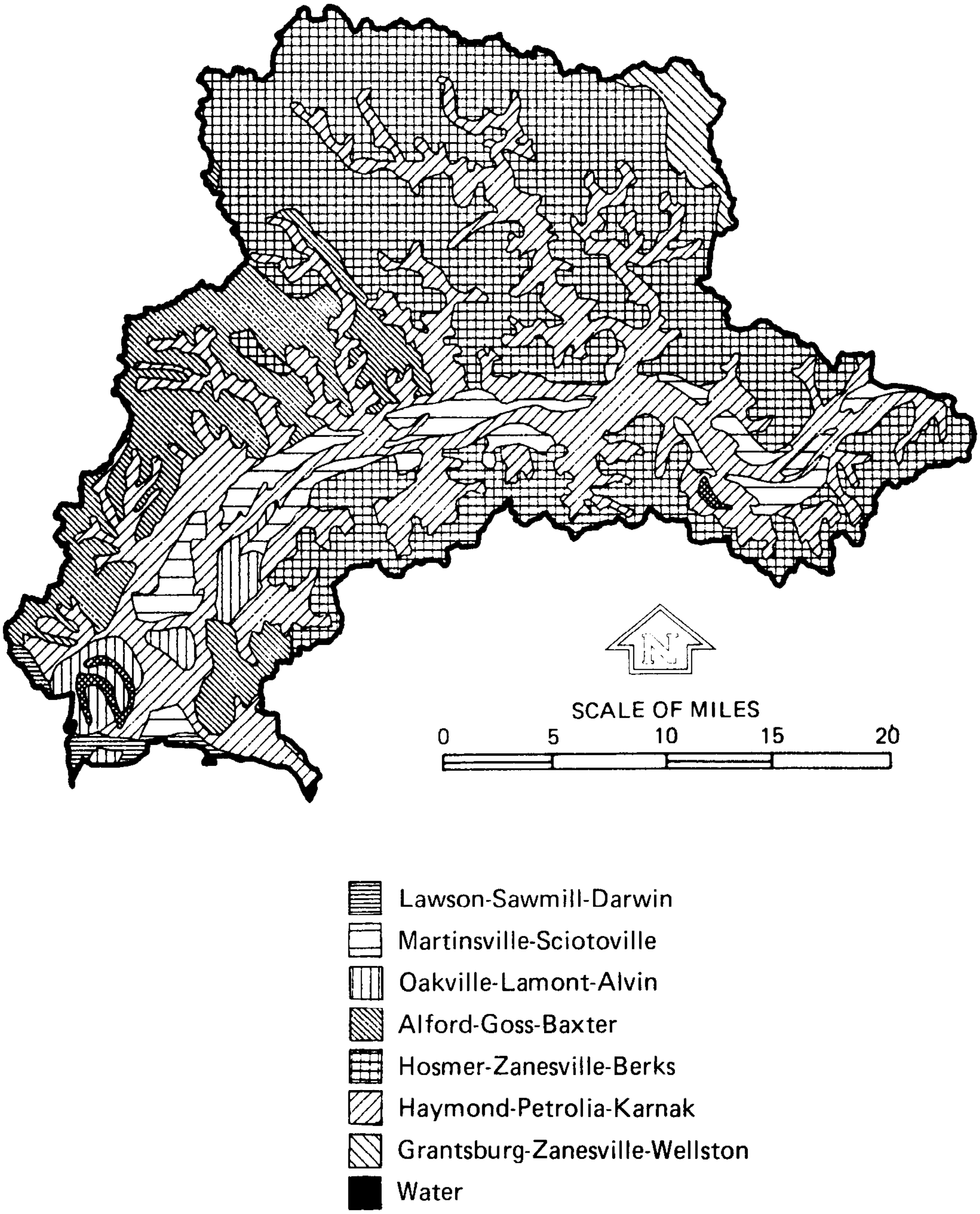


Figure 7. Distribution of soil associations in the Cache River basin

clayey to sandy alluvium, can be poor- or well-drained soil, and is found in nearly level to gently sloping areas. The problems associated with this type of soil include flooding, wetness, and low organic content.

The next most abundant soil association in the Cache River valley is the Martinsville-Sciotoville, which is associated with sediments deposited by the Ohio River in this part of the state. It is formed in thin or silty or loamy materials on sandy, Wisconsinan outwash and has a light color. It is generally well drained and has moderate water-holding capacity. It can have an erosion problem in sloping areas.

The Oakville-Lamont-Alvin soil association is found around Horseshoe Lake and two other areas just east of the lake. This soil association is high in sand content and was deposited by wind or by water from rivers, streams, and glacial outwash. It is formed in sandy glacial outwash, sandy alluvium, or sandy aeolian material. It occurs on nearly level to very steep terraces and on uplands, is generally well drained, and has moderate to low available-water holding capacity. The main problems with this type of soil are related to erosion and droughtiness.

The Lawson-Sawmill-Darwin soil association is found only in the extreme southwestern tip of the watershed. However, this type of soil is found in all major floodplains in Illinois and is dominant along the Mississippi and Illinois Rivers. It is formed in stratified clayey to sandy alluvium. It is dark or moderately dark-colored and is found mostly on nearly level ground, and occasionally on gently sloping ground. Its natural drainage is generally poor, and thus its major problems are associated with flooding and wetness.

Drainage

Drainage in the Cache River basin can be grouped into two distinct groups: upland and bottomland drainage. Upland areas are found throughout the watershed, except in the Cache River valley, which runs from the Reevesville levee on the east to the Mississippi River on the west as shown in figure 8. In the uplands, drainage is generally fast because of the steep slopes of the watersheds. Stream slopes in the uplands are generally about 15 feet per mile. The profiles of the major tributary streams in the watershed are shown in figure 9. As can be seen from the figure, the streams have steep slopes in the uplands and gradually flatten out as they reach the Cache River valley. There are no serious drainage problems in the uplands except in a few isolated areas. In the bottomlands, however, drainage is a major problem because of the slope of the Cache River valley. The slope of the Cache River valley from the Ohio River to the Cache River mouth at the Mississippi River is shown in figure 10. As shown in the figure, the valley is extremely flat, and thus the movement of floodwater through the valley is slow. All of

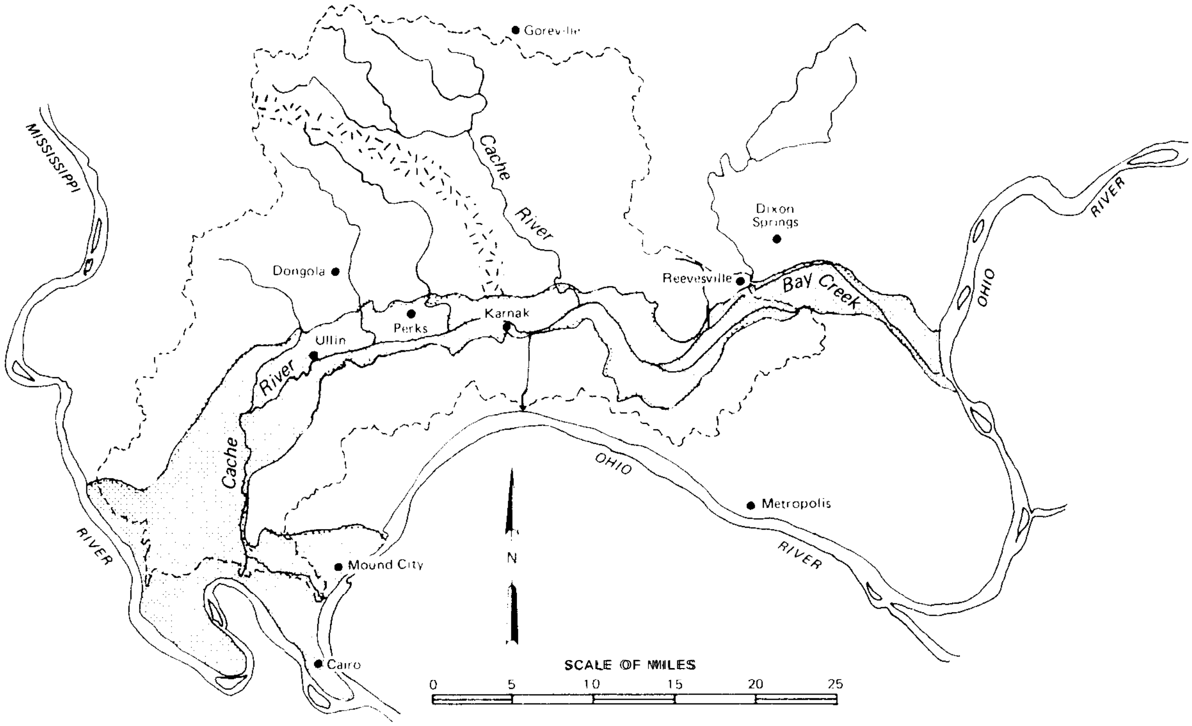


Figure 8. The Cache River valley

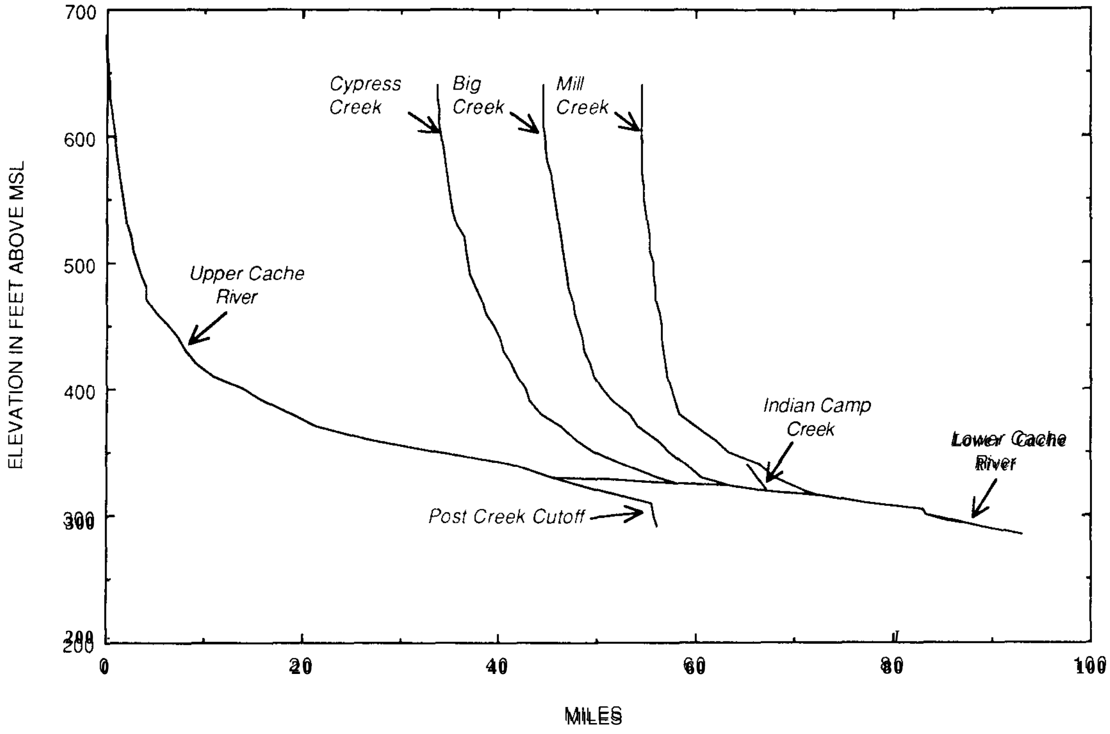


Figure 9. Profiles of major tributaries in the Cache River basin

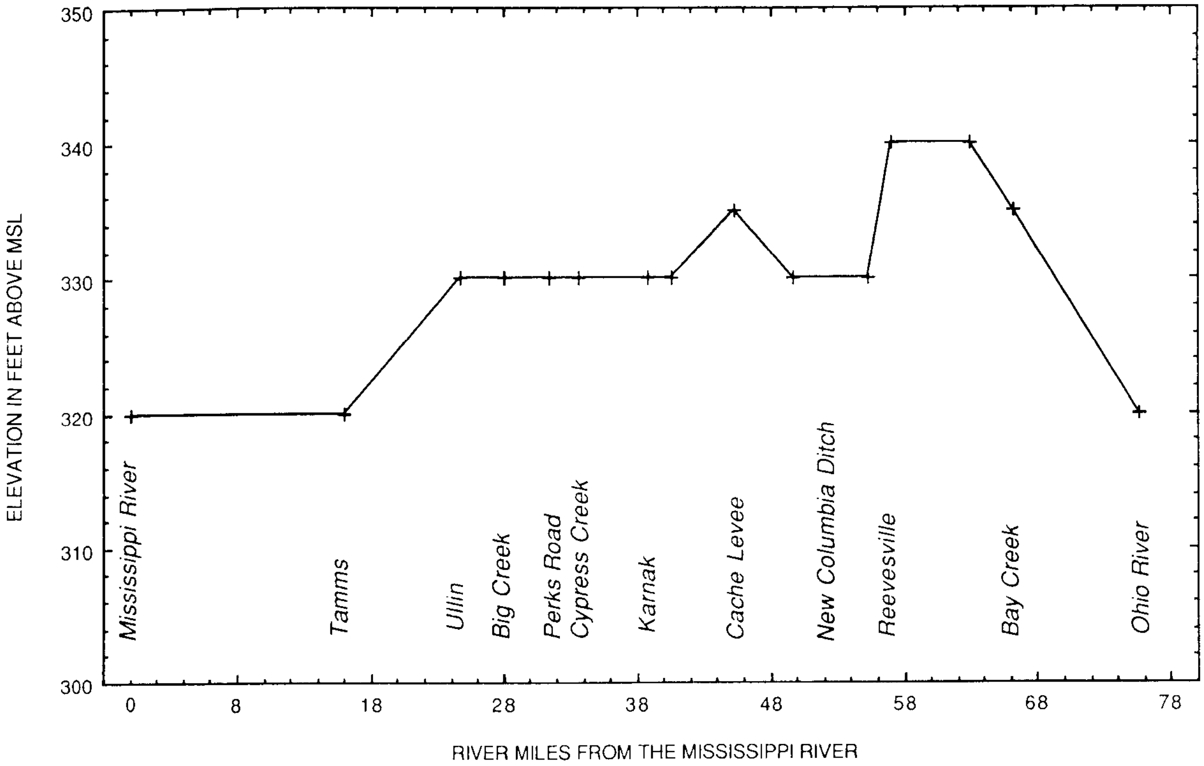


Figure 10. Profile of the Cache River valley

the upland streams discharge their floodwaters into the valley, creating backwater conditions throughout the valley and further upstream into the tributary stream channels.

The Lower Cache River is separated from the Upper Cache River and Main Ditch by the Cache River levee. While the flows from the Upper Cache River and Main Ditch drain through the Post Creek Cutoff, the flows from Cypress, Big, and Mill Creeks and Ketchell and Limekiln Sloughs still drain through the Lower Cache River. During most major storms, all of the creeks draining through the Lower Cache River dump their floodwaters into the valley in a short period of time. However, the floodwaters do not flow out of the Lower Cache River rapidly. The situation is almost similar to that in a flood-control reservoir, where floodwaters from upstream are stored and then gradually released downstream. During major floods, the flow velocities through the Lower Cache River valley are almost negligible, as floodwaters are stored in the valley.

To illustrate the storage and release of floodwaters in Buttonland Swamp, figure 11 was prepared. This figure shows the stage hydrographs for two flood events for Big and Cypress Creeks (two of the tributary streams draining into the Cache River), as well as for the middle (at Route 37) and the outlet (at Route 51) of the upper portion of the Lower Cache River. As shown in the figures, the hydrographs for Big and Cypress Creeks, which are the major tributaries discharging their water into the valley, rise and fall quickly. On the other hand, the hydrographs of the Cache River at Routes 37 and 51 rise quickly as flood waters are stored in the valley and recede slowly as the stored water is gradually drained.

In addition to these natural drainage characteristics, major floods in the Mississippi and Ohio Rivers back up water in the valley all the way to the Cache River levee. Therefore during major floods, drainage out of the Cache River valley is controlled by the Mississippi and Ohio Rivers. Thus in general, the natural drainage characteristics of the Cache River valley are poor. These poor drainage characteristics are the primary reason why the entire Cache River valley used to be swamps and wetlands.

Historical Developments

In addition to the physical characteristics of a watershed and natural processes such as climate, human activities greatly influence the hydrologic and hydraulic response of a watershed. Therefore, even under unchanged natural conditions, the hydrologic and hydraulic response of a watershed is under constant change due to different human activities in the watershed. Most of the significant human activities in a watershed are related to changes in land use practices, stream channel alterations, and dam and levee construction.

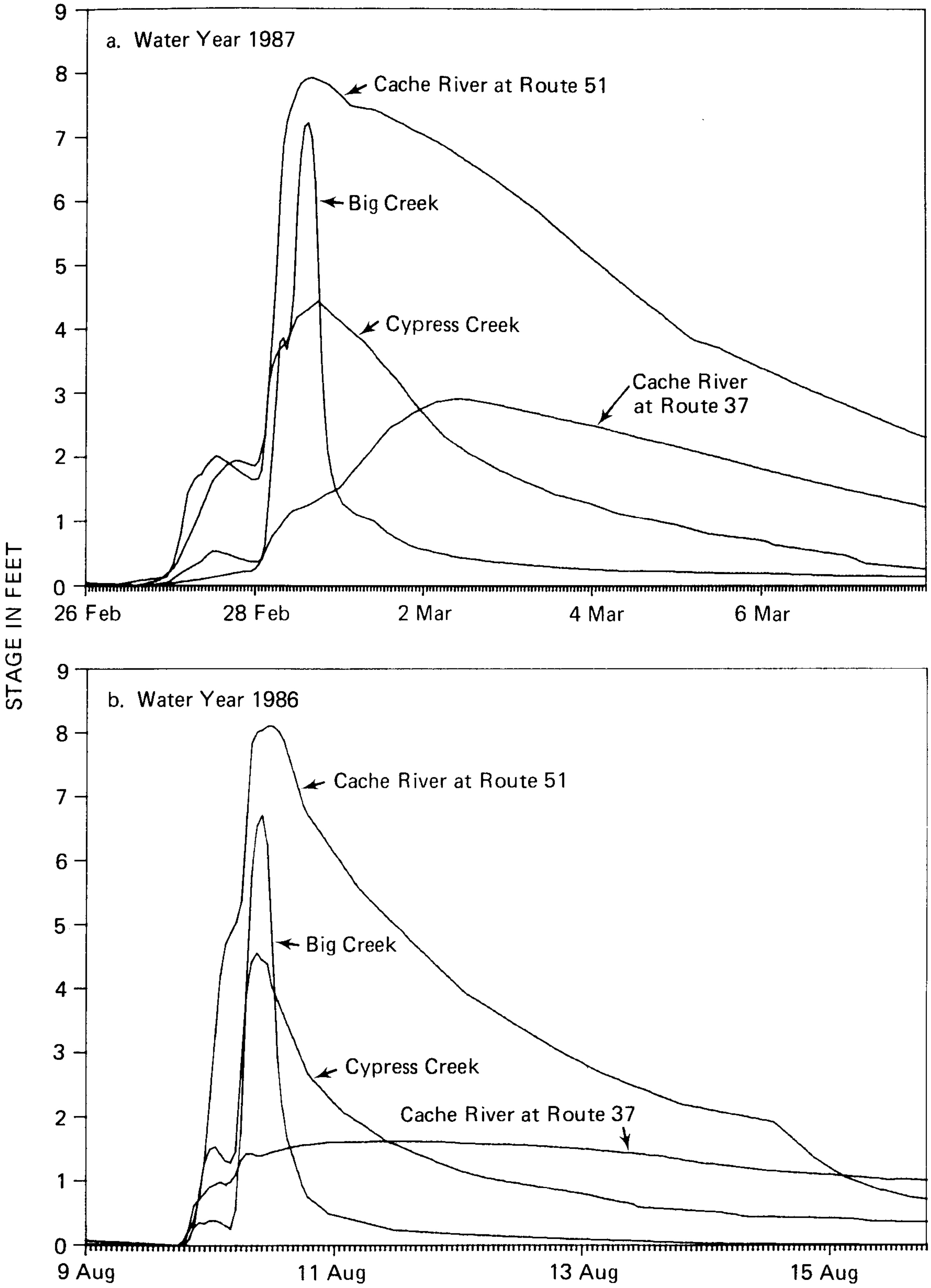


Figure 11.Comparison of stage hydrographs for the Lower Cache River and its tributary streams

In the Cache River basin, human activities including land use changes, stream channel alterations, and levee construction have had significant impact on the hydrology and hydraulics of the basin. A brief discussion of these changes is presented in the following sections.

Land Use

The primary reason for the shrinking acreage of wetlands in Illinois has been the drainage and conversion of wetlands into agricultural lands. As has been true for most of the state, agricultural development has played a significant role in the Cache River watershed. Presently, the predominant land use in the basin is agriculture, with more than 70% of the watershed (345,000 acres) in agricultural production. The second major land use, comprising about 20% of the watershed (99,000 acres), is forest. This is primarily due to the Shawnee National Forest, part of which is located in the northern and western parts of the watershed. The small remnants of a vast area of wetlands in the Lower Cache River basin make up only about 4% of the watershed (20,000 acres). Thus most of the wetlands in the watershed have been transformed into agricultural lands. The distribution of the different land uses in the basin, based on GIS information at the Illinois State Water Survey, is shown in figure 12. Agricultural lands are distributed throughout the basin, with forest concentrated primarily within the Shawnee National Forest. Most of the wetland areas are located within the Cache River valley.

The most significant changes in land use in the Cache River basin have occurred prior to 1930 and in the period from 1970 to the present. This can be seen in figure 13a, which shows the total acreage for agricultural crops since 1929 for the six counties located totally or partially in the watershed. The same information is also summarized in table 1. The initial agricultural development in the basin occurred during the late 1800s and early 1900s; since then the major increase in agricultural acreage has taken place since 1970. The total agricultural acreage increased very gradually from 1931 to 1953 and decreased sharply from 1953 to 1961 when some agricultural lands were removed from production. From 1962 to 1967, acreage sharply increased, most probably due to the recultivation of old farms that had been removed from production. However, the total agricultural acreage in 1967 was still less than in 1953. Acreage decreased from 1968 to 1970, followed by a steady and high rate of increase up to 1984. Since 1985, agricultural acreage has decreased.

Another significant observation regarding land-use changes in the Cache River watershed concerns the trend in acreages for the leading crops in the region. This is illustrated in figure 13b, where the acreages for corn, soybeans, and sorghum from 1929 to 1987 are plotted. Initially, corn was by far the main crop in the area. In 1937, soybeans were reported for the first time. Since then, soybean acreage has increased and corn acreage has decreased

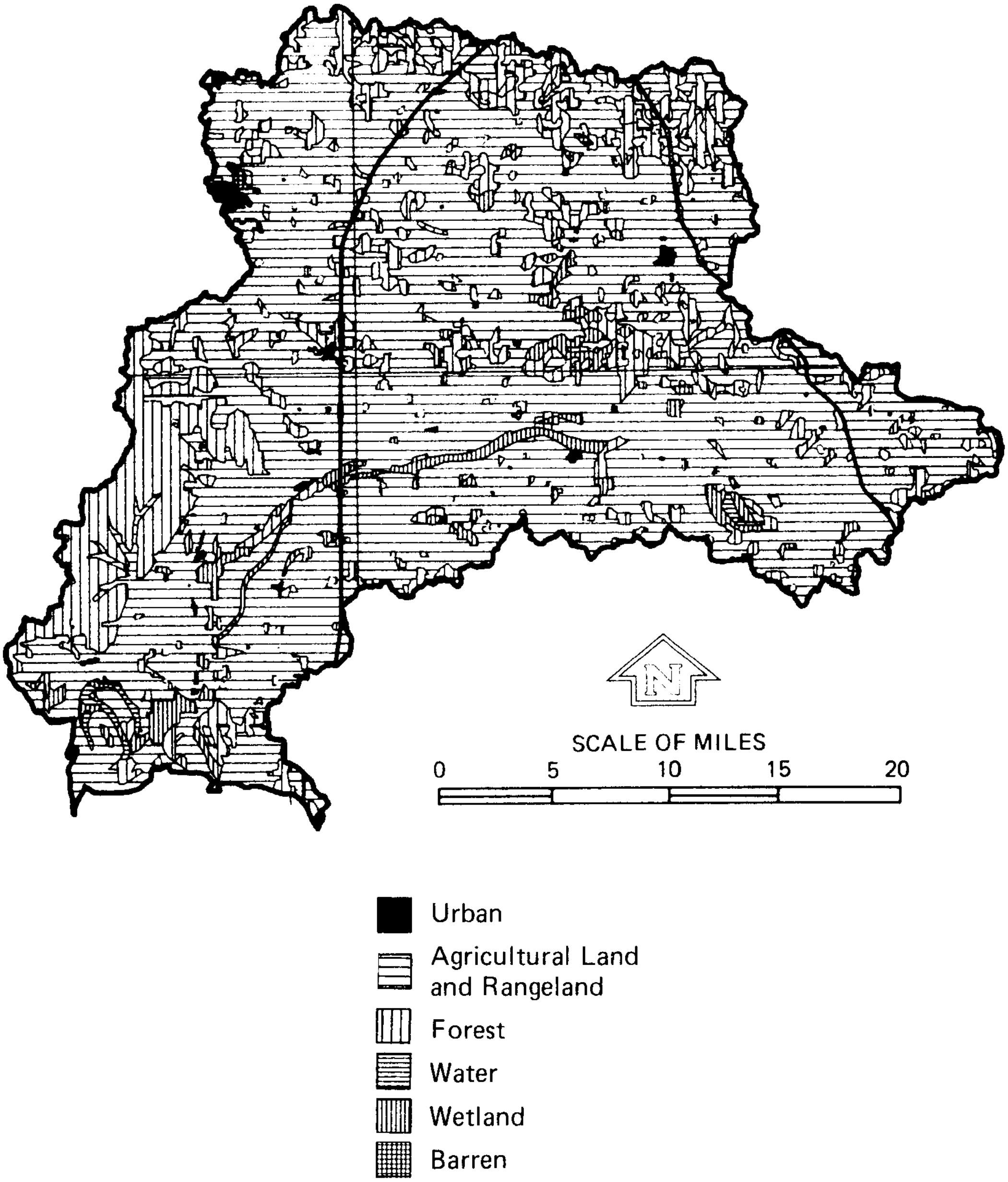


Figure 12. Land uses in the Cache River basin

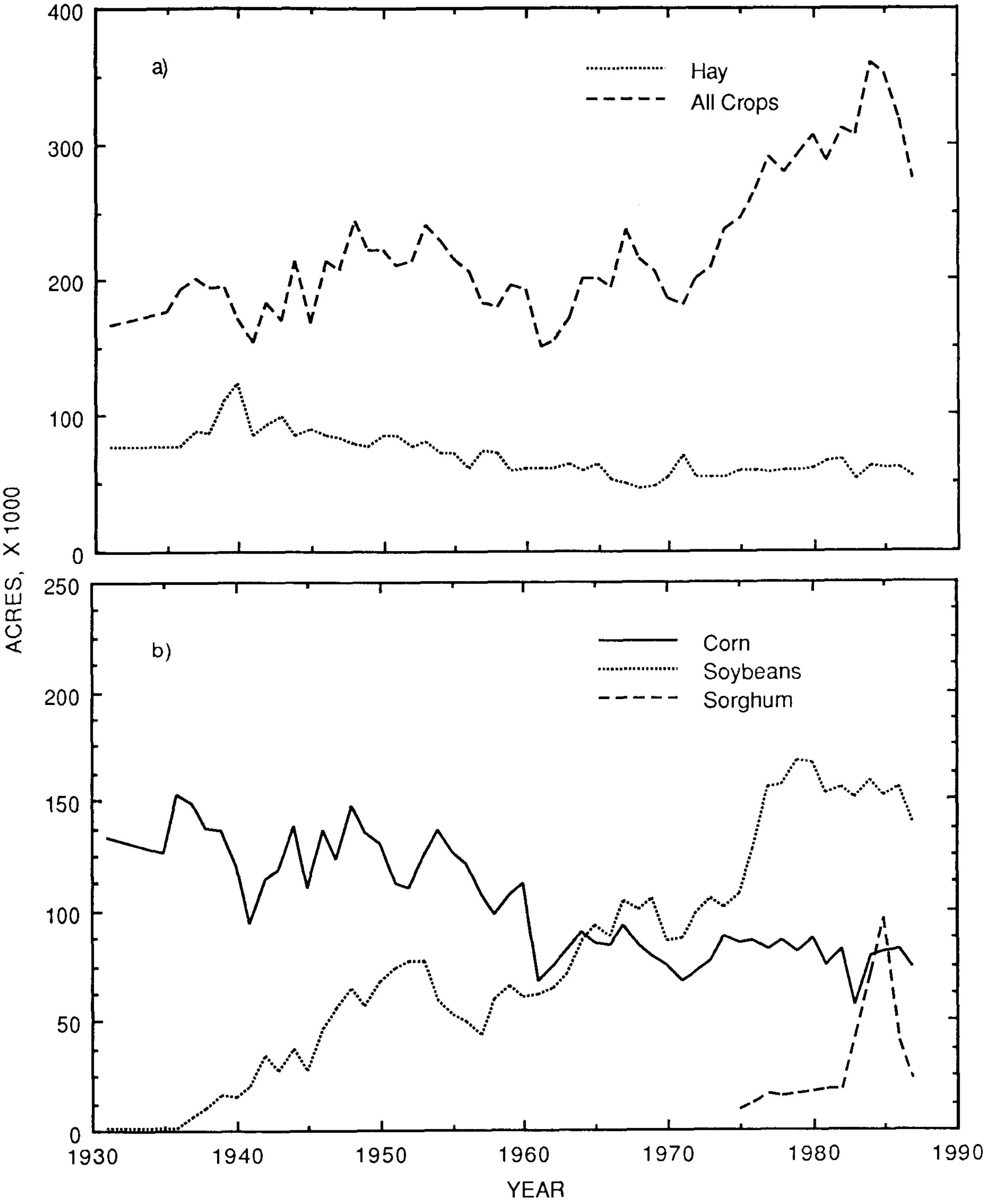


Figure 13. Variations in acreage of the agricultural lands in the Cache River basin area since 1929

Table 1. Land Use in the Cache River Basin (in Acres)

County	***Agriculture***	***Rangeland***	***Forest***	***Wetland***	***Water***	***Urban***
Alexander	37441	-_	30064	4292	1443	540
Johnson	81602	598	29210	5854	134	1756
Massac	53096	3035.6	7093	2676	438	586
Pulaski	76188	-	9027	5900	322	1590
Union	94298	20.8	23661	856	121	2816
Pope	2038	--	359	--	--	--
Total for the watershed	344,663	654.4	99,414	19,578	2,458	7,286

(From U.S. Geological Survey, Land Use Series, 1980) steadily. Eventually, in 1965, soybeans surpassed corn as the number one crop in the region and have remained the dominant crop. Another crop that is becoming more important in the basin is sorghum, which was first reported in 1975 but surpassed corn as the number two crop in the region in 1985. However, there was a major decline in sorghum in 1986 and 1987.

The historical changes in agricultural acreage show that most of the conversion of wetlands into agricultural lands has occurred since 1970, primarily because of the flood protection provided by the major levee systems built to protect urban areas.

Drainage, Flood, and Water-Level-Control Projects

In an attempt to improve drainage and reduce flooding, major channelization and levee projects have been implemented in different parts of the basin. Most of the projects have been directed towards improving the poor drainage characteristics of the Lower Cache River and preventing flooding from the Ohio and Mississippi Rivers. The most significant projects that have impacted the hydraulics and drainage pattern of the Cache River are listed in table 2.

Table 2. Drainage, Flood, and Water-Level-Control Projects
in the Cache River Basin

Period	*Project*
1905	Major channelizations, including the Post Creek Cutoff, proposed by the Cache River Drainage Commission
1915	Post Creek Cutoff and Forman Floodway constructed
1930s	Channelization of the lower Cache River
1950	Lower Cache River outlet diverted from the Ohio to the Mississippi River
1952	Reevesville and Cache River levees constructed by the COE
1960s	Dredging and clearing of the Lower Cache River in the Buttonland Swamp area
1982	Low-head channel dam built in Buttonland Swamp by Save the Cache, Inc.
1986	Cache River levee breached by Big Creek Drainage District #2; levee repaired by drainage district as ordered by the COE

The natural drainage of the Cache River prior to 1915 is shown in figure 14. Streams and creeks from the upland areas of the whole watershed drained into the Cache River valley and then slowly into the Ohio River near Mound City, Illinois. During major floods, the Ohio

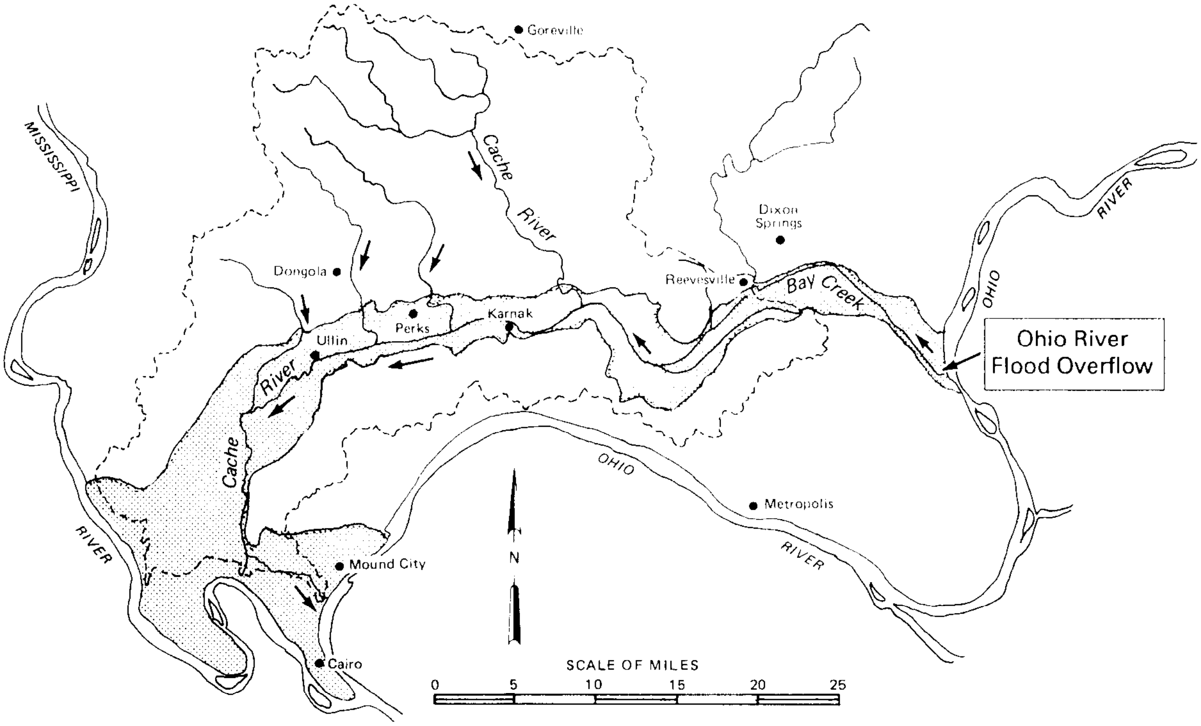


Figure 14. Natural drainage and flow pattern of the Cache River prior to 1915

River overflowed through the Cache River valley towards the Mississippi River. When in flood, the Mississippi River backed up water through much of the valley.

In 1915, the Cache River Drainage Commission completed the construction of the Post Creek Cutoff, which essentially split the watershed into two halves: the Upper and Lower Cache River watersheds (figure 15). The Post Creek Cutoff is the project that altered the drainage pattern in the Cache River basin most significantly, allowing drainage from the Upper Cache River watershed to flow directly to the Ohio River through the cutoff. This alteration improved drainage in the Main Ditch watershed and reduced the flow from the Upper Cache to the Lower Cache, even though there was still a connection between the Upper and Lower Cache Rivers during major floods. The near-total separation of the Upper and Lower Cache Rivers took place much later as a result of the construction of the Cache River levee.

The next major project was the Lower Cache River diversion, which moved the Lower Cache River outlet from the Ohio River to the Mississippi River in 1950, as shown in figure 15. This diversion project did not have any significant impact on drainage or flooding in the Cache River.

In 1952, two levees were completed by the Army Corps of Engineers in the Cache River valley, which resulted in significant impacts on drainage, flooding, and land use patterns in the Cache River valley. The two levees were the Reevesville and Cache River levees, as shown in figure 16. The Reevesville levee was built to prevent floodwater flow from the Ohio River from the east into the Cache River valley. The Cache River levee was constructed to provide protection for the Lower Cache River valley from floodwaters from the Upper Cache River and from backwaters from the Ohio River entering through the Post Creek Cutoff. The economic justification for both levees was based primarily on the flood protection they would provide to the towns of Karnak and Ullin in the Cache River valley. At the same time, however, they provided incentive for the conversion of more wetlands in the Cache River valley to agricultural lands.

The two levees accomplished their purposes effectively in that the Reevesville levee stopped Ohio River overflow into the Cache River valley, and the Cache River levee stopped floodwaters from the Upper Cache River and backwaters from the Ohio River from reaching the Lower Cache River. Provisions were made to drain a small area west of the Cache River levee into the Post Creek Cutoff by installing two culverts through the levee. Currently, these two culverts are the only connections between the Lower and Upper Cache Rivers. Water can flow only from the Lower Cache River to the Post Creek Cutoff because of flap gates on the culverts.

Since completion of the two levees, no major structural projects have been constructed in the river basin; however, there has been extensive channel straightening and some minor work in the Lower Cache River. In the 1960s, major channel clearing and dredging were performed

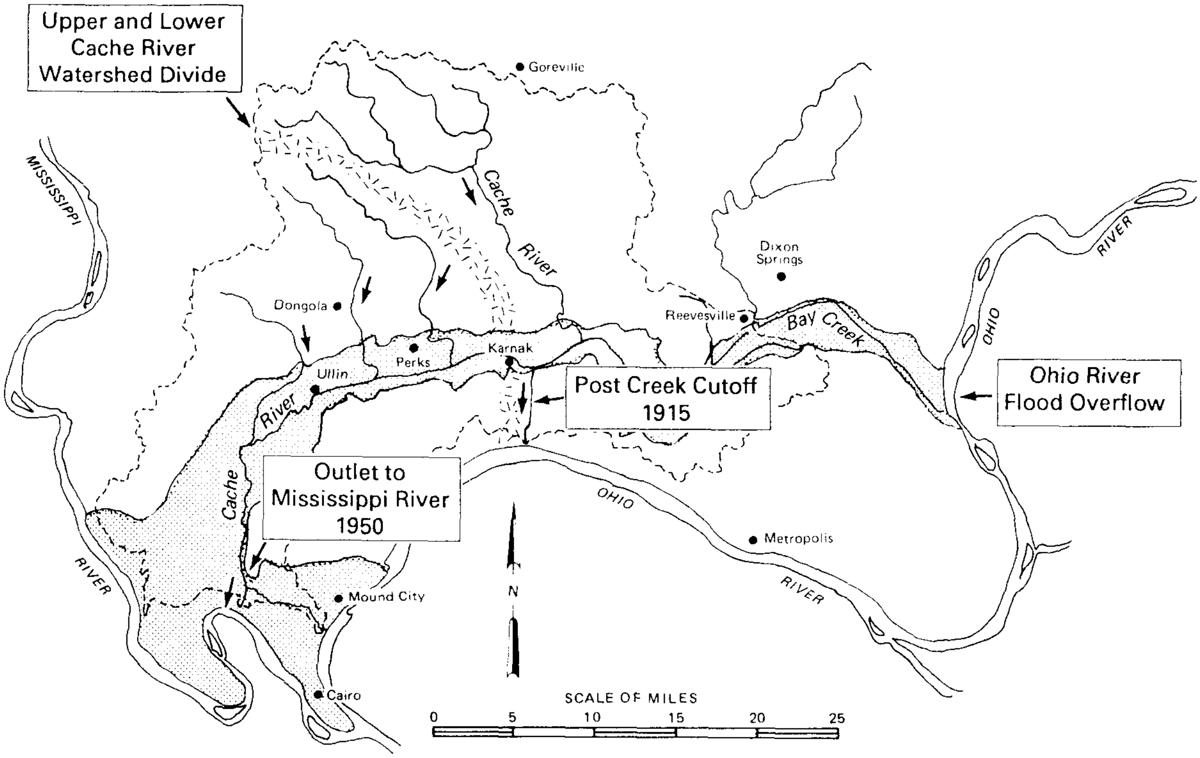


Figure 15. Drainage pattern in the Cache River after construction of the Post Creek Cutoff

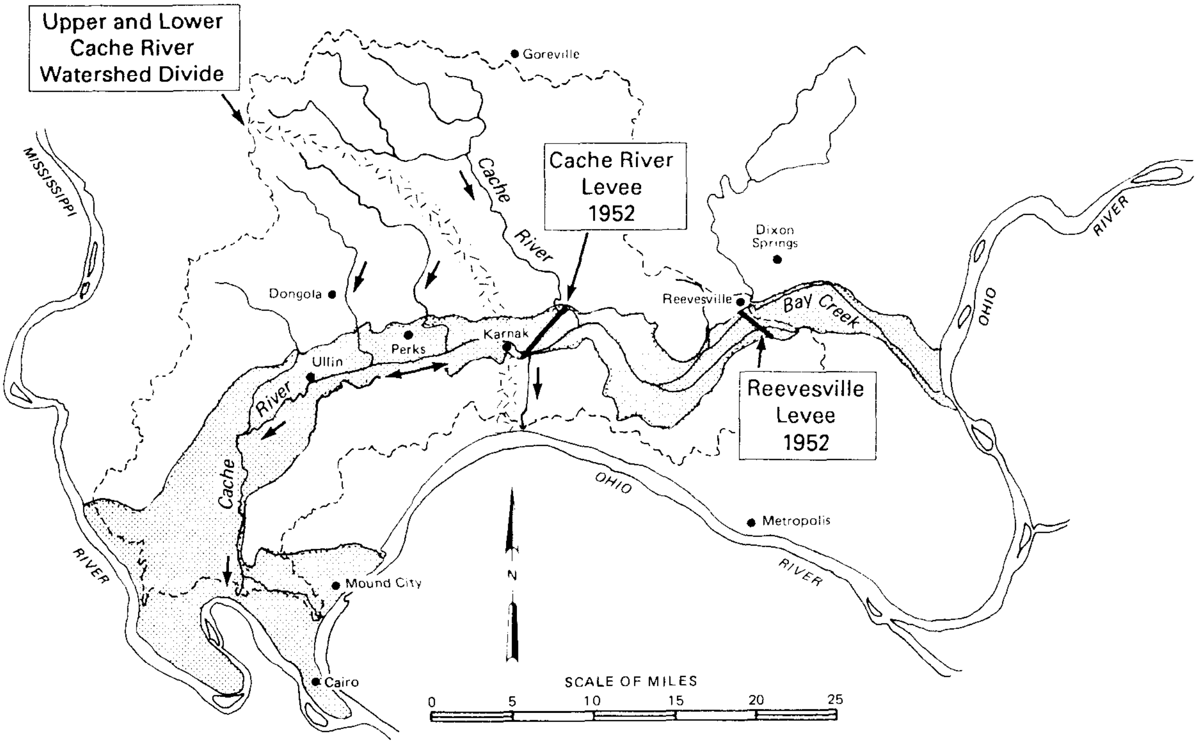


Figure 16. Drainage pattern in the Cache River after construction of the Cache River and Reevesville levees

in the Lower Cache River. The present stream channel in the Buttonland Swamp area of the Lower Cache is most probably a remnant of that channelization and dredging.

In 1982, a low-head channel dam was installed by Save the Cache, Inc., to maintain some water in the Buttonland Swamp area. The top of the dam is about 1.5 feet below the top of the streambank. Because of its height and location, and the width of the Cache River valley, the dam does not have any significant impact during high and medium flows that overtop or come close to the top of the streambank. It does, however, retain from 3 to 3.5 feet of water in the stream channel east of the dam during low-flow periods.

In 1986, Big Creek Drainage District #2 breached the Cache River levee during a major flood in the Lower Cache River. The purpose of the breach was to provide increased outlet capacity towards the Post Creek Cutoff, in addition to that provided by the two 48-inch culverts. The Corps of Engineers later ordered the drainage district to repair the levee to its original condition, which they have done.

Wetlands and Natural Areas

The Cache River basin is one of the most unique and important areas in the nation. Remnants of some of the most important and valuable wetlands in the state and in the nation are found within this watershed. Four of the major physiographic provinces of the United States -- the Coastal Plain, the Interior Low Plateaus, the Ozark Plateaus, and the Central Lowland -- all converge in and around the Cache River basin, providing the Cache River with a unique mix of habitats and plant communities. The basin is one of only six areas in the entire United States where four or more physiographic provinces converge.

The Lower Cache River floodplain is within the Coastal Plain Physiographic Province and thus was formerly a cypress-tupelo swamp like those found in Arkansas and Mississippi. The original extent of cypress-tupelo forest in southern Illinois before logging, clearing, and drainage activities began was about 250,000 acres. As a result of logging and the subsequent drainage of these swamps for agriculture, only a few, small, scattered remnants of this forest remain today. Two of these remnants in the Cache River basin, totaling 4,861 acres, are on the Illinois Natural Areas Inventory. They are Little Black Slough-Heron Pond Nature Preserve in the Upper Cache River, owned by the Illinois Department of Conservation, and the Lower Cache River Natural Area (LCRNA) in the Buttonland Swamp area of the Lower Cache River, a National Natural Landmark, currently owned in part by private individuals, The Nature Conservancy, and the Illinois Department of Conservation. Two of the largest swamp trees in the United States, twelve state champion trees, and the reported oldest living stand of swamp trees east of the Mississippi River occur in and along the shallow floodplains of this basin and the Lower Cache River.

Wetlands are important not only for the diverse biological communities they harbor, but also because they serve valuable hydrologic functions such as flood peak reductions, increased low flows, entrapment of sediment and nutrients, water quality improvements, ground-water recharge, stabilization of streambanks, and erosion control. The existence and functions of wetlands in the Cache River basin are threatened by increased erosion and sedimentation induced by the human activities in the watershed.

The Little Black Slough-Heron Pond wetland area is threatened by the entrenchment of the Upper Cache River channel and the gully formation that accompanies channel entrenchment. The entrenchment of the Upper Cache River channel is a direct result of the construction of the Post Creek Cutoff. The Cache River is the only outlet for water from these wetlands. As the Cache River stream channel is lowered to establish a new hydraulic equilibrium condition compatible with the Post Creek Cutoff, deeper and wider lateral gullies are formed by the erosive forces of runoff and seepage on the streambank. The continual gully formation and deepening of stream channels may drain wetlands, whose elevation becomes significantly higher than the stream channel because of channel bed scour. There are ample examples of the above process in the Cache River basin. Bird Spring Pond has already been drained, and extensive gully formation and bank erosion are taking place in the Heron Pond area.

The problem in the LCRNA is quite the opposite. Instead of the excessive erosion and channel entrenchment in the Upper Cache River, there are excessive sedimentation and channel aggradation. Because of the reduced flow in the Lower Cache River, most of the sediment from tributary streams draining into the Lower Cache River is deposited near the mouth of the tributary streams and within the LCRNA This has reduced the depth of water within Buttonland Swamp and has degraded the aquatic and plant habitat within the area.

HYDROLOGY AND HYDRAULICS

The hydrology of a watershed and the hydraulics of flow in its streams are the dominant natural forces that influence the behavior of the watershed. The Cache River watershed has been subject to severe channel erosion in the Upper Cache River area and to sediment deposition in the Lower Cache River since the construction of the Post Creek Cutoff and the two levees in the Cache River valley (Cache River and Reevesville levees). Information on the hydrology of the Cache River watershed and the hydraulics of streamflows is essential to an understanding of the impacts of such dynamic changes.

The hydrology of a basin is influenced by many factors, including the general geographic location of the watershed and the corresponding climatic conditions. Local watershed characteristics such as topography, slope, geology and soil types, land use, and vegetative cover are all important factors that influence the hydrologic response of a particular watershed. Watershed characteristics, land use, vegetative cover, and geographic location were discussed in the previous section. Precipitation data, including historical data, current data, and data collection methods and procedures, are discussed in this section,

The streamflow hydraulics is influenced by discharge, channel geometry, roughness of the channel bottom, and stream morphology. Only two historical discharge gaging stations are located inside the Cache River basin. An analysis of annual floods, based on historical data, is important in determining the frequency and severity of flooding. Such analysis is included for the two stations. To better understand the movement of water in the Cache River and from its tributaries, the Illinois State Water Survey established a streamflow monitoring program for the Cache River basin. The collected data and the analyses based on the data are presented.

Because of its location, the Cache River interacts with the Ohio and Mississippi Rivers through backwater effects. Backwater effects and river stage of the Ohio and Mississippi Rivers are discussed in the final part of this section.

Precipitation

The southern part of the state, where the Cache River basin is located, receives the highest amount of average annual rainfall in the state, as shown in figure 17 for the period since data have been available. The average annual precipitation in the Cache River basin ranges from about 44 to 47 inches. In general, precipitation in the southern part of the state is highly variable because of the hills and valleys in the area. Jones, Huff, and Changnon (1974) estimated that on the average the hills in southern Illinois increase the warm season rainfall by 10 to 15%.

Because of the variability of precipitation in the region, analyses must be performed based on data from several rainfall stations. For this study, precipitation records from all

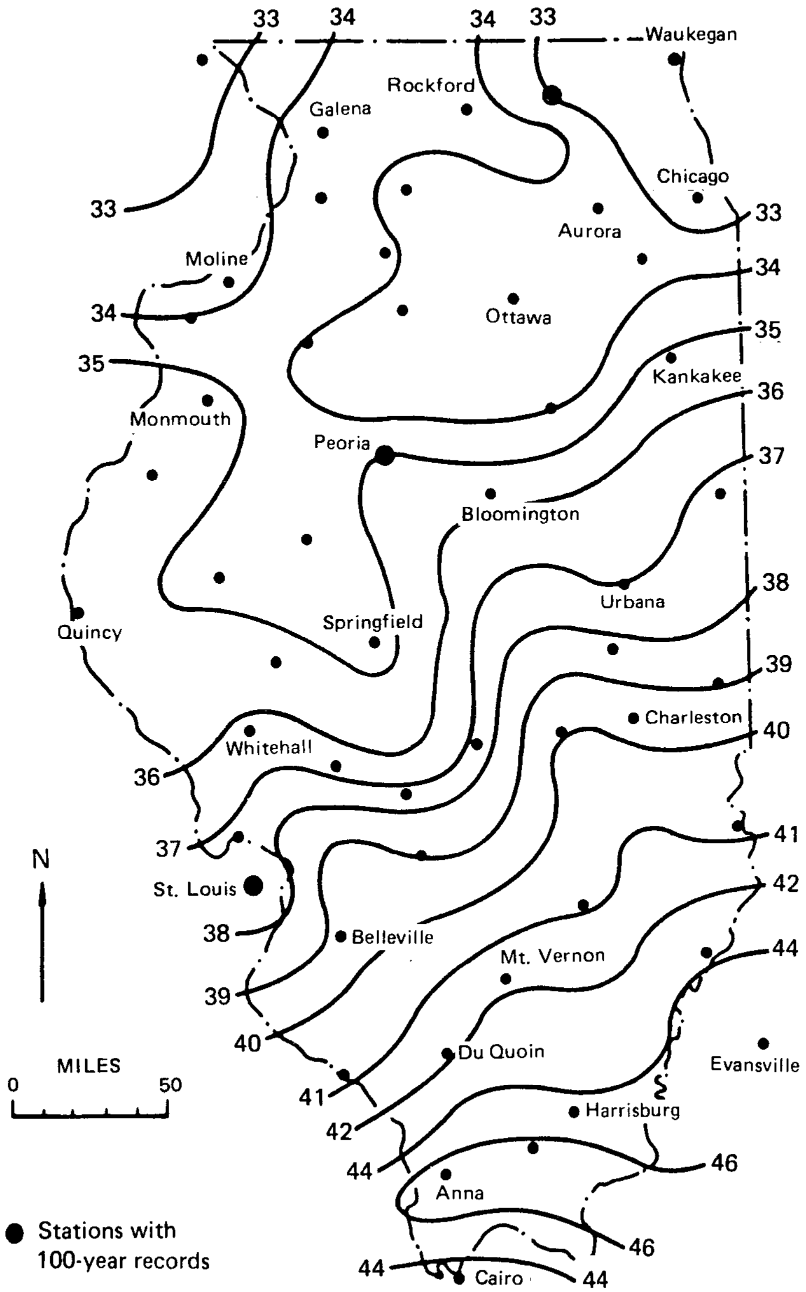


Figure 17. Average annual precipitation in Illinois (from Changnon, 1987)

existing climatic stations in the vicinity of the Cache River basin and from new stations established for the project were used in the analysis. The existing climate stations operated and reported by the National Oceanic and Atmospheric Administration (NOAA) that were included in the analysis are those at Anna, Brookport Lock & Dam, Cairo, Carbondale, and Dixon Springs in Illinois, and at Cape Girardeau in Missouri. The locations of the stations with respect to the Cache River basin are shown in figure 18. The stations are all outside the watershed boundary, except for Anna, which is located in the northwest portion of the watershed. The lengths of the precipitation records and the annual mean, maximum, and minimum annual precipitation at the six stations are given in table 3. The Anna and Cairo stations have the longest precipitation record, which goes back to 1901. Carbondale, Brookport Lock & Dam, and Cape Girardeau have records starting from 1914, 1929, and 1946, respectively. Dixon Springs has the shortest record, starting in 1968. However, the precipitation record at Glendale, Illinois, a short distance from the Dixon Springs Experiment Station, can be used to extend the Dixon Springs record back to 1941.

The new rainfall gaging stations established for the Cache River basin project are shown in figure 18 as RG1, RG2, and RG3. These stations were established within the watershed to supplement the data from the NOAA stations. Data from two rainfall gaging stations near Horseshoe Lake, identified as HL1 and HL2 in figure 18, were also used when needed. The results for the Water Survey gaging stations will be discussed later in the section on current data,

Historical Data

The mean annual precipitation in the region ranges from 44.0 inches at Carbondale to 47.7 inches at Dixon Springs. The mean for the longer period at Anna is 47.5 inches, which is nearly equal to that of Dixon Springs. The maximum annual precipitation amounts range from a high of 74.5 inches at Carbondale in 1945 to a low of 68.0 inches at Brookport Lock & Dam in 1945. The annual minimums range from 26.5 for Carbondale in 1963 to 30.4 at Anna in 1980.

The variations in the annual precipitation amounts for the period of record for the six stations are shown in figures 19 through 24. Also shown in the figures are the long-term means and the 5-year moving averages. These plots show that there have been no clear increasing or decreasing trends in the annual precipitation amounts. However, the annual precipitation amounts since 1986 have been less than normal, even though each of the years from 1981 to 1985 was wetter than normal at all the recording stations.

The monthly distributions of average precipitation for the four stations with the longest records are shown in figure 25. As can be seen in the figure, the average precipitation in the region is almost uniformly distributed throughout the year. Slightly more precipitation generally occurs in March, April, and May than in the rest of the year. The monthly mean precipitation ranges from a low of 2.36 inches at Carbondale in October to a high of 5.26 inches at Brookport Lock & Dam in March. It is important to note that the values shown in figure 25 are long-term means (1951-1980) and thus show less variation in the monthly values than the year-to-year precipitation would indicate. To demonstrate the variation in monthly precipitation from year to year, the precipitation records for the six stations for the project period (from 1985 to 1988) are shown in figures 26 through 31. The long-term mean averages are also shown (dashed lines) for comparison purposes. As can be seen in the figures, the monthly precipitation amounts are highly variable and are sometimes several times greater than the long-term mean.

Current Data

In the region in which the Cache River basin is located, precipitation is highly variable, as discussed in the preceding section. All except one of the existing precipitation gages are located outside the basin. Although the data from these gages are useful for analysis and for comparison of recent data, the absence of a sufficient number of gages within the watershed led to the installation of additional gages within the watershed. The purpose of these gages is to monitor the expected spatial precipitation variation within the basin.

As mentioned previously, precipitation has been monitored at three new locations established for this project within the Cache River watershed, shown in figure 18 as State Water Survey (SWS) precipitation gages RG1, RG2, and RG3. The sites are located in such a way that both the temporal and spatial variations of precipitation can be obtained by using the historical and the new stations. Data from two gages located at Horseshoe Lake in Alexander County, shown in figure 18 as HL1 and HL2, also were used.

Data Collection Methods and Procedures. Belfort Universal recording raingages (weighing type) are used to collect data at all three stations, and they provide a continuous time distribution graph of precipitation. A photograph of a raingage at one of the Water Survey stations is shown in figure 32. From graphs of precipitation (rain and/or snow) on the charts of the raingages, the total amount and rate of precipitation can be obtained. The charts are collected from the raingages on a weekly basis and sent to the Water Survey for digitization. Once in a digital form, the records can be analyzed for different purposes.

Results. Widespread variations were observed in the amount of precipitation in the Cache River basin during the monitoring period. These variations were due in part to the large size of the basin as well as to factors such as the track of the storms and the topography. Therefore, no one raingage site is representative of the entire basin.

The data from the three NOAA raingages that are in or closest to the basin are presented first, because of their proximity to the basin and because they cover the entire duration of the project. These stations are Anna, Cairo, and Dixon Springs. The monthly results for these stations for Water Years 1985 through 1988 are presented in table 4. These results include the total monthly precipitation amounts, the departures from normal, and the maximum daily rainfall within each month (for the departures from normal, the norms for Anna and Cairo were calculated from 1951-1980 data, and those for Dixon Springs were calculated from data for the period 1968-1988). This table shows extreme variation between the stations for the same month, and for the same station over the course of several months. These variations become apparent when the monthly totals are ranked. The greatest monthly precipitation amounts were recorded during August 1985 at Anna and Dixon Springs. However, the monthly precipitation total for the month of August ranked seventh for Cairo. Significant amounts of rainfall were recorded at all three sites in May 1986.

Wide variations in the maximum daily precipitation occur among the stations. Only the month of May 1986 was uniformly ranked as having the second-highest rainfall amounts during the project period.

Table 5 provides a monthly summary of the data collected at the three Water Survey precipitation gages. Any month for which only partial or no data were available is noted by an asterisk. It is interesting to note how significantly the precipitation can vary within the watershed for some periods.

Discussion. The NOAA precipitation data collected during the study show that precipitation was well above normal in Water Year 1985 and below normal in Water Years 1986, 1987, and 1988. Overall, precipitation during the project period was below normal, as can be seen in table 4.

The major flooding event during the project duration took place in May 1986. The storm event that produced the May 1986 flooding will be discussed by using the data from four NOAA precipitation gages. Two of the three Water Survey gages in the Cache River basin were installed by this date; however, both failed during the event.

In table 6, the recurrence intervals for the May 1986 event recorded at the NOAA stations are presented. Cape Girardeau recorded the greatest 1-day rainfall, which had a recurrence interval of 18 years. The rain recorded by the Cairo gage on the same day had less than a 2-year recurrence interval. For rainfall on two consecutive days, the rainfall amounts and recurrence intervals increased substantially, so that both the Anna and Cape Girardeau stations recorded 35-year rainfall amounts. The lower values experienced by the Cairo and Dixon Springs stations indicate that the majority of the rainfall fell over the northwest portion of the Cache River basin.

(Text continues on page 55)

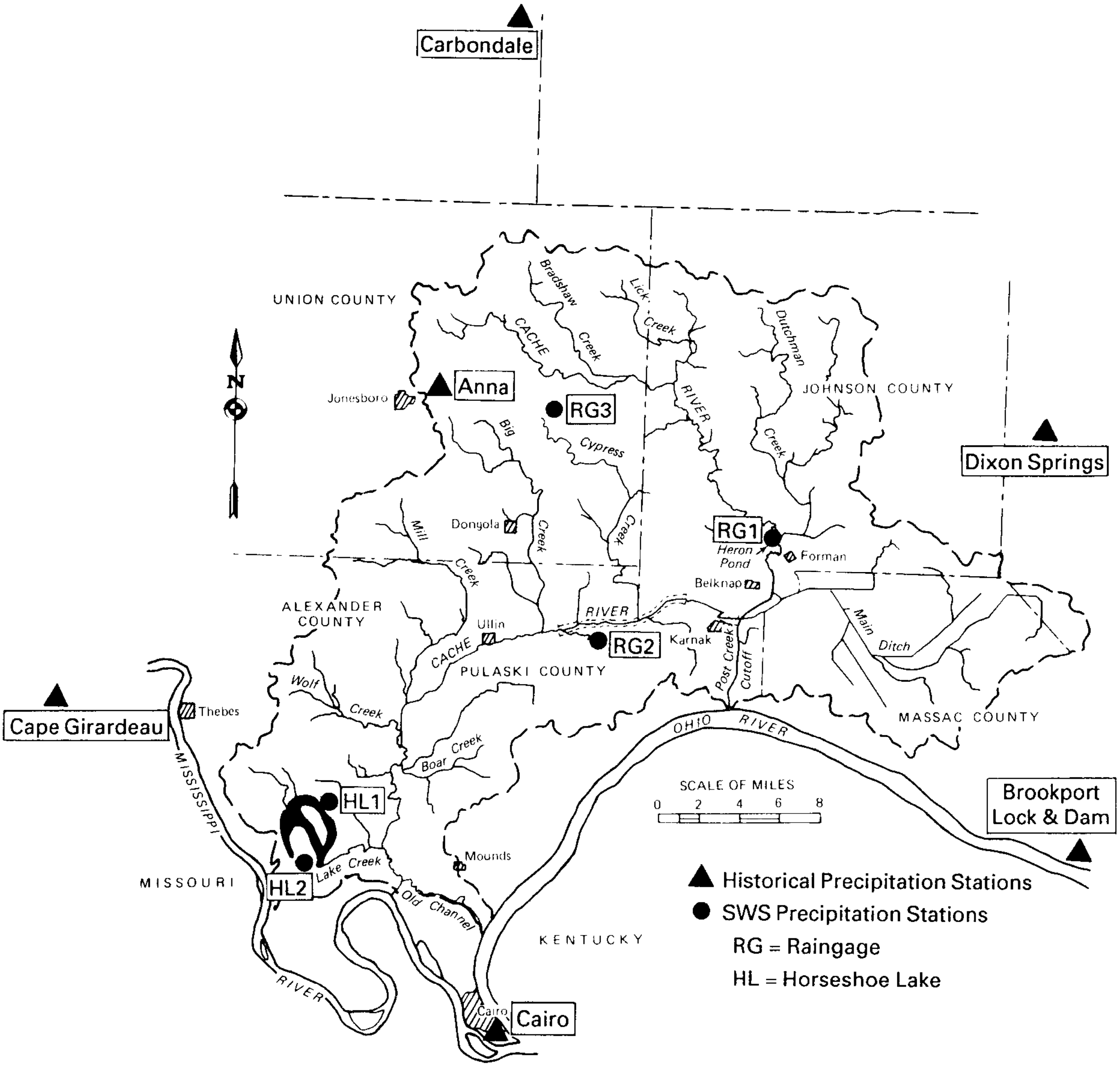


Figure 18. Locations of precipitation gaging stations in and near the Cache River basin

Table 3. Annual Precipitation Records at Six Stations in the Vicinity of the Cache River Basin

Station	***Period of record***	***Mean (in.)***	***Maximum (in.)***	***Minimum (in.)***
Anna, IL	1901-1988	47.5	71.7	30.4
Cairo, IL	1901-1988	44.2	73.0	27.7
Carbondale, IL	1914-1988	44.0	74.5	26.5
Dixon Springs, IL	1968-1987	48.9	60.8	34.4
Dixon Springs, IL*	1941-1988	47.7	71.4	29.5
Brookport Lock & Dam, IL	1929-1988	46.4	68.0	29.1
Cape Girardeau, MO	1946-1988	45.3	68.3	26.7

*Extended from 1941 to 1968 by using records at Glendale, IL

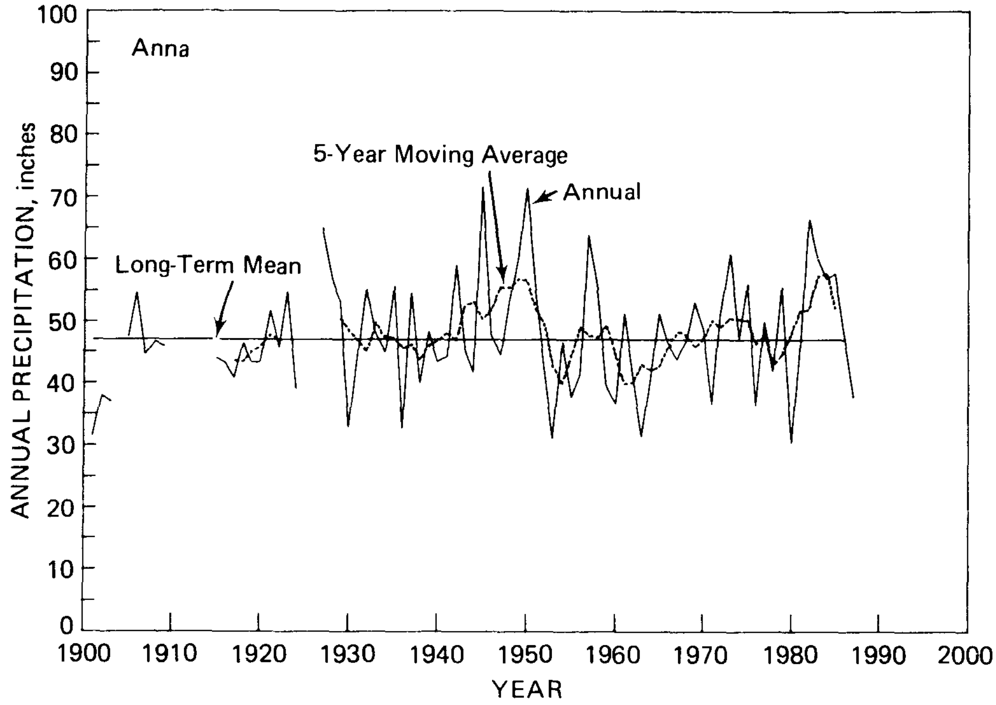


Figure 19. Annual precipitation at Anna

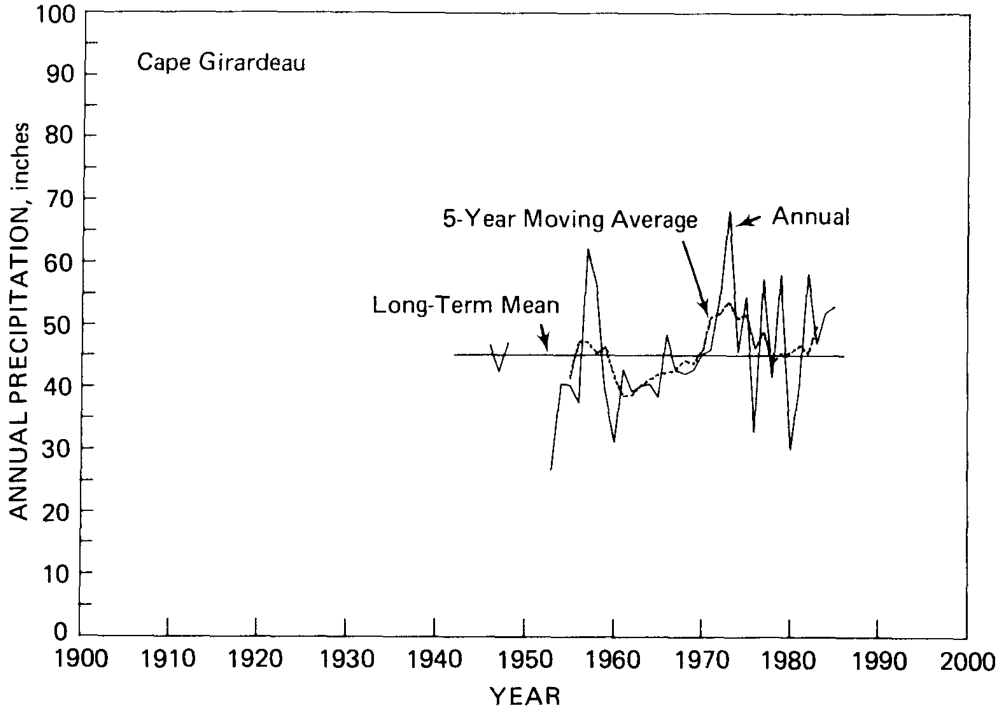


Figure 20. Annual precipitation at Cape Girardeau

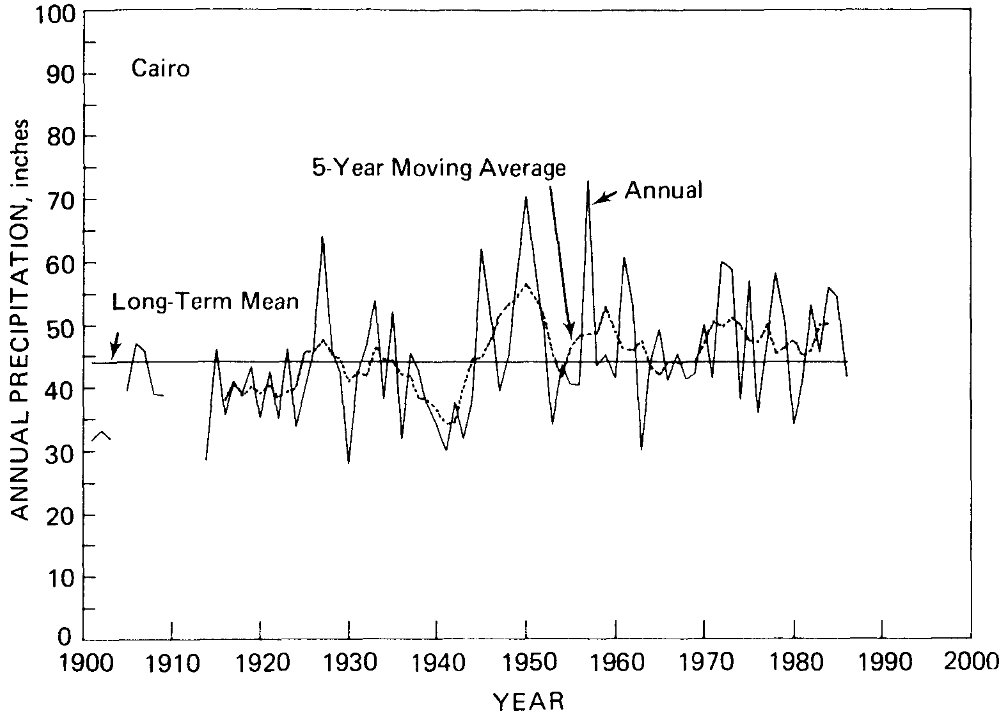


Figure 21. Annual precipitation at Cairo

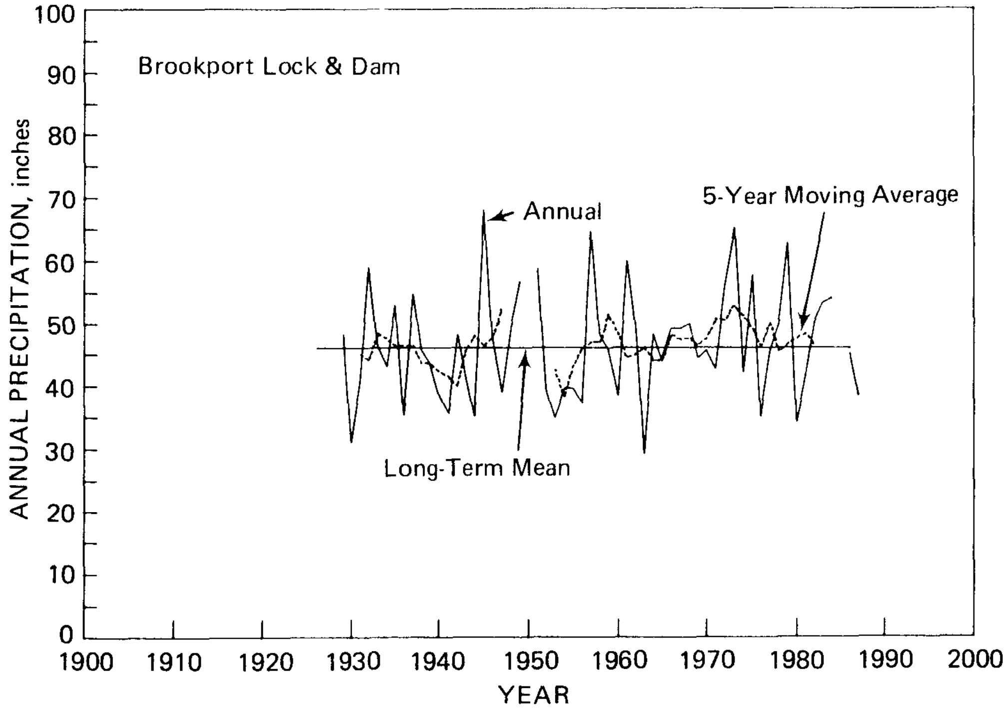


Figure 22. Annual precipitation at Brookport Lock & Dam

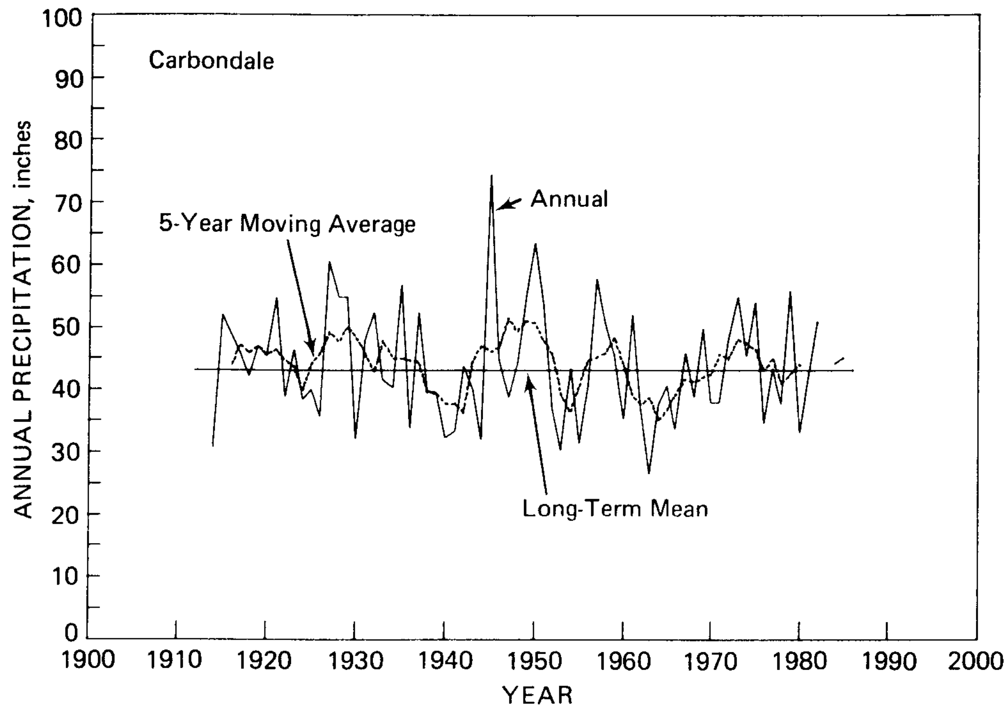


Figure 23. Annual precipitation at Carbondale

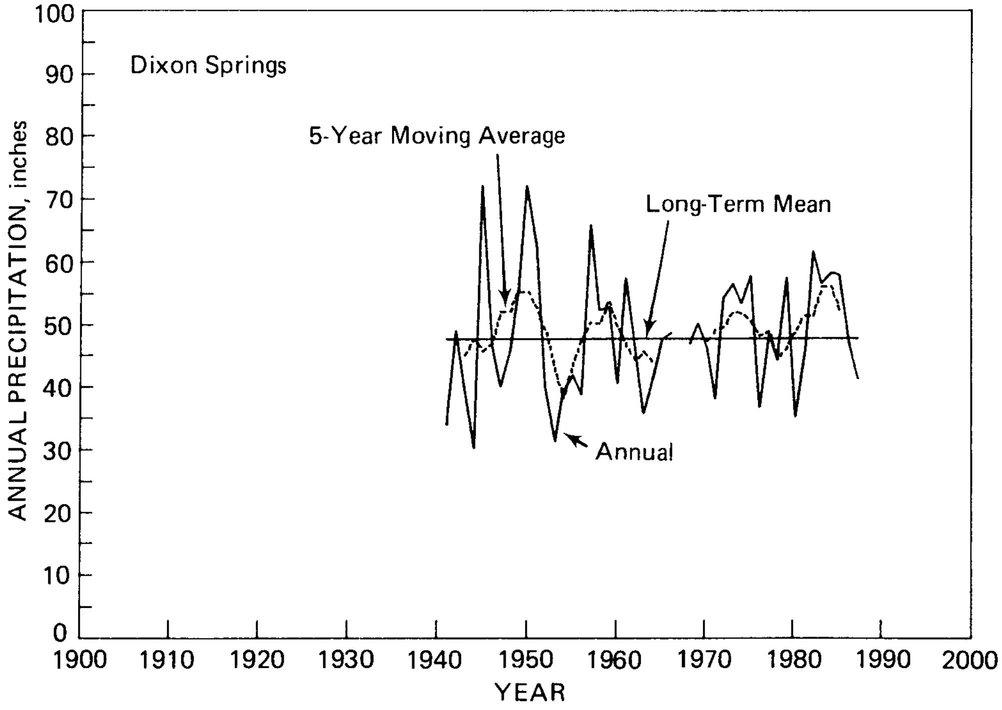


Figure 24. Annual precipitation at Dixon Springs

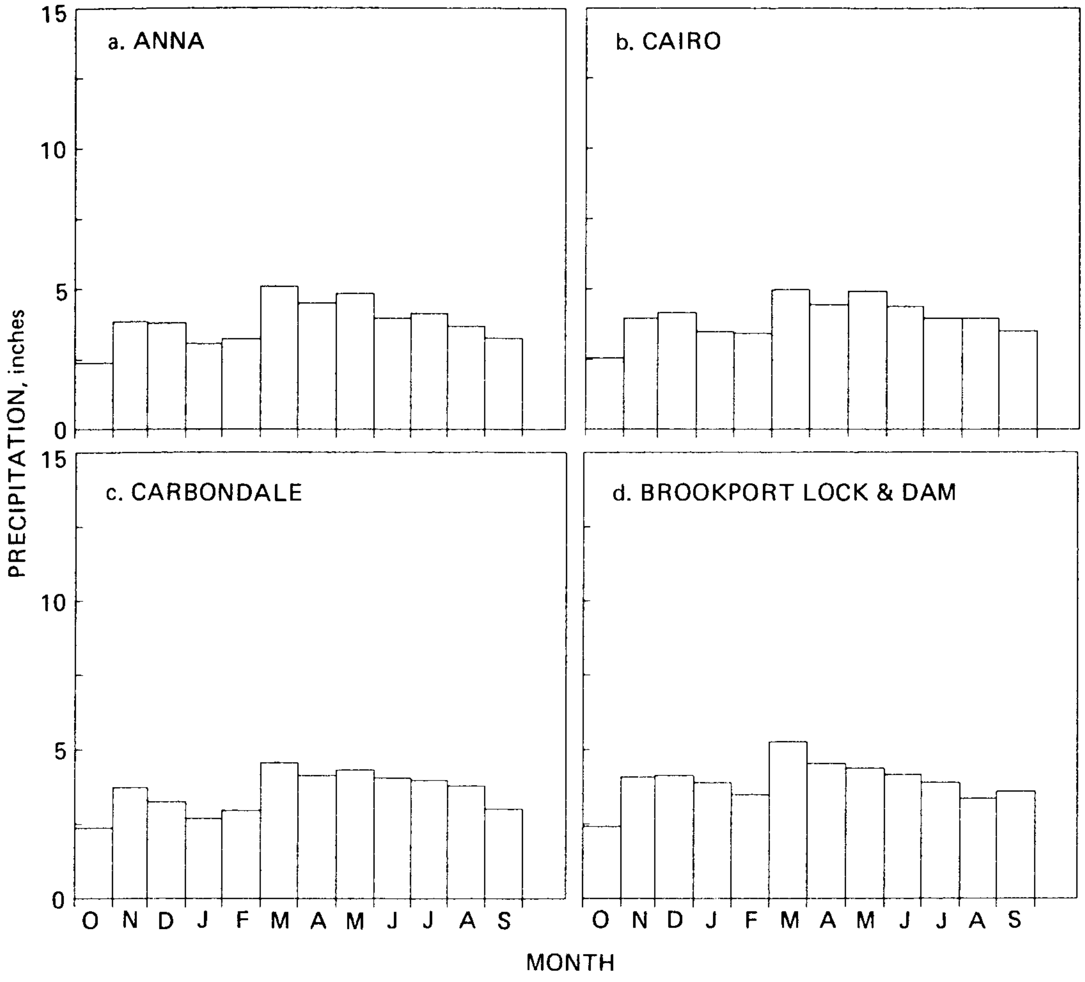


Figure 25. Long-term mean monthly precipitation for four stations in and near the Cache River basin

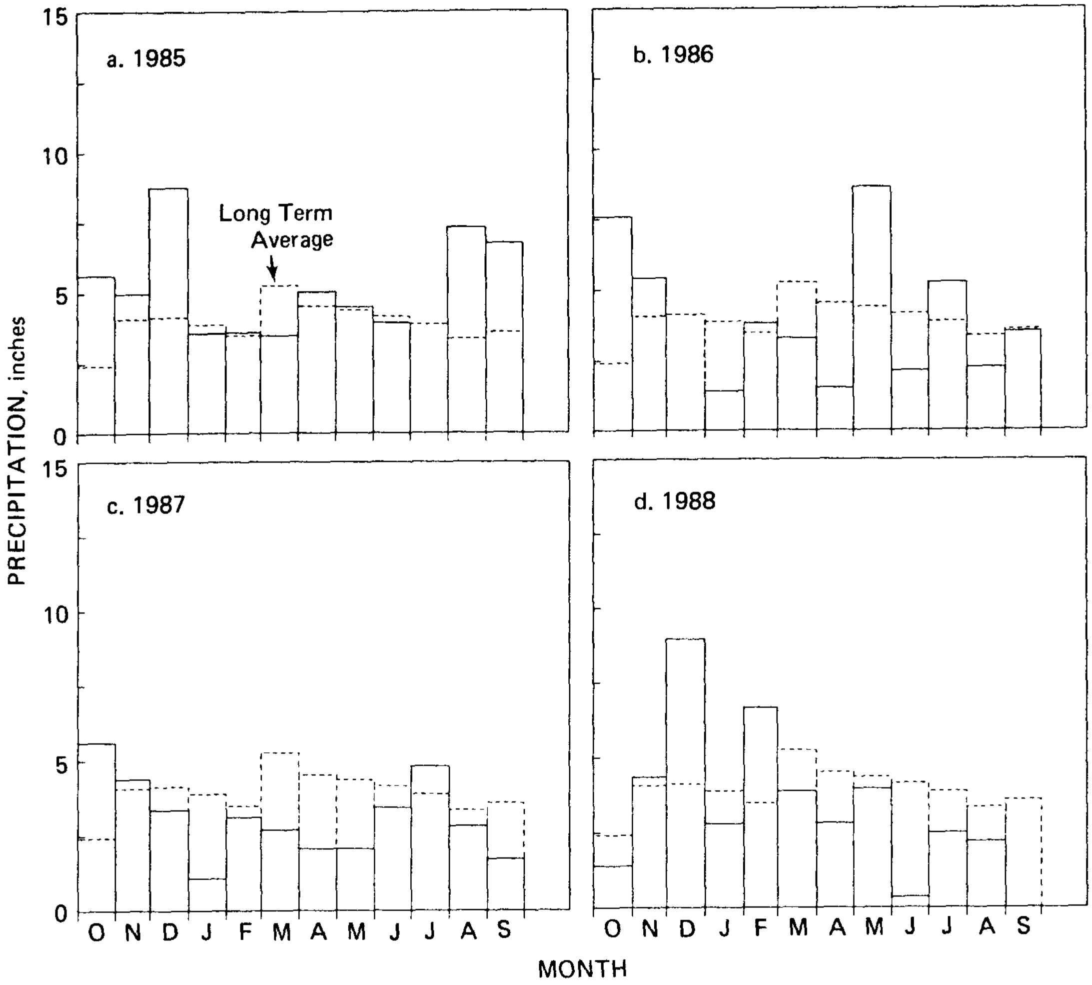


Figure 26. Monthly precipitation for the period from 1985 to 1988 at Anna

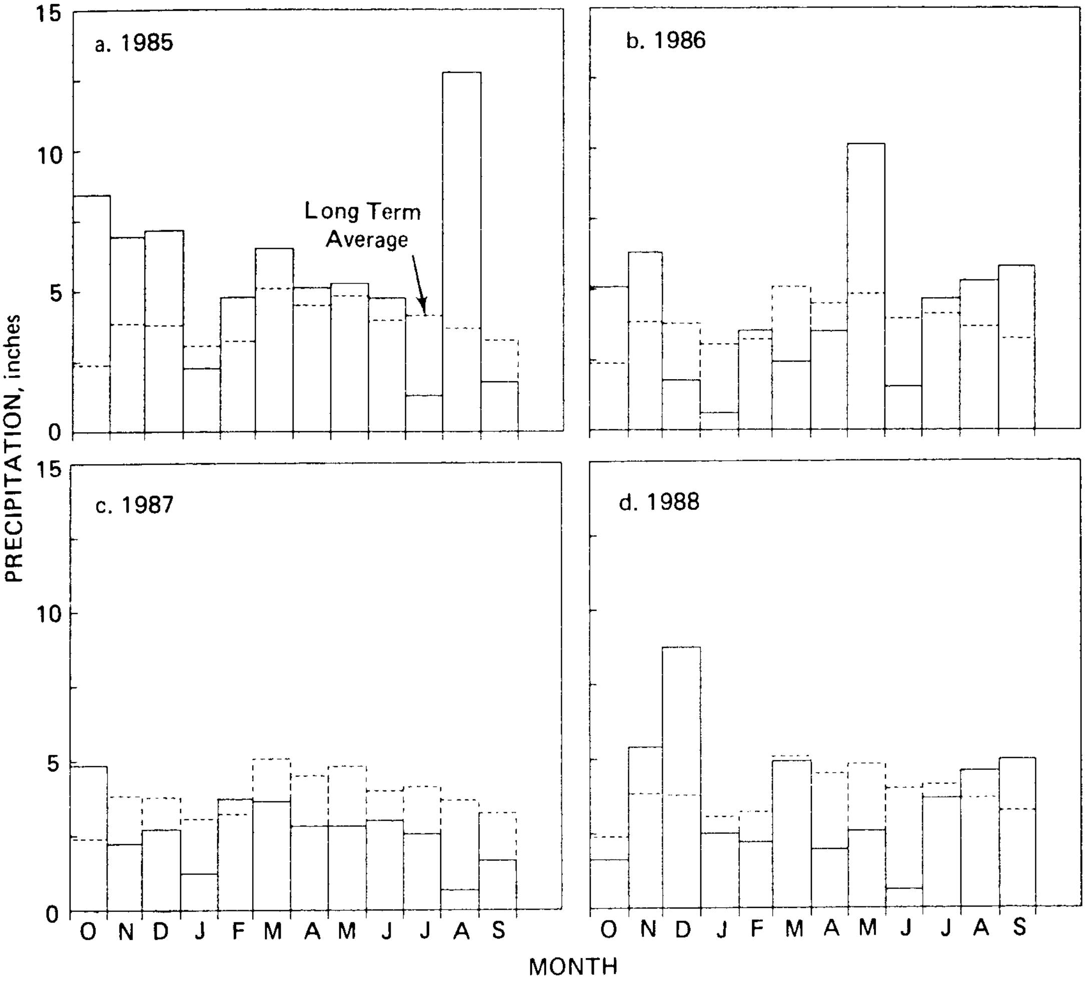


Figure 27. Monthly precipitation for the period from 1985 to 1988 at Brookport Lock & Dam

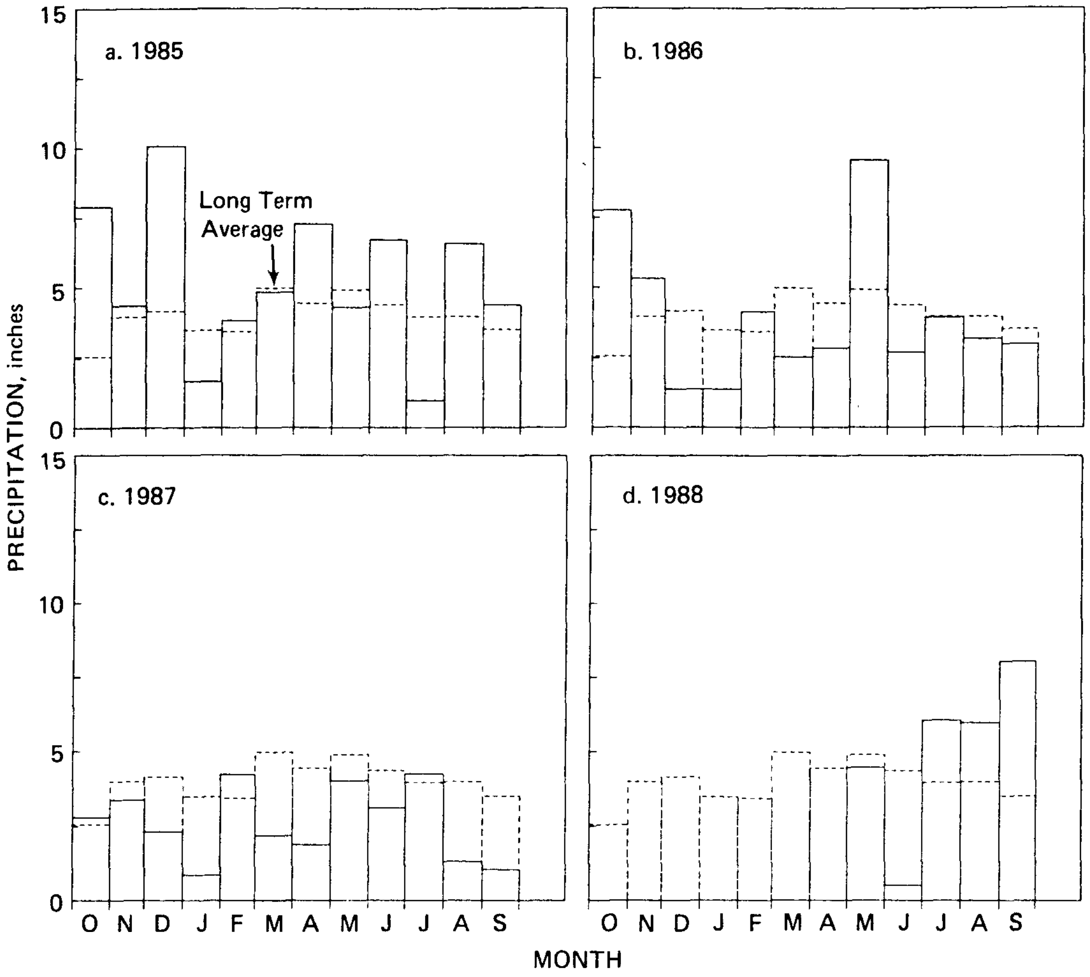


Figure 28. Monthly precipitation for the period from 1985 to 1988 at Cairo

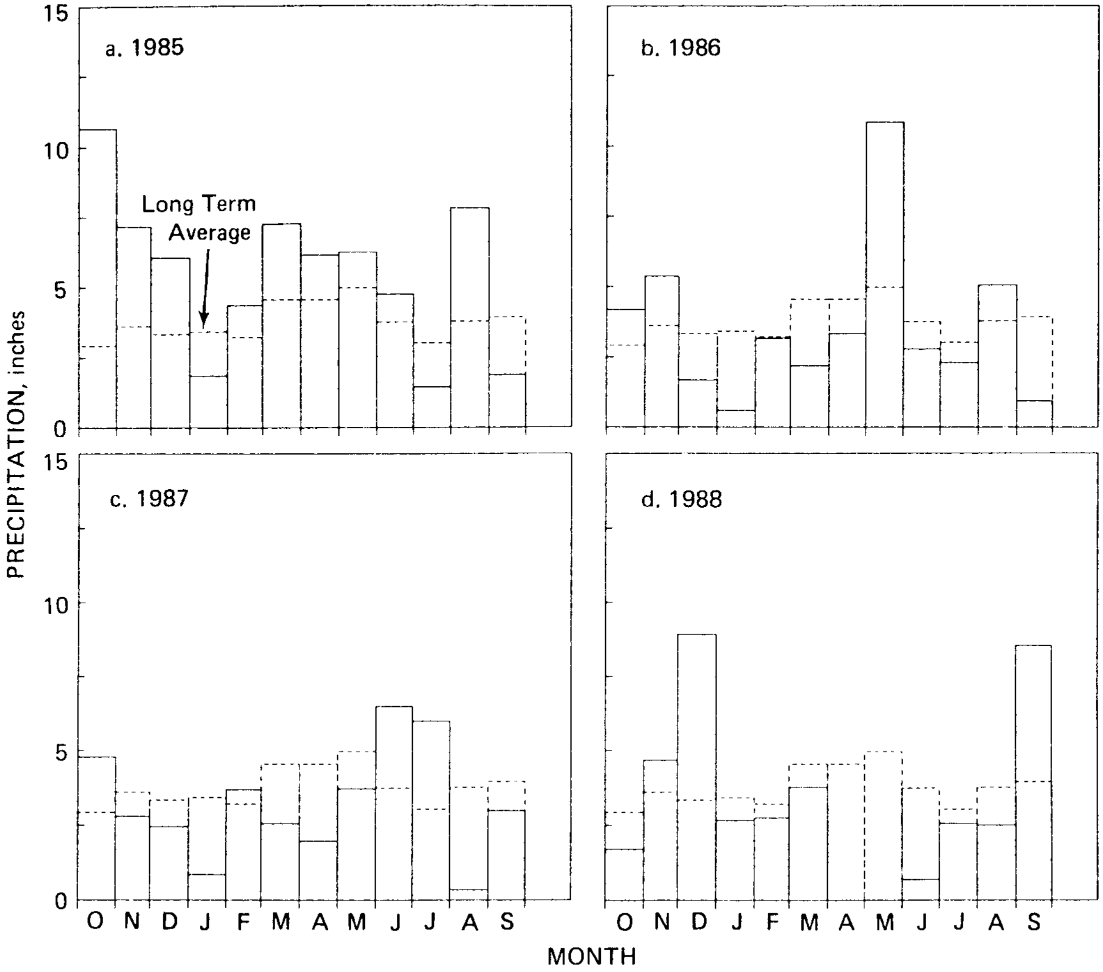


Figure 29. Monthly precipitation for the period from 1985 to 1988 at Cape Girardeau

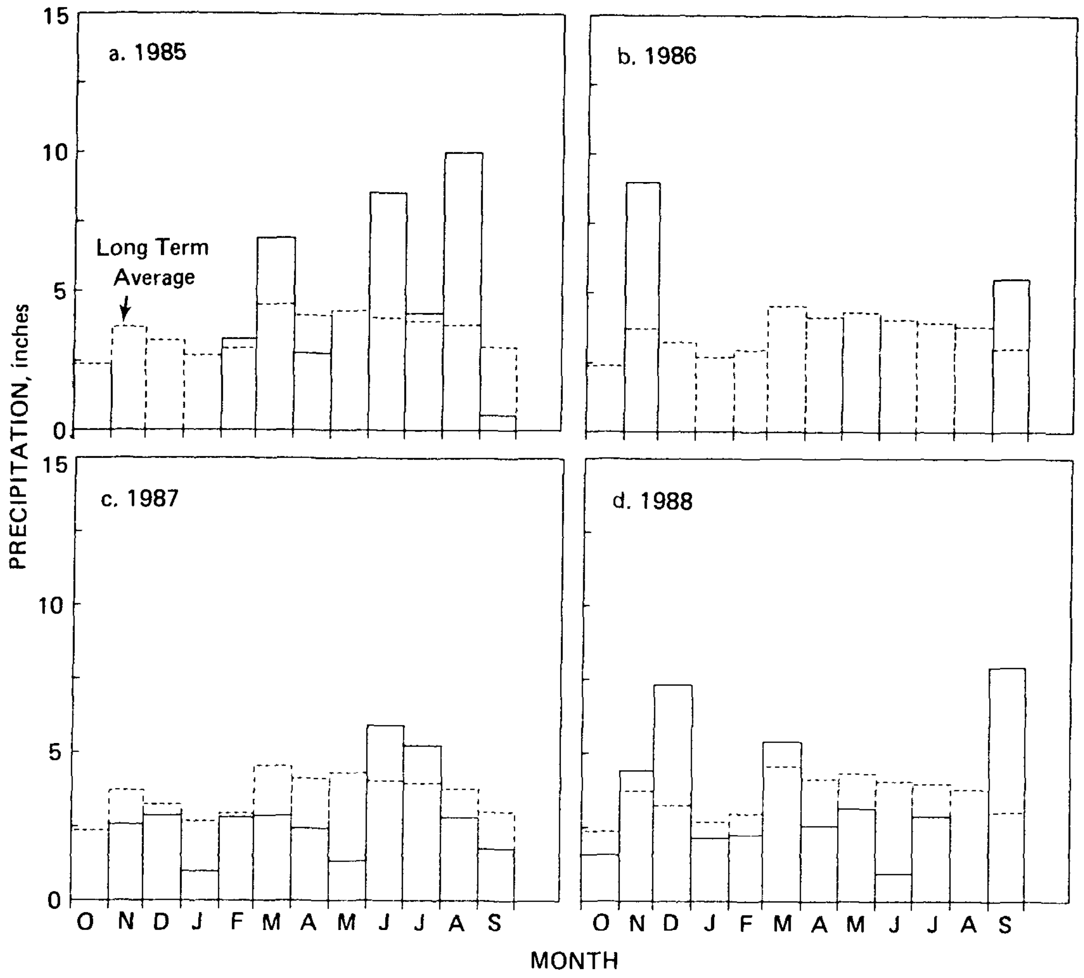


Figure 30. Monthly precipitation for the period from 1985 to 1988 at Carbondale

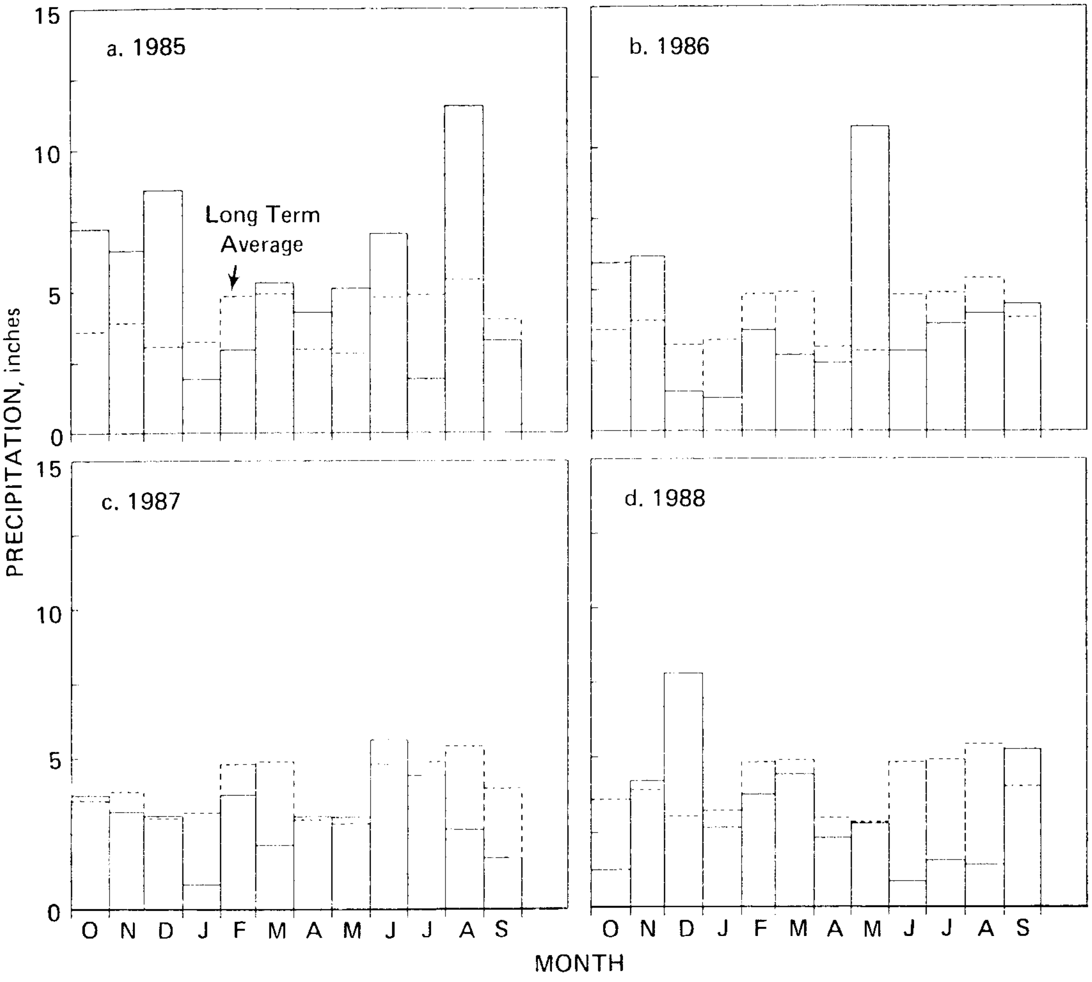


Figure 31. Monthly precipitation for the period from 1985 to 1988 at Dixon Springs

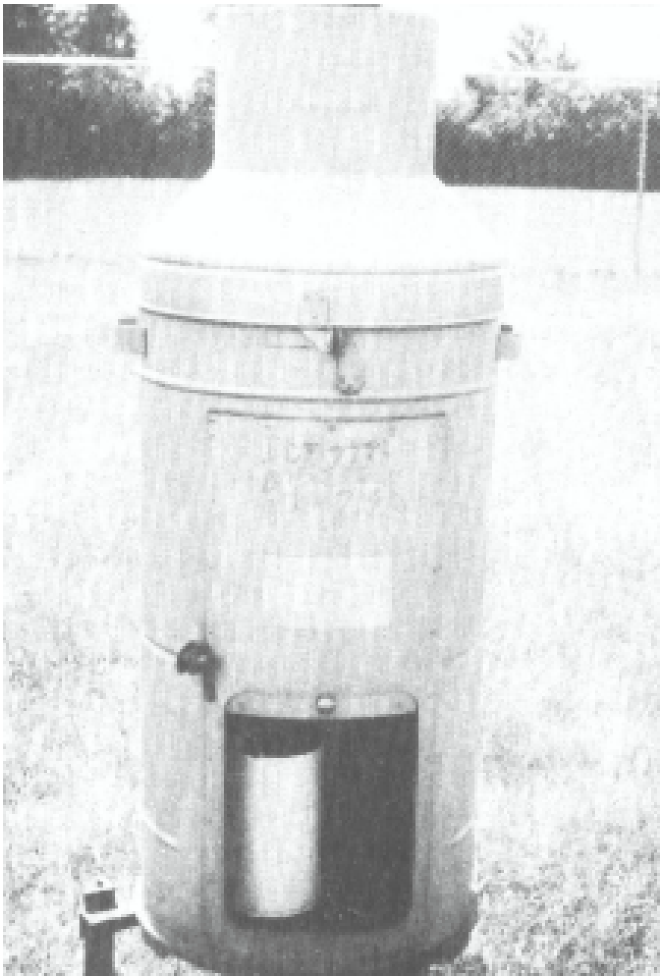


Figure 32. Belfort Universal recording raingage used to collect precipitation data in the Cache River basin

Table 4. Monthly Precipitation Summary for Three NOAA Stations, Water Years 1985 through 1988

	Anna			**Cairo**			**Dixon Springs**		
Date	***Total (in.)***	***Departure* (in.)***	***Maximum day (in.)***	***Total (in.)***	***Departure* (in.)***	***Maximum day (in.)***	***Total (in.)***	***Departure* (in.)***	***Maximum day (in.)***
1985 Water Year									
1984									
Oct	8.43	6.06	2.05	7.89	5.35	1.94	7.21	3.61	1.79
Nov	6.93	3.09	3.75	4.33	0.36	1.64	6.47	2.56	1.66
Dec	7.17	3.40	2.17	10.07	5.91	3.19	8.56	5.52	3.04
1985									
Jan	2.28	-0.77	0.37	1.65	-1.82	0.46	1.89	-1.32	0.43
Feb	4.78	1.56	1.57	3.27	-0.15	1.29	2.94	-1.88	1.37
Mar	6.53	1.45	3.95	4.83	-0.13	2.06	5.31	0.41	2.58
Apr	5.11	0.62	0.98	7.29	2.85	2.49	4.27	1.31	1.27
May	5.28	0.46	2.06	4.29	-0.61	2.17	5.11	2.27	1.89
Jun	4.75	0.78	1.42	6.72	2.36	1.78	7.05	2.24	1.19
Jul	1.28	-2.83	0.70	0.97	-2.99	0.63	1.91	-2.98	0.84
Aug	12.77	9.10	3.71	6.57	2.60	2.16	11.57	6.15	4.07
Sep	1.76	-1.49	1.10	4.37	0.87	3.24	3.29	-0.72	1.94
1985 Water Year Total	67.07			62.25			65.58		

Table 4. Continued

	Anna			Cairo			Dixon Springs		
Date	**Total (in.)**	**Departure* (in.)**	**Maximum day (in.)**	**Total (in.)**	**Departure* (in.)**	**Maximum day (in.)**	**Total (in.)**	**Departure* (in.)**	**Maximum day (in.)**
1986 Water Year									
1985									
Oct	5.09	2.72	1.40	7.75	5.21	1.56	5.96	2.36	1.63
Nov	6.31	2.47	1.18	5.31	1.34	1.32	6.18	2.27	1.63
Dec	1.75	-2.02	0.76	1.35	-2.81	0.90	1.39	-1.65	0.86
1986									
Jan	0.62	-2.43	0.48	1.37	-2.10	1.35	1.18	-2.03	0.92
Feb	3.54	0.32	1.60	4.12	0.70	1.75	3.56	-1.26	1.63
Mar	2.44	-2.64	1.16	2.53	-2.43	1.47	2.68	-2.12	1.58
APr	3.50	-0.99	1.25	2.83	-1.61	0.96	2.41	-0.55	0.70
May	10.16	5.34	3.80	9.55	4.65	2.52	10.75	7.91	3.28
Jun	1.53	-2.44	0.61	2.69	-1.67	0.75	2.84	-1.97	1.11
Jul	4.65	0.54	1.40	3.93	-0.03	1.08	3.79	-1.1	0.88
Aug	5.31	1.64	3.04	3.16	-0.81	0.95	4.16	-1.26	1.10
Sep	5.81	2.56	2.05	2.96	-0.54	1.33	4.49	0.48	2.38
1986 Water Year Total	50.71			47.55			49.39		

Table 4. Continued

	Anna			**Cairo**			**Dixon Springs**		
Date	*Total (in.)*	***Departure* (in.)***	***Maximum Day (in.)***	***Total (in.)***	***Departure* (in.)***	***Maximum Day (in.)***	***Total (in.)***	***Departure* (in.)***	***Maximum day in.)***
1987 Water Year									
1986									
Oct	4.83	2.46	1.82	2.80	0.26	0.90	3.77	0.17	0.97
Nov	2.23	-1.61	0.69	3.37	-0.60	0.77	3.24	-0.67	0.87
Dec	2.70	-1.07	1.20	2.32	-1.84	0.63	3.11	0.07	1.67
1987									
Jan	1.22	-1.83	0.36	0.85	-2.62	0.30	0.81	-2.4	0.26
Feb	3.71	0.49	1.32	4.21	0.79	1.93	3.81	-1.01	1.75
Mar	3.63	-1.45	1.32	2.17	-2.79	0.73	2.11	-2.79	0.67
APr	2.83	-1.66	1.40	1.84	-2.60	0.73	3.09	0.13	1.39
May	2.83	-1.99	1.01	4.00	-0.90	1.65	3.05	0.21	0.76
Jun	3.00	-0.97	0.97	3.10	-1.26	0.90	5.62	0.81	1.40
Jul	2.56	-1.55	1.12	4.25	0.29	1.06	4.43	-0.46	1.87
Aug	0.65	-3.02	0.52	1.30	-2.67	0.88	2.65	-2.77	1.03
Sep	1.64	-1.61	0.56	1.03	-2.47	0.70	1.69	-2.32	1.02
1987 Water Year Total									
	31.83			31.24			37.38		

Table 4. Concluded

	Anna			Cairo			Dixon Springs		
Date	***Total (in.)***	***Departure* (in.)***	***Maximum day (in.)***	***Total (in.)***	***Departure* (in.)***	***Maximum day (in.)***	***Total (in.)***	***Departure* (in.)***	***Maximum day (in.)***
1988 Water Year									
1987									
Oct	1.60	-0.77	0.71	--	--	--	1.26	-2.34	0.55
Nov	5.39	1.55	0.94	--	--	--	4.20	0.29	0.84
Dec	8.75	4.98	3.20	--	--	--	7.80	4.76	2.40
1988									
Jan	2.49	-0.56	1.22	--	--	--	2.65	-0.56	1.46
Feb	2.19	-1.03	0.88	--	--	--	3.75	-1.07	1.95
Mar	4.91	-0.17	2.03	--	--	--	4.41	-0.49	1.27
Apr	1.97	-2.52	0.93	--	--	--	2.32	-0.64	0.78
May	2.57	-2.25	0.94	4.47	-0.43	1.40	2.80	-0.04	0.98
Jun	0.60	-3.37	0.51	0.50	-3.86	0.37	0.83	-3.98	0.36
Jul	3.66	-0.45	1.29	6.06	2.10	1.78	1.53	-3.36	0.42
Aug	4.57	0.90	1.88	5.99	2.02	3.98	1.39	-4.03	0.45
Sep	5.96	2.71	1.72	7.57	4.07	2.70	5.25	1.24	1.43
1988 Water Year Total									
	44.66						38.19	-10.22	

* Departures are deviations from the norm, which are calculated from long-term historic data.
For Anna and Cairo, the time spans for norm calculation are from 1951-1980.
For Dixon Springs, the time span for norm calculation is from 1968-1988.

Table 5. Monthly Precipitation Summary for Water Survey Gages (in Inches)

		RG1	*RG2*	*RG3*
Water Year 1986				
1985	Oct	-	-	-
	Nov	-	-	-
	Dec	1.35	1.09	-
1986	Jan	0.74	0.00	-
	Feb	3.59	2.89	-
	Mar	1.91	1.67	-
	Apr	2.53	2.39	-
	May	3.40*	5.99*	-
	Jun	0.00	3.81	-
	Jul	1.12*	5.05	-
	Aug	4.15	4.92	-
	Sep	3.43	3.08	-
Water Year 1987				
1986	oct	3.44	4.22	2.75
	Nov	3.05	2.77	2.04
	Dec	2.16	2.24	2.21
1987	Jan	0.65	0.50*	0.73
	Feb	3.32	3.54	3.42
	Mar	0.77*	2.63	2.46
	Apr	2.19	1.88	2.22
	May	1.69	1.81*	1.69
	Jun	6.91	7.22	4.99
	Jul	2.38	4.29	3.65
	Aug	0.04	0.54	0.42
	Sep	2.04	1.89	1.42
Water Year 1988				
1987	Oct	1.08	1.60	1.47
	Nov	4.06	4.43	4.36
	Dec	7.79	7.75	7.98
1988	Jan	2.51	2.49	2.22
	Feb	2.71	2.57	2.82
	Mar	4.08	4.71	4.78
	Apr	1.93	1.64	1.65
	May	3.26	3.02	2.72
	Jun	0.34	0.82	0.58
	Jul	3.13	4.68	3.56
	Aug	2.27	5.64	1.28
	Sep	6.74	7.42	5.51

* Significant missing data

The event that occurred in May 1986 was a long-duration storm. The critical duration of rainfall was 2 days for Cape Girardeau, 3 days for Anna, and 5 days for Cairo and Dixon Springs. The widespread flooding in the Lower Cache River basin was therefore caused by the long-duration rainfall and not by a short-duration high-intensity rainfall.

Table 6. Precipitation Recurrence Intervals for the May 1986 Flooding Event

	Consecutive days of precipitation									
	1		2		3		5		*10*	
Station	***Total (in.)***	***T (yr)***	***Total (in.)***	***T (yr)***	***Total (in.)***	***T (yr)***	***Total (in.)***	***T (yr)***	***Total (in.)***	***T (yr)***
Anna	3.80	4	7.23	35	8.09	37	8.58	27	8.93	16
Cairo	2.06	<2	4.03	4	4.03	3	5.51	5	5.93	3
Dixon Springs	3.28	2	5.53	11	6.25	12	7.92	20	8.46	12
Cape Girardeau	5.64	18	7.26	35	7.68	27	8.44	25	9.08	17

Note: T is the recurrence interval

Streamflow

Streamflow in the Cache River basin has been monitored at only two locations for any significant period. These locations, the Cache River at Forman and Big Creek near Wetaug, are shown in figure 33. The Cache River at Forman has a complete daily flow record from the 1925 water year to the present. The station at Big Creek near Wetaug has a complete daily flow record from the 1941 to the 1971 water years and only a partial peak flow record since then. The flow record of the Cache River at Forman represents the conditions in the Upper Cache River basin and does not reflect flow conditions in the Lower Cache River. Because of the highly variable precipitation and thus streamflow conditions in the basin, the relatively long record of streamflow at the Forman station cannot be used for the Lower Cache River. The Big Creek flow record will, however, be useful in assessing flow conditions from tributary streams in the Lower Cache River. In any case, analysis of the existing records at the two stations will provide a historical framework for the streamflow data being collected in the present project.

Because of the complex streamflow conditions in the Cache River basin and the inadequacy of the existing streamflow data to explain these complex flow conditions and to provide sufficient information for sediment transport computations, additional streamflow gaging stations were established as part of the Cache River basin project. The locations of the gaging stations, the methods of data collection, and the results are discussed in the section on current data.

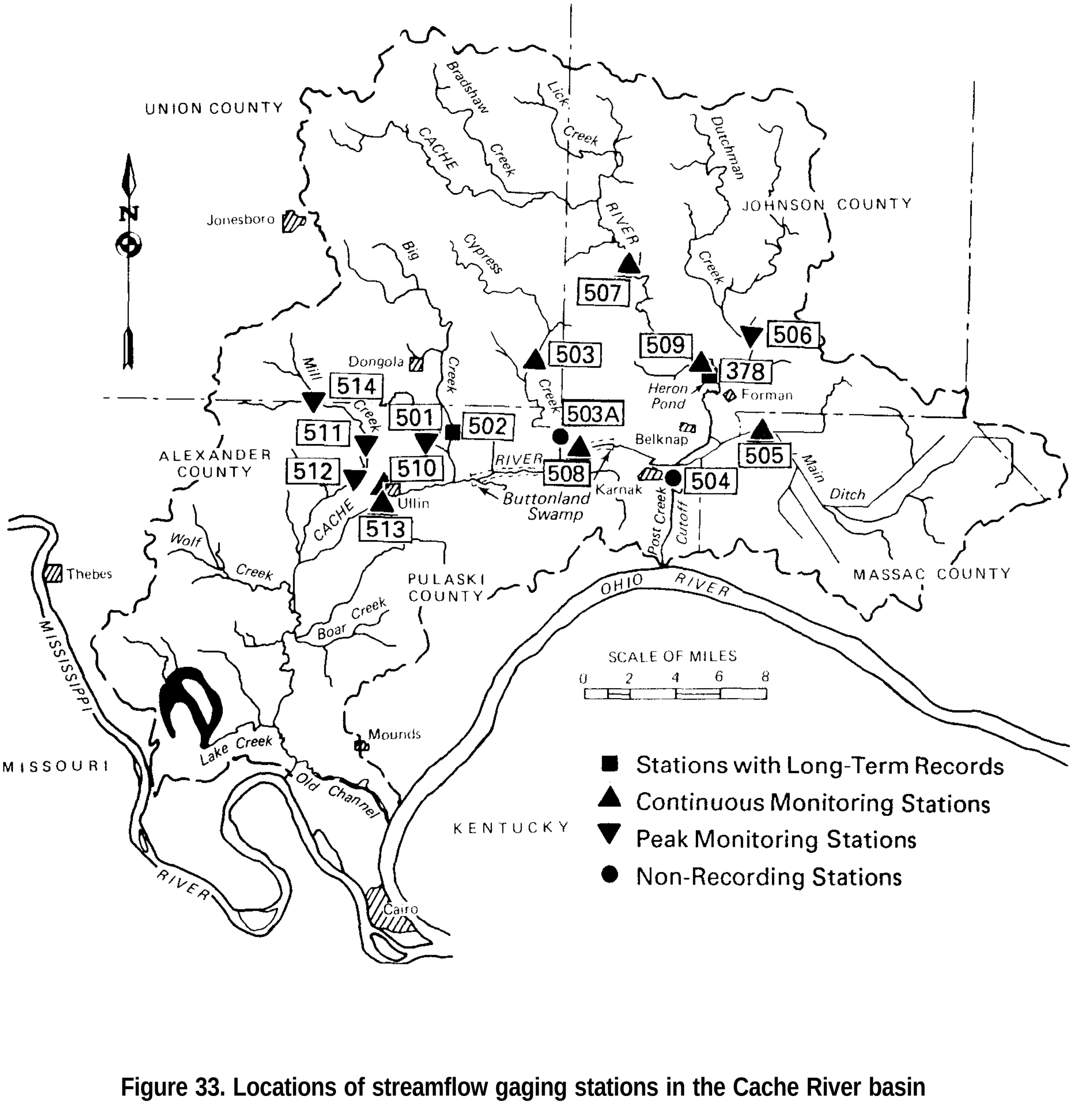


Figure 33. Locations of streamflow gaging stations in the Cache River basin

Historical Data

The historical flow records of the stations on the Cache River at Forman and Big Creek near Wetaug are analyzed in the following sections.

Cache River at Forman. As mentioned above, the streamflow record of the Cache River at Forman spans the years from the 1925 water year to the present. Thus several types of analysis could be performed on the data. First, the variation in annual streamflow for the period of record was analyzed since this is used in distinguishing between wet and dry periods and in determining if there are any trends of increasing or decreasing flows. The results of this analysis are shown in figure 34, along with the long-term mean and the 5-year moving average. The 5-year moving average was included to assist in identifying any trend that might have existed. As can be seen in the figure, there is no clear trend of increasing or decreasing streamflow in the Upper Cache River. The wettest year on record was 1950, followed by 1927. The driest year was 1941, followed by 1931. The drought periods were 1938-1944, 1953-1956, and 1963-1968. The project period from 1985 to the present, has generally been dry, even though 1985 was a wet year.

The next analysis is an evaluation of the annual maximum daily discharge, which indicates the extreme event of the year. The data for the Forman gage are plotted in figure 35. Again there is no clear trend of increasing or decreasing extreme flooding in the Upper Cache River, as indicated by the annual maximum floods. The annual maximum floods were ranked in descending order, and the ranked discharges with the calculated recurrence intervals are presented in table 7. The procedure for calculating the recurrence interval is as follows. First the annual maximum discharges are selected from the historical data and arranged in descending order, with the highest flood first and the lowest flood last. The frequency or recurrence interval of each annual maximum discharge is then determined by the equation:

$$T = \frac{m}{n+1} \tag{1}$$

where

T = the recurrence interval in years

m = the order of the annual maximum discharge

n = the period of record in years, or the number of annual maximum discharges

As shown in table 7, the highest flood was on January 26, 1929, with a daily discharge of 8,780 cubic feet per second (cfs), followed by the floods of March 13, 1935, and January 5, 1950, with daily discharges of 8,460 and 8,300 cfs, respectively.

To determine the frequency of floods, the annual maximum floods of the Upper Cache River at Forman given in table 7 were fitted to the Log-Pearson Type III probability

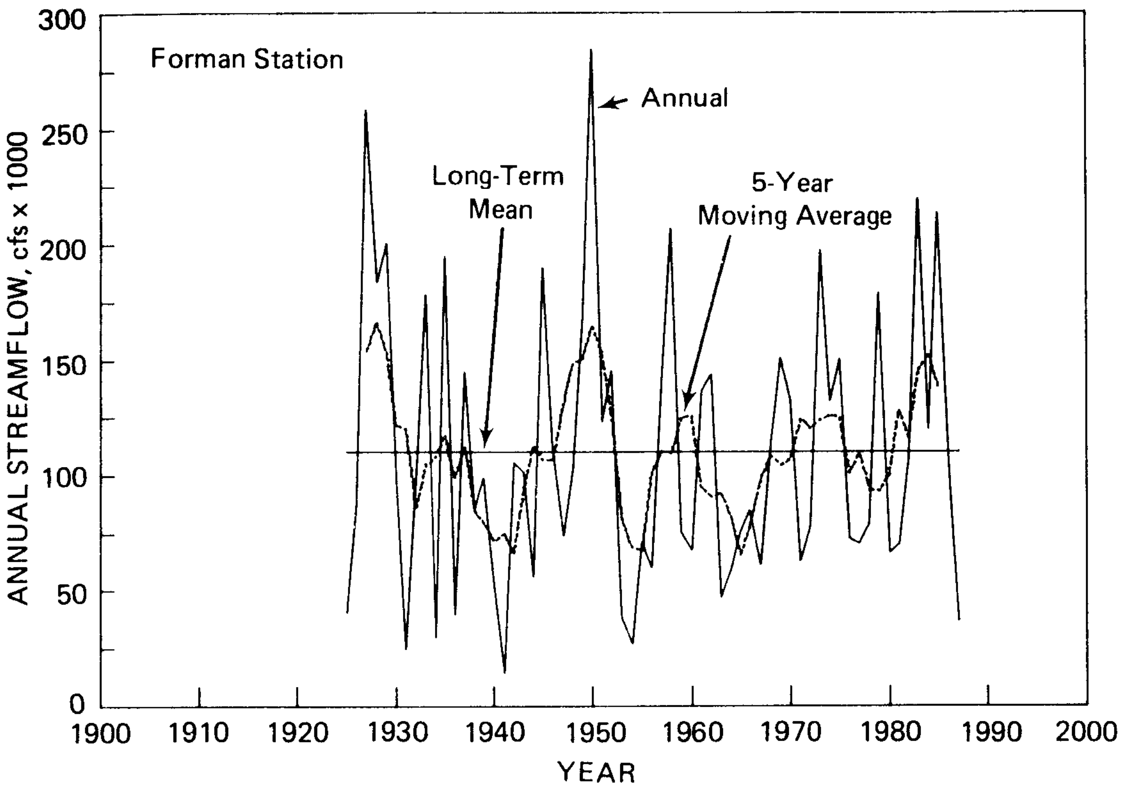


Figure 34. Annual streamflow and 5-year moving average for the Cache River at Forman

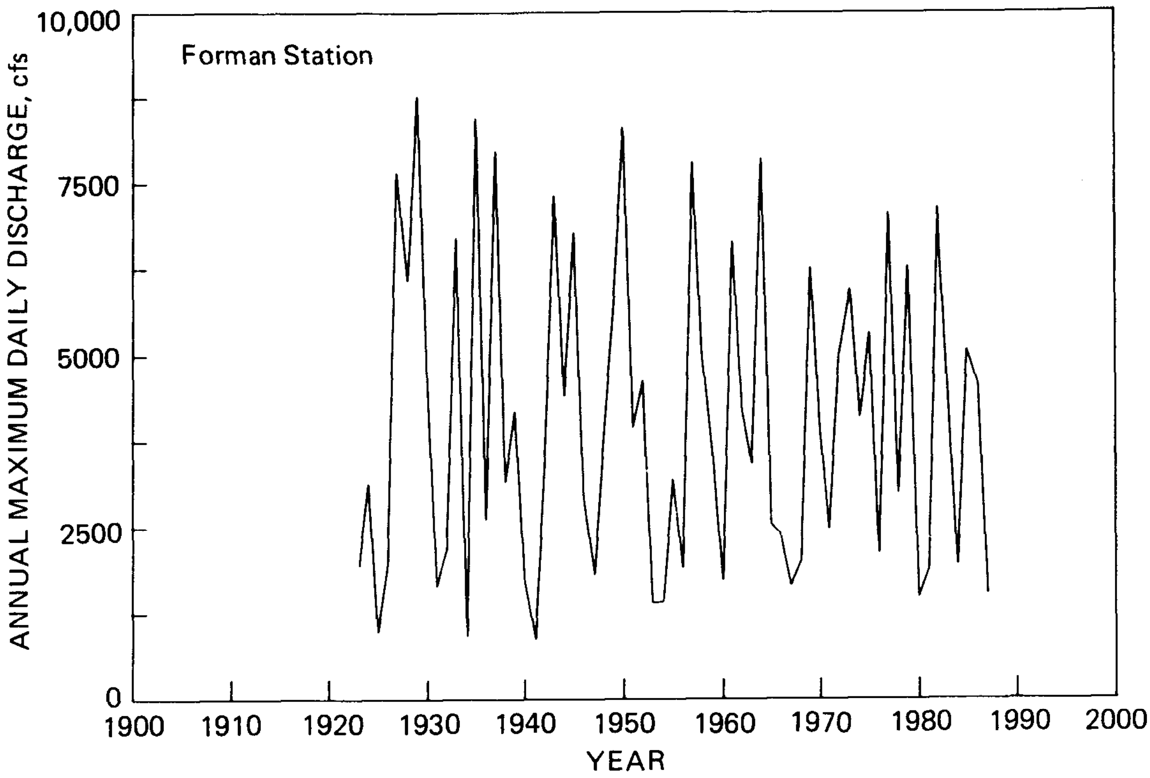


Figure 35. Annual maximum daily discharges for the Cache River at Forman

Table 7. Ranked Annual Maximum Discharges for Upper Cache River at Forman Station

Rank	***Year***	***Month***	***Day***	***Annual maximum (cfs)***	***T****
1	1929	1	26	8780	66.00
2	1935	3	13	8460	33.00
3	1950	1	5	8300	22.00
4	1937	1	16	7980	16.50
5	1964	3	11	7860	13.20
6	1957	5	24	7800	11.00
7	1927	3	19	7660	9.43
8	1943	3	20	7310	8.25
9	1982	2	2	7130	7.33
10	1977	3	30	7050	6.60
11	1982	12	27	6890	6.00
12	1945	3	8	6780	5.50
13	1933	1	1	6700	5.08
14	1961	5	9	6650	4.71
15	1979	4	2	6280	4.40
16	1969	1	31	6260	4.13
17	1928	12	15	6080	3.88
18	1973	5	28	5950	3.67
19	1949	1	26	5760	3.47
20	1975	3	30	5300	3.30
21	1985	4	2	5070	3.14
22	1972	4	17	4990	3.00
23	1958	7	20	4990	2.87
24	1952	3	12	4620	2.75
25	1930	1	15	4590	2.64
26	1986	5	18	4570	2.54
27	1944	4	13	4390	2.44
28	1962	2	28	4200	2.36
29	1939	3	6	4170	2.28
30	1974	11	28	4070	2.20
31	1951	1	16	3930	2.13
32	1970	4	25	3880	2.06
33	1948	4	15	3830	2.00
34	1959	1	22	3700	1.94
35	1942	4	10	3580	1.89
36	1963	3	20	3400	1.83
37	1955	3	23	3180	1.78
38	1938	4	1	3140	1.74
39	1924	12	24	3130	1.69
40	1978	3	16	2980	1.65
41	1946	5	27	2950	1.61
42	1936	4	7	2600	1.57
43	1965	2	12	2540	1.53
44	1971	2	24	2460	1.50
45	1966	4	28	2410	1.47
46	1932	1	19	2180	1.43
47	1976	2	19	2100	1.40
48	1968	4	5	1990	1.38
49	1926	11	8	1960	1.35
50	1923	5	17	1960	1.32
51	1984	11	28	1940	1.29
52	1956	2	19	1900	1.27
53	1981	5	20	1870	1.25
54	1947	4	12	1800	1.22
55	1940	4	20	1740	1.20
56	1960	12	18	1720	1.18
57	1967	5	15	1630	1.16
58	1931	3	9	1630	1.14
59	1987	3	1	1530	1.12
60	1980	3	18	1480	1.10
61	1954	4	7	1420	1.08
62	1953	3	4	1400	1.06
63	1925	3	18	960	1.05
64	1934	3	28	920	1.03
65	1941	1	24	853	1.02

*T= recurrence interval in years

distribution. The Log-Pearson Type III is a 3-parameter distribution that uses the logarithms of the variable instead of the actual variable. The three parameters are α, β, and γ, which represent the scale, shape, and location of the distribution respectively. The values of α, β, and y are calculated directly from the data. Once the parameters are determined, they are used to compute the mean u_y, standard deviation σ_y, and coefficient of skew k_y for the distribution. After these variables are computed, the logarithm of the discharge for a T-year return period can be computed from

$$\text{In } Q_T = u_y + K \sigma_y \tag{2}$$

where

Q = discharge
K = frequency factor
T = return period
In = natural log

The frequency factor K can be determined by using the sample probability density function, can be approximated by a polynomial equation (Kite, 1977), or can be found by using tables (e.g., Linsely, Kohler, and Paulhus, 1958).

For flood frequency analysis, the β value has to be greater than 1 and the $1/\alpha$ value greater than 0 (Kite, 1977). As shown by the Log-Pearson Type III parameters listed below and in the next subsection, these criteria are satisfied for the Cache River and Big Creek data:

Log-Pearson Type III Parameters for Cache River at Forman

Mean	*Standard deviation*	*Skewness*	*Alpha*	*Beta*	*Gamma*
8.147	0.384	-0.377	0.118	28.08	4.84

The Log-Pearson Type III distribution fits the data well as shown in figure 36, although there is a slight deviation at the high end. Generally, the fit is good and could be used to determine flood frequencies in the Upper Cache River. The 100-, 50-, 25-, 10-, 5-, and 2-year floods in the Upper Cache River, based on the Log-Pearson Type III distribution, are given in table 8.

Another method of investigating flooding in a river basin is to look at those floods that overtop the streambank and cause some level of flooding in the floodplains. The 2-year flood is generally accepted to be the flood that overtops the streambanks. The distribution of floods greater than the 2-year flood in 5-year periods for the Cache River at Forman is shown in figure 37. Based on this analysis, four periods stand out as having had more than 15 floods that exceeded the 2-year flood. The period from 1926 to 1930 had the largest number of floods, with 34 floods greater than the 2-year flood. The period from 1946 to 1950 had the second-largest

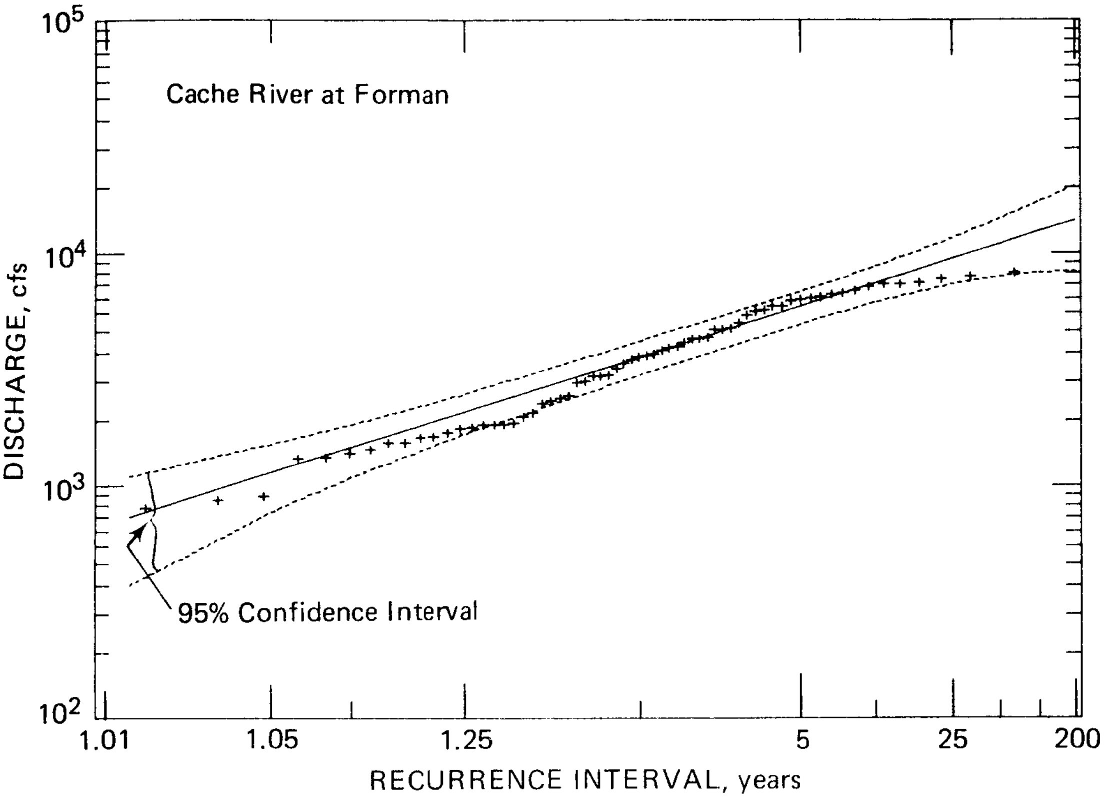


Figure 36. Log-Pearson Type III distribution fit to the annual maximum discharges for the Cache River at Forman

number of such floods with 22, followed by the period from 1981 to 1985 with 19 and then the period from 1931 to 1935 with 16. The most recent period from 1986 through 1988, which is only three years long, had only three floods exceeding the 2-year flood. Two more years of data are needed (1989 and 1990) for a comparable 5-year period.

Table 8. Flood Discharges of the Cache River at Forman
for Different Return Periods

Return period (years)	***Discharge (cfs)***
100	12400
50	10950
25	9470
10	7460
5	5890
2	3590

Big Creek near Wetaug. As mentioned earlier, the streamflow record of Big Creek is not as long or as complete as that of the Cache River at Forman. However, the Big Creek record and the flooding in the Mississippi and Ohio Rivers are more indicative of conditions for the Lower Cache River than the flow record of the Upper Cache River. Therefore the Big Creek flow record is very important to an understanding of the hydrology of the Lower Cache River.

A similar analysis was performed for the Big Creek record as for the Upper Cache River record. However, the total annual flow at Big Creek near Wetaug was not anaIyzed, because since 1971, only the peak discharges have been recorded. The variation in the peak discharges for the period of record is shown in figure 38 and represented in table 9. To make the analysis consistent for the period of record, the peak discharge is used for the Big Creek data as opposed to the maximum daily discharge used for the Cache River at Forman. The peak discharge is higher than the maximum daily flow but is generally correlated with the maximum daily flow. The highest peak discharge of 7,200 cfs was recorded on March 19, 1943. The peak flow distribution shown in figure 38 does not show any significant trend of increasing or decreasing peak floods in the Big Creek watershed, even though the three highest floods all occurred in the 1940s.

The peak flood records were then fitted to the Log-Pearson Type III probability distribution as shown in figure 39 so that floods of specified frequencies could be determined. The data fit the probability distribution very well. The Log-Pearson parameters for Big Creek

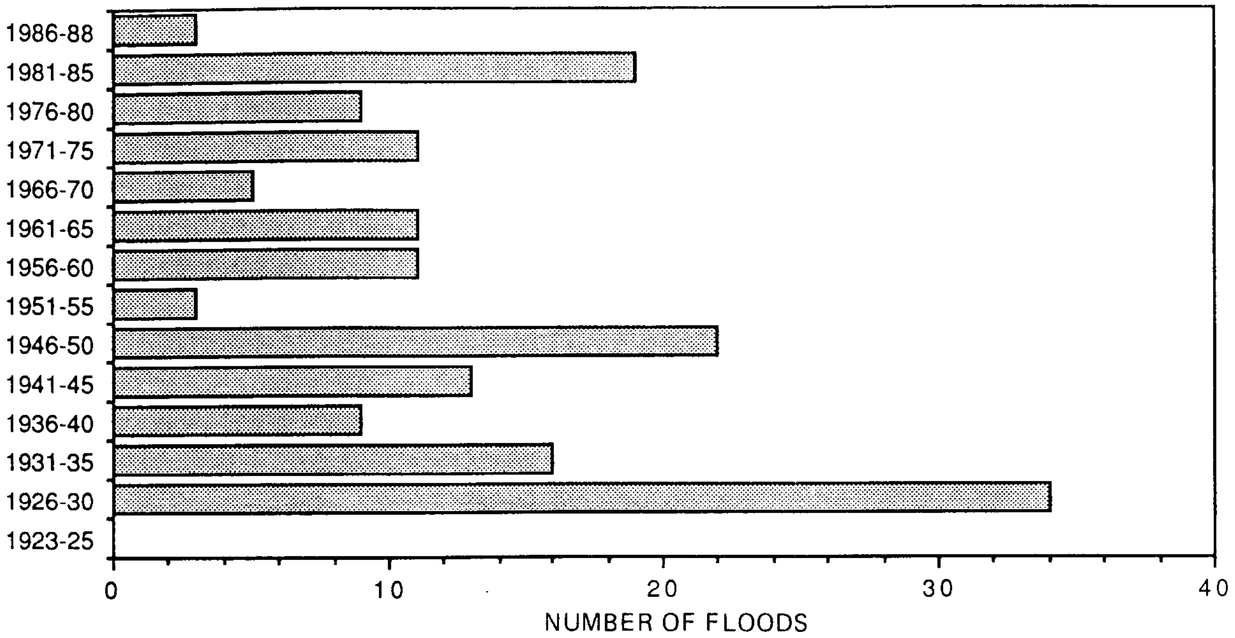


Figure 37. Number of floods greater than the 2-year flood in the Upper Cache River

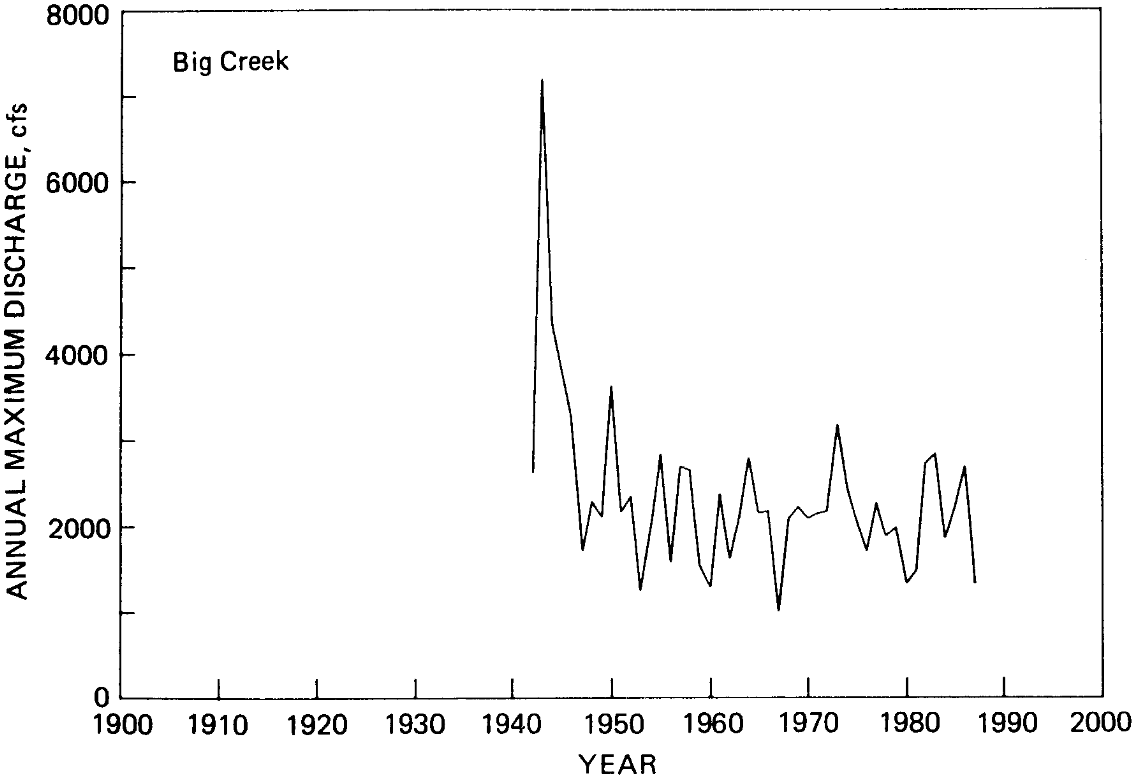


Figure 38. Annual maximum peak discharges for Big Creek near Wetaug

Table 9. Ranked Annual Maximum Discharges for Big Creek near Wetaug

Rank	*Year*	*Month*	*Day*	*Annual maximum (cfs)*	*T**
1	1943	3	19	7200	47.00
2	1944	4	11	4350	23.50
3	1945	3	6	3800	15.67
4	1950	1	4	3620	11.75
5	1946	5	25	3260	9.40
6	1973	5	27	3180	7.83
7	1983	12	25	2830	6.71
8	1955	5	13	2830	5.88
9	1964	3	9	2790	5.22
10	1982	1	31	2720	4.70
11	1986	5	16	2680	4.27
12	1957	5	23	2680	3.92
13	1958	7	18	2630	3.62
14	1942	4	8	2620	3.36
15	1974	5	22	2430	3.13
16	1961	5	7	2370	2.94
17	1952	3	10	2340	2.76
18	1948	1	1	2280	2.61
19	1977	3	28	2270	2.47
20	1969	1	30	2220	2.35
21	1985	3	31	2190	2.24
22	1972	4	15	2170	2.14
23	1966	4	27	2170	2.04
24	1951	2	20	2160	1.96
25	1971	2	22	2150	1.88
26	1965	2	10	2140	1.81
27	1963	3	16	2100	1.74
28	1949	1	24	2100	1.68
29	1970	4	19	2080	1.62
30	1968	4	4	2080	1.57
31	1975	4	28	2040	1.52
32	1954	6	3	2030	1.47
33	1979	1	31	1980	1.42
34	1978	3	14	1880	1.38
35	1984	11	23	1840	1.34
36	1976	7	3	1700	1.31
37	1947	4	11	1700	1.27
38	1962	2	26	1610	1.24
39	1956	2	15	1560	1.21
40	1959	1	21	1540	1.18
41	1981	6	20	1480	1.15
42	1987	2	28	1330	1.12
43	1980	3	17	1320	1.09
44	1960	1	14	1280	1.07
45	1953	4	18	1240	1.04
46	1967	7	29	1000	1.02

*T = recurrence interval in years

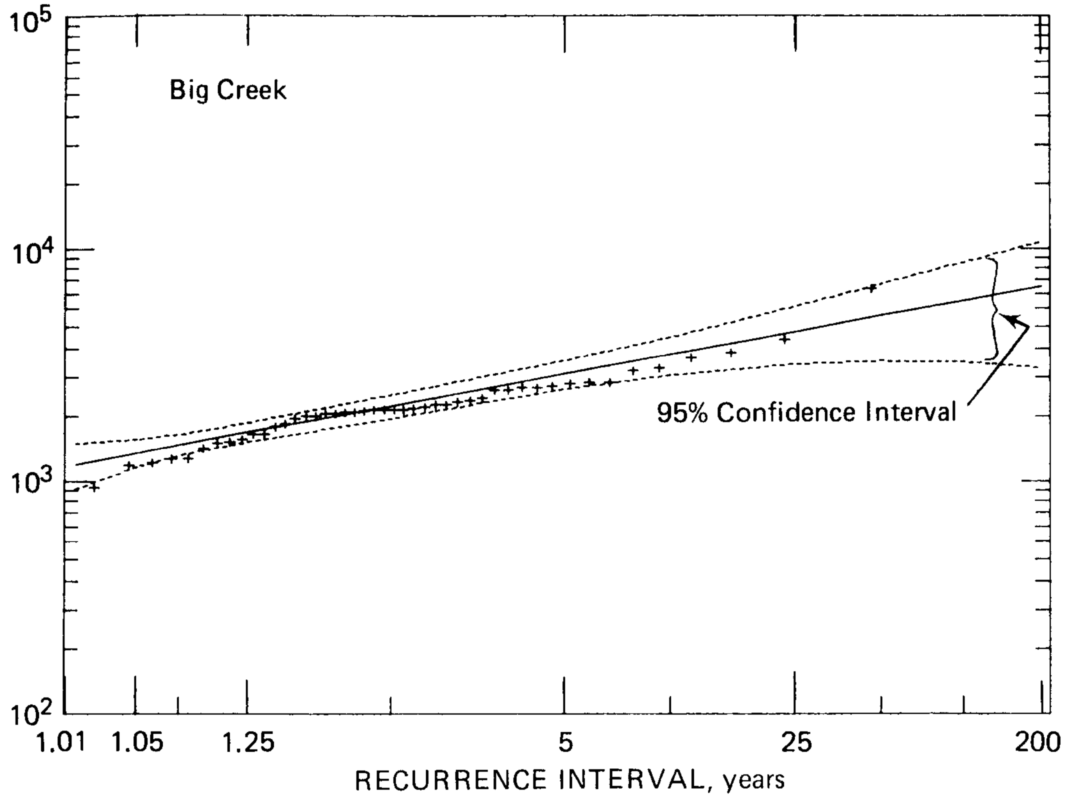


Figure 39. Log-Pearson Type III distribution fit to the annual maximum peak discharges for Big Creek near Wetaug

are listed below. The 100-, 50-, 25-, 10-, 5-, and 2-year floods, based on the Log-Pearson Type III distribution, are given in table 10.

Log-Pearson Type III Parameters for Big Creek near Wetaug

Mean	***Standard deviation***	***Skewness***	***Alpha***	***Beta***	***Gamma***
7.695	0.121	0.732	0.129	7.46	6.73

Table 10. Flood Discharges of Big Creek near Wetaug for Different Return Periods

Return period (years)	***Discharge*** *(cfs)*
100	6000
50	5160
25	4400
10	3510
5	2900
2	2100

Current Data

As mentioned earlier, stage and streamflow are being monitored at various new locations in the Cache River basin as well as at the two USGS gaging stations. The monitoring sites were selected so that the hydrologic response of different watersheds and the streamflow dynamics could be monitored in both the Upper and Lower Cache River basins. The names of the streams, locations of the monitoring stations, and types of data being collected at these sites are presented in table 11. The station locations were shown in figure 33. A total of 16 stations monitor stage in the Cache River basin. Stage is the height of the water surface above a fixed datum. Of the 16 stations in the basin, 9 are used to monitor stage continuously, while 5 record the peak and 2 are nonrecording. The sites used to monitor stage continuously also monitor discharge, with the exception of the Heron Pond gage. The peak stage sites also can provide information on the peak discharge.

In addition to these 16 monitoring stations, 8 additional water-level monitoring stations were established in the Lower Cache River from the Cache River levee to the Cache Chapel Road bridge to intensively monitor water-level fluctuations and flow directions in the Buttonland Swamp area during flood events. Even though the data from those 8 stations are not presented in a similar manner to those from the regular monitoring stations, the information collected from those stations has been used in this and other reports to explain flow dynamics in the Buttonland Swamp area.

Table 11. Streamflow and Stage Monitoring Stations
in the Cache River Basin

Station number	***Location***	***Drainage area (sq mi)***	***Date of installa-lation***	***Continuous stage***	***Peak stage***
378	Cache River @ Forman	241	09/24*	X	
501	Little Creek @ Perks Road	12.7	05/85		X
502	Big Creek @ Perks Road	31	04/85**	X	
503	Cypress Creek @ Dongola Road	24	02/86	X	
503a	Cypress Creek @ Perks Road	44			
504	Post Creek Cutoff @ Route 169	352			
505	Main Ditch @ Route 45	97	04/85	X	
506	Dutchman Creek @ Route 45	70	05/85		X
507	Cache River @ Route 146	122	06/85	X	
508	Cache River @ Route 37	12.5	05/85	X	
509	Heron Pond		06/85	X	
510	Indian Camp Creek @ Ullin	4.1	02/86	X	
511	Mill Creek @ Section 10	31	02/86		X
512	Mill Creek @ Section 22	34	02/86		X
513	Cache River @ Route 51	164	02/86	X	
514	Mill Creek @ Section 32	16.6	*02/86*		X

*Monitored by USGS
**Prior to being a continuous station, had been a peak station since 05185

Data Collection Methods and Procedures. Three methods are used by the Water Survey to measure stage in the Cache River basin. These methods are nonrecording, peak, and continuous.

Nonrecording measurements of stage occur during regular monitoring site visits. The measurement is made from a fixed datum to the water surface by using a surveying rod or a cable with a distance meter installed. These site visit measurements assure that the monitoring equipment is operating correctly. These measurements are made at the continuous, peak, and nonrecording stations as well as at other locations within the basin when needed.

Peak stage measurements are made with a crest gage. The gage is constructed of 2-inch-diameter pipe that is mounted vertically with a wooden rod positioned inside the pipe. Attached to the rod is a reservoir of cork, which leaves a mark on the rod. Water enters the pipe through holes located at the bottom of the gage. The mark left on the rod corresponds to the peak stage. After the gage is read, it is reset so it can record the peak stage of the next major flood. A typical crest gage installation is shown in figure 40.

At monitoring stations where continuous stage records are collected, data are obtained through the use of either a Leopold & Stevens type F or type A recorder. Both recorders operate in a similar fashion, with the main difference being the type of chart used. These

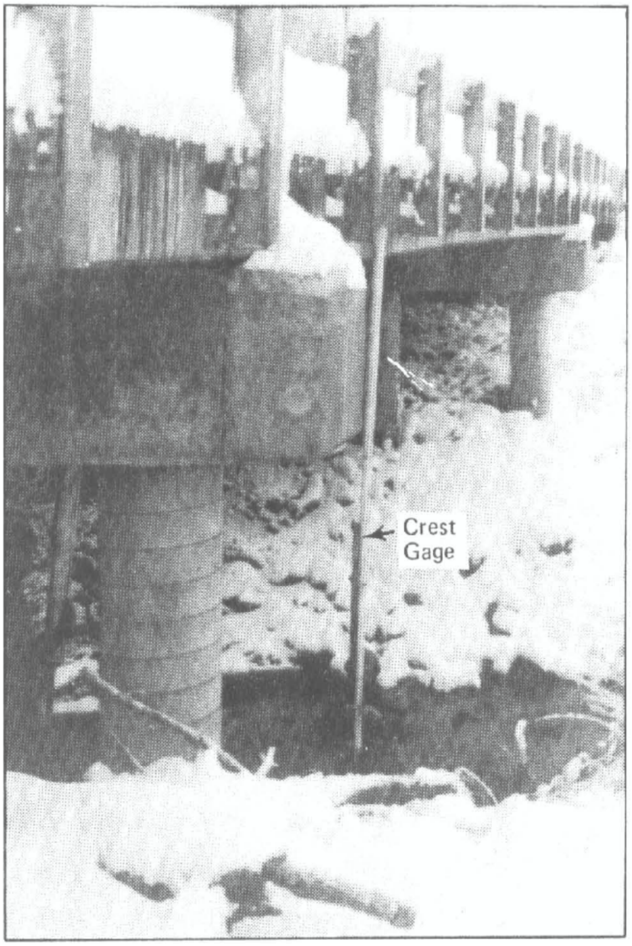


Figure 40. Typical crest gage installation

recorders function on a pulley basis so that as the water level rises or falls, a float rises or falls accordingly. The movements of these water-level fluctuations are recorded on a chart. Depending on the type of recorder, either the pen or chart moves at a constant rate. The trace that is recorded on the chart provides the change in stage over time. A photograph of a typical type A recorder is presented in figure 41. Each continuous-water-level recorder is housed in a vandal-resistant shelter and is installed on top of a stilling well constructed of corrugated metal pipe. The pipe, with its longitudinal axis oriented vertically, is attached directly to a bridge pier, abutment, or beam. The stilling well eliminates minor fluctuations in the stage caused by wind or waves. The recorders are placed above high-water levels so that they are readily accessible during floods. They are checked periodically to determine whether they are operating properly. The charts are removed periodically and replaced and are brought to the office for analysis at a frequency dictated by the recorder type. A typical stilling well installation at a gaging station is shown in figure 42, and the typical instrument configuration is presented in figure 43.

To obtain streamflow from the stage data, a stage-discharge relationship generally referred to as a rating curve is used. The stage-discharge relationships are obtained for the gaging station sites by discharge measurements made at different stages in the stream. The discharge measurements are made by using a current meter of a rotating bucket type, shown in figure 44, and following the standard USGS procedure (Buchanan and Somers, 1969). For each stage, velocity measurements are made at from 10 to 20 locations across the stream channel. Each measurement location should correspond to an equal discharge, but since the distribution of discharge across the stream is unknown before the measurement, the field procedure is to make measurements at equally spaced intervals. Depending on the depth of water, one or two velocity measurements are made at each location. When one measurement is used, it is made at 0.6 of the total depth measured from the water’s surface. When two measurements are made, the depths are 0.2 and 0.8 of the total depth. The two velocities are averaged to provide a single representative velocity for each vertical. These multiple vertical measurements are necessary to adequately describe the distribution of discharge in the stream. The results of the velocity measurements made at each location are then applied to specific cross-sectional areas to obtain the incremental discharges by equation 3:

$$\Delta Q_j = d_j \times \left[\left(\frac{b_j - b_{j-1}}{2} \right) + \left(\frac{b_{j+1} - b_j}{2} \right) \right] \times V_j \qquad (3)$$

where

bj = distance from an initial point to the measurement location

dj = depth of water at the measurement location

Vj = average velocity at location j

ΔQ_j = incremental discharge at location j

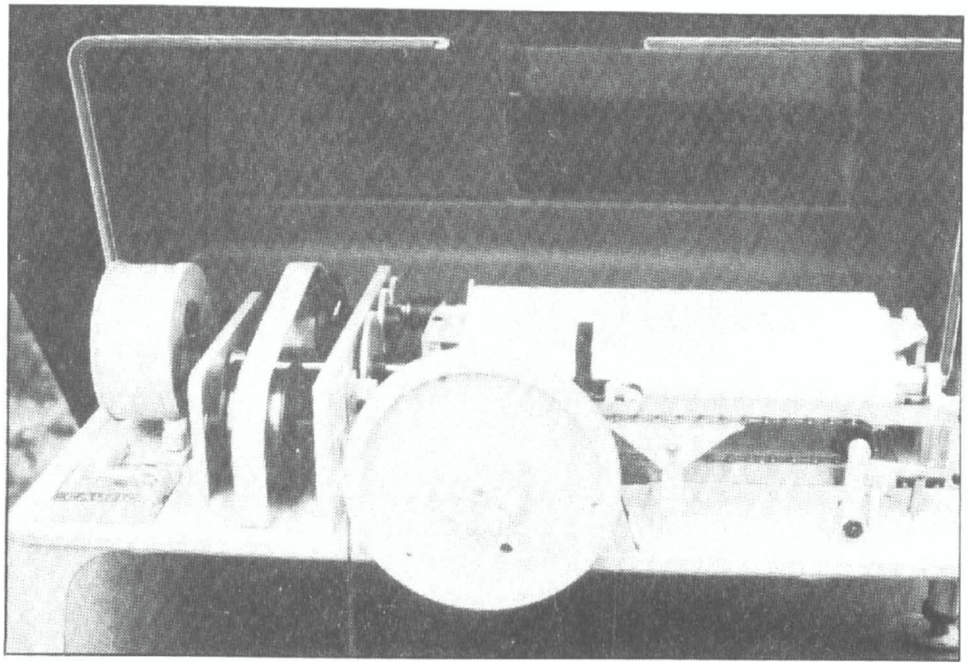


Figure 41. Leopold & Stevens type A stage recorder

Figure 42. Gaging station installation at Route 146

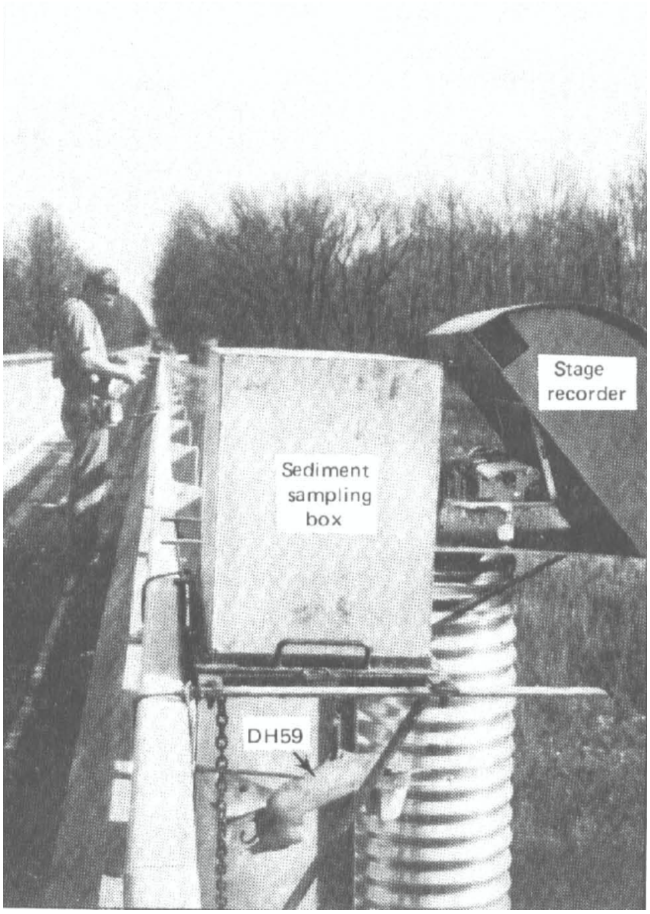


Figure 43. Typical instrument configuration for a gaging station with a sediment sampling instrument

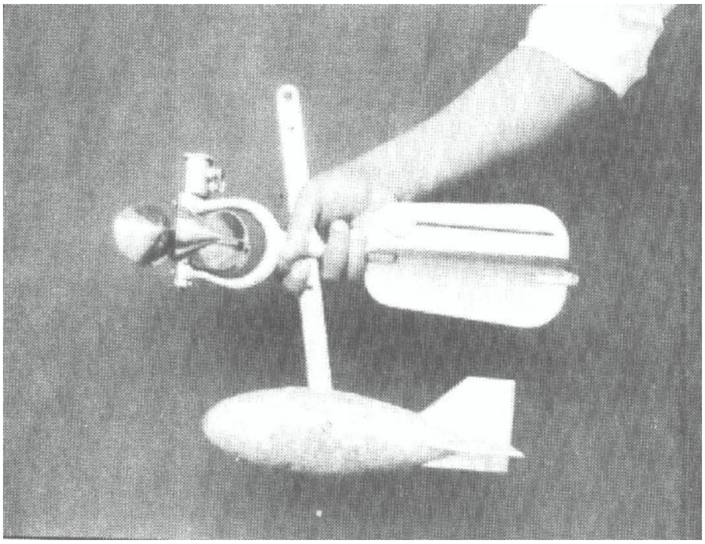


Figure 44. A rotating bucket current meter

These cross-sectional areas are determined as the area between the midpoint between the prior vertical measurement (j-1) and the present measurement (j), and the midpoint between the present measurement (j) and the following measurement (j+1), as shown in figure 45. This procedure is repeated until calculations have been made for the entire cross section. Objects such as piers are subtracted from the calculations since they can totally obstruct the flow. The incremental discharges are then summed for all the measurement locations, as shown in equation 4, to provide the total discharge that corresponds to a specific stage.

$$Q = \sum_{j=1}^{N} \Delta Q_j \qquad (4)$$

where Q = total discharge at a cross section.

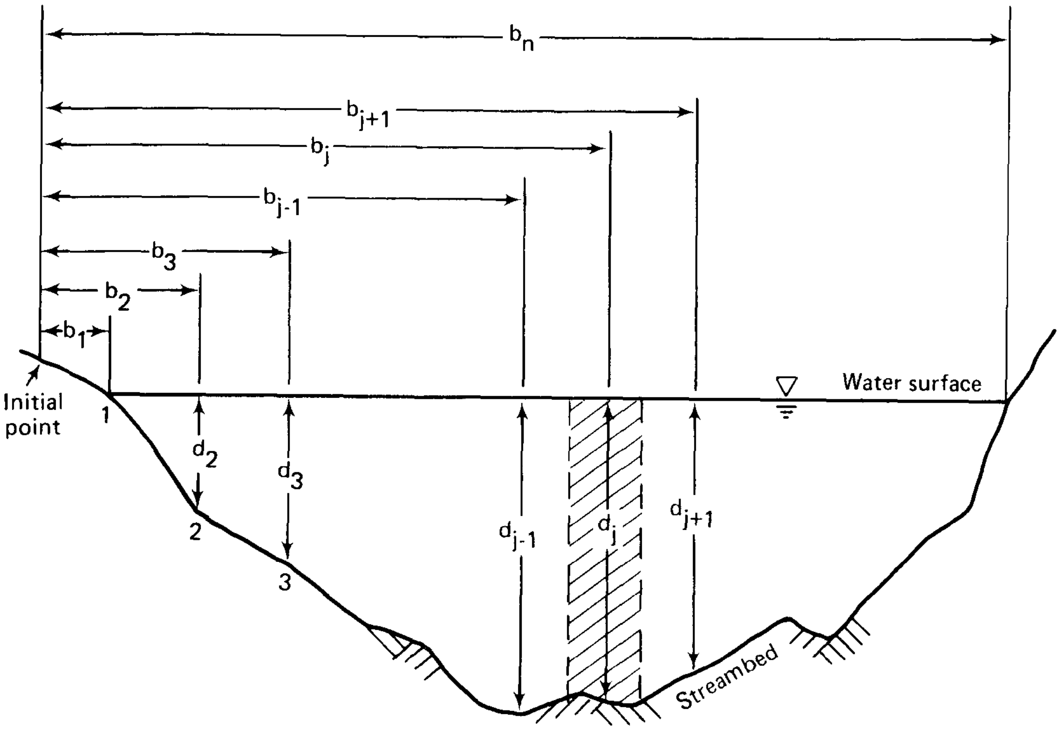
The discharges and the corresponding stages are generally plotted on semi-logarithmic graph paper by using the logarithm of discharge and the stage. A curve is then fitted through the points to develop the discharge rating curve. An example of a rating curve (for the Cache River at Route 146) is shown in figure 46. This relationship (or rating curve) is then used to calculate discharges from the stage data collected at the gaging stations.

Results. The results of stage data collected at the seven continuous monitoring sites are presented in appendix A. These data are presented over time for the 1985 through 1988 water years. The data for individual water years are presented in separate plots for clarity. Although the data are presented as stages above gage datum, relations are provided for converting the stages to elevations above mean sea level (msl).

To convert the stage data into discharge data, rating curves were needed for the seven sites that continuously monitor runoff in the Cache River basin, as discussed in the preceding section. These relations had to be developed for Cypress Creek at Dongola Road (503), Main Ditch at Route 45 (505), Cache River at Route 146 (507), Indian Camp Creek at Ullin (510), and Cache River at Route 51 (513). Rating curves from the U.S. Geological Survey existed for Cache River at Forman (378), which continues to be operated as a continuous-gage station, and Big Creek at Perks Road (Wetaug) (502), which has functioned as a peak-gage station since being discontinued in 1971 as a continuous-gage station. Periodic discharge measurements are made at these and all other sites to ensure accuracy of the rating curves. The rating curves for each of the streamflow measuring stations are shown in appendix B.

In appendix C, the streamflow data are presented for the seven streamflow monitoring stations for each water year in a manner similar to the presentation of the stage data.

The results of streamflow measurements are summarized in table 12 in terms of monthly streamflow in inches. In this table, the streamflow is divided by the drainage area upstream of the gaging station to determine the streamflow in inches. This is a convenient way of



1,2,3,..........n	Observation points
$b_1, b_2, b_3, \ldots, b_n$	Distance from the initial point to the observation point
$d_1, d_2, d_3, \ldots, d_n$	Depth of water at the observation point

Figure 45. Definition sketch for computing cross-sectional areas for discharge computations

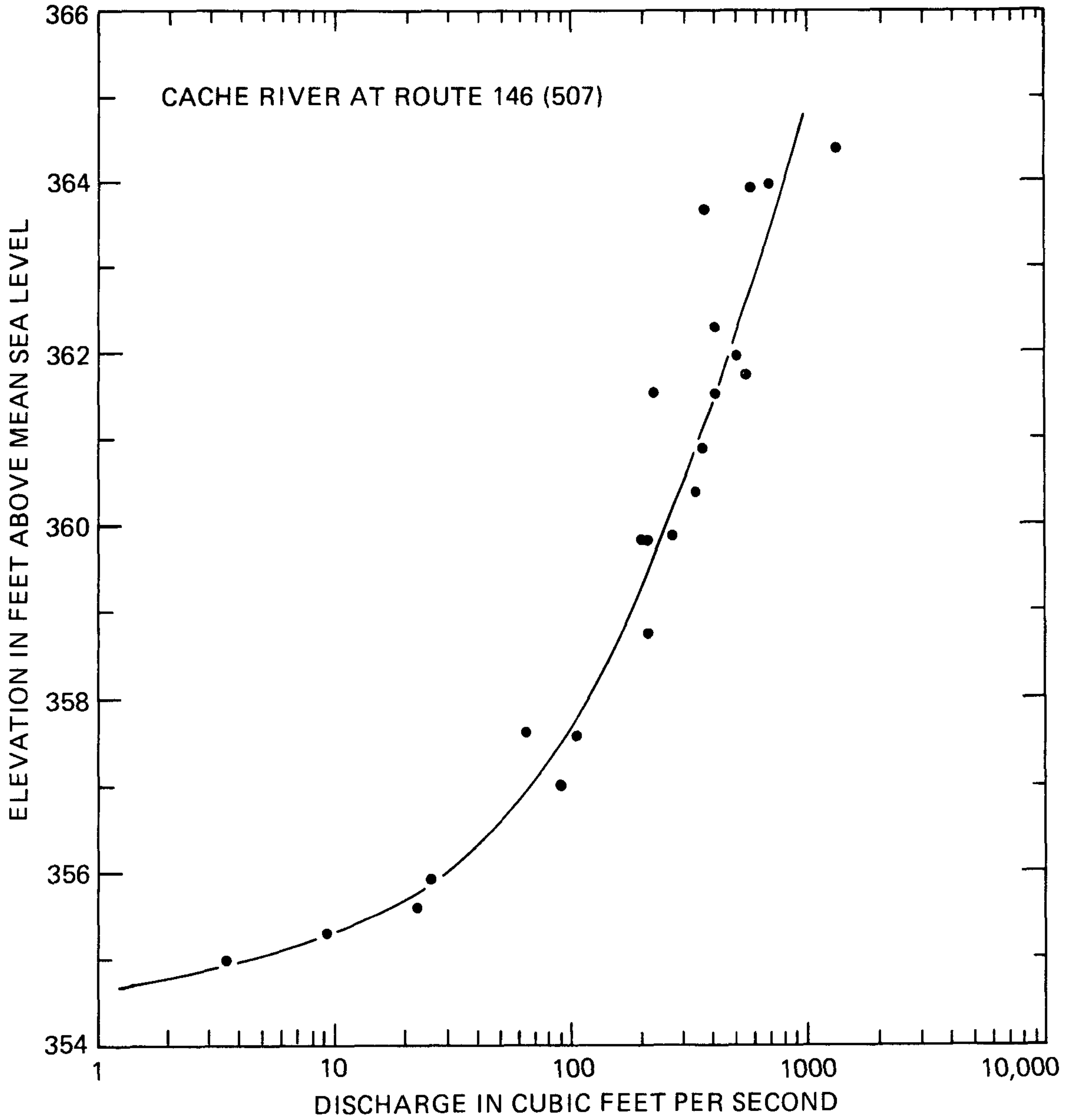


Figure 46. Discharge rating curve for the Cache River at Route 146

Table 12. Summary of Monthly Streamflow Data at Seven Gaging Stations (in Inches)

		Station						
		Big Creek *(502)*	***Cypress Creek*** *(503)*	***Main Ditch*** *(505)*	***Cache R. at Rt. 146*** *(507)*	***Indian Camp Creek*** *(510)*	***Cache R. at Rt. 51*** *(513)*	***Cache R. at Forman*** *(378)*
Water Year 1985								
1984	Oct	-	-	-	-	-	-	1.85
	Nov	-	-	-	-	-	-	4.60
	Dec	-	-	-	-	-	-	4.53
1985	Jan	-	-	-	-	-	-	2.29
	Feb	-	-	-	-	-	-	3.61
	Mar		-	1.53*	-	-	-	1.89
	Apr	0.86*	-	4.95	-	-	-	4.76
	May	2.32	-	1.83	-	-	-	2.91
	Jun	0.72	-	0.45	0.32*	-	-	1.44
	Jul	0.12	-	0.21	0.15	-	-	0.16
	Aug	3.24	-	1.95	3.18	-	-	3.95
	Sep	0.70	-	3.53	0.53	-	-	0.90
Water Year 1986								
1985	Oct	0.71	-	1.39	0.40	-	-	0.53
	Nov	2.52	-	3.46	2.98	-	-	3.02
	Dec	0.90	-	1.09	1.14	-	-	1.91
1986	Jan	0.24	-	0.62	0.16	-	-	0.33
	Feb	1.93	0.92*	2.67	1.70	0.95*	1.02*	2.23
	Mar	1.05	1.43	1.39	1.01	1.06	0.69	1.23
	Apr	0.40	0.50	0.23	0.49	0.37	0.13	0.57
	May	2.98	2.14	6.29	2.11	1.36*	2.49	4.59
	Jun	0.50	0.35	0.40	0.58	**	0.89	0.76
	Jul	0.39	0.14	0.14	0.21	0.20*	0.22	0.17
	Aug	0.56	0.26	0.06	0.25	1.15	0.37	0.24
	Sep	0.24	0.20	0.10	0.23	0.26	0.14	0.19
Water Year 1987								
1986	Oct	0.68	0.24	0.10	0.45	0.36	0.23	0.27
	Nov	0.17	0.07	0.19	0.27	0.28	0.16	0.19
1987	Dec	0.50	0.41	0.57	1.03	0.46	0.43	0.73
	Jan	0.16	0.04	0.02	0.29	0.25	0.08	0.20
	Feb	0.91	0.39	0.52	0.73	0.86	0.26	0.64
	Mar	1.16	0.79	0.84	1.97	1.34	1.08	1.86
	Apr	0.63	0.31	0.46	1.03	0.66	0.25	0.98
	May	0.22	0.01	0.13	0.11	0.26	0.07	0.11
	Jun	0.30	0.30	0.29	0.18	0.29	0.08	0.24
	Jul	0.32	0.53	0.43	0.37	0.44	0.37	0.45
	Aug	0.05	0.00	0.03	0.06	0.17	0.03	0.04
	Sep	0.05	0.00	0.01	0.02	0.15	0.02	0.00

Table 12. Concluded

		Station						
		Big Creek *(502)*	***Cypress Creek*** *(503)*	***Main Ditch*** *(505)*	***Cache R. at Rt. 146*** *(507)*	***Indian Camp Creek*** *(510)*	***Cache R. at Rt. 51*** *(513)*	***Cache R. at Forman*** *(378)*
Water Year 1988								
1987	Oct	0.07	0.00	0.00	0.02	0.18	0.01	0.00
	Nov	0.10	0.03	0.01	0.11	0.19	0.03	0.07
	Dec	1.95	1.63	3.58	1.77	2.56	1.06	2.20
1988	Jan	0.86	0.60	1.76	1.41	1.19	0.66	2.00
	Feb	1.21	0.95	2.31	1.49	2.09	0.49	1.77
	Mar	1.19	0.64	0.94	1.29	1.79	0.70	1.17
	Apr	1.12	0.55	1.25	1.42	1.74	0.96	2.31
	May	0.17	0.01	0.29	0.10	0.52	0.14	0.11
	Jun	0.06	0.00	0.03	0.11	0.17	0.03	0.01
	Jul	0.07	0.01	0.01	0.13	0.13	0.03	0.04
	Aug	0.07	0.02	0.01	0.06	0.11	0.03	0.02
	Sep	0.13	0.04	0.07	0.08	0.14	0.09	0.08
WY85	Total	7.96*	–	14.45*	4.18*	-	-	32.87
WY86	Total	12.43	5.93*	17.83	11.26	5.35*	5.94*	15.77
WY87	Total	5.14	3.09	3.59	6.52	5.50	3.04	5.71
WY88	Total	6.99	4.48	10.27	8.00	10.82	4.25	9.79

- no data
* Partial record
** Missing data

representing streamflow so that it can be compared directly with rainfall. The totals for each water year are given at the end of the table.

The monthly streamflows tabulated in table 12 are plotted in figures 47 and 48 for comparison purposes. Station 510 was excluded from the comparison because it is not in the same general area as the other streams and does not influence the Buttonland Swamp area. In figure 47, the streamflows for the three stations in the Upper Cache River -- Cache River at Route 146 (507), Cache River at Forman (378), and Main Ditch at Route 45 (505) -- are plotted together. In figure 48, the streamflows for the three stations in the Lower Cache River -- Big Creek at Perks Road (502), Cypress Creek at Dongola Road (503), and Cache River at Route 51 (513) -- are plotted together. The plots are separated according to the different water years to avoid cluttering, and thus for each group there are plots for Water Years 1985, 1986, 1987, and 1988. It should be mentioned that data collection started at different times for the different stations and that only in Water Years 1987 and 1988 did all the stations have complete data.

Discussion. The results of the precipitation analyses indicated that, overall, the period in which data were collected was drier than normal, except for 1985. Only one long-term set of streamflow data allows comparison with the ongoing data collection program. The Cache River at Forman site has 64 years of runoff data (including the 1988 water year). The average discharge over the period of record is 16.64 inches per year (Stahl et al., 1989). The 1985 water year had a total discharge of 32.51 inches, the 1986 water year had 15.59 inches, the 1987 water year had 5.67 inches, and the 1988 water year had 8.96 inches (Fitzgerald et al., 1986; Stahl et al., 1987, 1988, 1989). The annual discharges for the Upper Cache River as monitored at the Forman gaging station during the project period are compared to the long-term mean in figure 49. The 1985 water year was abnormally wet, with runoff nearly double that of the long-term average. However, the 1987 and 1988 water years were extremely dry, consistent with the rest of the state. The 1986 water year was below- but near-normal. Therefore three out of the four years of data collection were drier than normal.

A closer look at the distribution of streamflow in the Upper Cache River based on figure 47 confirms that the May 1986 flood was the most significant flood during the project period. The monthly streamflows for the Cache River at Forman and Main Ditch at Route 45 were 4.59 and 6.29 inches respectively. However, Cache River at Route 146 recorded only 2.11 inches, indicating that most of the heavy rainfall was in the southern part of the basin. Another observation from figure 47 relates to the extreme low streamflows in the Upper Cache River during most of 1987 and 1988. Figure 47 also indicates that the different sub-watersheds of the Upper Cache River basin generally generate similar runoff amounts for similar rainfall amounts. The difference in the monthly streamflows between the stations is largely due to the spatial variation in precipitation.

Figure 48 also shows that the May 1986 flood was the major flood during the project period, resulting in monthly runoff of 2.98, 2.14, and 2.49 inches for Big Creek at Perks Road, Cypress Creek at Dongola, and Cache River at Route 51 respectively. Even though the streamflows in the Lower Cache River were lower than those recorded in the Upper Cache River, they were still the highest monthly streamflows recorded at the respective stations. Another similar observation between the Upper and Lower Cache Rivers is the low flow conditions in the Lower Cache River in 1987 and 1988. In Water Year 1987, streamflow in the Lower Cache River exceeded 1 inch only in the month of March. For the rest of the year, streamflow was below 1 inch at all stations in the Lower Cache River. One significant observation from the streamflow data for the Lower Cache River is the fact that Big Creek tends to generate more runoff than any of the other streams under similar rainfall conditions. This is most probably due to differences in land use and to the absence of any wetlands along Big Creek.

It is important to recognize that runoff from the Lower Cache River basin flows in two opposite directions, either east towards two 4-foot-diameter culverts in the Cache River levee and then into the Post Creek Cutoff, or west through the original river channel to the Cache River diversion channel and then to the Mississippi River. The elevation of the channel bottom of the Cache River at Route 51 and the inverts of the culverts is approximately 318 feet msl. The elevation of the top of a 2.5-foot dam used to maintain water levels in the Buttonland Swamp area is about 328.4 feet msl. Therefore the head difference between the channel bottom in Buttonland Swamp and the Cache River at Route 51 and the culverts is about 8 feet. There is another 25-foot drop from the Cache River at Route 51 to the Mississippi River at low-water level. The stream slope is about 1.2 feet per mile. The channel bed elevation for the Cache River from Route 51 to the Cache River levee is shown in figure 50 along with water surface elevations on selected days. It can be seen from this figure why water flows in both directions. This figure also shows the influence of the low-head channel dam in Buttonland Swamp on low-water elevations and its lack of influence on high-water elevations.

How the Buttonland Swamp area responds is dependent on the particular event under discussion. Factors that influence flow patterns are the amount of water in Buttonland Swamp, downstream water levels, and which tributary is contributing the most water. The location where the flow divides to flow east or west is not constant and varies during an event. One event that was intensively monitored in the Buttonland Swamp area occurred on July 2-3, 1987. The results of this data collection are presented in figure 51. In this figure, the water-surface elevations are presented in three 12-hour increments. The flow toward the east and the west is clearly identifiable based on the water-surface slope. During this event, flow in the Buttonland Swamp area was dominated by inflow from Cypress Creek. In this figure, it can be

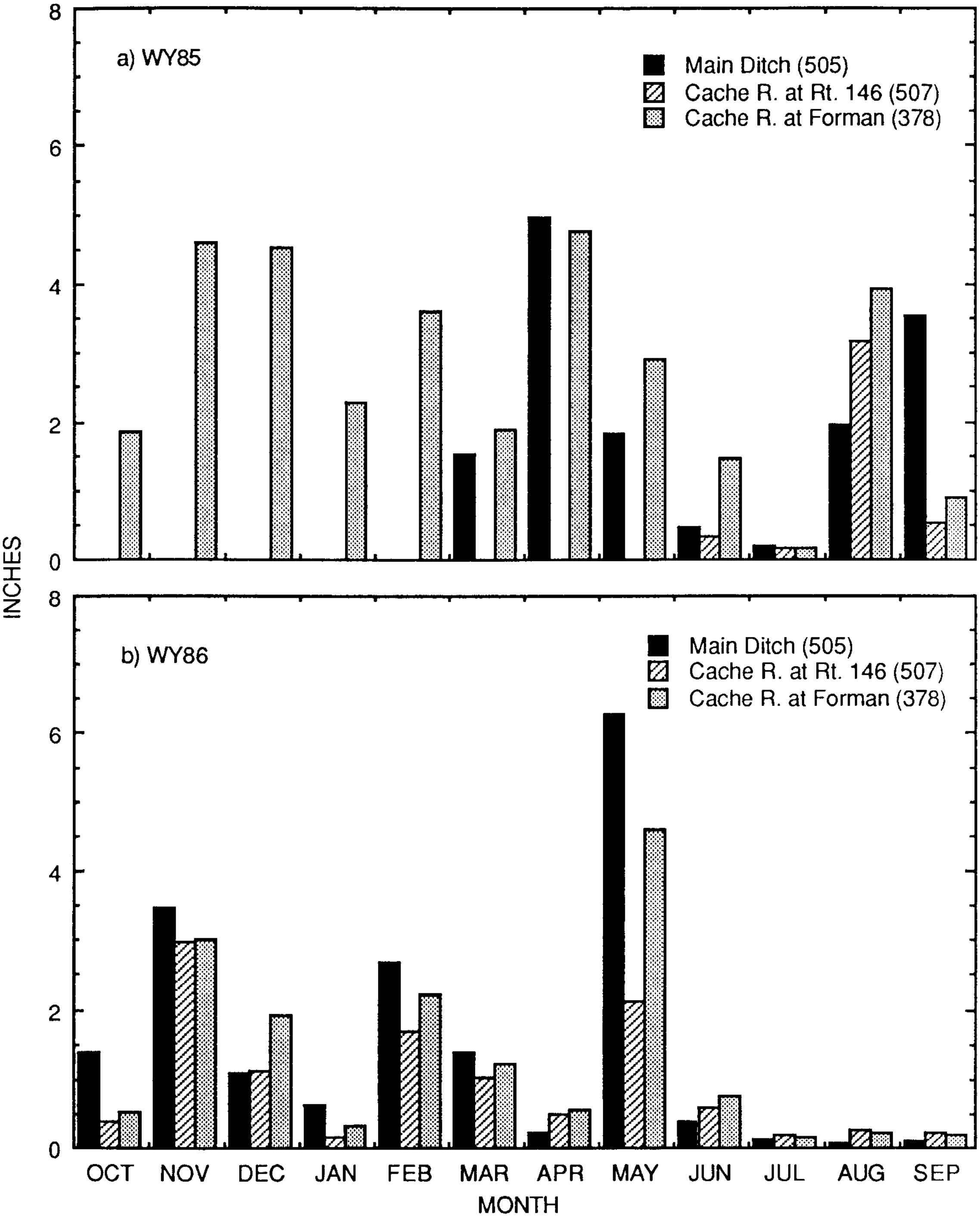


Figure 47. Streamflows in the Upper Cache River

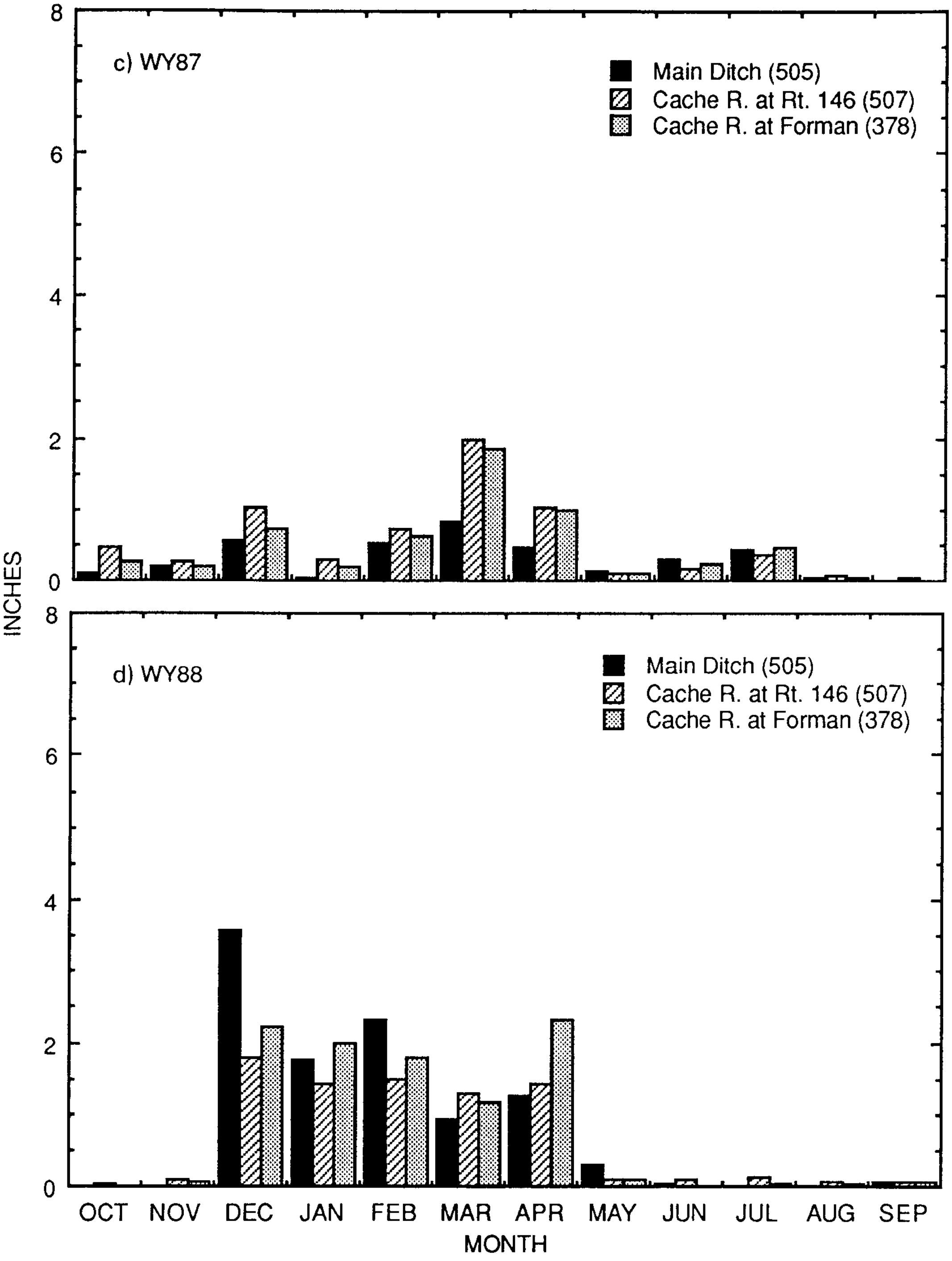


Figure 47. Concluded

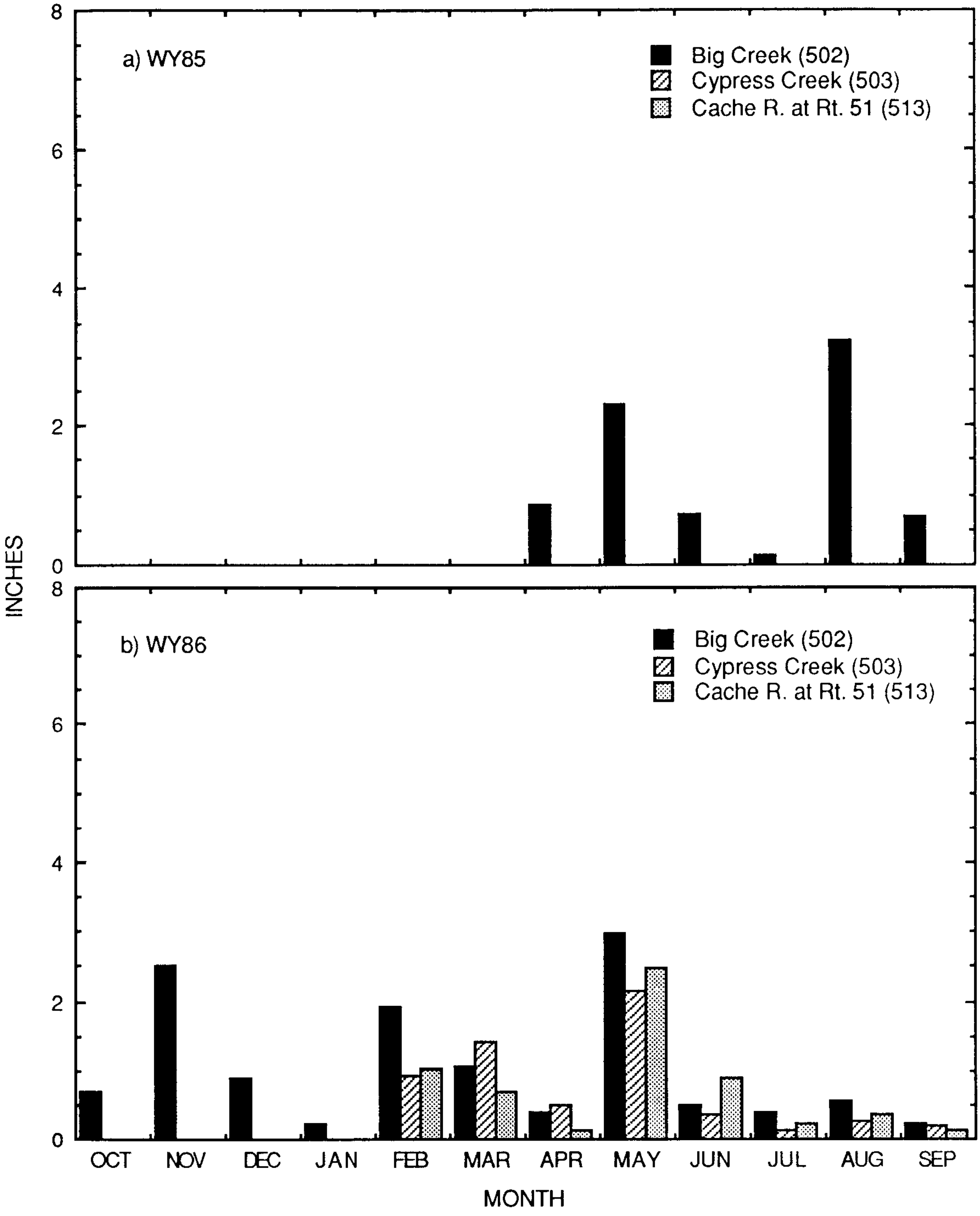


Figure 48. Streamflows in the Lower Cache River

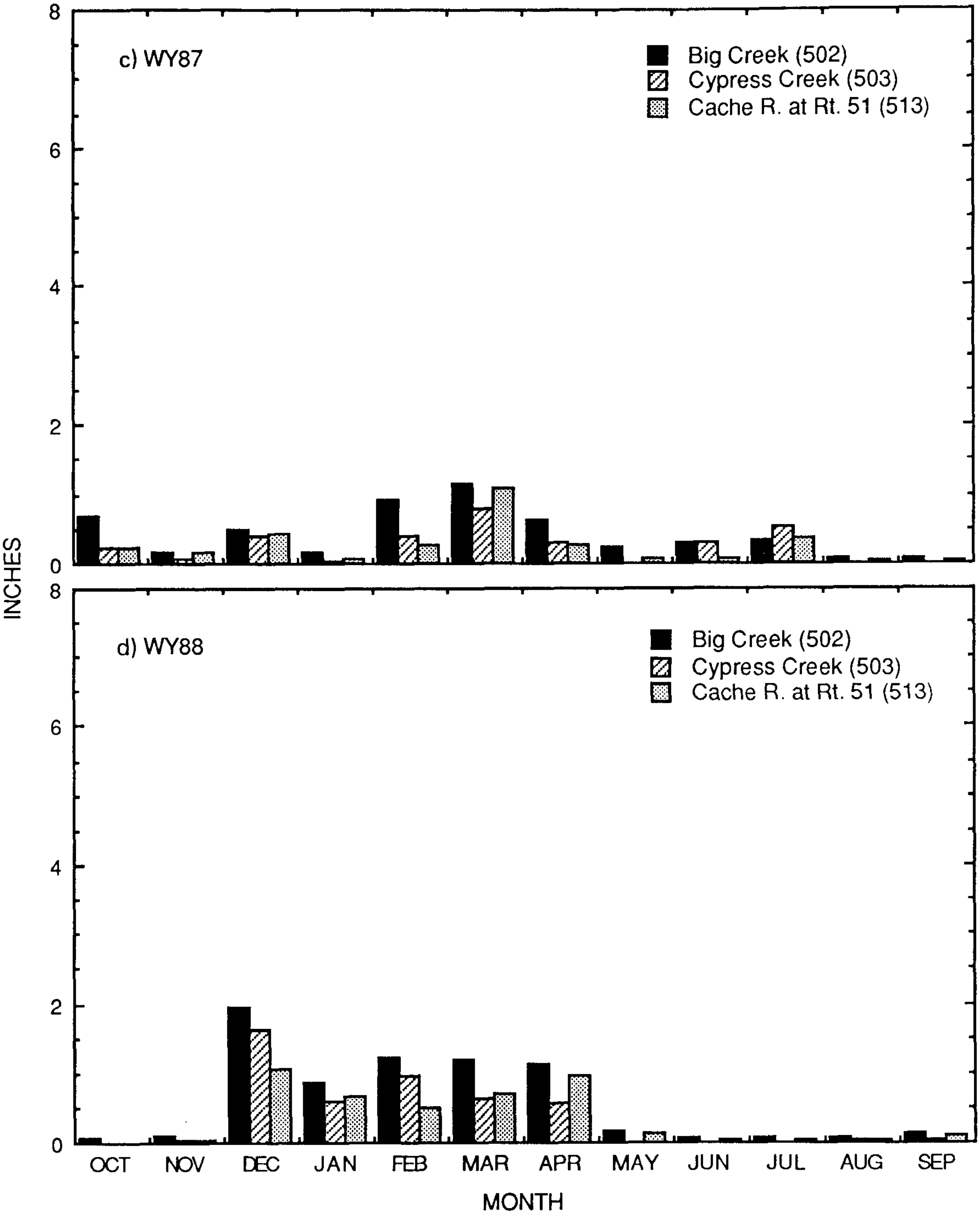


Figure 48. Concluded

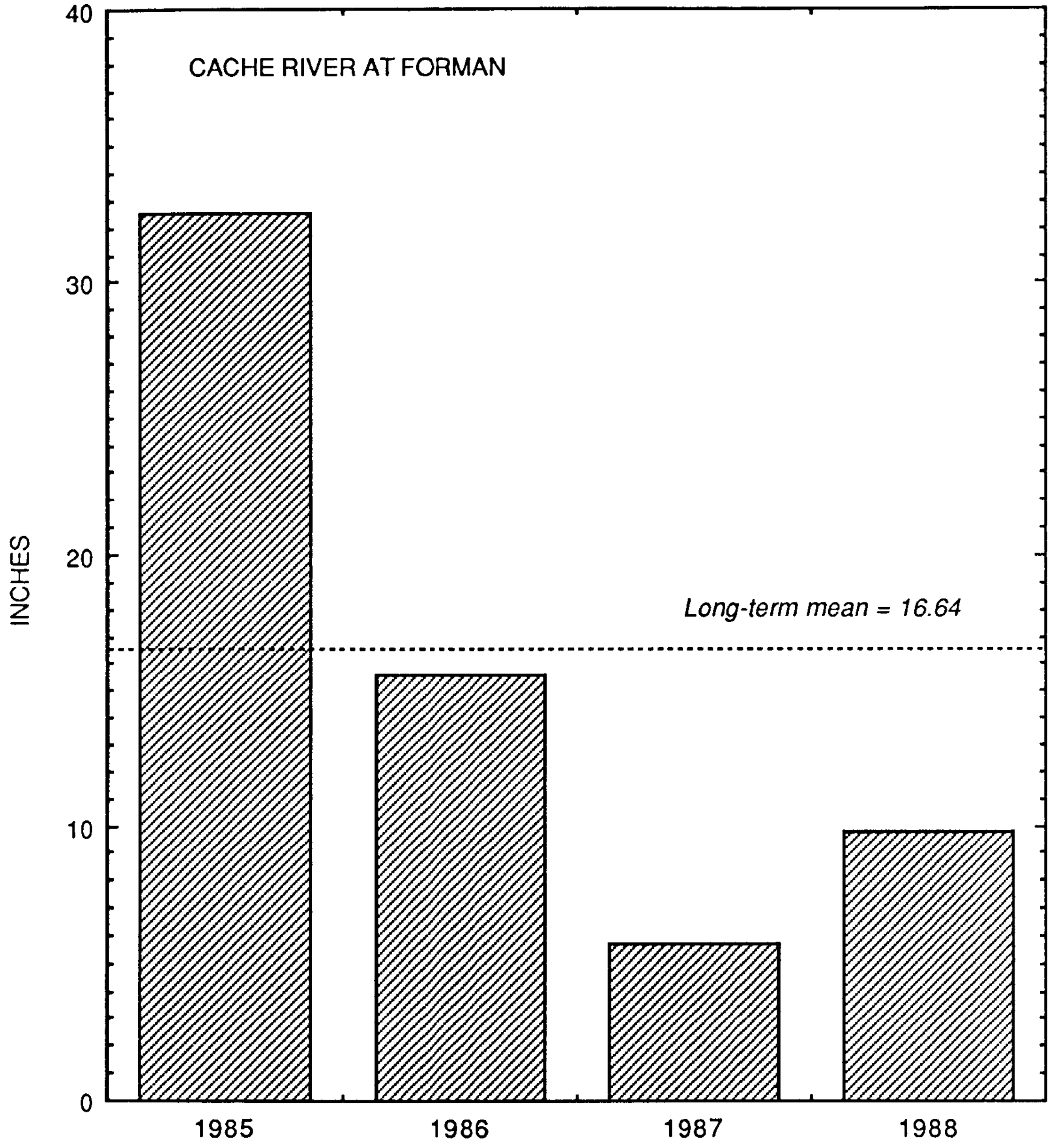


Figure 49. Annual discharges for the Upper Cache River at Forman during the project period

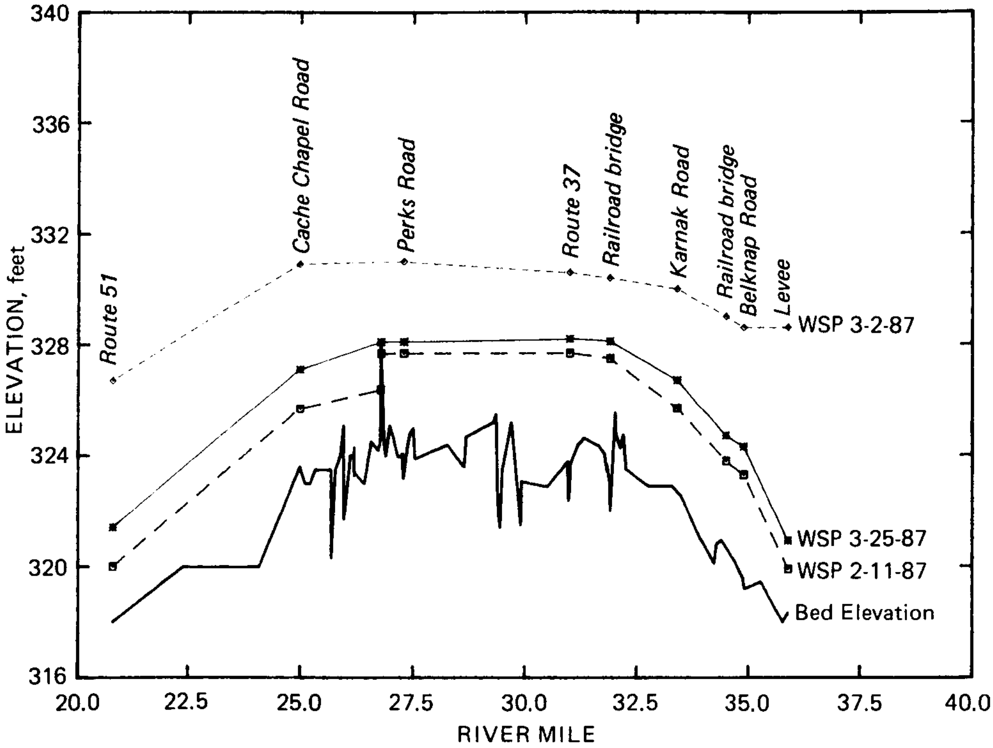


Figure 50. Channel and water-surface profiles along the Lower Cache River from Route 51 to the Cache River levee

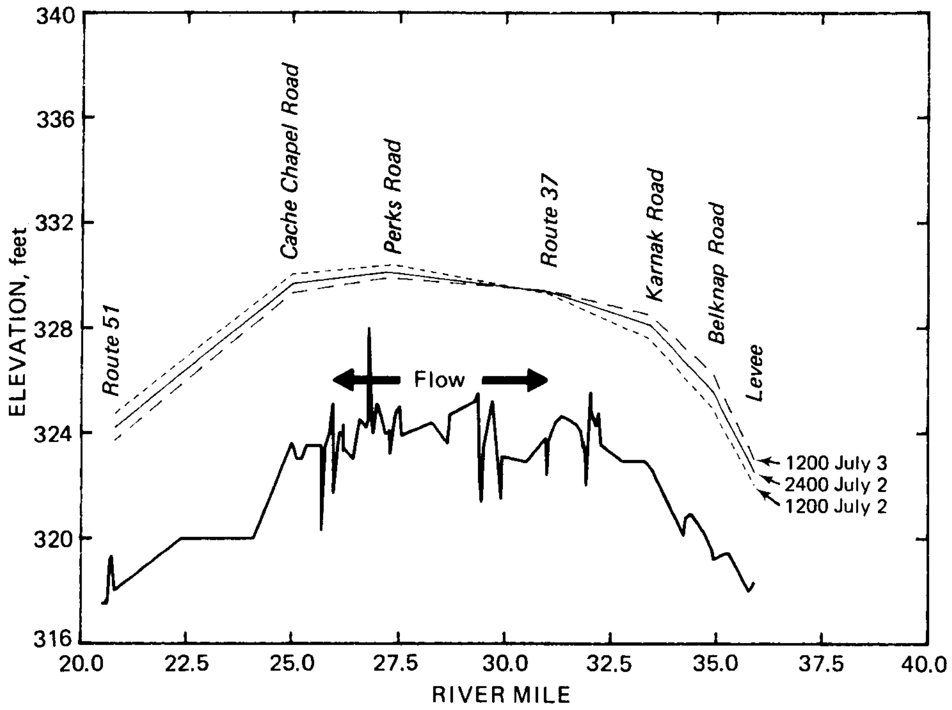


Figure 51. Water-surface profiles along the Lower Cache River for the July 1987 flood

seen that as water levels dropped on the west end, they continued to rise in the east. Velocities measured at the Cache River at Route 37 were in excess of 1.5 feet per second, as were velocities at Cache Chapel Road, Karnak Road, and Belknap Road. Velocities at Route 51 were 2.5 feet per second.

The largest event in the Cache River basin that occurred during the monitoring period took place in May 1986. Return intervals were calculated for this flood at the two sites for which long-term data are available: Cache River at Forman and Big Creek at Perks Road. For Big Creek at Perks Road the return interval was 3.9 years, and for Cache River at Forman it was 2.5 years. This indicates that: 1) the return interval was greater in the Lower Cache than in the Upper Cache River, and 2) the peak flows were not extremely severe. Nevertheless, flooding in the Lower Cache was extensive. The flooding was caused by precipitation that occurred over a long duration rather than during a short-duration high-intensity storm.

The water-surface elevations for May and June 1986 during the flood event at four monitoring sites in the Lower Cache (Big Creek at Perks Road, Cypress Creek at Dongola Road, Cache River at Route 37, and Cache River at Route 51) are presented in figure 52. Also shown with the water-surface elevations are the daily precipitation amounts. The peak stage at the Cache River at Route 37 was 336 feet msl. The Cache River at Route 37 and at Route 51 responds to storms very slowly. The stage at Route 37 rises slowly and falls very slowly. This is due to the vast storage of water in the Buttonland Swamp area. The tributary streams draining into the Buttonland Swamp area behave similarly to any small stream where the stages rise and fall quickly, as shown in figure 52 for Cypress and Big Creeks. Big Creek reacts much more quickly than Cypress Creek and reaches higher stages above base flows. At the same time, it takes less time for the stages to fall at Big Creek than at Cypress Creek.

Influence of the Ohio and Mississippi Rivers

The Ohio and Mississippi Rivers play a significant role in the flooding and drainage characteristics of the Cache River. The Upper Cache River empties into the Ohio River through the Post Creek Cutoff 22.2 miles above the confluence with the Mississippi River near Cairo. The mouth of the Post Creek Cutoff is located at River Mile 957.8 within Pool 53, controlled by Lock and Dam 53 near Olmsted, Illinois (river miles on the Ohio River are measured starting from Pittsburgh, Pennsylvania, where the Monongahela and Allegheny Rivers converge to form the Ohio River). The normal pool elevation of Pool 53 is maintained at 290 feet msl. During flood stages, Lock and Dam 53 does not control the water-surface elevation in the Ohio River since all the gates at the dam are opened.

During flood stages, the Ohio River backs up through the Post Creek Cutoff and controls the flood elevations and drainage in the Upper Cache River. Backups of the Ohio River through

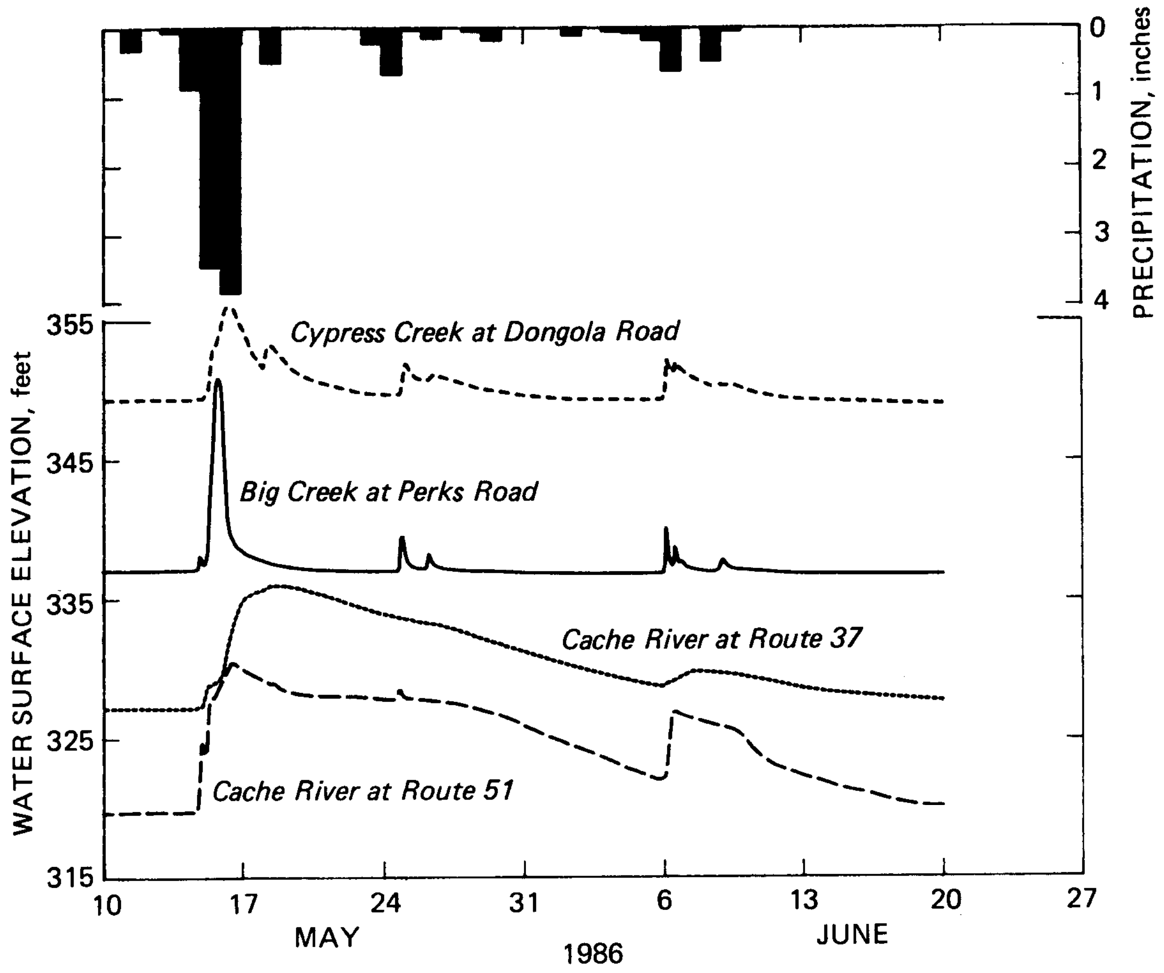


Figure 52. Water-surface elevations for the May 1986 flood at four gaging stations in the Lower Cache River

the Post Creek Cutoff have little influence in the Lower Cache River because of the Cache River levee and the flap gates at the two culverts in the levee. However, any breach in the levee which might allow the Ohio River to back up into the Lower Cache River could alter the existing condition.

The Lower Cache River outlet is located on the Mississippi River at River Mile 13.2. (River miles on the Mississippi River are measured starting from the junction of the Ohio with the Mississippi, just south of the mouth of the old Cache River, at Cairo, Illinois.) Because of the close proximity of the junction of the two major rivers, any major flood in the Ohio River controls the water-surface elevation at the mouth of the Lower Cache River on the Mississippi River through backwater effects. Therefore any flood on both major rivers has a major impact on flooding and drainage in the Lower Cache River.

Because of the important roles the Ohio and Mississippi Rivers play in the hydraulics of the Cache River, the historical flood stage records on both the Ohio and Mississippi Rivers are examined in the following sections. Furthermore, since the stage recorder on the Mississippi River at the mouth of the Cache River was discontinued in 1970, a need exists to develop a methodology for determining the stage of the Mississippi River at the mouth of the Cache River based on current stage recording stations on the two major rivers.

Backwater Effects

Since the influence of the Ohio and Mississippi Rivers is felt in the Cache River mainly because of the backwater they create, a brief discussion on backwater effects is presented here.

In natural channels where the slopes are mild, the flow in the channels is defined as subcritical flow. In this flow condition, the control sections are located at the downstream end of the channel. The control section, in a channel having subcritical flow, controls the depth of water upstream of the control. The control section always maintains a fixed water-surface elevation for a given discharge. The water-surface elevations upstream of that control section are further controlled by the water-surface elevation at the control section.

When a control section maintains a water-surface elevation upstream higher than what it would have been under normal flow conditions, a backwater effect exists. The effect of a backwater is therefore to increase the water-surface elevations upstream of a control section.

The hydraulics of a backwater effect is illustrated by figure 53, where the water-surface elevation in the main river at the mouth of a tributary stream is shown to control the water depth in the tributary stream for some distance. The increase in water-surface elevation along the tributary stream due to the backwater effect is shown by the shaded area in the figure. Had the water-surface elevation in the main river been lower than shown in the figure, the effect of the backwater would have been less, and vice versa.

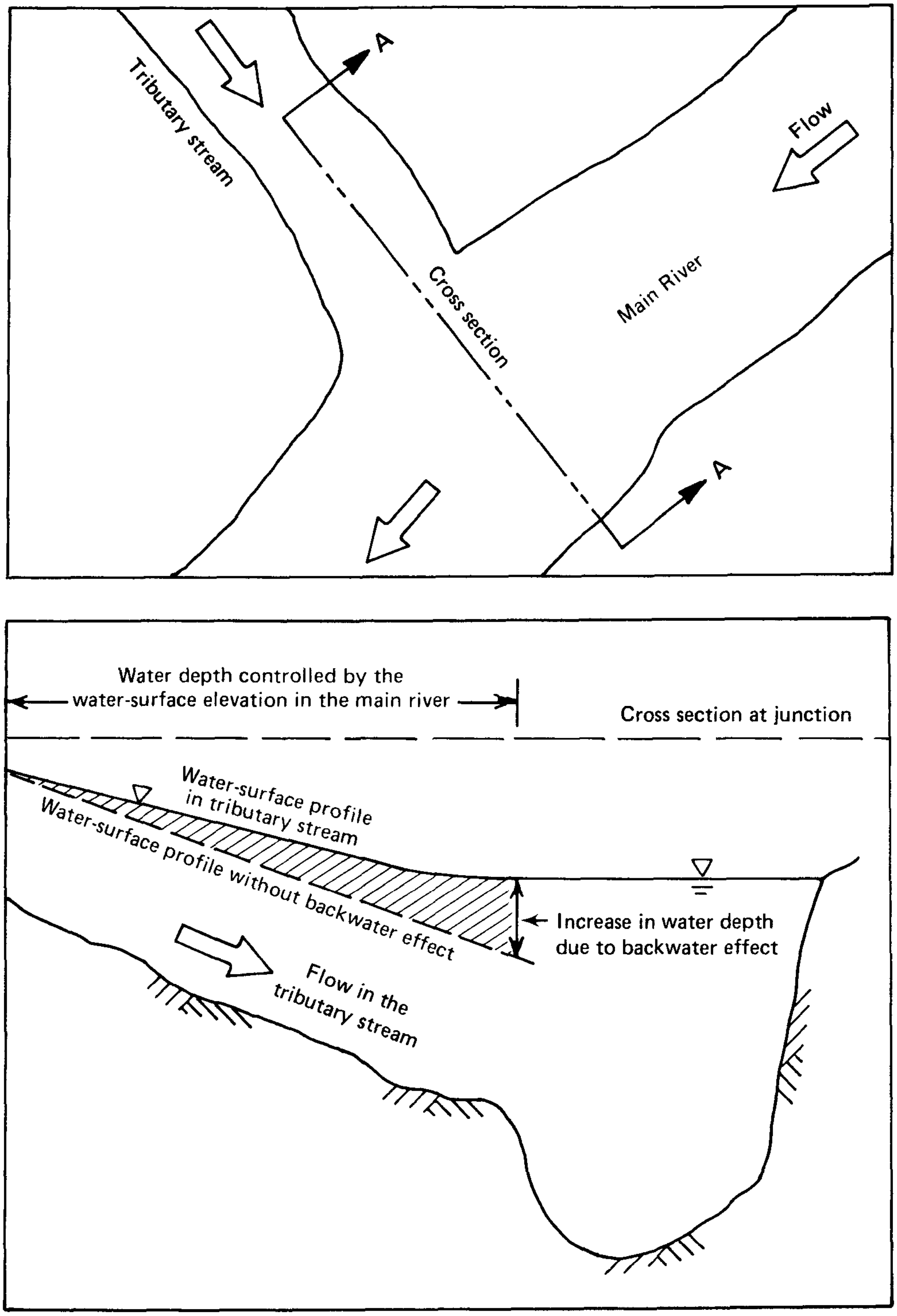


Figure 53. Backwater effect on the water-surface elevation of a tributary stream

The confluence of the Mississippi and the Ohio Rivers forms a control section for one of the rivers, depending on the relative flow conditions and stages in each river. When the water-surface elevation in the Mississippi River is higher than that in the Ohio River, the junction forms a control section for the Ohio River, and thus the water-surface elevation in the lower Ohio River is controlled by the Mississippi River and is higher than it would have been under normal flow conditions. Similarly, when the water-surface elevation in the Ohio River is higher than that in the Mississippi River, the junction forms a control section for the Mississippi River; thus the water-surface elevation in the Mississippi River upstream of the confluence is controlled by the Ohio River, resulting in higher water-surface elevations than would have existed under normal flow conditions.

The purpose of the above discussion is to illustrate that the water-surface elevations in both the Ohio and Mississippi Rivers just upstream of their confluence are controlled by the water-surface elevation in either river, depending on which one is higher. Thus any major flooding in either the Ohio or the Mississippi Rivers has a major influence on flooding and drainage in the Cache River basin by controlling the water-surface elevation at the Cache River outlet.

The Mississippi River at the mouth of the Cache River is the control section for the Lower Cache River under most flood conditions, thus controlling water-surface elevations in the Lower Cache River. Furthermore, since the slope in the Lower Cache River is small, the backwater effect of the Mississippi River at high flood stages extends for a long distance upstream of the mouth of the Cache River all the way to Buttonland Swamp.

River Stage Analyses

In the following sections, the analyses of the stages of the Mississippi and Ohio Rivers in the vicinity of the Cache River are presented. Data from four stations, two each on the Mississippi and Ohio Rivers, are used in these analyses.

The locations of these stations with respect to the Cache River are shown in figure 54. Pertinent data about the stations, including distance upstream of the junction, period of record, datum above mean sea level, and time of observation, are given in table 13. The Beechridge and Birds Point stations are located 2.0 and 13.2 miles upstream of the junction on the Mississippi River, respectively. The Beechridge station, which was discontinued in 1970, is located at the mouth of the Cache River. The Cairo and Lock & Dam 53 stations are located on the Ohio River 2.4 and 18.8 miles upstream of the junction, respectively.

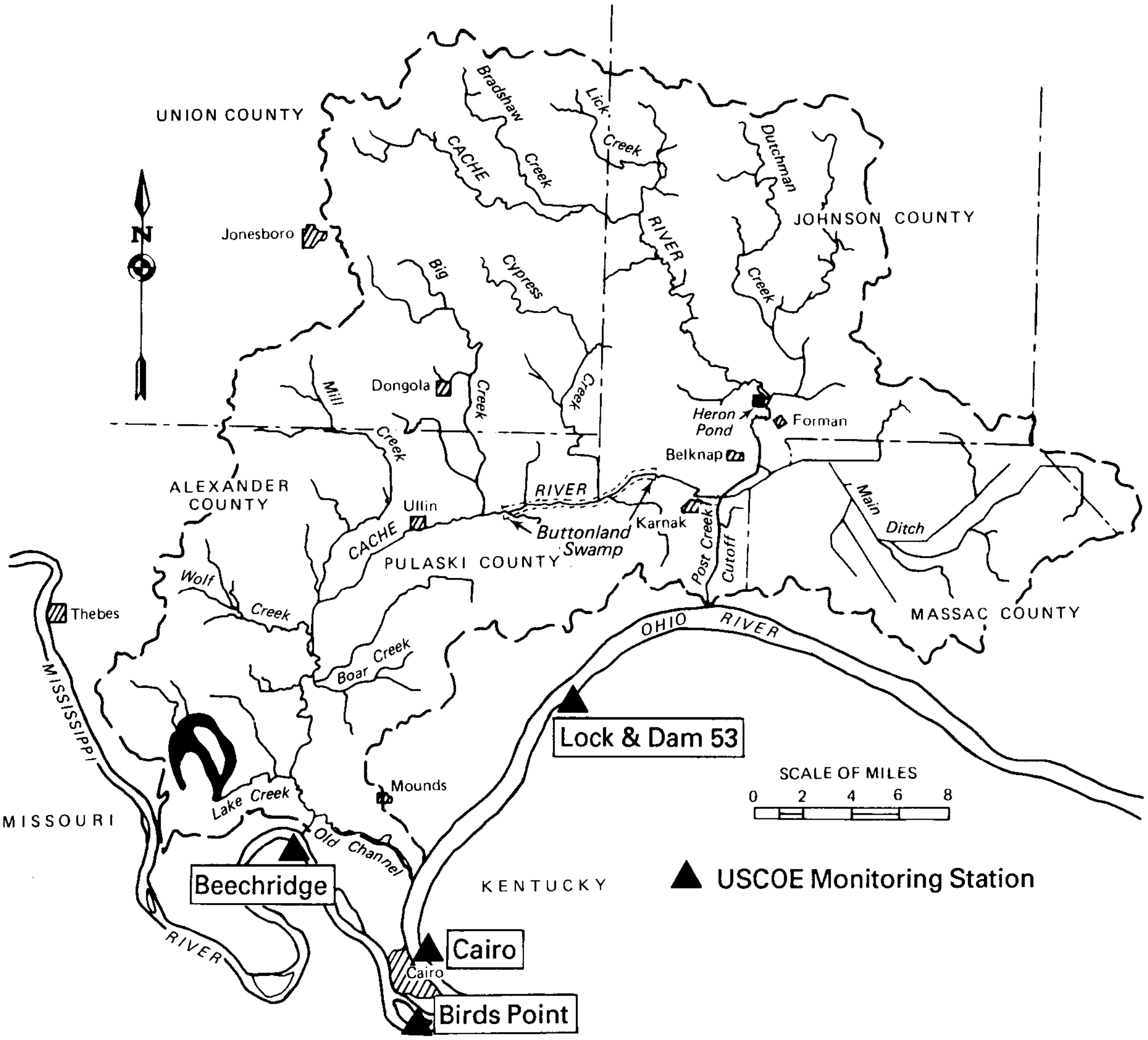


Figure 54. Locations of water-surface-elevation monitoring stations on the Ohio and Mississippi Rivers

Table 13. Information on the Four Stations Used in This Analysis

Station name	***Distance from confluence (miles)***	***Period of record***	***Datum (ft, msl)***	***Time of observation***
Mississippi River at Beechridge	13.2	1901-1970*	282.88	8 a.m.
Mississippi River at Birds Point	2.0	1933-1987**	274.53	8 a.m.
Ohio River at Cairo	2.4	1930-1987***	270.90	6 a.m.
Ohio River at Lock & Dam 53	18.8	1930-1987****	273.10	6 a.m.

* Digitized data available from 1930-1970
** Digitized data available from 1961-1985
*** Digitized data available from 1930-1981
**** Digitized data available from 1930-1984

The daily stage records at the four stations were obtained from the U.S. Army Corps of Engineers, St. Louis and Louisville Districts. All the analysis and results that follow are based on those data. Two types of analysis, stage-duration and stage-frequency, were performed on the stage records of each of the four stations. The methods used and the results of the two sets of analyses are presented in the following sections.

Stage-Duration Analysis. The stage-duration analysis involves developing stage-duration curves for each station, which provide information on how often a particular stage will be equaled or exceeded on the average for selected durations.

The procedure for developing stage-duration curves is as follows: First the daily stage records are arranged in order of their descending magnitudes. Then the range of stage records is subdivided into a number of intervals (in this case, 35). The percent of time for a stage interval to be equaled or exceeded is then determined by dividing the accumulated number of stage records greater than and in that interval by the total number of stage records. The stage-duration curves can be developed for a year, a season, or a month. For this study, only the yearly and monthly stage-duration curves were developed, and only the yearly analysis is included in this report.

The yearly stage-duration curves for the four stations are shown in figures 55 through 58. These curves were developed by using the digitized daily stage values for each station. The four stage-duration curves are plotted together in figure 59 for comparison purposes. As can be seen in the figure, the stations farther upstream from the junction (Beechridge and Lock & Dam 53) on both the Mississippi and Ohio Rivers experience higher stages during flood events than those near the junction (Birds Point and Cairo), as expected. The stage-duration curves

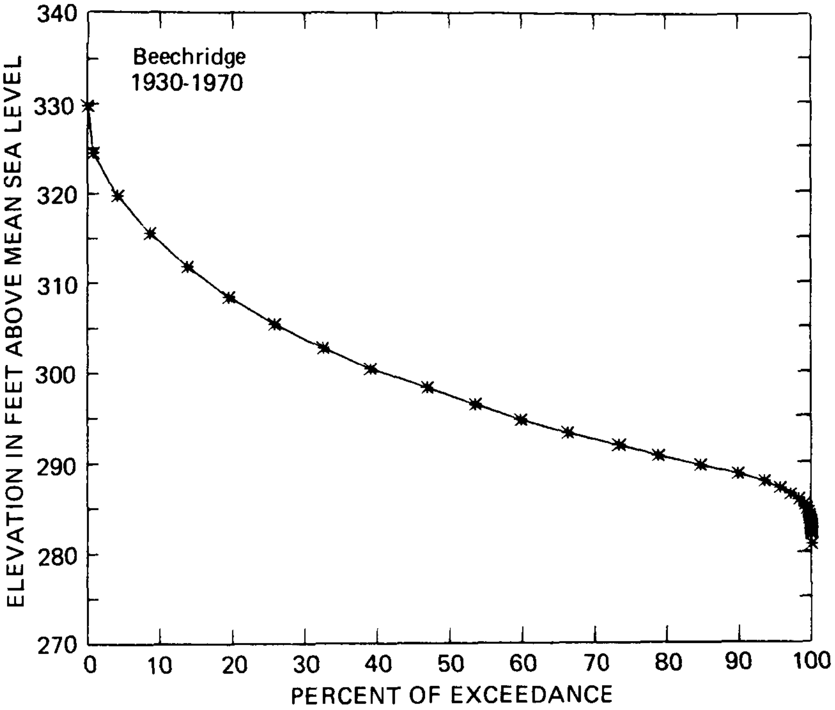


Figure 55. Stage-duration curve for the Mississippi River at Beechridge

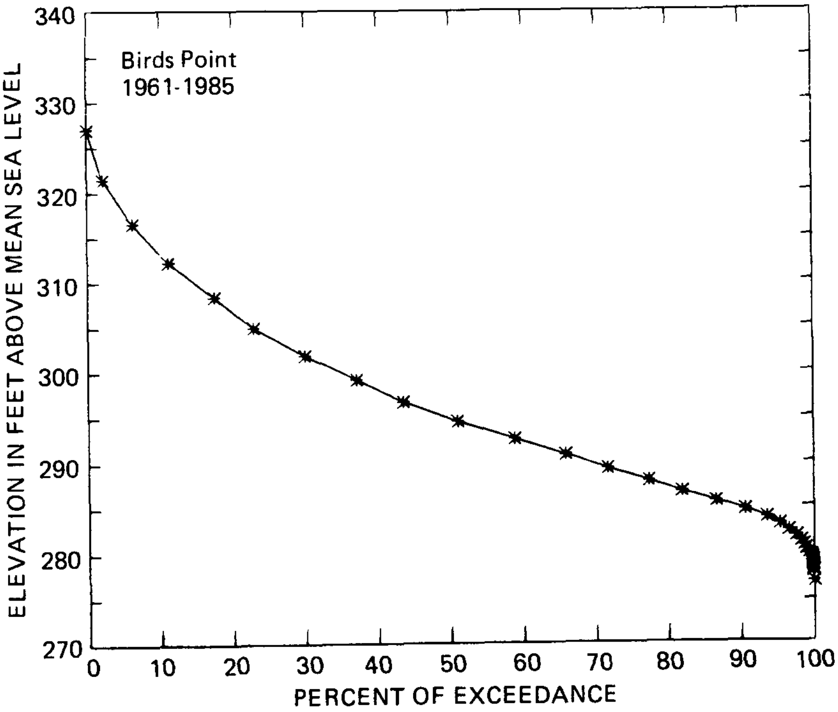


Figure 56. Stage-duration curve for the Mississippi River at Birds Point

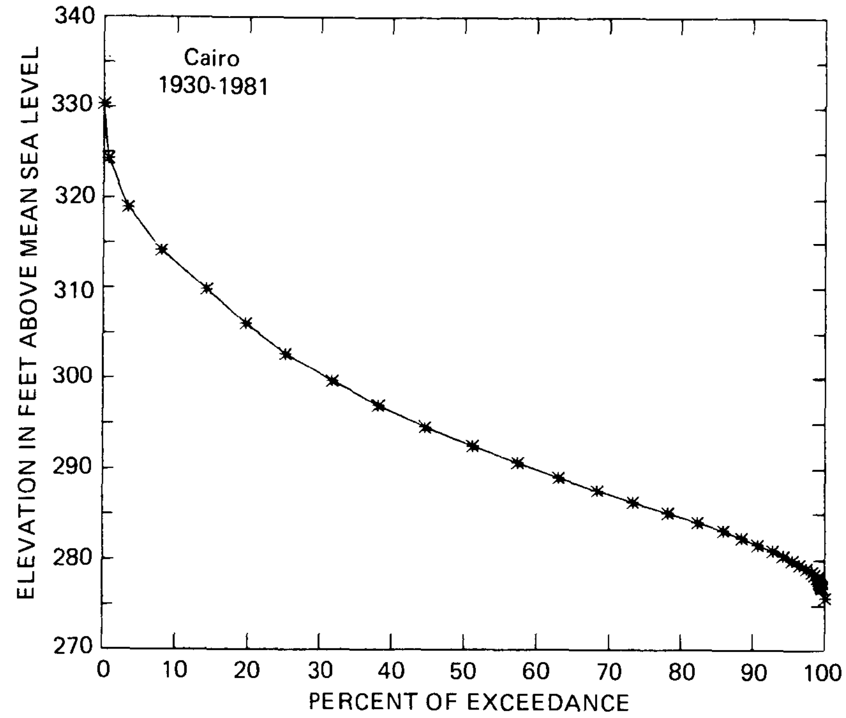


Figure 57. Stage-duration curve for the Ohio River at Cairo

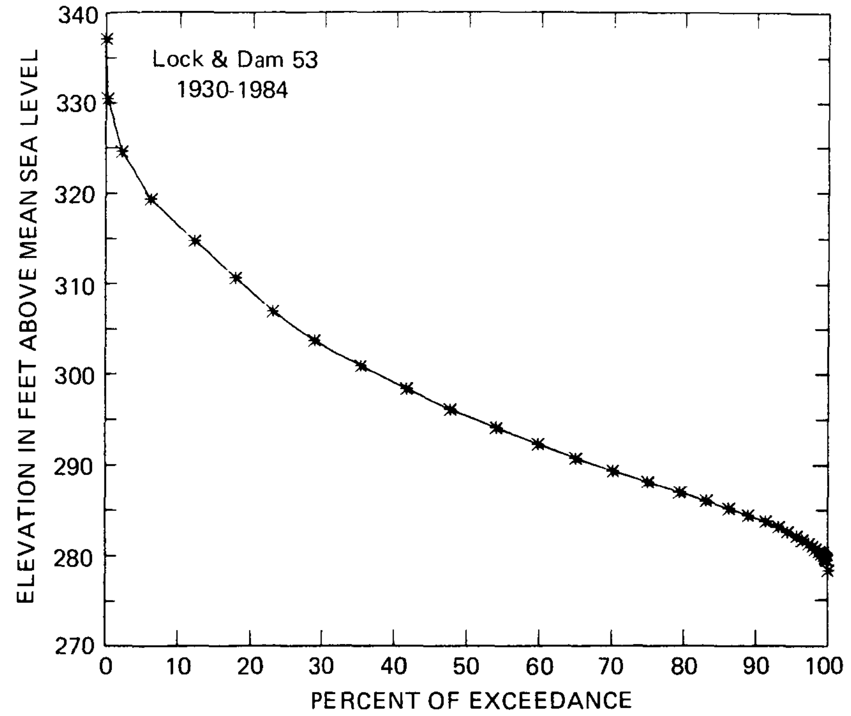


Figure 58. Stage-duration curve for the Ohio River at Lock & Dam 53

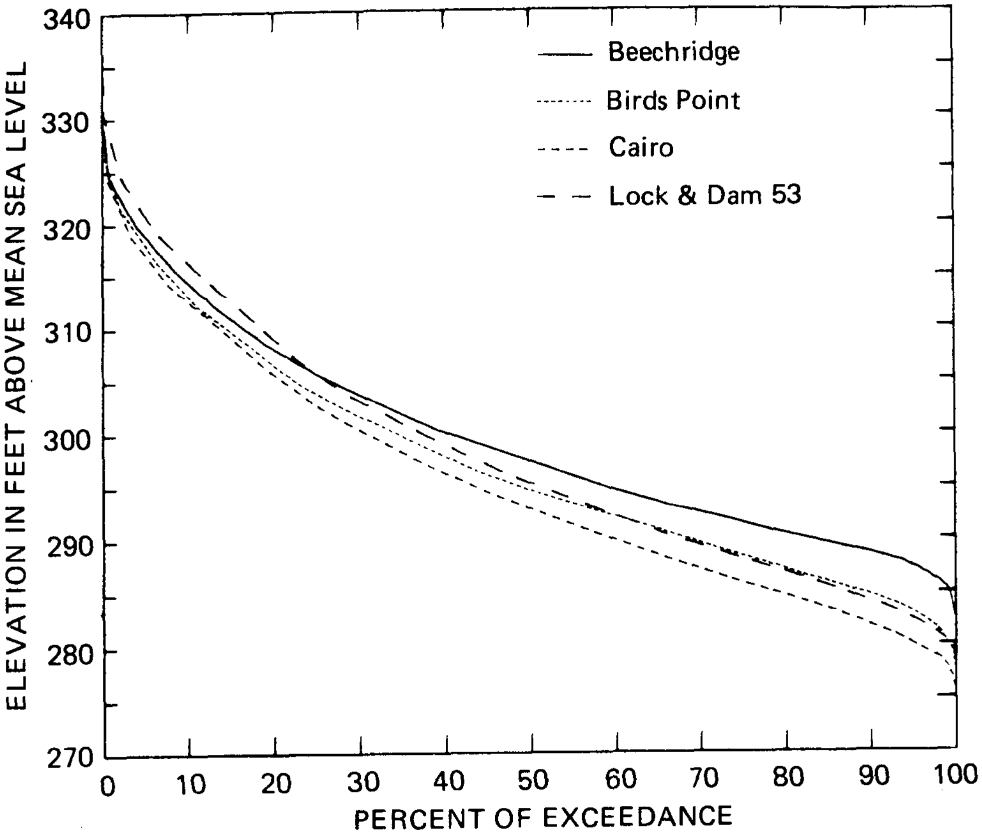


Figure 59. Comparison of the stage-duration curves at four stations

for the Birds Point and Cairo stations are similar to each other, with the Birds Point station showing higher stages during low and average flow conditions than the Cairo station, and the Cairo station showing slightly higher stages during the extreme events. The curves for the Beechridge and Lock & Dam 53 stations also compare to those of Cairo and Birds Point in that Beechridge has higher stages during lower flows, while Lock & Dam 53 has higher stages during major floods. This is because the Mississippi River stage is generally higher than the Ohio River stage during low and average flows, and the Ohio River generally has the most extreme floods.

Stage-Frequency Analysis. The second set of analyses involves the frequency of high stages. In this analysis, the recurrence intervals of historical high stages are determined and fitted to frequency distributions. From the fitted functions, it is possible to estimate stages that are expected to be equaled or exceeded for selected recurrence intervals such as 10, 50, and 100 years. The procedure for developing stage-frequency curves is similar to that used for streamflows.

The data for the stage-frequency analysis are summarized in tables 14 through 17, where the rank of the annual maximum flood stages, the date of occurrence, the observed stage, and the recurrence interval, T, based on the period of record, are given. Because the stage data at Beechridge have not been recorded since 1971, a method was developed to extend the data for this station. Table 18 contains the ranked stages determined after this modification. The method of extension of the Beechridge data is discussed in the following section.

It is interesting to note that even though the most extreme flood was the 1937 flood, more extreme floods have taken place since 1970 on both the Mississippi and Ohio Rivers. For example, for the Cairo station, 7 of the highest twenty floods have taken place since 1970, while only 3 of the lowest 20 floods have taken place during the same period. Similarly, for the Ohio River at Lock & Dam 53, 6 of the top 20 floods have been recorded since 1970, while only 3 of the bottom 20 floods have been recorded during the same period.

A frequency distribution curve is fitted to the stage-frequency relations by determining the parameters of the particular function from the data. The forms of the equations and the parameters used are discussed in the section on streamflows. The only difference here is that the actual values are used instead of the logarithmic values used for streamflows.

The Pearson Type III distributions as fitted to the stage-frequency relations are shown in figures 60 through 63 for the four stations under investigation. Figure 64 shows the Pearson Type III fit for the extended data at the Beechridge station. In the figures, the "+" symbols represent the annual maximum stages obtained from the records, the solid lines represent the fitted distribution, and the dashed lines represent the 95% confidence curves.

Table 14. Ranked Annual Maximum Stages
at Beechridge on the Mississippi River

Rank	***Year***	***Month***	***Day***	***Stage (ft msl)***	***T****
1	1927	4	20	336.64	61.00
2	1916	2	4	333.83	30.50
3	1929	5	23	333.13	20.33
4	1913	4	4	332.83	15.25
5	1912	4	4	332.63	12.20
6	1937	2	3	329.78	10.17
7	1907	1	26	329.23	8.71
8	1943	5	29	328.88	7.63
9	1961	5	15	328.48	6.78
10	1917	4	4	328.03	6.10
11	1904	4	14	327.98	5.55
12	1945	4	4	327.78	5.08
13	1950	2	15	327.08	4.69
14	1909	7	19	326.68	4.36
15	1928	6	24	326.23	4.07
16	1906	4	9	325.93	3.81
17	1948	4	2	325.38	3.59
18	1915	6	6	325.03	3.39
19	1944	4	29	324.88	3.21
20	1946	1	16	324.78	3.05
21	1908	5	20	324.63	2.90
22	1962	4	1	324.38	2.77
23	1933	5	20	324.33	2.65
24	1926	10	11	324.33	2.54
25	1939	4	23	324.18	2.44
26	1936	4	15	323.58	2.35
27	1960	4	12	323.48	2.26
28	1952	3	27	323.48	2.18
29	1963	3	26	322.78	2.10
30	1947	7	5	322.78	2.03
31	1965	4	20	322.48	1.97
32	1970	5	6	322.28	1.91
33	1930	1	18	322.03	1.85
34	1951	2	25	321.88	1.79
35	1949	1	30	321.78	1.74
36	1903	3	17	321.68	1.69
37	1969	4	26	321.18	1.65
38	1955	3	28	321.08	1.61
39	1910	3	15	321.08	1.56
40	1935	3	18	320.93	1.53
41	1911	4	15	320.53	1.49
42	1914	4	11	320.08	1.45
43	1932	2	17	318.93	1.42
44	1958	7	26	318.88	1.39
45	1964	3	22	318.58	1.36
46	1938	4	3	318.48	1.33

Concluded on next page

Table 14. Concluded

Rank	***Year***	***Month***	***Day***	***Stage (ft msl)***	***T****
47	1957	5	28	318.28	1.30
48	1905	5	23	318.03	1.27
49	1942	7	2	317.08	1.24
50	1931	12	21	317.03	1.22
51	1968	6	3	316.28	1.20
52	1967	5	18	315.58	1.17
53	1940	5	2	315.18	1.15
54	1966	2	18	314.48	1.13
55	1956	2	27	313.98	1.11
56	1959	2	20	311.98	1.09
57	1941	11	10	311.88	1.07
58	1934	3	15	310.93	1.05
59	1953	4	5	310.38	1.03
60	1954	5	9	303.78	1.02

*T = recurrence interval in years

Table 15. Ranked Annual Maximum Stages at Birds Point on the Mississippi River

Rank	**Year**	**Month**	**Day**	**Stage (ft msl)**	***T****
1	1937	2	4	329.13	56.00
2	1975	4	3	326.93	28.00
3	1973	4	2	326.73	18.67
4	1950	2	15	326.43	14.00
5	1979	4	18	326.03	11.20
6	1983	5	8	325.53	9.33
7	1961	5	16	325.13	8.00
8	1984	5	14	324.83	7.00
9	1945	4	4	324.83	6.22
10	1943	5	30	324.37	5.60
11	1936	4	15	322.93	5.09
12	1946	1	17	322.73	4.67
13	1974	2	1	322.23	4.31
14	1948	4	3	322.13	4.00
15	1944	4	29	322.13	3.73
16	1963	3	26	322.03	3.50
17	1933	5	21	321.97	3.29
18	1978	3	29	321.83	3.11
19	1939	3	18	321.63	2.95
20	1952	3	27	321.43	2.80
21	1949	1	31	321.13	2.67
22	1962	3	16	321.03	2.55
23	1955	3	28	320.53	2.43
24	1985	3	4	320.13	2.33
25	1970	5	6	320.03	2.24
26	1935	3	22	319.87	2.15
27	1951	2	27	319.63	2.07
28	1972	4	27	319.43	2.00
29	1980	4	2	318.83	1.93
30	1971	3	5	318.83	1.87
31	1982	3	26	318.73	1.81
32	1964	3	22	318.43	1.75
33	1960	4	13	318.33	1.70
34	1965	4	9	318.03	1.65
35	1969	2	12	317.93	1.60
36	1947	4	20	317.93	1.56
37	1957	2	13	316.03	1.51
38	1938	4	16	315.73	1.47
39	1940	5	3	314.83	1.44
40	1958	7	27	314.73	1.40
41	1968	6	6	314.53	1.37
42	1967	5	18	314.13	1.33
43	1956	2	27	313.93	1.30
44	1942	3	25	313.93	1.27
45	1987	4	19	312.92	1.24
46	1981	5	23	312.53	1.22

Concluded on next page

Table 15. Concluded

Rank	***Year***	***Month***	***Day***	***Stage (ft msl)***	***T****
47	1966	2	19	312.43	1.19
48	1976	2	25	312.33	1.17
49	1986	10	11	312.08	1.14
50	1977	4	11	311.73	1.12
51	1934	3	15	310.97	1.10
52	1959	2	25	310.93	1.08
53	1953	5	21	308.73	1.06
54	1941	11	10	302.63	1.04
55	1954	1	27	301.53	1.02

*T = recurrence interval in years

Table 16. Ranked Annual Maximum Stages at Cairo on the Ohio River

Rank	***Year***	***Month***	***Day***	***Stage (ft msl)***	***T****
1	1937	2	3	330.4	59.00
2	1975	4	3	327.3	29.50
3	1950	2	15	326.8	19.67
4	1973	4	2	326.6	14.75
5	1979	4	18	325.5	11.80
6	1961	5	16	325.4	9.83
7	1983	5	8	325.1	8.43
8	1984	5	15	324.9	7.38
9	1945	3	11	324.8	6.56
10	1943	5	30	323.9	5.90
11	1936	4	16	323.7	5.36
12	1974	2	1	323.1	4.92
13	1946	1	17	323	4.54
14	1933	4	4	322.7	4.21
15	1963	3	20	322.4	3.93
16	1948	4	3	322.4	3.69
17	1944	4	29	322.1	3.47
18	1939	3	18	321.9	3.28
19	1952	3	27	321.6	3.11
20	1978	3	28	321.5	2.95
21	1962	3	16	321.4	2.81
22	1949	1	31	321.4	2.68
23	1955	3	28	321	2.57
24	1935	3	23	320.8	2.46
25	1985	3	5	320.1	2.36
26	1972	4	27	320	2.27
27	1970	5	7	320	2.19
28	1932	2	15	320	2.11
29	1951	2	26	319.9	2.03
30	1980	4	1	319.2	1.97
31	1964	3	22	319.1	1.90
32	1971	3	5	318.8	1.84
33	1982	3	26	318.7	1.79
34	1965	4	8	318.3	1.74
35	1960	4	12	318.3	1.69
36	1969	2	12	318.2	1.64
37	1947	4	19	318	1.59
38	1957	2	13	316.6	1.55
39	1938	4	16	316	1.51
40	1940	5	3	315.5	1.48
41	1930	1	18	315.1	1.44
42	1968	6	6	314.8	1.40
43	1958	7	27	314.7	1.37
44	1956	2	27	314.5	1.34
45	1967	5	20	314.4	1.31
46	1942	3	25	314.3	1.28
47	1976	2	26	312.9	1.26

Concluded on next page

Table 16. Concluded

Rank	***Year***	***Month***	***Day***	***Stage (ft msl)***	***T****
48	1987	4	18	312.8	1.23
49	1966	2	19	312.8	1.20
50	1977	4	12	312.3	1.18
51	1934	3	16	312.1	1.16
52	1986	12	13	311.77	1.13
53	1959	2	25	311.2	1.11
54	1953	5	21	308.9	1.09
55	1931	4	12	304.2	1.07
56	1981	3	2	303.9	1.05
57	1954	1	27	302.1	1.04
58	1941	6	16	301.7	1.02

*T = recurrence interval in years

Table 17. Ranked Annual Maximum Stages at Lock & Dam 53 on the Ohio River

Rank	***Year***	***Month***	***Day***	***Stage (ft msl)***	***T****
1	1937	2	2	337.1	59.00
2	1950	2	15	331.5	29.50
3	1975	4	3	330.7	19.67
4	1945	3	11	329.4	14.75
5	1979	3	9	328.5	11.80
6	1973	4	1	328.5	9.83
7	1936	4	16	328.4	8.43
8	1984	5	14	328.1	7.38
9	1961	5	17	328	6.56
10	1963	3	20	327.7	5.90
11	1983	5	26	327.4	5.36
12	1939	2	23	327.2	4.92
13	1933	4	4	327	4.54
14	1946	1	18	326.4	4.21
15	1962	3	12	326.2	3.93
16	1955	3	28	326	3.69
17	1974	2	4	325.7	3.47
18	1949	1	31	325.6	3.28
19	1932	2	12	325.4	3.11
20	1964	3	22	325.2	2.95
21	1943	3	30	325.2	2.81
22	1935	3	23	325.2	2.68
23	1952	3	27	324.6	2.57
24	1948	4	2	324.6	2.46
25	1978	3	27	323.9	2.36
26	1980	3	31	323.7	2.27
27	1944	4	26	323.6	2.19
28	1951	2	26	323.4	2.11
29	1957	2	11	322.8	2.03
30	1972	4	28	322.6	1.97
31	1970	5	6	322.5	1.90
32	1971	3	4	322.2	1.84
33	1985	3	6	322.1	1.79
34	1969	2	12	322	1.74
35	1965	4	6	321.8	1.69
36	1982	3	25	321.3	1.64
37	1956	2	27	320.8	1.59
38	1940	5	3	320.8	1.55
39	1930	1	19	320.2	1.51
40	1947	4	19	319.6	1.48
41	1960	4	13	319.4	1.44
42	1958	5	17	319.1	1.40
43	1967	5	24	318.9	1.37
44	1938	4	16	318.8	1.34
45	1968	6	6	318.7	1.31

Concluded on next page

Table 17. Concluded

Rank	*Year*	*Month*	*Day*	*Stage (ft msl)*	*T**
46	1942	3	25	318.3	1.28
47	1934	3	15	318	1.26
48	1976	2	26	317.7	1.23
49	1977	4	11	317.6	1.20
50	1987	3	4	317.18	1.18
51	1966	5	9	316.6	1.16
52	1959	2	25	315.8	1.13
53	1986	12	12	314.8	1.11
54	1981	6	9	314.2	1.09
55	1953	3	9	313.1	1.07
56	1931	4	12	309.5	1.05
57	1954	1	27	308.1	1.04
58	1941	6	16	303.2	1.02

*T = recurrence interval in years

Table 18. Ranked Annual Maximum Stages
at Beechridge on the Mississippi River
(Data have been extended to 1987)

Rank	***Year***	***Month***	***Day***	***Observed Data***	***T****
1	1982	5	8	335.1	58.0
2	1983	5	14	332.4	29.0
3	1979	4	18	331.8	19.3
4	1973	3	31	331.4	14.5
5	1937	2	3	329.8	11.6
6	1961	5	15	329.8	9.7
7	1943	5	29	328.9	8.3
8	1975	3	31	328.3	7.3
9	1981	3	26	328.1	6.4
10	1945	4	4	327.8	5.8
11	1950	2	15	327.1	5.3
12	1978	3	30	326.6	4.8
13	1974	1	31	326.4	4.5
14	1962	3	28	326.3	4.1
15	1984	3	5	325.9	3.9
16	1948	4	2	325.4	3.6
17	1944	4	29	324.9	3.4
18	1933	5	20	324.8	3.2
19	1946	1	16	324.8	3.1
20	1970	5	2	324.6	2.9
21	1939	4	23	324.2	2.8
22	1972	4	27	323.8	2.6
23	1936	4	15	323.6	2.5
24	1952	3	27	323.5	2.4
25	1960	4	12	323.5	2.3
26	1965	4	18	323.5	2.2
27	1963	3	26	323.0	2.1
28	1947	7	5	322.8	2.1
29	1969	4	29	322.4	2.0
30	1951	2	25	321.9	1.9
31	1949	1	30	321.8	1.9
32	1935	3	18	321.4	1.8
33	1955	3	28	321.1	1.8
34	1971	2	28	320.4	1.7
35	1980	3	31	319.9	1.7
36	1932	2	17	319.4	1.6
37	1958	7	26	318.9	1.6
38	1964	3	22	318.7	1.5
39	1938	4	3	318.5	1.5
40	1957	5	28	318.3	1.5
41	1987	4	18	317.6	1.4
42	1942	7	2	317.1	1.4
43	1986	12	13	316.4	1.3
44	1968	5	31	316.2	1.3

Concluded on next page

Table 18. Concluded

Rank	*Year*	*Month*	*Day*	*Observed Data*	*T**
45	1967	5	19	316.0	1.3
46	1930	1	18	315.2	1.3
47	1940	5	2	315.2	1.2
48	1966	2	19	314.7	1.2
49	1953	4	23	314.2	1.2
50	1956	2	27	314.0	1.2
51	1976	2	25	313.4	1.1
52	1977	4	12	312.5	1.1
53	1959	2	20	312.0	1.1
54	1934	3	15	311.4	1.1
55	1941	4	25	310.2	1.1
56	1931	4	12	304.3	1.0
57	1954	5	9	303.8	1.0

*T = recurrence interval in years

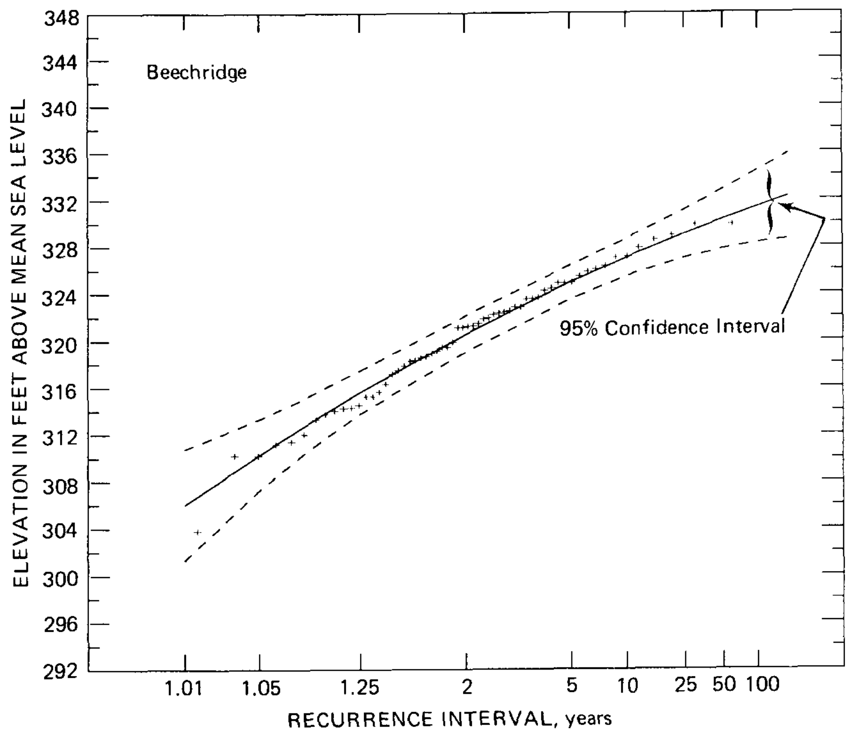


Figure 60. Pearson Type III distribution fit to the annual maximum river stages for the Mississippi River at Beechridge

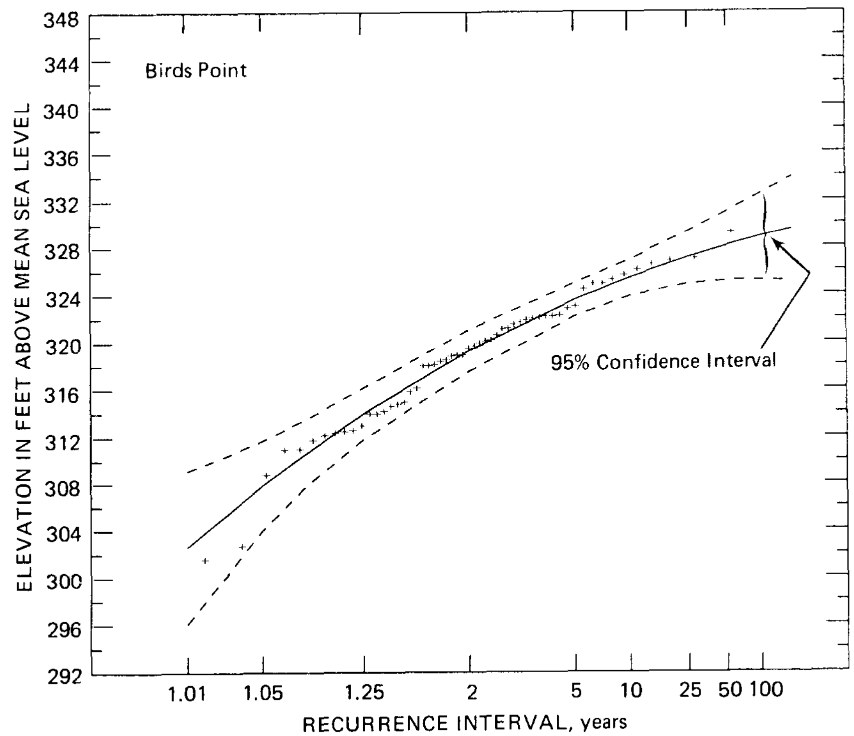


Figure 61. Pearson Type III distribution fit to the annual maximum river stages for the Mississippi River at Birds Point

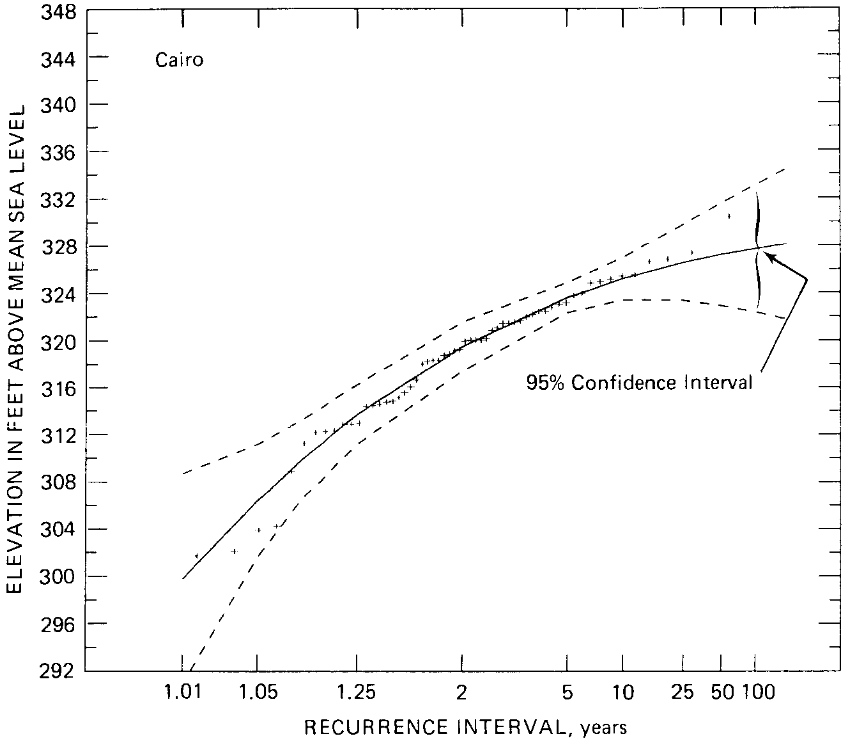


Figure 62. Pearson Type III distribution fit to the annual maximum river Stages for the Ohio River at Cairo

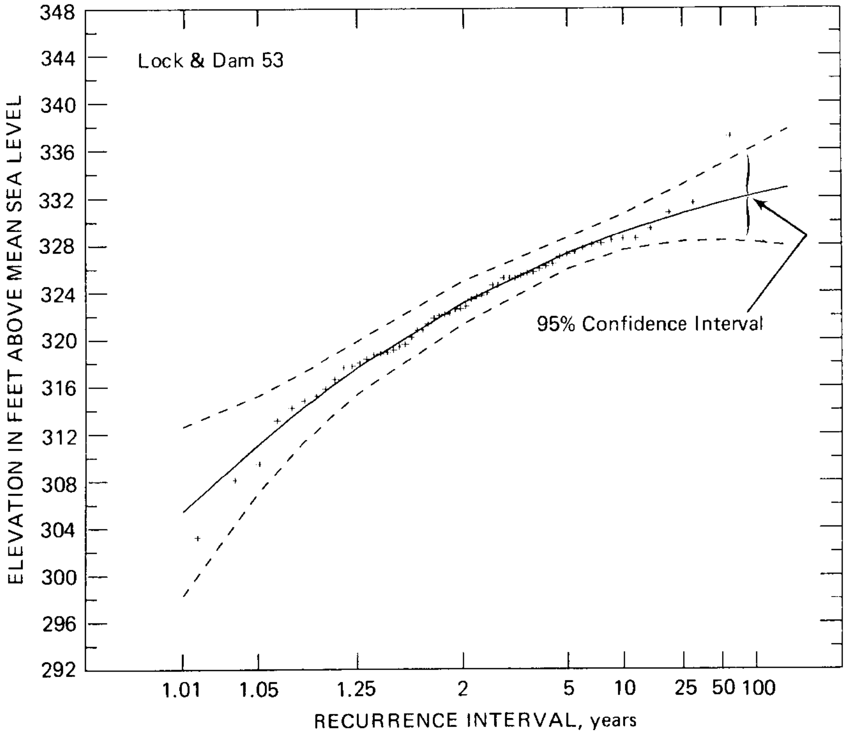


Figure 63. Pearson Type III distribution fit the annual maximum river stages for the Ohio River at Lock & Dam 53

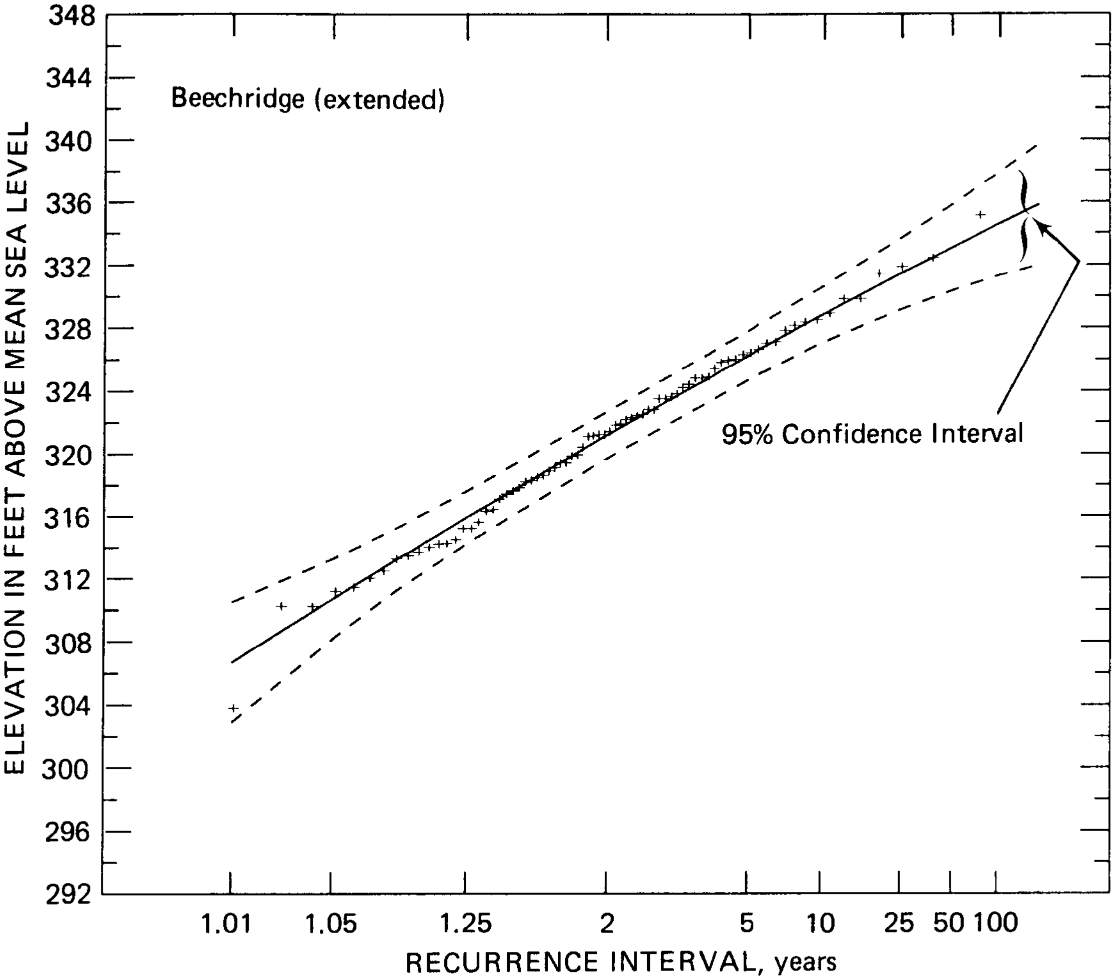


Figure 64. Pearson Type III fit for extended stages at Beechridge

The Pearson Type III distribution fits the data well and can be used to estimate river stages for various recurrence intervals, However, caution should be taken in extending any frequency distribution beyond the length of record.

The parameters for the Pearson Type III distribution for the four stations plus the extended Beechridge data are given in table 19. The 2-, 5-, 10-, 25-, 50-, and l00-year stages of the Mississippi and Ohio Rivers at the four stations computed from the Pearson Type III distribution are given in table 20.

Table 19. Statistical Parameters of Pearson Type III Distribution

Station	*Mean*	*Standard deviation*	*Skewness*	*Alpha*	*Beta*	*Gamma*
Beechridge	320.1	30.6	-.442	1.234	20.434	294.9
Birds Point	318.5	33.4	-.765	2.228	6.843	303.2
Cairo	318.3	38.7	-.922	2.894	4.704	304.7
Lock & Dam 53	322.3	34.7	-.763	2.269	6.868	306.7
Beechridge with extended data	321.0	36.8	-. 163	0.496	151.5	245.8

Table 20. Mississippi River and Ohio River
Stages of Specified Recurrence Intervals
Computed from Pearson Type III Distribution

Station	*2-year*	*5-year*	*1 0-year*	*25-year*	*50-year*	*100-year*
Beechridge	320.5	324.9	327.0	329.0	330.2	331.3
Birds Point	319.2	323.5	325.3	326.9	328.0	328.8
Cairo	319.2	323.6	325.5	327.1	328.5	328.7
Lock & Dam 53	323.0	327.4	329.2	331.0	332.0	332.8
Beechridge with extended data	321.2	326.2	328.7	331.4	333.0	334.5

Relationship between the Mississippi and Ohio River Stages

As mentioned earlier, the mouth of the Lower Cache River is at the Beechridge station on the Mississippi River. For the present study on the Cache River, the most useful Mississippi River stage will be at the Beechridge station. However, the Beechridge station was discontinued in 1970. Therefore, a need exists to generate the stage of the Mississippi River at Beechridge based on the current stage records of the Birds Point station on the Mississippi River and the Cairo and Lock & Dam 53 stations on the Ohio River. Two different methods were attempted for generating Beechridge stage data. The first was a simple regression analysis between the stages at Birds Point and Beechridge on the Mississippi River. The second method used the slopes on the Ohio and Mississippi Rivers to generate the stages at Beechridge. The procedures and the results for the two methods are presented below.

Regression Equation Based on Birds Point Record. The first attempt to generate the missing data for Beechridge was to develop a regression equation between the stages of the Mississippi River at Beechridge and Birds Point based on the period of concurrent record (from 1961 to 1970), and to use that regression equation to generate Mississippi River stages at Beechridge. The following regression equation was determined from the data:

$$H_{BR} = 46.04 + 0.86 \times H_{BP} \tag{5}$$

where

H_{BR} = Mississippi River stage at Beechridge

H_{BP} = Mississippi River stage at Birds Point

The correlation coefficient for the regression equation is 0.963, which indicates a good relation. The regression equation and the data points used to develop the equation are shown in figure 65. Also shown are the 95% confidence lines, where 95% of the data points are bounded. The standard error of estimate is 2.4 feet. As shown in the figure, the relationship between the two stages is predominantly linear; that is, when the stage at Birds Point increases, the stage at Beechridge also increases, or vice versa. However, the spread of the data above and below the regression line is wide. The standard deviation and error of estimate for equation 5 are 9.10 feet and 2.4 feet, respectively. Thus it is possible to underestimate or overestimate the stage at Beechridge by high values if equation 5 is used. Figure 66 shows a comparison of the observed and estimated stages at Beechridge based on equation 5. As can be seen in the figure, there is a wide spread of estimated stages above and below the line of perfect agreement. If the regression equation were a perfect model, all the data points would fall on the line; however, that is rarely achieved. The better the model is, the narrower the spread will be.

Because of the wide spread in estimated stage based on equation 5, it was decided that a simple regression equation between the stages at Beechridge and Birds Point would not be adequate to estimate the Mississippi River stage at Beechridge. An improved relation that considers the backwater effect of the Ohio River on the Mississippi River was needed. Such a relation is discussed in the following section.

Slope Method. The main reason a simple regression relation between the two stations on the Mississippi River did not work well in generating stage data at one station based on data at the other is the backwater effects of the Ohio River. When the Ohio River stage is higher

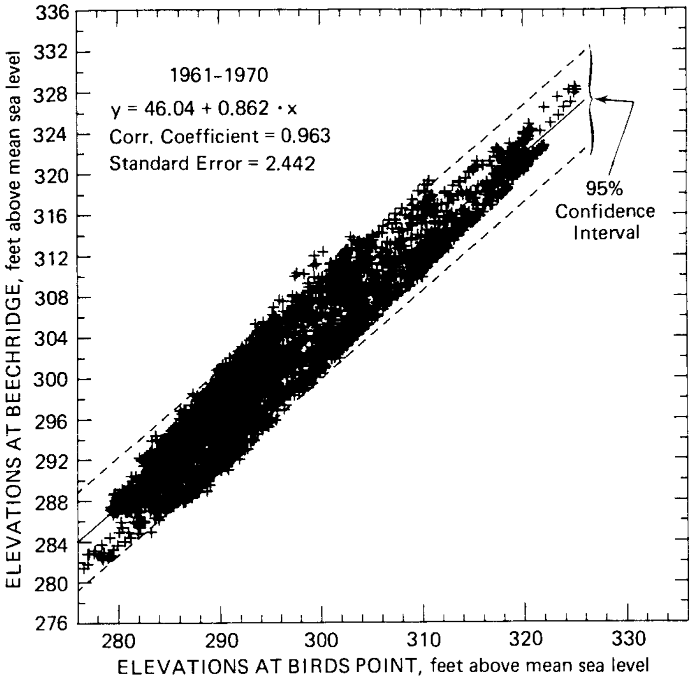


Figure 65. Relationship between water-surface elevations of the Mississippi River at Beechridge and Birds Point

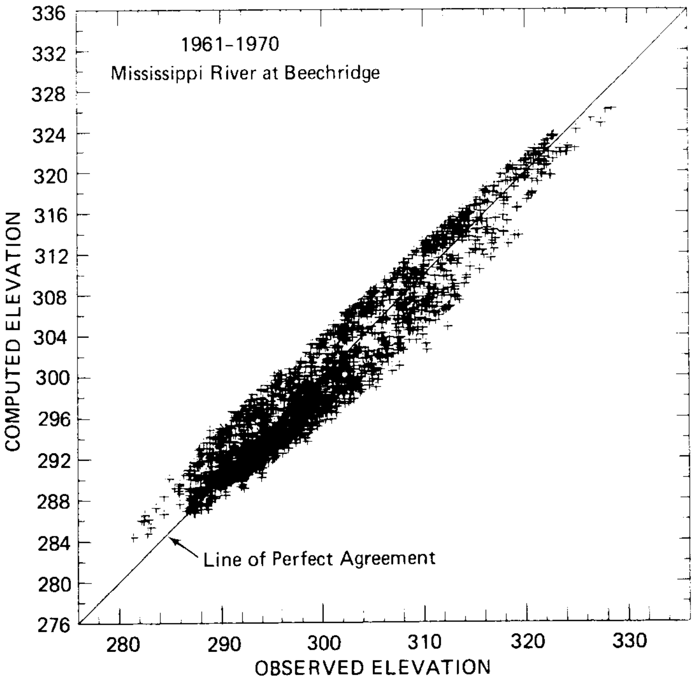


Figure 66. Comparison of observed and computed water-surface elevations at Beechridge

than that of the Mississippi River near their junction, the water-surface slope on the Mississippi River is smaller than it would have been under normal flow conditions without backwater effects. Most of the time, the Mississippi River stages are higher than those of the Ohio River, and thus the Mississippi River stages are not affected by the Ohio River. However, during most floods on the Ohio River, the stages in the Ohio River are higher than those of the Mississippi River, even if the Mississippi River is also experiencing flooding. Therefore the Ohio River has a strong influence on the Mississippi River stages during flood events.

Figure 67 shows the relation between the water-surface slopes of the Mississippi and Ohio Rivers near their junction. The data set for the same ten years (1961-1970) used in the regression analysis was used. Water-surface slopes were determined by dividing the stage differences between two stations by the distance between them. The distances between the stations are 11.2 miles between Beechridge and Birds Point on the Mississippi River and 16.4 miles between Cairo and Lock & Dam 53 on the Ohio River. As discussed earlier, the water-surface slope of the Mississippi River is lower when the Ohio River slope is high and vice versa. Such a distribution suggests an inverse relationship between the water-surface slope of these two rivers near their junction. The relation is not, however, a simple linear relationship. Generally the water-surface slope on the Mississippi River is much higher than that of the Ohio River. As shown in figure 67, the water-surface slopes on the Mississippi sometimes are greater than 1 foot/mile, while the maximum slope on the Ohio River is just over 0.4 foot/mile.

Table 21 lists basic statistics on the relations between water-surface slopes on the Ohio and Mississippi Rivers for the ten-year data (1961-1970). The water-surface slopes on the Ohio River are first divided into 11 equal intervals, and the mean slope on the Ohio River for each interval is determined. For each of the intervals, the statistics for the corresponding slopes on the Mississippi River, including the mean, maximum, minimum, and standard deviation, are determined. The numbers of days on which the slope fell within the different intervals are listed in the table.

From table 21, one can note that most of the time the water-surface slopes on the Ohio River lie in a range from 0.00 to 0.15 foot/mile. The corresponding range for water-surface slope on the Mississippi is from 0.09 to 1.06 feet/mile. When the Mississippi River has relatively high water-surface slopes, the Ohio River is practically under flat-pool conditions, with little or no slope. In some instances, during the rising stages of major floods on the Mississippi River, the Ohio River experiences negative slopes. Similarly, when the water-surface slopes on the Ohio River become higher, the slopes on the Mississippi River become flat, except for one daily event out of ten years of records, when the surface slopes on both rivers were high. This occurred on March 9, 1964, during a high-flood period.

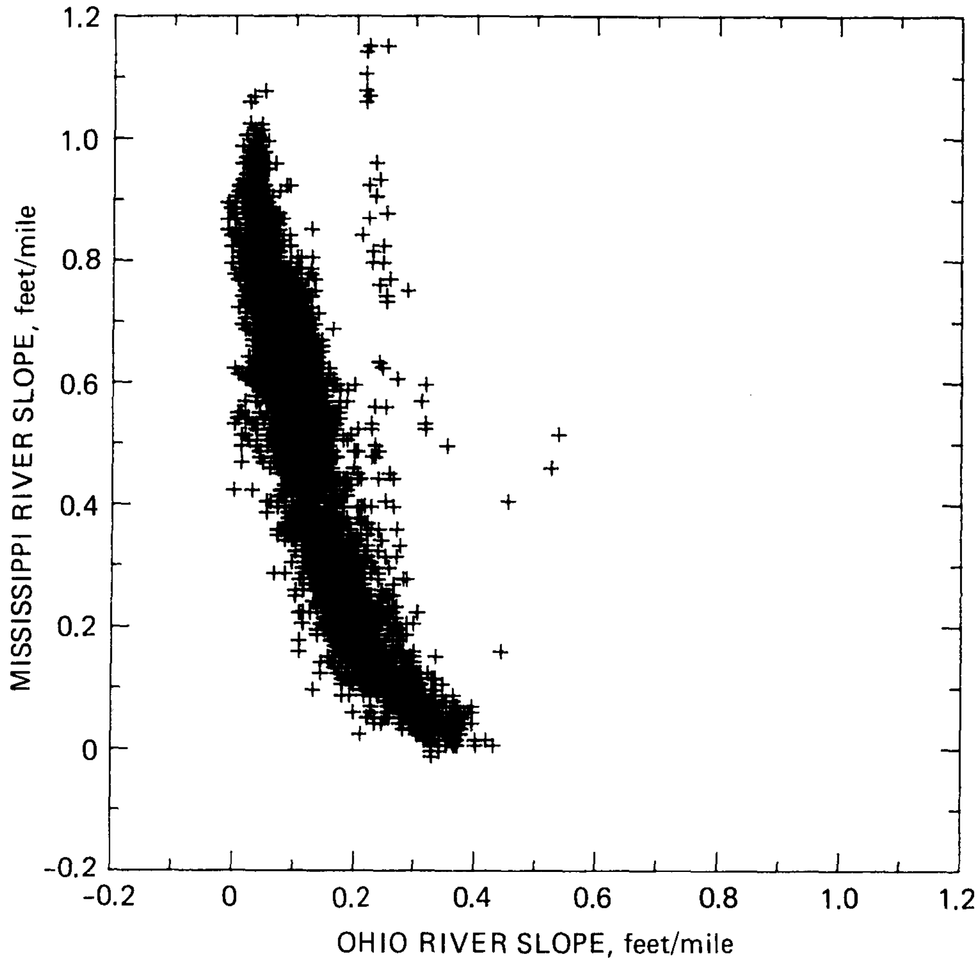


Figure 67. Relationship between water-surface slopes of the Ohio and Mississippi Rivers

Table 21. Water-Surface Slope Statistics and Relations between the Ohio and Mississippi Rivers

Slopes on the Ohio River			*Slopes on the Mississippi River*				
Interval	*Range*	*Mean*	*Mean*	*Max*	*Min*	*S.D.*	*Number of cases in each interval*
1	-.05 to 0.00	.009	.84	.88	.78	.03	7
2	0.00 to .05	.036	.78	1.06	.42	.11	642
3	.05 to .10	.074	.63	.98	.28	.11	993
4	.10to.15	.123	.50	.84	.09	.13	736
5	.15to.20	.172	.32	.67	.09	.12	430
6	.20 to .25	.221	.24	1.13	.02	.17	372
7	.25 to .30	.272	.16	1.13	.03	.14	277
8	.30to.35	.320	.08	.59	-.01	.09	137
9	35to.40	.369	.05	.49	.01	.07	47
10	.40 to .45	.412	.03	.07	.01	.02	7
11	.45 to .50	.451	.16				1

Because of the interdependence of the water-surface slopes of the Mississippi and Ohio Rivers, a model that takes this into consideration was developed. Because the relation between the slopes of the two rivers is not linear, a non-linear equation was needed.

Several curve-fitting techniques were tested in order to find a best-fitted equation for the data. The methods used, and their least square errors, are:

Fitting techniques	*Least square error*
Cubic spline fit; variable knots	0.104
2nd order polynomial equation	0.122
3rd order polynomial equation	0.121
Nonlinear equation $y = \alpha e^{\beta X}$	0.125

Figure 68 shows the fitted curves for the four methods and the mean values for the Mississippi River slopes in each interval (from table 21). The cubic spline fit has the lowest least-square error, but it does not pass through the mean values for all the intervals. Based on the comparison shown in this figure and in the above listing, the second-order polynomial equation was chosen as the better method. Further refinements were made in the method so that a second-order polynomial equation was fitted for the slopes on the Ohio River between 0.0 and 0.45. For negative slopes on the Ohio River, a constant slope on the Mississippi River was

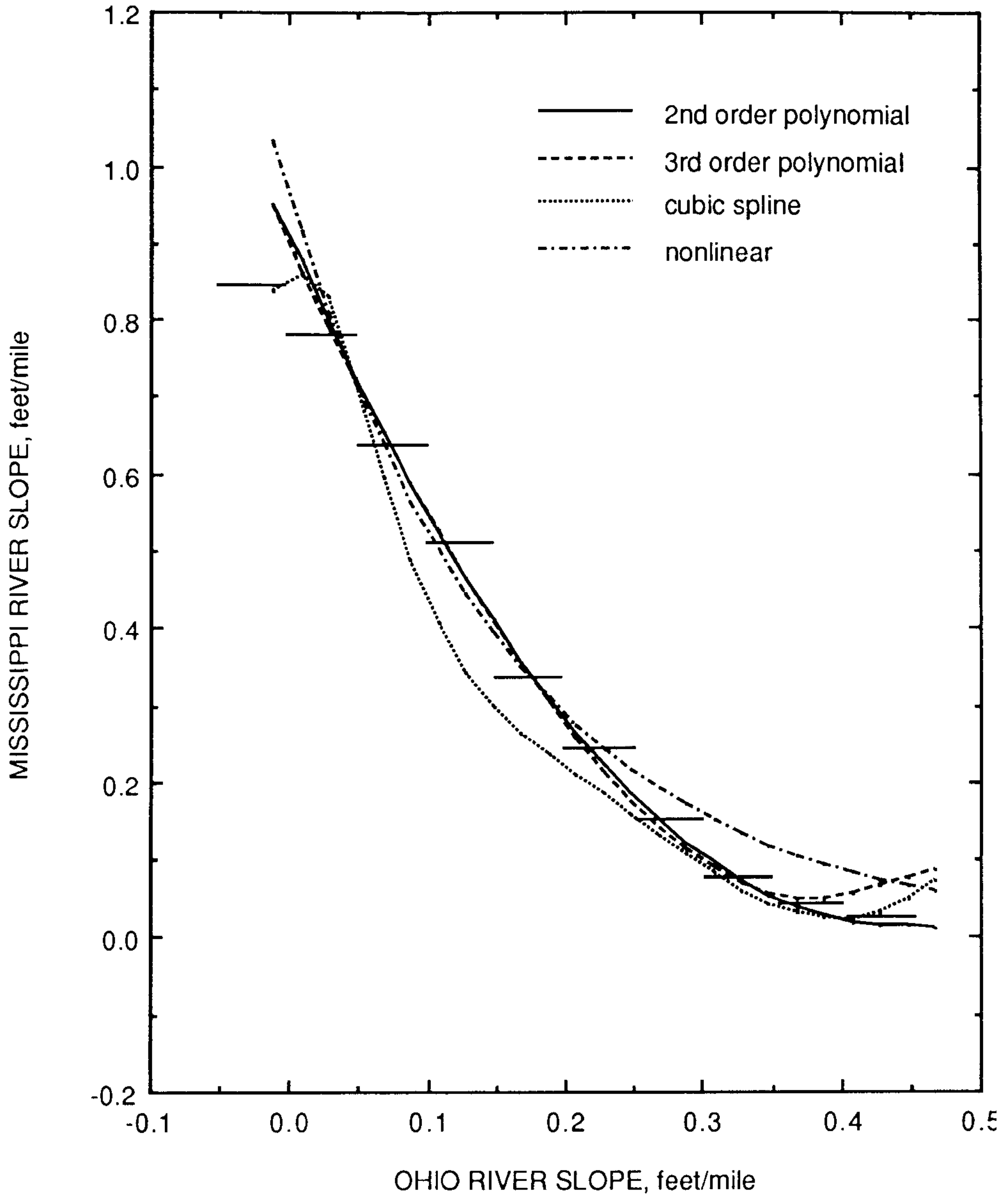


Figure 68. Comparison of approximation functions for the surface slopes on the Mississippi River

assumed. In summary, the water-surface slopes on the Mississippi River were calculated by using the following equations:

$$S_M = 0.855 \qquad \text{when } S_0 < 0.0$$

$$S_M = 0.91 - 4.06\, S_0 + 4.60(S_0)^2 \qquad \text{when } 0.0 \leq S_0 < 0.45 \tag{6}$$

where

S_M = the water-surface slope on the Mississippi River

S_0 = the water-surface slope on the Ohio River

Once the slope for the Mississippi River was found, the stage at the Beechridge station (St_{BR}) could be derived as:

$$H_{BR} = H_{BP} + S_M * 11.2 \tag{7}$$

This method was tested by comparing the computed and observed stages between 1961 and 1970. Only four years (1963, 1965, 1969, and 1970) were selected for presentation in this report. The comparisons between the computed and observed stages for these years are shown in figure 69. As can be seen in the figure, the computed values are very close to the observed data, especially for peak values in most cases.

This method was applied to generate the annual peak stages from 1971-1987 for the Beechridge station (except for 1981, when data were missing at the Birds Point station) by using equations 6 and 7. The data generated by using this method were combined with the observed data to determine the Pearson Type III parameters for the Beechridge station based on a longer period of record. The results of the analyses were presented earlier in table 20 along with the results for the other stations.

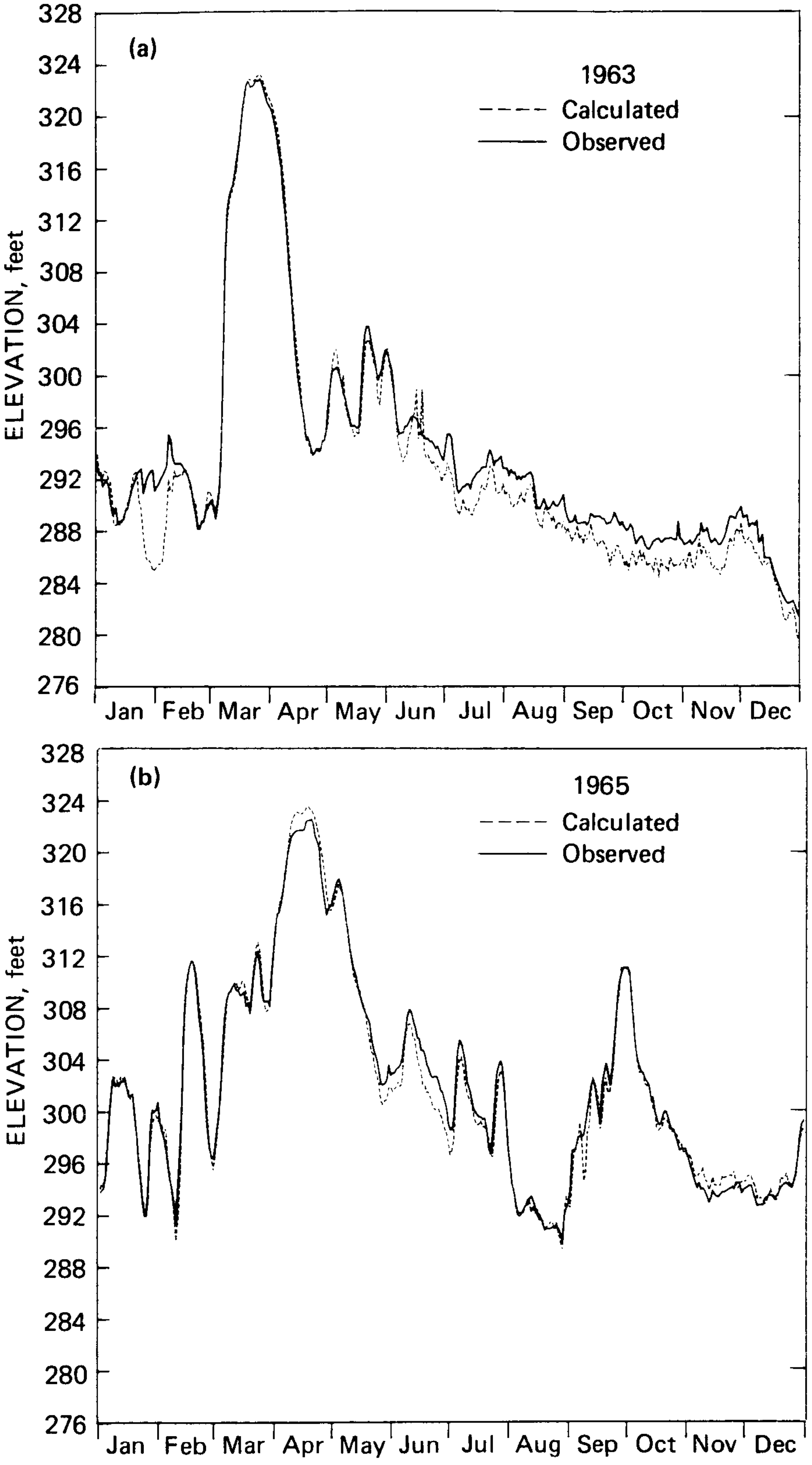
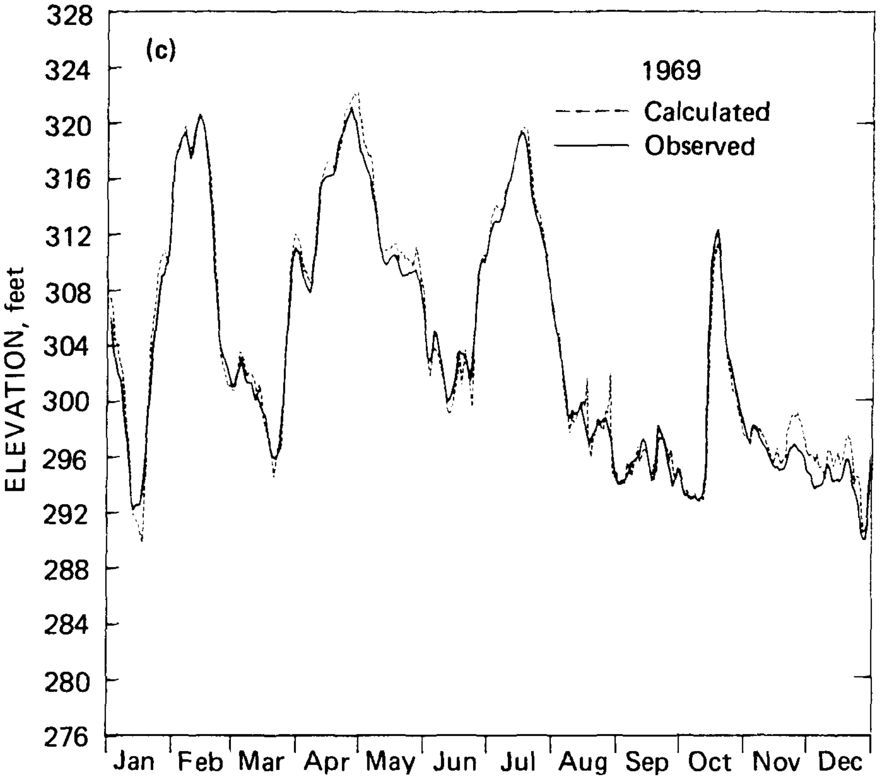


Figure 69. Comparison of observed water-surface elevations at the Beechridge station and elevations calculated by the slope method



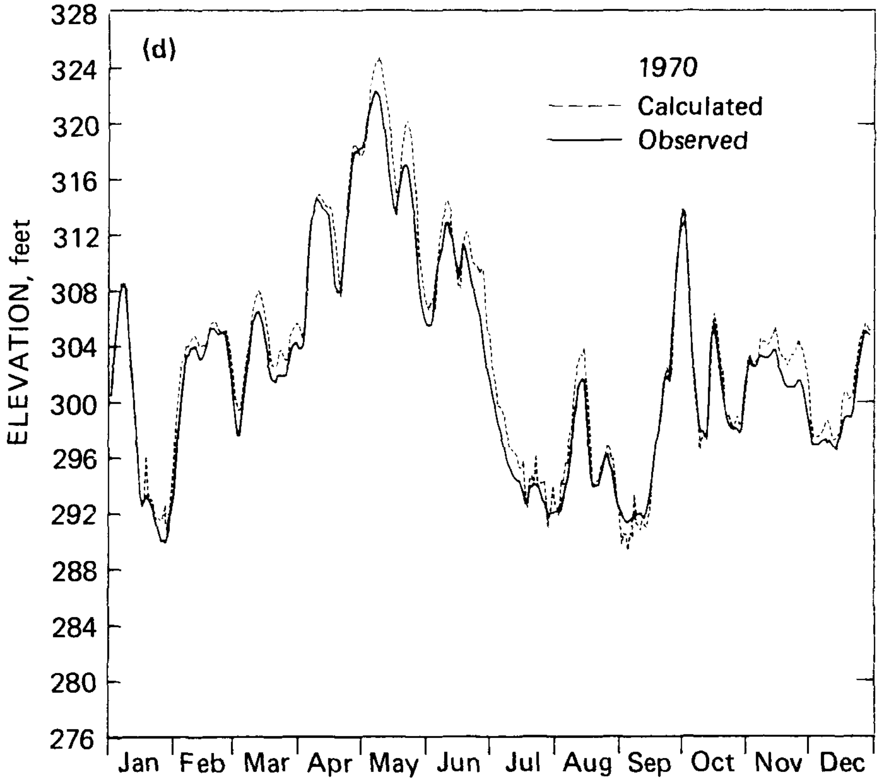


Figure 69. Concluded

EROSION AND SEDIMENT TRANSPORT

Erosion and sedimentation are major sources of the problems in the Cache River basin. Because of the locations of the natural areas and wetlands, the major emphasis of this project has been on the stream channels and floodplains along the main stem of the Lower and Upper Cache Rivers. Therefore the erosion and sedimentation issues analyzed are limited in scope to channel scour and sedimentation in stream channels and floodplains. Upland erosion has not been dealt with in any detail in this study, other than through the quantification of the sediment yield from the major watersheds in the basin based on the data collected at the gaging stations. An analysis of upland erosion and its impact on agricultural production is out of the scope of this project. The main emphasis for this project is channel erosion (scour) and sedimentation in stream channels and floodplains and their impact on the hydrologic integrity of the natural areas and wetlands in the basin. The problems associated with erosion and sedimentation in the Cache River basin are different for the Upper and Lower Cache Rivers.

In the Upper Cache River, the main problem is related to the construction of the Post Creek Cutoff, which altered the state of dynamic equilibrium for the Upper Cache River stream channel. Because of the new state of stream dynamics imposed on the Upper Cache River after construction of the Post Creek Cutoff, the stream started to entrench. The original design of the Post Creek Cutoff considered the entrenchment possibilities as positive developments that would improve the drainage characteristics of the Upper Cache River. However, what was not realized were the negative impacts the entrenchment would have in the areas around the Post Creek Cutoff and the wetlands in the Upper Cache River. Presently, the Post Creek Cutoff channel is roughly two times wider and at least two times deeper than the original design in some locations. The lateral gullies that have formed along the cutoff are in the range of 30 to 40 feet deep and negatively impact farmlands in the area by eroding valuable farmland and access roads. Farther upstream in the Upper Cache River, the entrenchment of the stream channel has reached bedrock in some places, resulting in increased bank erosion and gully formations that are threatening the existence of some of the most important wetlands and natural areas in the state.

The problem in the Lower Cache River is the opposite of that in the Upper Cache River. Instead of stream channel entrenchment, the problem is excessive sedimentation in stream channels and wetlands. The accumulation of sediment in stream channels retards the flow in the stream and increases flooding, while the continuous accumulation of sediment in wetlands changes the hydrologic balance in the wetland and could in the long run result in a change in the types of plants and animals that could survive in the area.

The sediment data collection and analysis portion of this project is designed to quantify the magnitude of the problem and to assist in the development of the best alternative solutions for reducing the negative impacts of erosion and sedimentation in the two areas of critical problems. Analyses and discussions of existing and new sediment data are presented in the following sections of the report.

Historical Data

Historical sediment data for the Cache River are limited. The most useful data available include stream channel geometry data for different times and suspended sediment data collected by the Water Survey in the Cache River at Forman since 1981. Although these records are not complete and are for short durations, they provide valuable information and were used in this study. There were no historical data on streambed and bank materials or on sedimentation rates.

Channel Geometry

The channel geometry data available are primarily for the Post Creek Cutoff and the Upper Cache River. The data include the original design of the cutoff, as well as data from a stream survey conducted by the Soil Conservation Service in relation to channel improvement investigations in 1965 and 1972. For the Lower Cache River, no stream channel survey data or sufficiently detailed sketch have been found. Thus the discussion in this section concentrates on the survey data that have been recovered and analyzed for the Post Creek Cutoff and the Upper Cache River.

To illustrate the extent of channel scour that has taken place since the construction of the Post Creek Cutoff, the channel bottom profiles of the Cutoff at different times are compared in figure 70. The original profile of the Cutoff was obtained from the design plans for the channel (Cache River Drainage Commission, 1905). The most recent survey was conducted in 1972. As seen in the figure, the Cutoff has entrenched significantly since 1905.

The Post Creek Cutoff not only entrenched downwards but also widened significantly as shown in figure 71, where the design channel size is compared to the channel geometries measured in 1972. From an original design width of about 100 feet, the channel has widened to approximately several hundred feet wide. The channel entrenchment and widening are also associated with creation of lateral gullies, which are bigger than the original cutoff channel itself. A plan view of the area around the Post Creek Cutoff, showing the major gullies that have been created because of the entrenchment of the Cutoff, is shown in figure 72.

Suspended Sediment

Prior to the establishment of the monitoring stations for this project, the station at the Cache River at Forman was the only suspended sediment data collection station in the Cache

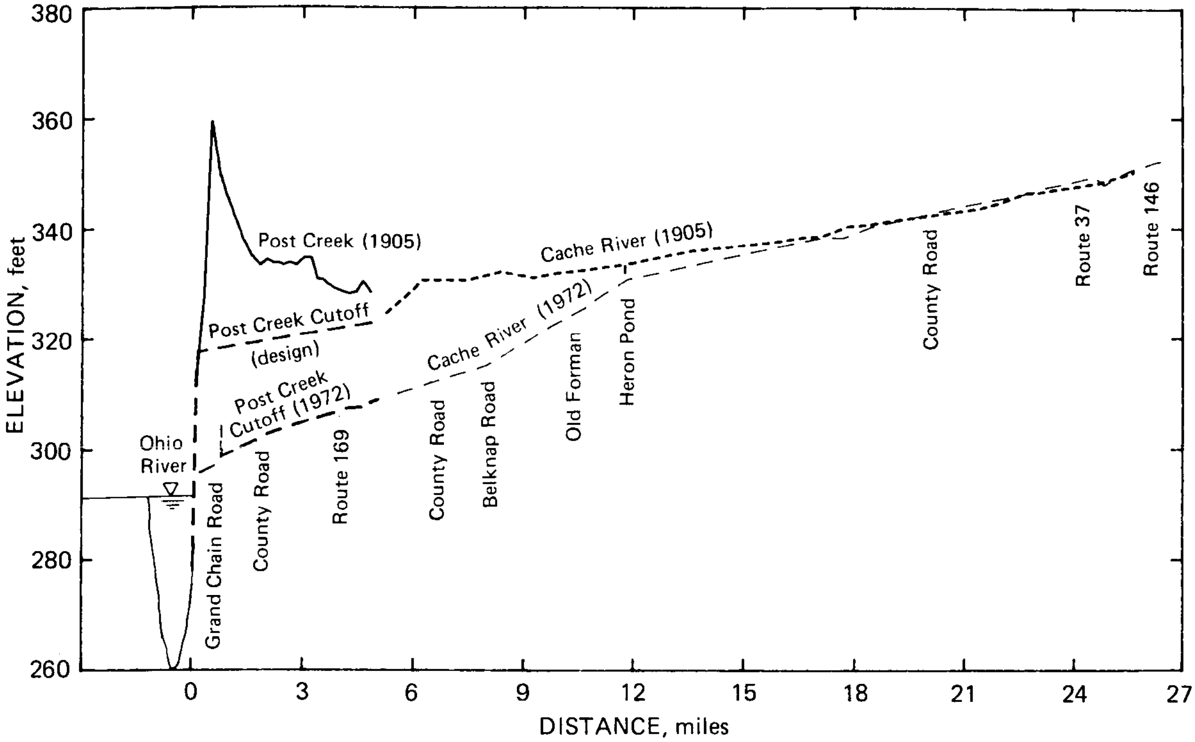


Figure 70. Bed profiles of the Post Creek Cutoff and Upper Cache segments in 1905 and 1972

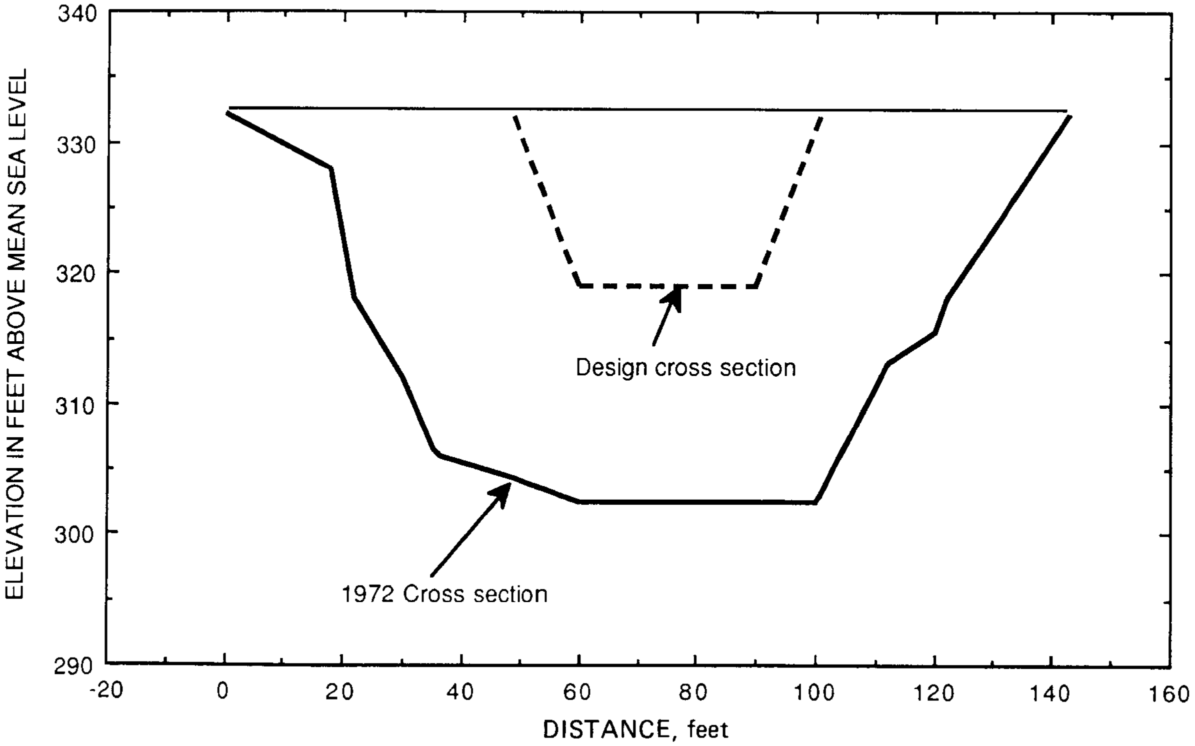


Figure 71. Comparison of an original Post Creek Cutoff channel and a cross section measured in 1972

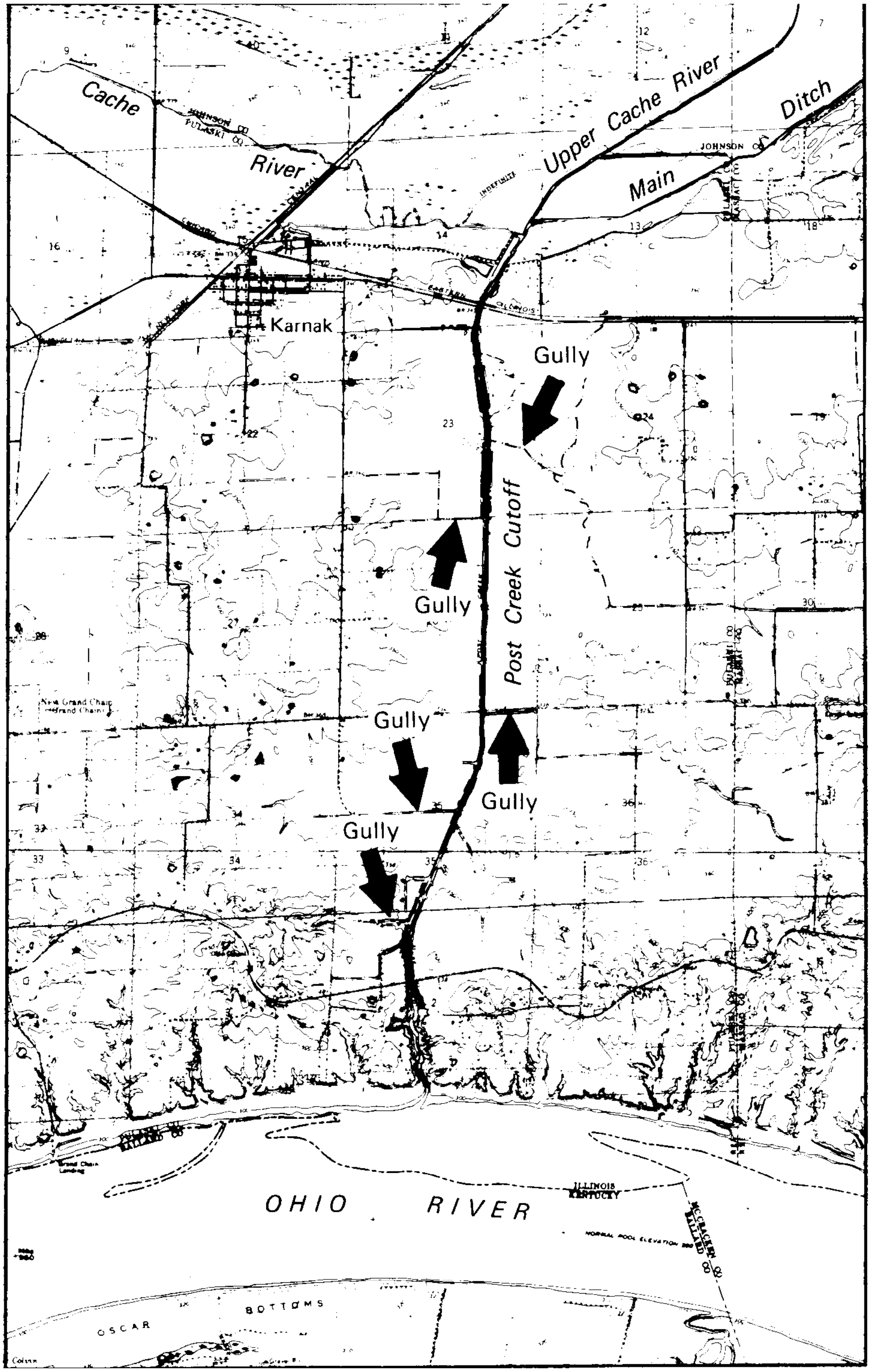


Figure 72. Plan view of major gullies along the Post Creek Cutoff

River basin. Data collection began at this site in the 1981 water year (October 1980) as part of the Illinois Instream Suspended Sediment Monitoring Network run by the Water Survey (Bonini et al., 1983). The frequency of data collection has been variable. The station was later included as part of the monitoring stations for the Cache River project. Through the 1984 water year, 327 samples were collected. The methods of sampling in the monitoring network are identical to those used in this study that are discussed in the section on data collection methods and procedures.

Sedimentation

Most of the sedimentation problems in the Cache River basin are confined in the Lower Cache River. Because of the great difference in the gradient of the tributary streams that drain the upper watershed and the main river in the Lower Cache River, sedimentation takes place in the stream channels and wetlands surrounding the stream channels. Although visual and field inspections indicate that the sedimentation rate in the Lower Cache River has been significant, no historical qualitative data are available. Nonetheless, sediment in the stream channels is one of the contributing factors to the flooding problems in the Lower Cache River. Continued sedimentation in the wetlands, especially in the Buttonland Swamp area, could be detrimental to the preservation of the wetlands in their natural state. Several sediment core samples were collected in the Buttonland Swamp area in 1988 for sedimentation rate analysis by means of Cesium 137. The analysis is not completed yet, but the data will provide a historical perspective when they become available.

Current Data

As discussed in the preceding sections, very limited and sometimes no sediment data were available prior to the start of the Cache River basin project. At the same time, most of the problems were associated with sediment, either in terms of channel scour or in terms of sediment accumulation at locations where it was undesirable. Therefore it was very difficult to evaluate and select any solution that might correct the problems without quantifiable data. One of the major objectives of the Cache River basin project was to collect sufficient sediment data that decisions could be made on the basis of what is really taking place in the basin rather than on the basis of assumed and unsubstantiated hypotheses.

The data that needed to be collected consisted primarily of data on the sediment loads of streams and the characteristics of the bank and bed materials. The stream sediment loads were regularly monitored, and streamflow was monitored continuously. The locations of these monitoring stations were shown in figure 33. The sediment load monitoring program had two primary objectives: 1) to quantify the amount of sediment being transported into the

Buttonland Swamp area by the different tributary streams, and 2) to quantify the amount of sediment that is being transported through the Upper Cache River and the Post Creek Cutoff so that the channel stability of the river could be analyzed by using mathematical models. In addition to determining the sediment load transported in a stream, it is important to know the characteristics of the sediment being transported. This is done by collecting additional sediment samples for particle size analysis.

Data on bed and bank material characteristics were also collected. This type of data is important in the analysis of channel and bank stability and sediment sources, and is essential input data for mathematical modeling of sediment transport.

The following sections discuss the data collection procedures for the two types of data, the data collected, and the results.

Suspended Sediment

Two parameters are used to describe suspended sediment: concentration and particle size. The sediment concentration, expressed in milligrams per liter, is used in conjunction with the discharge in the stream to compute the suspended sediment load. The sediment particle size is useful for determining the type of material being moved in various flow regimes, and for modeling purposes. The type and size of material carried as suspended sediment are indicative of the stream's energy and the source of sediment material and will vary depending on the flow condition.

Data Collection Methods and Procedures. The same method is used for collecting samples for determining both the suspended sediment concentration and the particle size, although two methods are used depending on the flow in the stream.

1) Grab sample: The sample bottle is dipped directly into the stream to grab a sample. This method is used only for periodic sampling during low flows when depth-integrated samples cannot be collected.

2) Depth-integrated sample: A specially designed sampler known as the DH-59, which provides a depth-integrated sample, is used in collecting the water-sediment mixture. This method is used for routine sampling during medium to high flows when the water is deep enough to submerge the sampler. A photograph of the DH-59 sampler is shown in figure 73. The DH-59 consists of a streamlined bronze casing 381 mm long and weighing 11 kg. A pint glass milk bottle is sealed against a gasket in the head cavity of the sampler by a hand-operated spring-tensioned pull-rod assembly at the tail of the sampler. The water-sediment mixture enters through the intake nozzle (three nozzles are available, calibrated to 1/8-, 3/16-, or 1/4-inch inside diameter) and is discharged into the bottle. The displaced air from the bottle is ejected downstream through the air exhaust alongside the head of the sampler. Tail fins

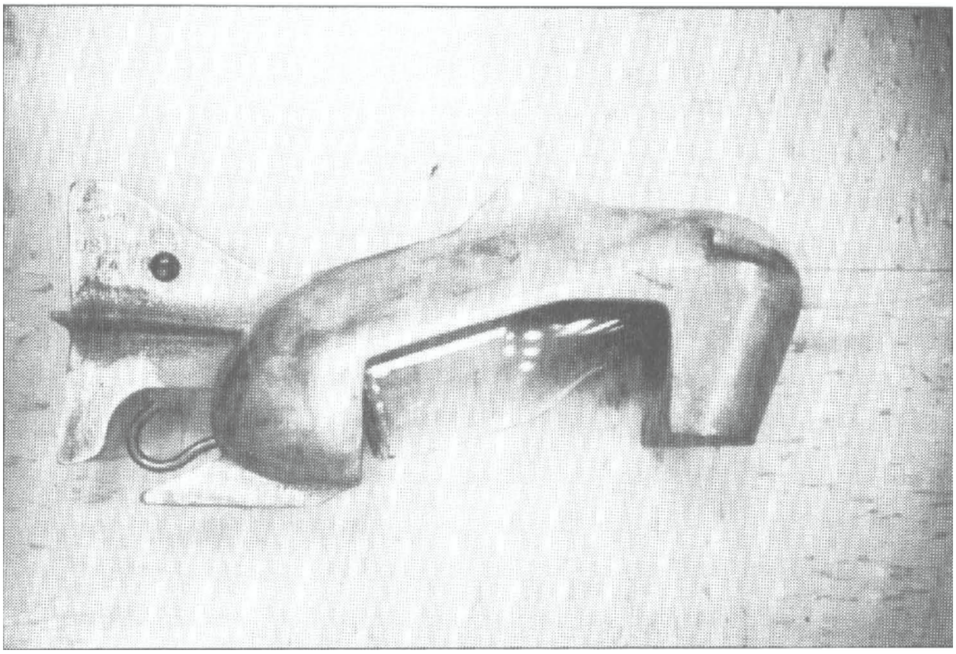


Figure 73. A DH-59 suspended sediment sampler

keep the sampler pointing into the current. The DH-59 is a depth-integrating sampler designed to accumulate a water-sediment sample from a stream at such a rate that the velocity in the intake nozzle is almost identical to the immediate stream velocity, while transversing the depth of water at a uniform speed. This sampler can be used in water depths up to 20 feet (Guy and Norman, 1982).

The depth-integrated sampler (DH-59) described above does not sample the whole flow region. Because of the design of the sampler, the lower 0.3 to 0.4 foot close to the channel bottom is not sampled. The sampled and unsampled zones in a stream channel are illustrated in figure 74 along with the normal velocity distribution and sediment concentration in a vertical. As shown in the figure, the velocity in the unsampled zone is lower than average but the sediment concentration is much higher than average for the vertical. Furthermore, the sediment in the unsampled zone is expected to be coarser than the vertical mean. In general, this unsampled suspended sediment discharge along with the sediment moving on the channel bottom (bed load) is referred to as the unmeasured sediment discharge. In most cases, the unmeasured sediment discharge is estimated on the basis of empirical relations developed from experience with other streams, canals, and rivers.

Another suspended sediment data collection method for the Cache River project was the use of automated pump samplers, which were installed at three of the sediment sampling stations in March 1987. The pump samplers in use are Instrument Specialties Corporation (ISCO) Model 1680 samplers. The purpose of installing the automated pump samplers is to complement the data collection effort of Water Survey field personnel and observers assigned to collect sediment samples once a week and more frequently during flood events. The samplers are programmed to sample twice a day and are reprogrammed to sample more often during flood events. The samplers are designed to provide a maximum of 28 discrete samples between servicing.

The sampler is generally mounted on a bridge at the gaging sites, and the intake hose is suspended from the sampler into the streamflow. At the preset sampling intervals, the sampler pumps air through the intake line to purge any water left from previous samples. It then pumps a set quantity of sediment-water sample from the stream into one of the 28 sample bottles. The pumping mechanism is a peristaltic pump designed to minimize possible sample contamination. The intake of the sampler is allowed to hang free into the streamflow at a depth of 1 to 2 feet below the stream surface. As the stream stage rises, the velocity of the water pulls the intake downstream slightly and maintains the 1- to 2-foot submergence depth. The free-hanging intake also helps prevent the accumulation of debris on the intake. Each week, the samplers are serviced and checked for malfunctions and contamination.

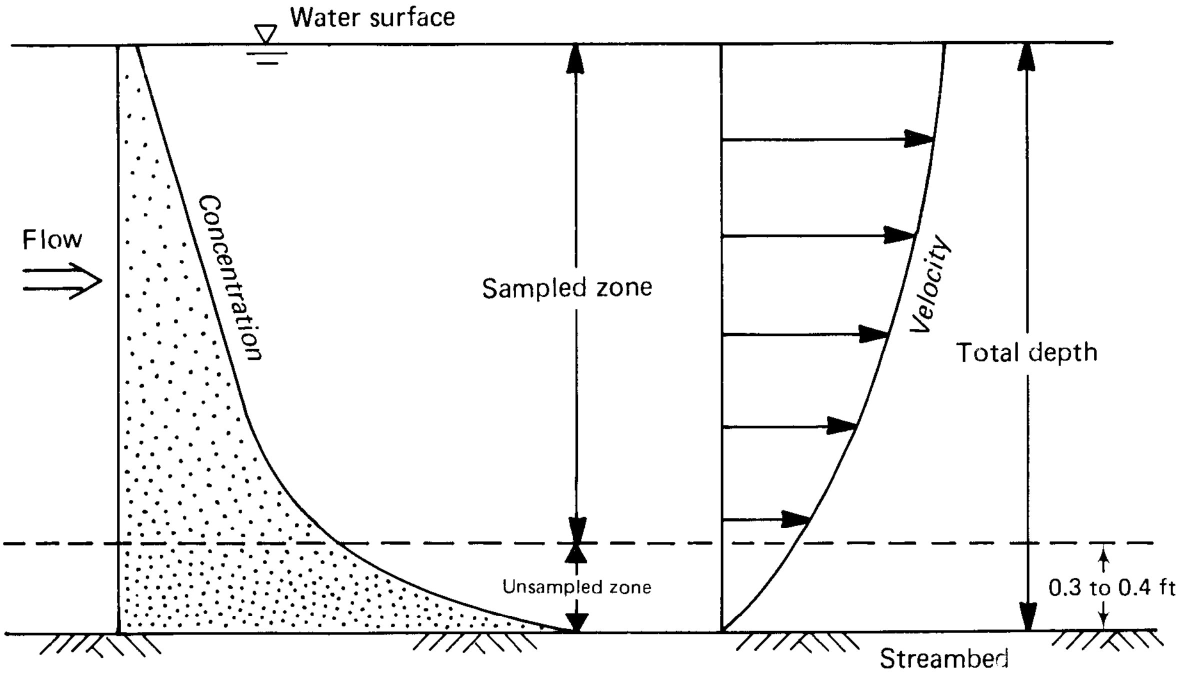


Figure 74. Sampled and unsampled zones in a stream sampling vertical with respect to velocity distribution and sediment concentration

All the suspended sediment samples collected in the field are catalogued and identified as to the gage site, date and time of sample collection, gage height, water temperature, and sample number before they are delivered to the Inter-Survey Geotechnical Laboratory for analysis. Most of the samples are analyzed for concentration only, and a few are analyzed for particle size. The amount of particle size analysis is limited because of the large number of samples required and the cost for analysis. Once the laboratory analysis is completed, the results are sent to the Water Survey, where they are checked against field notes and then entered into the computer for sediment load calculations and other analyses related to variability of sediment concentration and load in time and space.

Results. Sediment concentration measurements were made primarily to determine sediment loads in the stream. Concentration data were collected at eight sites with recording gages. Plots of suspended sediment concentration for all the stations are shown in appendix D. Suspended sediment concentration values vary widely over time in accordance with flow. Low-flow concentration values are around 50 mg/l or lower, while high-flow values range from 2,000 to 13,000 mg/l. The concentration at the sites did not exceed 4,000 mg/l except at Big Creek at Perks Road, where the concentration reached 13,000 mg/l. Although suspended sediment concentration correlates with discharge, it is also dependent on factors such as precipitation intensity and amount, land use, and season.

The suspended sediment loads were computed for six stations in the Cache River basin for the data collection period. Two stations where suspended sediment concentration data were collected were not included in the analysis because of their locations. Cache River at Route 37 (station 508) is located in the Buttonland Swamp area. Constant changes in flow direction during floods make it difficult to calculate sediment loads by using a conventional method. Indian Camp Creek (station 510) is a small creek outside the area of most interest in terms of long-term sediment accumulation. The daily suspended sediment load data are plotted over time in appendix E for all six stations. The results from the load computations are summarized in tables 22 and 23 on a monthly basis. The sediment loads in table 22 are in tons; in table 23, the loads are normalized by the area of the watershed upstream of the gaging stations and are in tons per 10 acres. The annual totals presented in the tables are the total values for the water years during the monitoring period.

Twenty-nine samples were analyzed for suspended sediment particle size. The results are presented in table 24. The finest mean particle sizes were found at the Cache River at Route 146 (507) and the Cache River at Route 37 (508), while the coarsest material was found at Big Creek at Perks Road (502). The coarsest material is classified as a medium silt. The greatest percentage of sand was found at the Cache River at Forman (378), which lies downstream of the Cache River at Route 146 (507), where little sand was found.

Discussion. For discussion and comparison purposes the sediment load data have been organized into two groups, one for the Upper Cache River and the other one for the Lower Cache River, because the problems associated with sediment in the two regions are different, as mentioned earlier in the report. In the Upper Cache River the problem is channel scour, while the problem in the Lower Cache River is sedimentation. Therefore in the Upper Cache River we wanted to determine the sediment transport characteristics of the river and its tributaries into the Post Creek Cutoff so that we could develop a well-calibrated mathematical model that would enable us to investigate the nature of the channel scour and alternative measures that could stabilize the stream channels in the Upper Cache River. On the other hand, the purpose of sediment data collection in the Lower Cache River is to quantify the sediment yield from the different watersheds and evaluate their impact on sedimentation in the Lower Cache River and its tributary stream channels. Of primary importance is the identification of the sources of sediment into Buttonland Swamp and their relative importance so that erosion control measures can be implemented in selected areas to maximize benefits.

The results shown in figure 75 compare the sediment yield in tons per 10 acres (data taken from table 23) for the three sediment monitoring stations in the Upper Cache River for the four water years from 1985 to 1988. Each water year is presented on a separate figure to avoid clutter. The 1985 water year was not complete because data collection had not started for all stations at the beginning of the water year. Several observations can be made from figure 75. The monthly sediment yield per 10 acres was less than 2 tons for all the stations in both Water Years 1987 and 1988. In Water Year 1986, the 2 tons was exceeded twice, once in February for the Cache River at Forman and once in May for Main Ditch, when the respective values were 2.3 and 3.3 tons. In August 1985 the sediment yield for both stations on the Cache River exceeded the 2 tons per 10 acres value, reaching 7.2 tons at Route 146 and 2.9 tons at Forman. It should be noted again that Water Years 1987 and 1988 were dry years, 1986 was near normal, and 1985 was a wet year. Therefore the sediment yields measured in 1987 and 1988 would be expected to be below normal. This is further illustrated in figure 76, where the total annual sediment yields from the three stations in the Upper Cache River for the four different water years are compared. The total sediment yield in tons is shown in figure 76a, while in figure 76b the annual sediment yield per 10 acres is shown. In terms of total sediment yield, the Cache River at Forman is always higher than the other two stations in the Upper Cache River. This is primarily due to the larger drainage area at that station. The total annual sediment yield for the Cache River at Forman ranged from a low of 30,100 tons in 1987 to a high of 145,700 tons in 1985. For the Cache River at Route 146, the low yield was 7,900 tons in 1988, while the high was in 1985 at 63,700 tons. For Main Ditch, the highest yield was in 1986 with 52,200 tons and the lowest was in 1987 with 9,000 tons. The sediment yields in Water Years 1987 and 1988 were less than those in 1985 and 1986.

For the Lower Cache River, the sediment yields in tons per 10 acres are compared for the four water years from 1985 to 1988 in figure 77. Similarly to the data for the Upper Cache River, the 1985 water year data were not complete, and only data for Big Creek for six months are shown. However, because 1985 is the only wet year for which there are some data, it provides good balance in evaluating the data collected during the project period. Two observations stand out from figure 77. The first one is the significantly higher sediment yields in 1985 and 1986 as compared to 1987 and 1988. The highest sediment yield recorded is the 25.7 tons per 10 acres in May 1986. The second highest is that of August 1985 at 18.4 tons per 10 acres. Both of these yields were measured at the Big Creek station. In comparison, the sediment yields in 1987 and 1988 never exceeded 5 tons per 10 acres in any one month at any of the stations. The second important observation is the dominance of Big Creek in terms of sediment yield in the Lower Cache River. In general, the sediment yield per unit area is higher for Big Creek than for Cypress Creek or for the whole Lower Cache River as monitored at Ullin. Only during some relatively low sediment yield periods such as June and July 1987 does sediment yield per unit area from Cypress Creek exceed that of Big Creek.

The total annual sediment yields from the three monitoring stations in the Lower Cache River for the four water years where some sediment data were collected are compared in figure 78. Figure 78a shows the total sediment yield in tons, while figure 78b shows the sediment yield in tons per 10 acres. In terms of total sediment yield, the Big Creek watershed generates more sediment than Cypress Creek and even more than the whole Lower Cache River upstream of Ullin that includes the Big Creek watershed itself. The sediment yield from the Lower Cache River at Ullin is less than that of Big Creek because a significant amount of the sediment from tributary streams entering the area is trapped within Buttonland Swamp and the adjoining wetlands and floodplains before it reaches the gaging station at Ullin.

On the basis of sediment yield per unit area, as shown in figure 78b, the sediment yields per 10 acres for 1986 were 43 tons for Big Creek, 5.3 tons for Cypress Creek, and 2.5 tons for the Lower Cache River. For 1987 they were 8.3 tons for Big Creek, 2.6 tons for Cypress Creek, and 0.8 for the Lower Cache River. In 1988 the yields were 8.8 tons for Big Creek, 3.9 tons for Cypress Creek, and 1.5 tons for the Lower Cache River. Therefore the sediment yield per unit area from Big Creek is from 2 to 5 times that of Cypress Creek and from 6 to 17 times that of the Lower Cache River.

The reasons why the Big Creek watershed yields more sediment per unit area than the Cypress Creek watershed must be related to differences in watershed characteristics, land use, stream channel characteristics, and floodplain wetlands. Since the watersheds are adjacent to each other, there is not much difference in climatic conditions or even in soil characteristics. Some factors that are evident are the differences in the stream channels and floodplains of the two creeks. While the floodplains of Big Creek are relatively void of trees, many places along Cypress Creek are forested and uncleared. These forested floodplains tend to trap sediment and reduce sediment yield downstream.

Examination of the suspended sediment load over time (plots shown in appendix E) clearly shows that the transport of sediment is not constant over time. During the majority of the time, relatively small amounts of sediment are transported compared to the large amounts transported during the storm events that occur over a short period of time in the year. To describe the variability of suspended sediment transport, sediment-duration curves were prepared for the stations at the Cache River at Forman, Big Creek at Perks Road, Cypress Creek at Dongola Road, Cache River at Route 51, Main Ditch at Route 45, and Cache River at Route 146. These curves are shown in appendix F. A sediment-duration curve represents the variability in the transport of sediment over time by plotting the percentage of the suspended sediment load against the corresponding percentage of time.

The fact that the sediment-duration curves are always concave down signifies that the majority of the sediment is transported during a brief period. This high rate of transport takes place during flood events, which are the peaks when suspended sediment load is plotted over time. To further illustrate the transport of sediment during flood events, table 25 was prepared. Listed in this table are the percentages of the total sediment transported during various percentages of the monitoring period. From this table it can be seen that the size of the watershed seems to be correlated to the time that is necessary for the transport of a given amount of sediment. The larger the watershed, the greater the percentage of time that is necessary. From table 25 it can be seen that 55% of the total sediment load is moved during 5% of the time for the Cache River at Forman (378), while for Big Creek at Perks Road (502), 96% of the total load is moved in 5% of the time. Therefore, it takes five times longer for a comparable percentage of sediment load to pass the Cache River at Forman than to pass Big Creek at Perks Road. On the other hand, watersheds with similar sizes such as Big Creek at Perks Road (502) and Cypress Creek at Dongola Road (503) have different values as a result of dissimilar watershed characteristics. To demonstrate that a large percentage of the sediment is transported during flood events that take place during a small percentage of the time, figure 79 was developed. This figure shows the percent of the load that is transported in 10% of the time for six of the monitoring stations in the Cache River basin. As shown in the figure, a large percentage of the load is transported in only 10% of the time.

Another step in sediment analysis is to know how much sediment is being transported by different discharges for a stream. This is generally done by developing a rating curve that describes the interrelationship between suspended sediment loads and discharges. The sediment rating curves for the Cache River at For-man, Big Creek at Perks Road, Cypress Creek at Dongola Road, Cache River at Route 51, Main Ditch at Route 45, and Cache River at Route 146 are presented in appendix G. The rating curves were developed by a linear least squares fit to the logarithms of both variables. The form of the equation is as follows:

$$\log Q_s = \log A + \log Q_w \tag{8}$$

where Q_s is sediment load in tons and Q_w is water discharge in cfs.

The plots in appendix G show good correlation. However, there is a certain degree of scatter in the data that is expected because of the many factors other than water discharge that influence sediment transport. Attempts have been made to modify the method of fitting the data by introducing a correction factor (Ferguson, 1986) or by using a nonlinear regression method instead of a linear regression method (Singh et al., 1986). Neither method improves the scatter in the data. For comparison of the sediment yield from different watersheds, the results of the linear least squares fit were used, and they are presented in table 26.

Suspended sediment load can be computed from equation 8 by using the values of A and B from table 26. The slope of the regression line for Big Creek at Perks Road (502) is greater than those of the other sites, which is an indication that this watershed conveys more suspended sediment load than the others for the same amount of discharge.

Streambed and Bank Materials

Streambed material may be correlated with the physical environment in which the material was formed. The size and gradation of streambed material are closely related to the stream channel geometry, sediment transport, and flow variables (Simons and Senturk, 1977). To predict the equilibrium of the stream (whether entrenchment or deposition will occur), the size and gradation of the streambed material must be known.

The size frequency distribution at the sampling location may be dependent on the size frequency distribution at the upstream source. Changes can occur in the size frequency distribution from the upstream source to the downstream site as a result of the transport process. Bed material can undergo a physical change by a wearing-down process, a portion can be added or deposited en route, or any combination thereof can occur. The flow regime may allow selective deposition because of the ability of the flow to transport a certain quantity and size of sediment (hydraulic sorting). Sediment particles above that size will be deposited.

No historical streambed and bank material data in the Cache River were available in the literature. Therefore, a relatively large number of bed and bank materials were collected in both the Lower and Upper Cache River for this project, and discussions of the data collection procedures and results follow.

Data Collection and Procedures. Streambed and bank material samples were collected during periods of low flows. At each sampling site, a minimum of three discrete samples of the bed and bank material were collected across a cross section of the stream. The samples were chosen to be representative of the entire cross section, and the cross sections were chosen to be representative of the reach of the stream. Preliminary site locations were made from topographic maps. The exact number and locations of these sites were determined on the basis of the conditions found in the field. Data were collected from two segments of the Cache River: **1)** the Post Creek Cutoff - Upper Cache River segment from the confluence of the Post Creek Cutoff with the Ohio River up the river 26 miles to the Route 146 bridge on the Upper Cache River (figure 80a), and 2) the Lower Cache River segment from Route 51 near the village of Ullin upstream 15 miles through Buttonland Swamp to the Post Creek Cutoff (figure 80b).

The method for collecting streambed material is dependent on the depth of water in the stream during sampling. When the water depth allowed wading, a scoop sample was taken. The material would be scooped from the streambed into the flow. When the depth of water would not allow wading, a boat was used along with a dredge. After it was collected, the bed material sample was placed in a plastic bag. This procedure would be repeated until a minimum of three representative samples for each cross section had been collected and placed in sample bags.

In addition to the collection of surficial bed material, core samples were taken in the Buttonland Swamp area that will allow an analysis of the particle size up to 2 feet below the substrate surface. This is necessary since this area has experienced significant deposition of sediment. Analysis of the material that lies below the substrate surface provides an insight into the flow regimes and sedimentation patterns that existed in the past. Samples were also collected for unit weight analysis. The unit weight of the sediment along with the volume of sediment will provide a means to calculate the weight of material deposited over the years. All samples were analyzed at the Inter-Survey Geotechnical Laboratory in Champaign.

Results. The laboratory results of the particle size analyses of the bed and bank materials are presented in terms of particle diameter and "percent finer," which represents the percentage of the total sample that is finer or smaller than a given particle size. The results of the laboratory particle size analysis are commonly plotted as percent finer by weight versus particle size. The coarser or larger particles are represented on the left side of the plot, and the sizes decrease to the right. The cumulative size frequency curves for all the samples analyzed are presented in appendix H. At some cross sections, several samples were taken. Usually one discrete or composited sample was collected in the stream channel and one on each bank. However, if the material changed considerably and could not be represented by one sample, additional samples were collected. All the samples collected at each cross section are presented on one figure in appendix H.

Although streambed and bank material samples were collected primarily for the analysis of erosion and sedimentation in the streams, statistical analyses may be made of the laboratory results on particle size distribution. The results of the statistical analysis are summarized in table 27. Presented in this table are the cross section number, river mile at which the cross section is located, d_{50} (median particle size), d_g (geometric mean), σ_g (geometric standard deviation), and Skg (skewness of distribution). An explanation of these parameters and how they are computed follows.

The median particle size, $d_{50,}$ is the particle size at which 50% of the material is finer and 50% is coarser. The geometric mean particle size, dg, is used to describe the overall average particle size of the bed material sample. The geometric mean is determined from the particle sizes at which 16 and 84% of the materials are finer by weight (d_{16} and d_{84}). The geometric mean is determined by equation 9 (Otto, 1939):

$$dg = (d_{16} \bullet d_{84})^{1/2} \tag{9}$$

where d_{16} and d_{84} = the particle diameters in millimeters at which 16 and 84% of the materials are finer by weight. If the distribution is symmetrical, the geometric mean and median are equal.

The geometric standard deviation, σ_g, is the measure of the spread of the particle sizes and is used as an estimate of the sorting of the particle sizes within the sample. Equation 10 is used to calculate the geometric standard deviation (Otto, 1939):

$$\sigma_g = (d_{84}/d_{16})^{1/2} \tag{10}$$

The geometric standard deviation has a range of 1 to infinity. When σ_g equals unity, the particles are of equal size. Conversely, if the value of σ_g approaches infinity, the sizes of individual particles become increasingly unique.

The skewness of distribution, Skg, is an estimate of the degree of asymmetry of a sample's particle size frequency distribution. Skewness indicates which end of the frequency distribution exerts a greater influence on the mean. In a symmetrical distribution, the geometric mean and median coincide, but if the distribution is skewed, the mean differs from the median. The value of the skewness gives the amount of departure of the distribution from a normal distribution. A positive value indicates an excess of fine particles, while a negative value indicates an excess of coarse particles. Skewness is calculated by using equation 11 (Inman, 1952):

$$Sk_g = [\log (d_g/d_{50})]/\log (\sigma_g) \tag{11}$$

Discussion. Streambed and bank materials vary widely in the Cache River. Table 28 presents selected parameters from table 27 on particle sizes for the channel samples only. The parameters are medium particle size (d_{50}), classification, geometric mean (d_g), geometric standard deviation (σ_g), , and skewness of distribution (S_{kg}). Only data for samples taken in the channel were selected, because they represent the channel conditions. From table 28, it can be seen that the classifications for the bed material vary from fine clay to medium gravel. The streambed material in the Upper Cache River is coarser than that in the Lower Cache River.

For the streambed materials collected in the Upper Cache River, 69% of the samples were in the silt class, 19% were sand, 12% were gravel, and none were in the clay class. The materials within each sample encompassed many different sizes as indicated by the geometric standard deviations. Most of the samples were negatively skewed or were biased to the coarser sizes.

For the streambed materials collected in the Lower Cache River, the silt class represented 50% of the samples, clay 38%, and sand 12%. There was no gravel. The size classes are not widely spread, and the average size class representing all the samples is fine silt. This is because in the Buttonland Swamp area, the swamp acts like a reservoir during major floods, resulting in low velocities. These low velocities contribute to the deposition of fine sediment particles in the area. Several moderately sized watersheds are the source of most of the sediment in this reach of the river. While the tributaries draining these watersheds undoubtedly contribute different types of sediment, there is a great deal of uniformity in bed material particle sizes within the Buttonland Swamp area of the Lower Cache River, unlike in the Upper Cache River.

Table 22. Suspended Sediment Loads at Six Monitoring Stations in the Cache River Basin (in tons)

		Station					
		Big Creek *(502)*	***Cypress Creek*** *(503)*	***Main Ditch*** *(505)*	***Cache R. at Rt. 146*** *(507)*	***Cache R. at Rt. 51*** *(513)*	***Cache R. at Forman*** *(378)*
Water Year 1985							
1984	Oct	-	-	-	-	-	6129
	Nov	-	-	-	-	-	7934
	Dec	-	-	-	-	-	18118
1985	Jan	-	-	-	-	-	2558
	Feb	-	-		-	-	8695
	Mar	-	--	6641*	-	-	11652
	Apr	2946*	-	8220	-	-	14289
	May	10666	-	3672		-	13876
	Jun	842	-	673	4496*	-	8553
	Jul	32		172	437	-	398
	Aug	36461	-	6133	56336	-	44037
	Sep	998	-	5186	2416	-	9493
Water Year 1986							
1985	Oct	624	-	2518	1046	-	4154
	Nov	2068	-	8732	4589	-	8351
	Dec	599	-	1496	1042	-	9768
1986	Jan	28	-	574	75	-	352
	Feb	18661	7*	10857	2801	1190*	34807
	Mar	2621	1076	6176	7093	1803	4692
	Apr	43	82	152	1106	134	1117
	May	50840	5119	20661	6712	12630	25184
	Jun	639	487	335	1923	2398	2110
	Jul	2388	490	429	3092	5617	685
	Aug	6053	729	**78**	2354	1212	947
	Sep	721	177	213	1251	740	656
Water Year 1987							
1986	Oct	1450	192	130	1562	682	863
	Nov	12	6	219	122	90	171
1987	Dec	194	146	1164	1272	625	1399
	Jan	9	1	6	51	21	52
	Feb	5942	432	1599	1634	317	6579
	Mar	7229	545	2502	10875	2827	8938
	Apr	163	264	994	1318	557	2977
	May	31	1	103	93	468	126
	Jun	884	1462	1123	488	725	2880
	Jul	506	981	1095	1135	2348	6017
	Aug	3	1	38	262	27	99
	Sep	7	0	24	17	14	5

Concluded on next page

Table 22. Concluded

		Station					
		Big Creek *(502)*	***Cypress Creek*** *(503)*	***Main Ditch*** *(505)*	***Cache R. at Rt. 146*** *(507)*	***Cache R. at Rt. 51*** *(513)*	***Cache R. at Forman*** *(378)*
Water Year 1988							
1987	Oct	1	0	1	8	10	2
	Nov	8	10	2	97	24	64
	Dec	9670	2106	8062	1686	2184	11606
1988	Jan	3457	1431	6959	1496	1032	23793
	Feb	1548	870	5564	1242	743	10214
	Mar	2337	1336	1315	1790	7309	5760
	Apr	326	232	2412	1095	3148	10707
	May	26	1	306	94	443	146
	Jun	7	0	13	54	33	7
	Jul	16	2	4	153	30	72
	Aug	8	21	5	33	42	18
	Sep	28	12	47	139	449	216
WY85		51945*		30696*	63686*		145732
WY86		85284	8166*	52222	33084	25723*	92822
WY87		16429	4030	8997	18828	8699	30104
WY88		17432	6019	24690	7885	15446	62605

- no data
* Partial record

Table 23. Suspended Sediment Loads at Six Monitoring Stations in the Cache River Basin (in tons per 10 acres)

		Station					
		Big Creek *(502)*	***Cypress Creek*** *(503)*	***Main Ditch*** *(505)*	***Cache R. at Rt. 146*** *(507)*	***Cache R. at Rt. 51*** *(513)*	***Cache R. at Forman*** *(378)*
Water Year 1985							
1984	Oct	-	-	-	-	-	0.397
	Nov	-	-	-	-	-	0.514
	Dec	-	-	-	-	-	1.173
1985	Jan	-	-	-	-	-	0.166
	Feb	-	-	-	-	-	0.563
	Mar	-	-	1.074*	-	-	0.755
	Apr	1.487*	-	1.330	-	-	0.925
	May	5.384	-	0.594	--	-	0.899
	Jun	0.425	-	0.109	0.575*	-	0.554
	Jul	0.016	-	0.028	0.056	-	0.026
	Aug	18.404	-	0.992	7.206	-	2.852
	Sep	0.504	-	0.839	0.309	-	0.615
Water Year 1986							
1985	Oct	0.315	-	0.407	0.134	-	0.269
	Nov	1.044	-	1.413	0.587	-	0.541
	Dec	0.302	-	0.242	0.133	-	0.633
1986	Jan	0.014	-	0.093	0.010	-	0.023
	Feb	9.419	-	1.756	0.358	0.113*	2.254
	Mar	1.323	0.701*	0.999	0.907	0.172	0.304
	Apr	0.021	0.054	0.025	0.142	0.013	0.072
	May	25.662	3.333	3.342	0.859	1.204	1.631
	Jun	0.323	0.317	0.054	0.246	0.229	0.137
	Jul	1.205	0.319	0.069	0.396	0.536	0.044
	Aug	3.055	0.475	0.013	0.301	0.116	0.061
	Sep	0.364	0.115	0.034	0.160	0.071	0.042
Water Year 1987							
1986	Oct	0.732	0.125	0.021	0.200	0.065	0.056
	Nov	0.006	0.004	0.035	0.016	0.009	0.011
1987	Dec	0.098	0.095	0.188	0.163	0.060	0.091
	Jan	0.005	0.001	0.001	0.007	0.002	0.003
	Feb	2.999	0.281	0.259	0.209	0.030	0.426
	Mar	3.649	0.355	0.405	1.391	0.270	0.579
	Apr	0.082	0.172	0.161	0.169	0.053	0.193
	May	0.016	0.001	0.017	0.012	0.045	0.008
	Jun	0.446	0.951	0.182	0.062	0.069	0.186
	Jul	0.255	0.639	0.177	0.145	0.224	0.390
	Aug	0.002	0.001	0.006	0.034	0.003	0.006
	Sep	0.003	0.000	0.004	0.002	0.001	0.000

Concluded on next page

Table 23. Concluded

		Station					
		Big Creek *(502)*	***Cypress Creek*** *(503)*	***Main Ditch*** *(505)*	***Cache R. at Rt. 146*** *(507)*	***Cache R. at Rt. 51*** *(513)*	***Cache R. at Forman*** *(378)*
Water Year 1988							
1987	Oct	0.001	0.000	0.000	0.001	0.001	0.000
	Nov	0.004	0.007	0.000	0.012	0.002	0.004
	Dec	4.881	1.371	1.304	0.216	0.208	0.752
1988	Jan	1.745	0.931	1.126	0.191	0.098	1.541
	Feb	0.781	0.566	0.900	0.159	0.071	0.661
	Mar	1.180	0.870	0.213	0.229	0.697	0.373
	Apr	0.165	0.151	0.390	0.140	0.300	0.693
	May	0.013	0.000	0.050	0.012	0.042	0.009
	Jun	0.004	0.000	0.002	0.007	0.003	0.000
	Jul	0.008	0.001	0.001	0.020	0.003	0.005
	Aug	0.004	0.014	0.001	0.004	0.004	0.001
	Sep	0.014	0.008	0.008	0.018	0.043	0.014
WY85		26.219*		4.966*	8.146*		9.437
WY86		43.048	5.313*	8.448	4.232	2.453*	6.011
WY87		8.292	2.624	1.455	2.408	0.829	1.949
WY88		8.799	3.919	3.994	1.009	1.473	4.054

\- no data
* Partial record

Table 24. Summary of Particle Sizes of Collected Suspended Sediment Samples

Station	***Date***	***Concentration (ppm)***	***Percent sand***	***Classification***	***Mean size (mm)***
378	05-16-86	733	2.79	very fine silt	.0042
378	08-12-86	344	.38	coarse clay	<,0020
378	04-16-87	169	4.97		*
378	01-21-88	255	3.98		*
378	03-31-88	330	2.00		*
502	08-16-86	1699	.04	coarse clay	.0026
502	07-01-87	304	.21		*
502	01-19-88	5346	1.43	medium silt	.0200
502	03-03-88	3148	.14	fine silt	.015
503	05-15-86	1531	.32	fine silt	.0085
503	08-16-86	1197	.41	very fine silt	.0048
503	12-09-86	143	1.11		*
503	07-01-87	413	1.90	coarse clay	.0038
503	03-03-88	1311	1.26		*
503	04-01-88	673	3.60		*
503A	07-15-86	2430	.04	medium clay	<.0020
503A	03-30-88	877	.93		*
503A	04-01-88	701	2.91		*
505	07-08-87	196	0.47		*
507	04-21-86	189	0.73		*
507	05-16-86	490	.20	fine clay	<<.0020
507	08-11-86	385	.23	medium clay	<.0020
507	03-31-88	155	1.00		*
508	05-15-86	2917	.57	coarse clay	.0031
508	07-15-86	1039	.20	fine clay	<<.0020
508	08-11-86	426	.10	medium clay	<.0020
508	04-01-88	239	.88		*
510	07-15-86	2401	.18	coarse clay	.0034
513	07-15-86	3736	.15	very fine silt	.0070

*Did not have enough samples greater than 0.63 mm to do sieve analyses

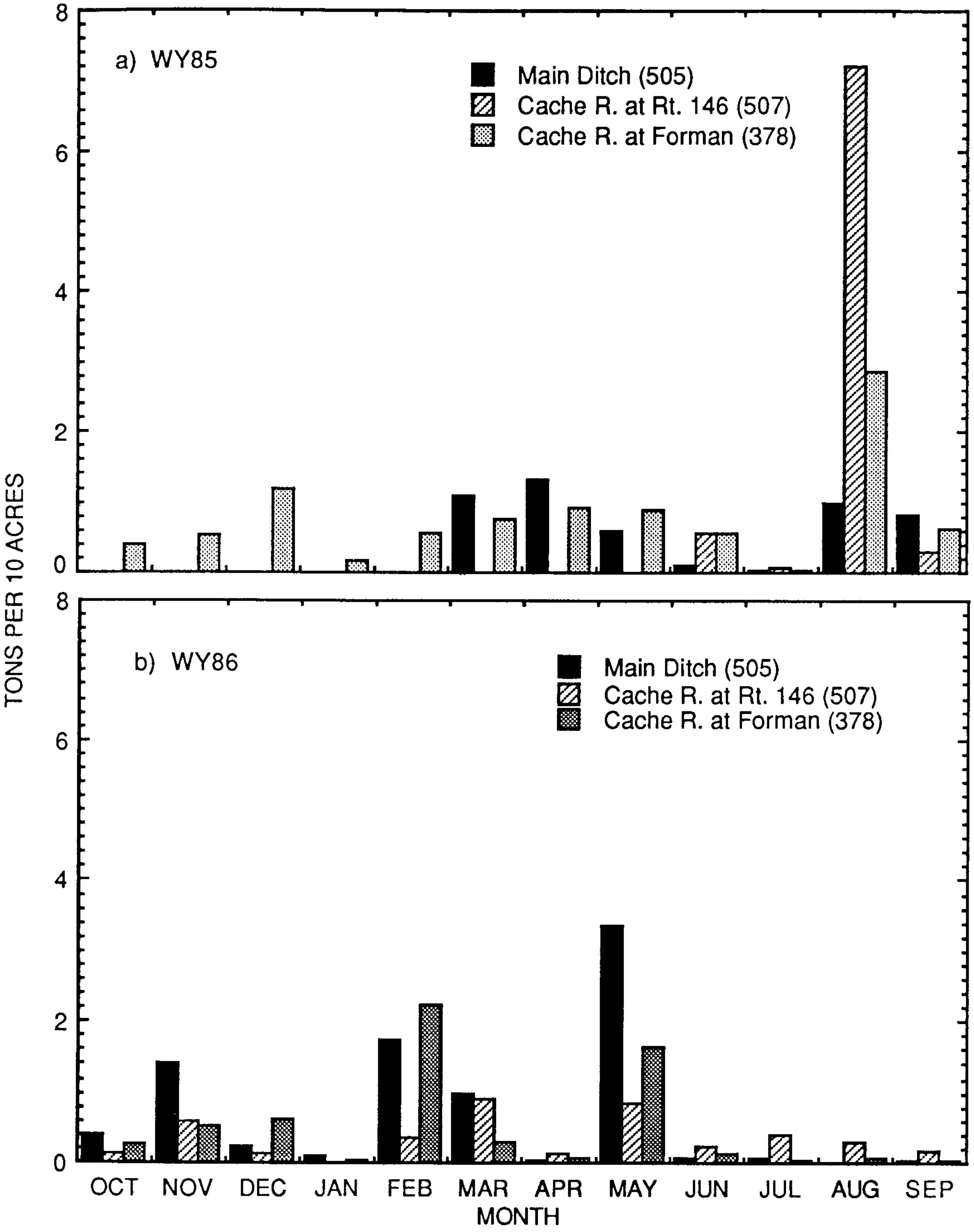


Figure 75. Sediment loads in the Upper Cache River

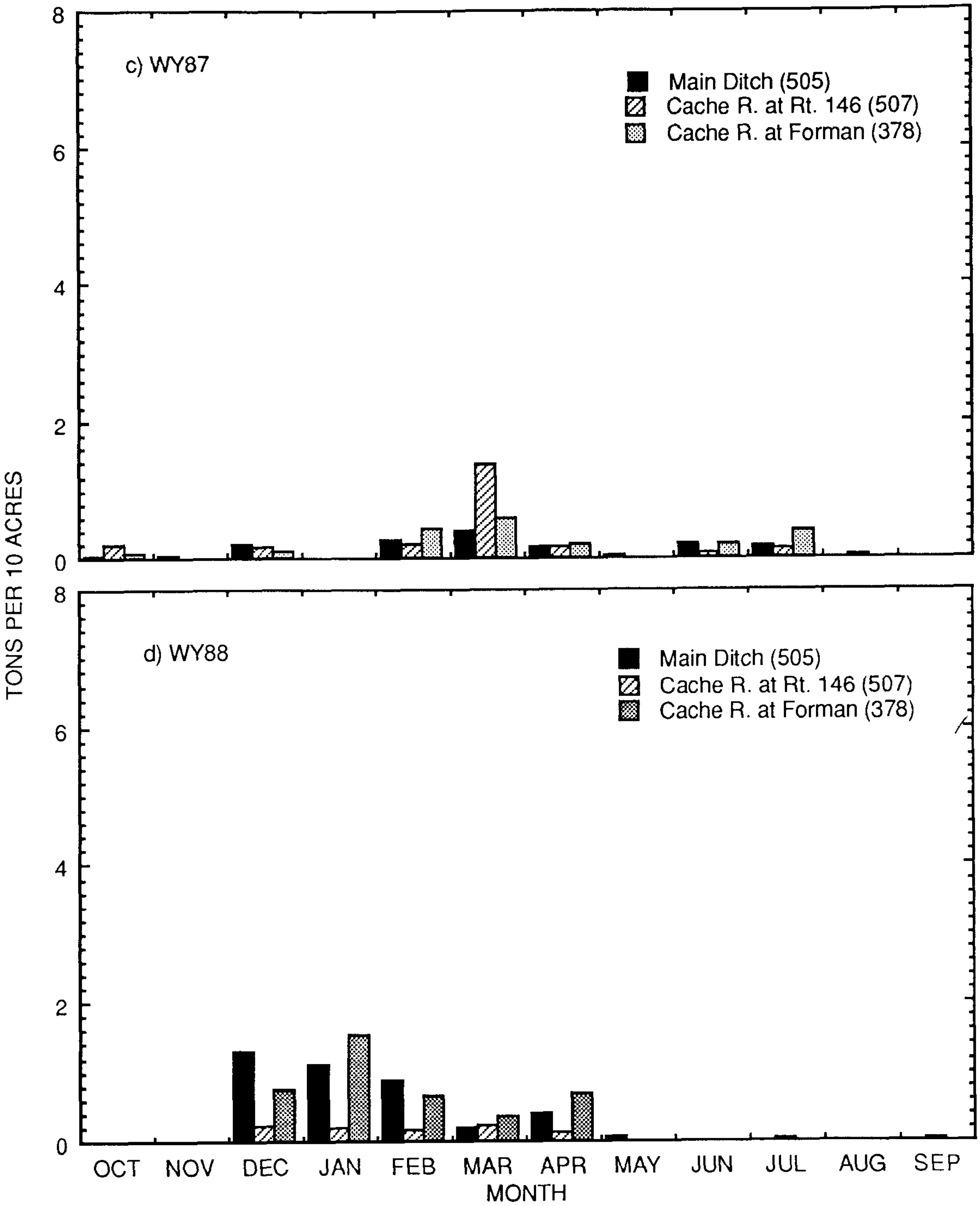


Figure 75. Concluded

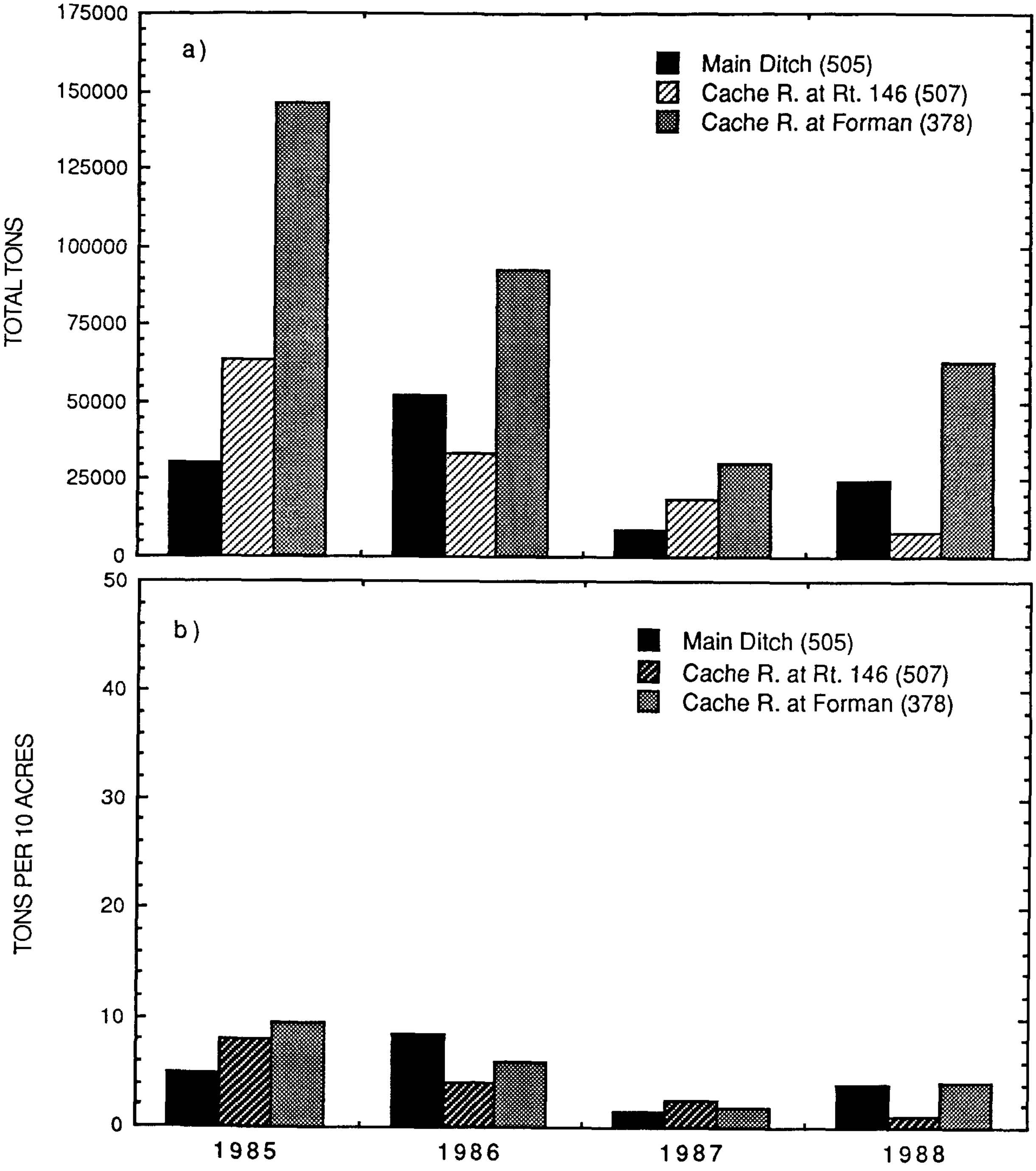


Figure 76. Annual sediment yield In the Upper Cache River

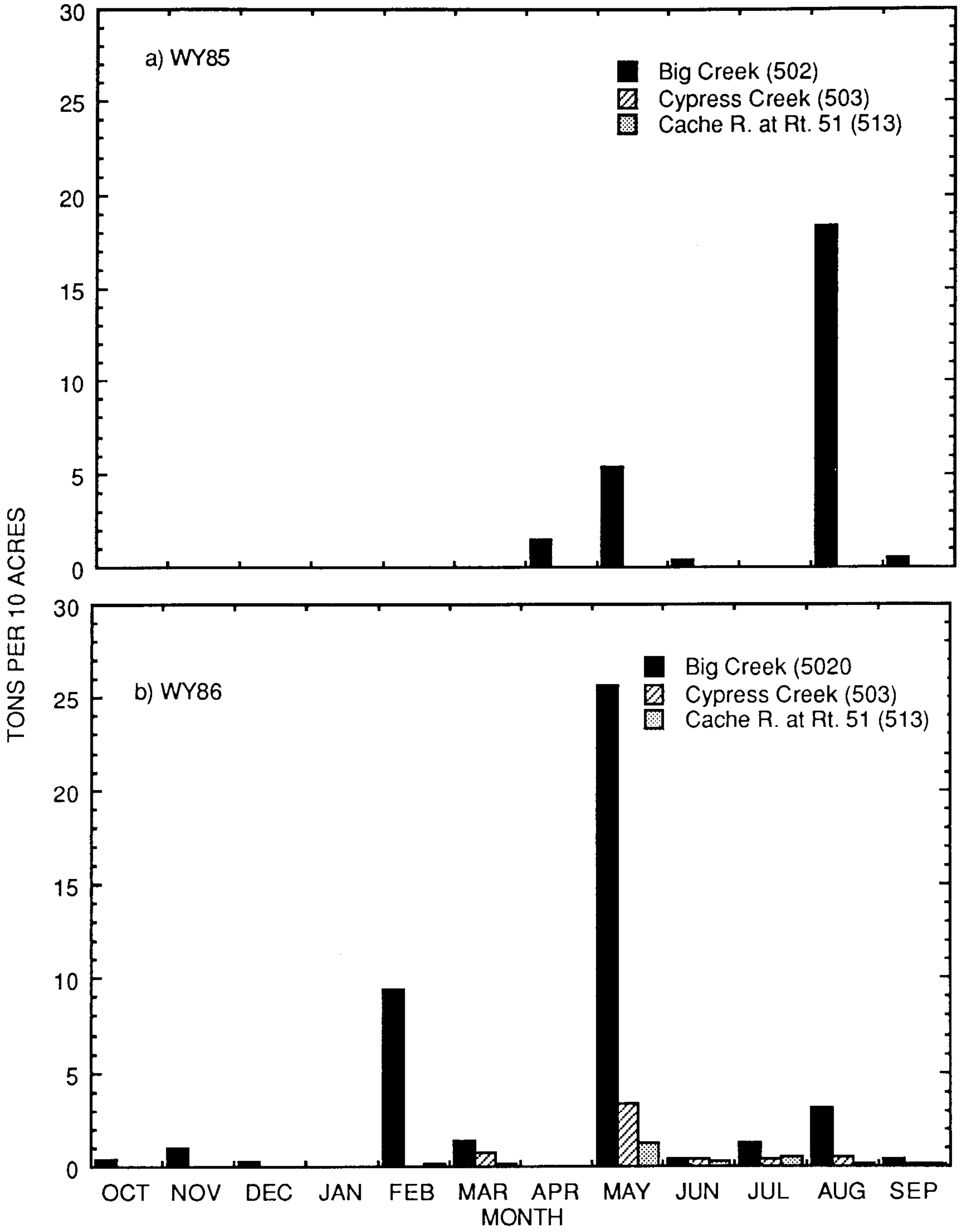


Figure 77. Sediment loads in the Lower Cache River

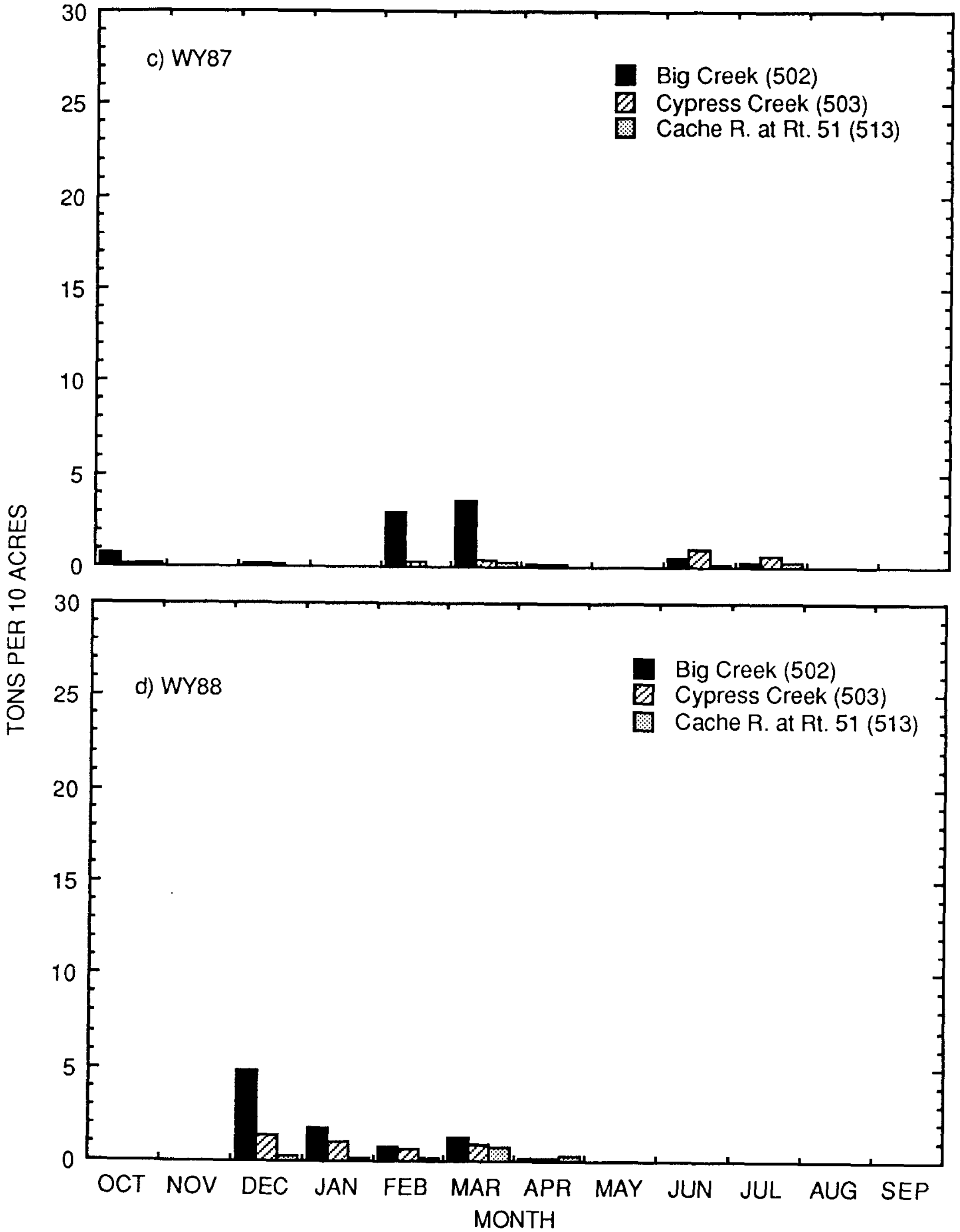


Figure 77. Concluded

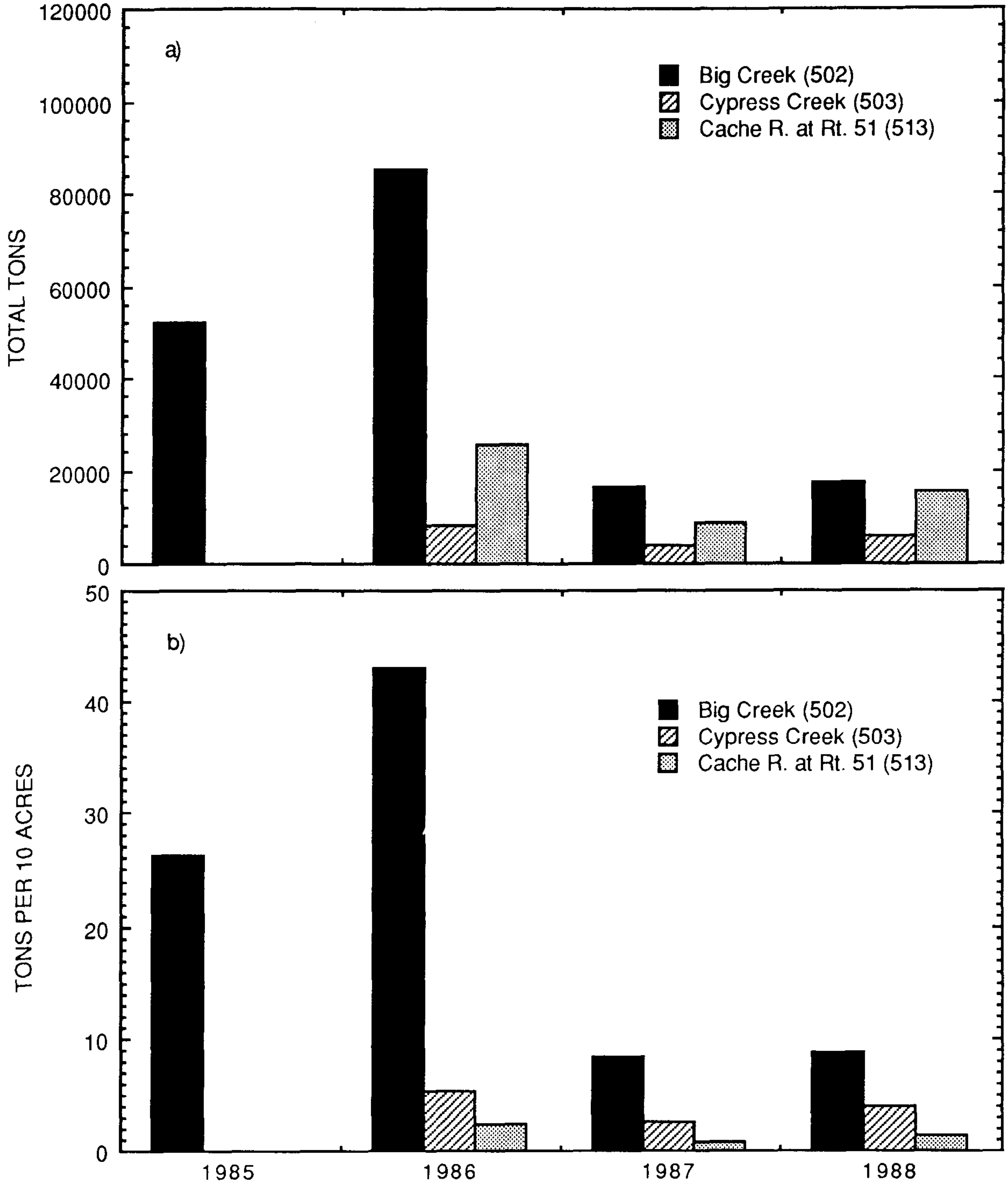


Figure 78. Annual sediment yield in the Lower Cache River

Table 25. Percentage of Suspended Sediment Load Transported during Monitoring Period

	Station *				
	Cache R. *at Forman* *378*	*Big Creek* *502*	*Cypress Creek* *503*	*Main Ditch* *505*	***Cache R.*** *at Rt. 146* *507*
Percent time	***Percent load***				
0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
5	55.1	96.3	83.6	78.4	73.6
10	70.2	98.7	95.3	*90.5*	*87.6*
25	88.5	99.7	99.3	97.4	97.7
50	98.3	99.9	99.8	99.7	99.5
100	100.0	100.0	100.0	100.0	100.0

* Values given for each station represent the percentage of the monitoring period during which the load passed the station

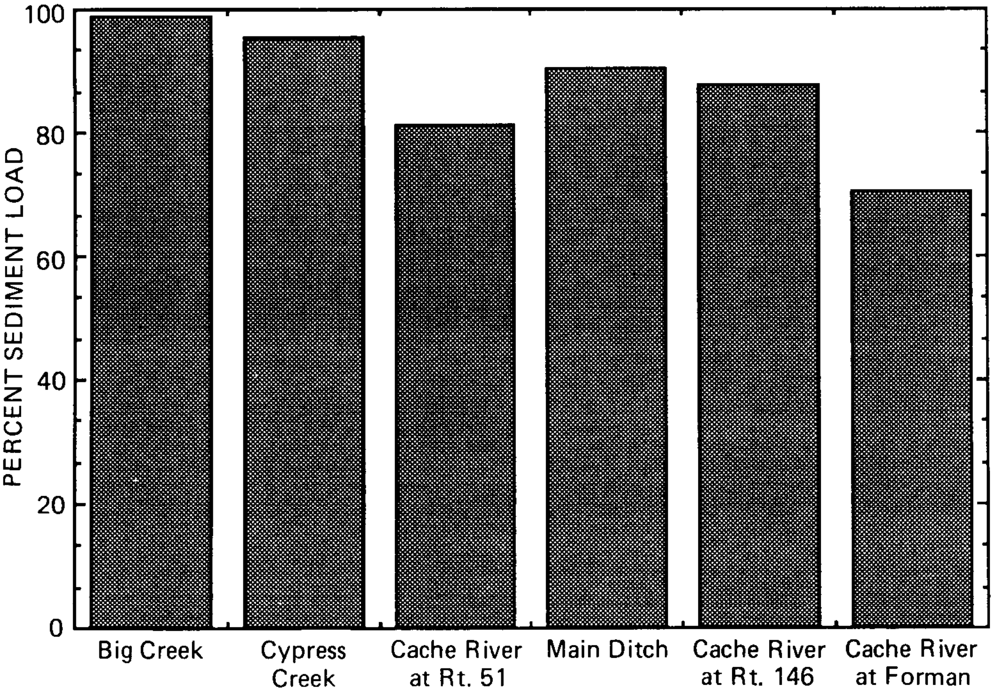
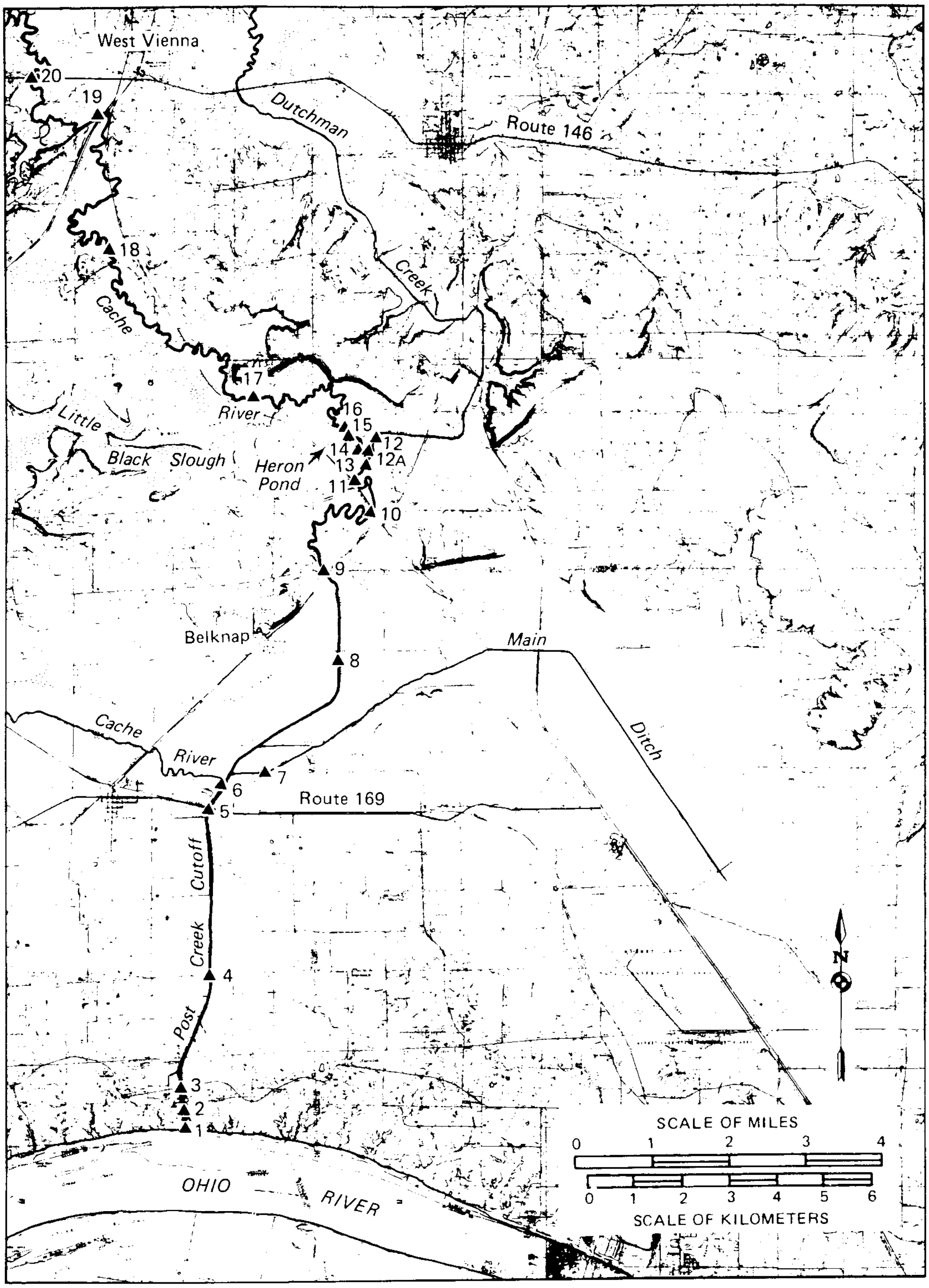


Figure 79. Percent of the sediment load transported in 10% of the time

Table 26 Results of the Regression of Water Discharge and Suspended Sediment Discharge

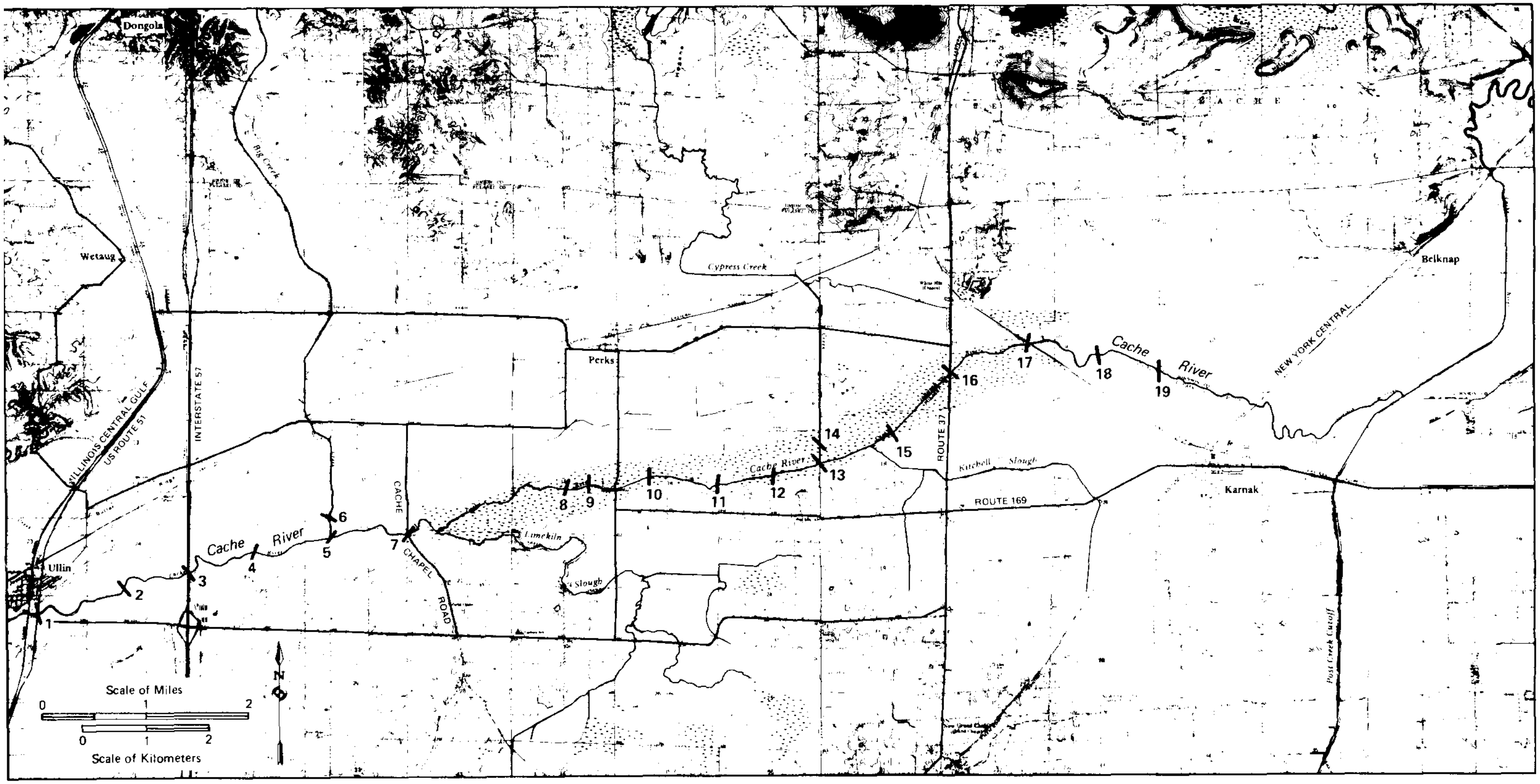
	Station					
*Regression parameter**	***Cache R. at Forman*** *378*	***Big Creek*** *502*	***Cypress Creek*** *503*	***Main Ditch*** *505*	***Cache R. at Rt. 146*** *507*	***Cache R. at Rt. 51*** *513*
Intercept, A	0.10	0.053	0.137	0.128	0.128	0.143
Slope, B	0.94	1.55	1.38	1.22	1.21	1.21
Correlation coefficient, R	.95	.91	.93	.97	.91	.93
Standard error of estimate	.31	0.43	0.43	0.33	0.42	0.32

*Equation has the form $\log Q_s = \log A + B \log Q_w$



a) Upper Cache River

Figure 80. Locations where particle size samples were collected



b) Lower Cache River

Figure 80. Concluded

Table 27. Particle Size Statistics for Channel Bed Material Samples

Lower Cache

Cross section	*Mile*	*d50 (mm)*	*d16 (mm)*	*d84 (mm)*	*dg* (mm)	σ_g	*Skg*
9-center	26.81	0.018	0.001	0.040	0.01	6.67	-0.58
10-center	27.54	0.011	0.000	0.029	0.00	8.51	-0.55
11-center	28.33	0.002	0.000	0.010	0.00	7.67	-0.07
13-center	29.40	0.330	0.225	0.490	0.33	1.48	0.02
15-center	29.88	0.015	0.000	0.035	0.00	10.80	-0.64
16-center	31.00	0.006	0.000	0.024	0.00	10.95	-0.42
18-center	32.65	0.001	0.000	0.015	0.00	14.64	0.05
19-center	33.40	0.002	0.000	0.023	0.00	13.30	-0.09

Upper Cache

Cross section	*Mile*	*d50 (mm)*	*d16 (mm)*	*d84* (mm)	*dg (mm)*	σ_g	*Skg*
1-east	**0.0**	0.140	0.028	0.230	0.08	2.89	-0.53
1-center	**0.0**	0.017	0.000	0.043	0.00	10.50	-0.61
1-west	**0.0**	0.140	0.023	0.210	0.07	3.02	-0.63
5-east	4.2	0.013	0.001	0.051	0.01	6.26	-0.25
5-center	4.2	0.625	0.325	1.125	0.60	1.86	-0.05
5-west	4.2	0.020	0.001	0.115	0.01	15.17	-0.36
6-east	4.6	0.120	0.002	0.220	0.02	10.24	-0.74
6-center	4.6	0.950	0.260	6.250	1.27	4.90	0.18
6-west	4.6	0.400	0.050	1.000	0.22	4.47	-0.39
7-south		0.014	0.000	0.045	0.00	18.61	-0.60
7-center		0.425	0.150	2.250	0.58	3.87	0.23
7-north		0.165	0.091	0.250	0.15	1.66	-0.18
8-east	6.9	0.110	0.008	0.165	0.04	4.54	-0.73
8-center	6.9	0.380	0.030	0.850	0.16	5.32	-0.52
8-west	6.9	0.032	0.003	0.200	0.02	8.16	-0.13
9-east	7.9	0.022	0.003	0.052	0.01	4.16	-0.40
9-center	7.9	0.022	0.004	0.165	0.03	6.42	0.08
9-west	7.9	0.040	0.002	0.320	0.03	12.65	-0.18

Table 27. Concluded

Upper Cache

Cross section	*Mile*	d_{50} *(mm)*	d_{16} *(mm)*	d_{84} *(mm)*	dg *(mm)*	σ_g	*Skg*
10-south	10.6	0.016	0.003	0.033	0.01	3.43	-0.41
10-center	10.6	0.015	0.002	0.440	0.03	17.13	0.20
10-north	10.6	0.013	0.001	0.033	0.01	6.42	-0.50
11-east	11.4	0.033	0.013	0.061	0.03	2.17	-0.21
11-center	11.4	0.023	0.006	0.054	0.02	3.00	-0.22
11-west	11.4	0.019	0.002	0.043	0.01	4.61	-0.47
12A	11.8	2.800	0.010	9.000	0.30	30.00	-0.66
13	12.0	0.028	0.002	2.000	0.06	32.44	0.23
14	12.3	0.004	0.000	0.032	0.02	3.00	-0.21
15-south	12.4	0.014	0.001	0.032	0.00	6.76	-0.57
15-center	12.4	13.000	5.500	18.000	9.95	1.81	-0.45
15-special	12.4	1.375	0.022	3.500	0.28	12.61	-0.63
16	12.6	0.018	0.002	0.045	0.01	5.48	-0.46
17-south	14.6	0.013	0.000	0.030	0.00	12.57	-0.65
17-center	14.6	0.035	0.003	3.000	0.10	31.11	0.29
17-north	14.6	0.019	0.001	0.045	0.01	5.88	-0.51
18-center	18.5	0.016	0.002	0.048	0.01	5.45	-0.36
19-center	23.2	0.018	0.001	0.040	0.01	5.35	-0.52
20-east	26.5	0.016	0.000	0.032	0.00	8.08	-0.67
20-center	26.5	0.020	0.002	0.035	0.01	3.82	-0.58
20-west	26.5	0.019	0.002	0.035	0.01	3.82	-0.54

Note:
center - center of stream channel
east, west, north, south - indicate locations of sample with respect to center of channel

Table 28. Selected Streambed Particle Size Statistics

Cross section	River mile	d_{50} (mm)	Classification	d_g (mm)	σ_g	SK_g
Lower Cache						
9	26.81	0.018	medium silt	0.01	6.67	-0.58
10	27.54	0.011	fine silt	0.0034	8.51	-0.55
11	28.33	0.002	medium clay	0.0013	7.67	-0.07
13	29.40	0.330	medium sand	0.332	1.48	0.02
15	29.88	0.015	fine silt	0.0032	10.80	-0.64
16	31.00	0.006	very fine silt	0.0021	10.95	-0.42
18	32.65	0.001	fine clay	0.0001	14.64	0.05
19	33.40	0.002	coarse clay	0.0017	13.30	-0.09
Upper Cache						
1	0.0	0.017	medium silt	0.004	10.50	-0.61
5	4.2	0.625	coarse sand	0.60	1.86	-0.05
6	4.6	0.950	coarse sand	1.274	4.90	0.18
8	6.9	0.380	medium sand	0.16	5.32	-0.52
9	7.9	0.022	medium silt	0.026	6.42	0.08
10	10.6	0.015	fine silt	0.026	17.13	0.20
11	11.4	0.023	medium silt	0.018	3.00	-0.22
12A	11.8	2.800	very fine gravel	0.30	30.0	-0.66
13	12.0	0.028	medium silt	0.063	32.44	0.23
14	12.3	0.004	very fine silt	0.018	3.00	-0.21
15	12.4	13.000	medium gravel	9.95	1.81	-0.45
16	12.6	0.018	medium silt	0.008	5.48	-0.46
17	14.6	0.035	coarse silt	0.097	31.11	0.29
18	18.5	0.016	medium silt	0.008	5.45	-0.36
19	23.2	0.018	medium silt	0.007	5.34	-0.52
20	26.5	0.020	medium silt	0.009	3.82	-0.58

WATER QUALITY

Water quality should be an important consideration in developing management plans for a river basin. The Cache River is not significantly impacted by urban and industrial development and the associated pollution problems, and thus it does not have serious water pollution problems. However, because of the Cache River's significance as a natural area, the impact of runoff and associated pollutants, including sediment from agricultural areas, on streams and wetlands needs to be monitored and evaluated continuously.

The U.S. Geological Survey (USGS) has had two water quality monitoring stations in the Cache River basin since 1978. In addition to the USGS sampling, the Water Survey uses a Hydrolab to monitor four water quality parameters at each of the major gaging stations on a monthly basis. The water quality data from both programs are presented in this segment of the report.

Historical Data

The USGS has been monitoring water quality statewide since 1978. Two sites within the Cache River basin have been sampled once per month since 1978. One site, in the Upper Cache River basin, is located on the Cache River at Forman, which is also a streamgaging location. The other water quality sampling site is on the Lower Cache River near Sandusky at River Mile 13.2, which is about 1.8 miles downstream of the confluence of Mill Creek with the Cache River.

The parameters that are measured vary from year to year and from station to station. The sampled parameters generally consist of heavy metals, nutrients, bacteria, organics, and inorganics. Other parameters that are analyzed include total and dissolved components.

The latest water quality data published by the USGS are for the 1987 water year (Stahl, 1987). The USGS data for the Cache River at Forman and the Cache River at Sandusky are presented in appendix I.

Current Data

Data Collection Methods and Procedures

A Hydrolab Model 4041 is used to measure four water quality parameters directly in the stream. The parameters measured are pH, dissolved oxygen, conductivity, and water temperature. Prior to measurements in the field, the Hydrolab must be calibrated according to set standards. Once in the field, the probe is lowered into the water and the parameters are read directly in the field. Conductivity and temperature are also reported when sediment samples are taken. A description of the four water quality parameters monitored by the Water Survey, and their significance, follows.

The pH of a solution refers to its hydrogen ion activity and is expressed as the logarithm of the reciprocal of the hydrogen ion activity in moles per liter at a given temperature. The practical pH scale extends from 0 (very acidic) to 14 (very alkaline), with 7 corresponding to exact neutrality at 25°C. The pH of most natural waters falls between 4 and 9, with the majority of waters slightly basic (American Public Health Association et al., 1975). The hydrogen-ion concentration is an important quality parameter of natural waters. The concentration range suitable for the existence of most biological life is quite narrow and critical (Metcalf and Eddy, Inc., 1979).

Dissolved oxygen levels in natural waters are dependent on the physical, chemical, and biochemical activities prevailing in the stream (American Public Health Association et al., 1975). Dissolved oxygen is required for the respiration of aerobic microorganisms as well as for all other aerobic life forms (Metcalf and Eddy, Inc., 1979). The time of day is relevant to the dissolved oxygen levels in that the morning hours experience lower dissolved oxygen concentrations than the afternoon. This is because the aquatic plants use oxygen during the night before producing oxygen in the day as part of the photosynthetic process (Makowski, Lee, and Grinter, 1986).

Conductivity is a numerical expression of the ability of water to carry an electric current. The conductivity value depends on the total concentration of the ionized substances dissolved in the water and the temperature at which the measurement was made. The results of conductivity are given in the units of micromhos per centimeter. The conductivity of potable waters ranges from 50 to 1500 micromhos per centimeter. Conductivity is an indicator of the degree of mineralization or total dissolved solids (American Public Health Association et al., 1975). Previous studies suggest that conductivity reaches a maximum value during low flow when ground water constitutes a principal portion of the flow, because ground water contains significant dissolved solids.

Water temperature is used in ecological studies to characterize habitats and to calculate viscosity and density for modeling purposes. Temperature is dependent on the time of year and time of day.

Results

The water quality data collected by the Water Survey are presented in tables 29 through 31 for water years 1986 to 1988.

Discussion

There is not a great deal of variation among the different sampling sites for each parameter. There is a degree of uniformity in the maximum and minimum values. During the winter months, the sampling frequency decreases and no samples are taken when the ice is thick or there is no flow. The minimum temperature values occur in winter and early in the morning, while the maximum values occur in the summer late in the day. How warm the water will get is dependent on a number of factors such as depth of water, degree of shade, and whether the water is flowing. The warmest water was found in Main Ditch.

The pH values seem to be dependent on the season and to a minor degree on time of day. The maximum pH values are usually found in the winter months, while the lower values are found in the summer. All the pH values collected fall between 4 and 9, a range given for most natural waters. Most of the water is slightly basic.

The dissolved oxygen levels vary among stations. The lowest levels were found in the Cache River at Route 37. Conditions at this site are similar to conditions found in a lake because there is at least a minimum of 2 feet of water in the channel. Under the present conditions, this segment of the river will not dry up except during an extreme drought. Dissolved oxygen levels below 5 mg/l may stress certain organisms. All sites except Big Creek and Cache River at Forman record levels below this. The lowest dissolved oxygen levels are recorded early in the morning before the photosynthetic process restores the levels. Aside from this diurnal cycle, the dissolved oxygen levels vary throughout the year, reaching the highest levels in the winter and the lowest in the summer. This is because the dissolved-oxygen solubility increases as the temperature of the water decreases.

Conductivity levels do not vary greatly among stations. The levels are not dependent on the time of day or year. Conductivity levels depend on stream discharge. At high flows, the water is composed mostly of rainwater, which has comparatively few dissolved substances and so has low conductivity. At low flow, much of the flow in streams is composed of seepage from ground water. As water percolates through the soil, it dissolves and picks up minerals, thereby increasing the conductivity. All conductivity values measured fall within the limits set for potable water.

Table 29. Water Quality Data at Water Survey Monitoring Stations for Water Year 1986

Station	*YrMoDy*	*Time*	*Elev. (msl)*	*TY*	*Temp* (^{0}C)	*pH*	*Do (mg/l)*	*Cond* (μ - *MHOS)*
378	860411	1421	321.31	1	16.6	7.6	8.5	298
378	860513	1422	320.20	1	22.3	7.4	7.0	358
378	860718	1341	321.17	1	28.3	7.2	6.3	170
378	860815	1309	320.27	1	24.8	7.2	8.0	193
378	860926	1246	322.04	1	24.3	7.3	6.4	180
502	860411	1235	337.13	1	16.1	7.9	9.6	377
502	860513	1224	337.00	1	22.3	7.5	7.3	452
502	860718	1127	336.63	1	27.2	7.1	6.3	252
502	860718	1150	336.63	1	28.0	7.3	6.8	237
502	860815	1133	336.58	1	23.6	7.1	7.5	264
502	860926	1125	336.59	1	23.8	7.1	7.5	217
503	860411	1106	395.92	1	16.7	7.4	7.7	278
503	860513	1118	395.51	1	20.4	7.3	4.4	363
503	860718	1028	395.23	1	26.8	7.1	3.3	162
503	860815	1033	395.05	1	23.5	6.8	5.1	142
503	860926	1022	348.87	1	24.0	6.9	4.1	149
503A	860411	1256	327.79	1	17.7	8.0	10.3	306
503A	860513	1300	327.29	1	23.7	7.9	9.6	379
503A	860718	1246		1	30.5	7.2	4.0	190
503A	8608 15	1222	328.28	1	25.5	7.0	5.2	151
503A	860926	1151	328.02	1	24.4	6.9	2.5	140
505	860411	1447	321.29	1	20.7	7.7	13.3	354
505	8605 13	1446	321.07	1	25.9	7.2	8.8	389
505	860718	1416	321.19	1	33.1	7.2	9.7	312
505	860815	1330	320.94	1	30.1	7.5	14.5	376
505	860926	1317	321.07	1	27.6	6.8	5.5	247
507	860411	1023	355.93	4	14.9	7.9	8.4	332
507	860411	1028	355.93	1	14.9	7.6	8.1	332
507	860411	1032	355.93	4	14.9	7.5	8.0	332
507	860513	1042	354.97	4	21.3	7.2	5.3	455
507	860513	1045	354.97	1	21.3	7.3	5.5	452
507	860513	1048	354.97	4	21.3	7.3	5.0	453
507	860718	958	355.44	1	27.7	7.1	3.5	173
507	8607 18	1000	355.44	1	27.7	6.9	3.6	172
507	860718	1001	355.44	1	27.7	6.8	3.6	173
507	860815	957	354.88	4	23.1	7.2	4.5	196
507	860815	1002	354.88	1	23.2	7.0	4.9	195
507	860815	1005	354.88	4	23.1	6.9	4.1	196
507	860926	944	355.97	4	24.1	7.1	4.6	193
507	860926	947	355.97	1	24.1	6.9	4.7	193
507	860926	949	355.97	4	24.1	6.9	4.4	192

Concluded on next page

Table 29. Concluded

Station	*YrMoDy*	*Time*	*Elev. (msl)*	*TY*	*Temp (°C)*	*PH*	*DO (mg/l)*	*Cond* (μ - *MHOS)*
508	860411	1327	327.51	4	19.2	7.4	8.2	306
508	860411	1333	327.51	1	19.2	7.4	7.6	293
508	860411	1343	327.51	4	19.0	7.2	7.6	304
508	860513	1324	327.18	4	25.6	7.3	9.0	333
508	860513	1328	327.18	1	25.3	7.3	8.7	333
508	860513	1333	327.18	4	25.3	7.3	7.4	315
508	8607 18	1303	327.80	1	30.0	6.9	2.7	177
508	860718	1307	327.80	1	30.4	7.0	3.1	177
508	860718	1312	327.80	1	30.6	7.1	3.1	177
508	860815	1238	328.10	4	25.1	6.7	2.6	146
508	8608 15	1243	328.10	1	25.5	6.7	2.9	147
508	860815	1246	328.10	4	25.7	6.7	3.0	146
508	860926	1209	327.91	4	25.1	6.8	1.6	158
508	860926	1212	327.91	1	25.2	6.6	1.5	157
508	860926	1215	327.91	4	25.5	6.6	1.8	159
510	860411	1144	327.30	1	16.2	8.5	13.0	276
510	8605 13	1149	326.83	1	22.3	7.4	6.8	386
510	860718	1058	327.21	1	27.8	7.2	5.6	294
510	8608 15	1103	327.07	1	24.6	7.3	6.2	295
510	860926	1104	327.01	1	24.7	7.1	5.5	245
513	860411	1205	320.19	1	16.2	7.9	9.2	384
513	860513	1204	319.71	1	22.9	7.5	7.8	454
513	8607 18	1112	320.81	1	28.3	6.9	4.5	180
513	8608 15	1116	320.42	1	24.7	6.9	6.0	174
513	860926	1053	321.00	1	24.2	6.9	4.3	163

Table 30. Water Quality Data at Water Survey Monitoring Stations for Water Year 1987

Station	*YrMoDy*	*Time*	*Elev. (msl)*	*TY*	*Temp (°C)*	*pH*	*DO (mg/l)*	*Cond* (μ - *MHOS)*
378	861112	1355	320.30	1	8.6	7.6	8.6	356
378	861212	1324	321.79	1	3.5	7.2	12.1	259
378	870212	1416	320.47	1	5.7	8.1	14.2	315
378	870402	1444	322.58	1	10.2	7.1	10.0	252
378	870507	1530	320.28	1	19.6	7.2	7.6	350
378	870604	1408	320.24	1	23.5	6.9	4.6	255
378	870707	1335	320.79	1	25.7	6.9	5.9	194
378	870716	1429	319.78	1	26.6	7.5	7.7	279
378	870827	1624	319.35	1	26.6	7.2	5.3	309
378	870924	1429	319.47	1	20.2	7.3	6.9	298
502	861112	1240	336.62	1	9.2	8.4	10.1	396
502	861212	1143	336.73	1	3.5	7.6	13.0	357
502	870212	1304	336.67	1	6.2	7.9	13.4	383
502	870402	1252	336.94	1	11.0	7.8	11.0	337
502	870507	1400	336.63	1	19.4	7.2	7.2	349
502	870604	1207	337.01	1	23.2	7.4	6.9	414
502	870707	1022	337.11	1	24.4	7.1	6.3	312
502	870716	1301	336.97	1	25.6	7.3	6.5	361
502	870827	1159	336.97	1	25.8	7.4	4.7	416
502	870924	1307	336.93	1	21.0	7.3	5.1	428
503	861112	1105	348.72	1	8.2	7.2	5.8	289
503	861212	1039	349.06	1	2.8	7.1	11.7	264
503	870212	1049	348.74	1	5.5	7.3	14.9	305
503	870402	1046	349.60	1	11.2	7.1	9.8	260
503	870507	1104	348.49	1	17.2	6.8	5.7	331
503	870604	1026	350.52	1	20.8	6.8	4.6	249
503	870707	956	349.45	1	24.5	6.6	4.0	216
503	870716	1038	348.10	1	22.4	6.7	5.0	234
503	870827	1019	347.86	1	24.0	6.8	2.9	292
503	870924	1053	347.82	1	15.6	7.1	4.7	393
503A	861112	1306	328.05	1	8.6	7.2	5.6	312
503A	861212	1238	328.15	1	2.5	7.2	11.2	258
503A	870212	1322	327.75	1	6.9	7.8	14.6	328
503A	870402	1334	328.21	1	11.1	7.5	9.2	280
503A	870507	1430	327.59	1	22.5	6.9	4.7	346
503A	870604	1311	327.26	1	25.0	7.1	3.8	331
503A	870707	1151	328.67	1	25.8	6.8	4.0	209
503A	870716	1332	327.49	1	29.1	7.7	6.7	245
503A	870827	1528	326.74	1	27.0	7.3	6.1	325
503A	870924	1333	326.64	1	20.8	7.0	4.6	336

Continued on next page

Table 30. Continued

Station	*YrMoDy*	*Time*	*Elev. (msl)*	*TY*	*Temp (°C)*	*pH*	*DO (mg/l)*	*Cond* (µ - *MHOS)*
505	861112	1420	321.88	1	8.0	7.0	9.5	325
505	861212	1347	322.00	1	4.9	6.7	11.4	267
505	870212	1453	321.84	1	10.9	7.3	13.1	335
505	870402	1521	323.02	1	11.4	6.9	10.0	250
505	870507	1609	321.30	1	26.6	6.8	8.9	332
505	870604	1450	321.25	1	28.6	7.0	6.7	341
505	870707	1318	327.33	1	24.8	6.2	4.4	101
505	870716	1503	321.02	1	32.1	7.7	15.1	319
505	870827	1646	320.87	1	27.8	7.1	6.3	321
505	870924	1508	321.56	1	23.8	7.1	9.3	317
507	861112	1015	355.72	4	8.4	7.7	7.4	379
507	861112	1018	355.72	1	8.2	8.0	7.2	376
507	861112	1021	355.72	4	8.1	7.4	7.0	377
507	861212	1002	356.92	1	3.1	7.0	12.4	256
507	870212	1018	355.86	1	5.0	8.1	13.1	364
507	870402	1006	357.16	1	9.5	7.2	10.1	264
507	870507	1013	355.43	1	17.5	7.0	5.2	422
507	870604	956	355.44	1	21.7	7.0	3.9	389
507	870707	1444	355.47	1	27.2	6.9	4.5	255
507	870716	1012	354.84	1	23.2	6.9	5.0	346
507	870827	1948	354.69	1	24.7	6.8	1.2	333
507	870924	1020	354.70	1	16.0	7.1	4.3	599
508	861112	1322	327.97	4	7.7	8.8	2.4	235
508	861112	1325	327.97	1	7.7	7.8	2.5	235
508	861112	1327	327.97	4	7.7	7.5	2.6	233
508	861212	1252	328.04	4	4.2	7.1	5.9	176
508	861212	1258	328.04	1	4.1	6.9	5.9	178
508	861212	1302	328.04	4	3.9	6.8	5.9	184
508	870212	1343	327.66	1	8.3	7.0	10.6	250
508	870402	1404	327.99	1	11.2	7.4	9.5	255
508	870507	1456	327.44	1	17.5	7.0	5.2	422
508	870604	1332	326.91	1	23.9	6.7	2.9	309
508	870707	1414	328.48	1	26.4	6.4	0.9	141
508	870716	1355	327.35	1	28.5	6.9	5.4	171
508	870827	1553	326.59	1	27.3	6.9	5.6	220
508	870924	1357	326.54	1	19.2	6.9	5.1	203
510	861112	1138	327.11	1	6.7	7.6	10.7	381
510	861212	1109	327.34	1	1.4	7.6	14.0	342
510	870212	1132	327.19	1	5.3	7.6	12.4	354
510	870402	1130	328.20	1	10.5	7.4	11.2	294
510	870507	1150	327.10	1	18.3	7.2	6.9	363
510	870604	1111	326.92	1	20.9	7.2	5.4	274
510	870707	1051	327.73	1	25.4	7.1	5.8	208
510	870716	1120	326.77	1	25.3	7.2	5.3	340

Concluded on next page

Table 30. Concluded

Station	*YrMoDy*	*Time*	*Elev. (msl)*	*TY*	*Temp (°C)*	*p H*	*DO (mg/l)*	*Cond (µ - MHOS)*
510	870827	1108	326.66	1	26.6	7.2	4.8	329
510	870924	1138	326.69	1	18.8	7.5	6.7	325
513	861112	1150	320.74	1	8.6	7.7	7.3	252
513	861212	1120	321.40	1	3.2	7.1	10.2	263
513	870212	1206	319.99	1	6.8	7.7	13.0	370
513	870402	1159	320.88	1	10.5	7.6	10.2	336
513	870507	1243	320.08	1	19.6	7.0	6.4	299
513	870604	1140	319.73	1	23.3	7.4	7.3	367
513	870707	1109	321.31	1	25.8	6.7	3.7	175
513	870716	1207	319.55	1	26.6	7.4	9.0	320
513	870827	1137	319.27	1	25.8	7.3	5.7	334
513	870924	1206	320.50	1	17.4	7.4	6.3	414

Table 31 Water Quality Data at Water Survey Monitoring Stations for Water Year 1988

Station	*YrMoDy*	*Time*	*Elev (msl)*	*TY*	*Temp (°C)*	*pH*	*DO (mg/l)*	*cond* (μ - *MHOS)*
378	871008	1419	319.35	1	14.5	7.7	8.7	330
378	871022	1439	319.28	1	9.3	8.0	8.7	370
378	871118	1436	319.62	1	10.5	7.1	6.8	412
378	871223	1416	320.67	1	4.0	7.2	11.9	261
378	880120	1457	330.98	1	4.8	6.6	10.6	127
378	880203	1540	330.78	1	5.1	6.6	10.5	133
378	880224	1457	321.46	1	5.6	7.2	11.6	231
378	880310	1414	321.87	1	9.6	7.0	10.0	225
378	880323	1455	320.82	1	13.6	7.3	10.0	299
378	880421	1457	320.83	1	15.5	7.5	10.3	312
378	880504	1553	320.23	1	17.2	7.2	8.4	340
378	880518	1521	319.72	1	23.2	7.3	8.3	374
378	880615	1432	319.32	1	26.5	7.6	7.9	415
378	880629	1448	319.18	1	24.3	7.4	6.5	450
378	880713	1418	319.25	1	26.5	7.3	5.9	454
378	880825	1354	319.40	1	27.2	7.4	5.9	460
378	880908	1413	319.47	1	19.7	7.4	7.2	346
378	880922	1402	319.95	1	21.7	7.0	6.3	254
502	871008	1255	336.96	1	13.9	7.6	6.4	423
502	871022	1317	337.01	1	11.0	7.8	6.7	414
502	871118	1310	337.03	1	10.6	7.0	9.1	347
502	871223	1147	337.05	1	4.3	7.2	11.6	307
502	880120	1100	337.84	1	5.8	6.8	11.8	145
502	880203	1321	337.88	1	5.5	6.9	12.0	187
502	880224	1300	337.18	1	7.3	7.5	11.8	332
502	880310	1247	337.24	1	10.6	7.5	11.3	341
502	880323	1310	337.13	1	14.2	7.9	11.3	345
502	880421	1313	337.16	1	15.4	7.8	10.4	360
502	880504	1342	337.42	1	16.4	7.4	8.6	369
502	880518	1347	337.02	1	22.7	7.4	8.5	425
502	880615	1257	336.99	1	24.1	7.5	7.4	423
502	880629	1315	336.94	1	24.8	7.4	5.3	431
502	880713	1245	337.02	1	24.8	7.2	5.7	424
502	880825	1133	336.92	1	25.7	7.3	3.8	373
502	880908	1301	336.92	1	20.2	7.0	4.8	287
502	880922	1254	336.97	1	21.8	7.1	4.7	258
503	871118	1041	348.58	1	9.5	6.7	4.0	276
503	871223	1007	348.75	1	3.3	6.9	11.2	226
503	880120	1022	352.38	1	4.9	6.6	10.3	104
503	880203	1028	351.96	1	4.7	6.7	10.5	123
503	880224	1025	349.07	1	5.3	6.9	10.9	235
503	880310	1031	349.15	1	9.1	6.9	10.1	242
503	880323	1056	348.96	1	14.1	7.1	10.8	246
503	880421	1043	348.71	1	14.1	7.1	9.4	283

Continued on next page

Table 31. Continued

Station	YrMoDy	Time	Elev (msl)	TY	Temp (°C)	pH	DO (mg/l)	Cond (µ - MHOS)
503	880504	1042	348.60	1	14.7	6.9	6.5	348
503	880518	1054	348.04	1	18.6	6.9	6.0	372
503	880713	1030	348.55	1	23.3	7.0	2.7	373
503	880825	1008	348.46	1	21.8	6.7	1.5	210
503	880922	1017	348.71	1	19.1	6.8	4.4	212
503A	871008	1326	326.44	1	14.1	6.9	7.1	371
503A	871022	1350	326.47	1	10.8	7.4	9.0	384
503A	871118	1345	326.77	1	10.5	6.4	2.1	433
503A	871223	1324	327.75	1	4.4	6.2	9.2	200
503A	880120	1130	332.81	1	4.7	5.8	10.5	93
503A	880203	1414	332.97	1	4.5	6.7	10.6	106
503A	880224	1358	328.31	1	6.4	6.8	10.2	240
503A	880310	1319	328.41	1	9.8	7.2	9.2	250
503A	880323	1354	327.95	1	15.0	7.4	9.7	261
503A	880421	1400	327.79	1	16.0	7.3	9.3	290
503A	880504	1434	327.88	1	17.9	7.2	7.4	341
503A	880518	1433	327.03	1	24.1	7.4	7.2	386
503A	880615	1336	326.77	1	26.2	7.2	6.5	418
503A	880629	1403	326.44	1	24.7	7.0	5.0	430
503A	880713	1326	326.44	1	25.7	6.9	2.9	423
503A	880825	1302	326.90	1	26.4	6.8	2.2	176
503A	880908	1339	327.13	1	20.0	7.0	4.4	224
503A	880922	1322	326.87	1	21.7	7.0	3.4	315
505	871008	1448	322.02	1	16.1	7.6	8.6	368
505	871022	1459	322.26	1	12.2	7.7	8.6	364
505	871118	1505	322.33	1	11.4	7.3	7.8	353
505	871223	1441	321.93	1	6.3	6.5	9.9	278
505	880120	1531	331.00	1	6.8	6.4	9.5	91
505	880224	1530	322.10	1	7.9	6.9	10.9	260
505	880310	1446	322.12	1	12.4	6.9	10.4	281
505	880323	1541	321.86	1	18.8	7.2	10.8	288
505	880421	1532	322.26	1	19.1	6.6	8.2	191
505	880504	1612	322.43	1	18.0	7.6	13.1	307
505	880518	1629	321.15	1	26.7	7.0	8.6	364
505	880615	1506	320.89	1	30.1	7.2	7.8	389
505	880629	1542	320.72	1	24.9	7.1	5.4	392
505	880713	1550	321.10	1	28.4	7.1	6.7	371
505	880825	1427	321.46	1	29.6	7.9	10.3	240
505	880908	1445	321.94	1	22.9	8.0	11.6	308
505	880922	1438	321.97	1	26.0	6.7	3.9	168
507	871008	1035	354.69	1	9.9	7.8	5.5	634
507	871022	1032	354.72	1	7.9	7.0	3.3	569
507	871118	1010	356.60	1	9.7	7.1	6.0	577
507	871223	1520	355.84	1	4.3	7.0	10.7	278

Continued on next page

Table 31. Continued

Station	YrMoDy	Time	Elev. (msl)	TY	Temp (°C)	pH	DO (mg/l)	Cond (μ - MHOS)
507	880120	952	362.74	1	4.3	6.7	10.7	123
507	880203	958	364.06	1	4.6	6.7	10.7	128
507	880224	952	356.87	1	5.2	7.0	10.7	259
507	880310	1005	357.23	1	8.9	7.1	9.8	285
507	880323	1015	357.17	1	12.1	7.2	9.3	346
507	880421	1010	356.09	1	13.6	7.2	8.7	370
507	880504	1009	355.31	1	15.7	7.0	6.4	418
507	880518	1004	355.11	1	20.2	6.9	3.0	456
507	880615	1009	355.50	1	23.1	7.0	2.1	465
507	880629	1021	355.68	1	23.6	6.9	1.8	516
507	880713	1000	355.52	1	24.6	7.0	1.5	522
507	880825	0945	355.03	1	23.6	6.8	2.1	333
507	880908	1027	354.97	1	17.1	7.3	5.3	526
507	880922	0953	355.19	1	19.4	6.9	4.7	288
508	871008	1352	326.36	1	13.4	7.3	8.2	206
508	871022	1407	326.34	1	10.5	7.7	7.9	246
508	871118	1406	326.55	1	10.3	6.9	5.9	381
508	871223	1344	327.59	1	4.9	6.8	7.9	197
508	880120	1415	329.90	1	3.5	6.2	4.4	101
508	880203	1440	330.07	4	4.6	6.6	9.7	102
508	880203	1442	330.07	4	5.9	6.4	6.0	122
508	880203	1445	330.07	4	5.2	6.5	7.8	107
508	880224	1422	328.03	1	7.2	6.8	8.7	213
508	880310	1339	328.27	1	10.6	6.8	8.5	195
508	880323	1421	327.71	1	14.7	6.9	8.9	244
508	880421	1423	327.58	1	17.6	7.0	9.1	265
508	880504	1455	328.01	1	15.3	6.8	7.2	103
508	880518	1452	326.89	1	25.5	7.0	8.2	245
508	880615	1354	326.75	1	27.2	7.2	4.9	401
508	880629	1415	326.25	1	25.4	7.1	5.3	446
508	880713	1344	326.09	1	26.7	7.3	3.9	413
508	880825	1314	326.78	1	25.3	6.7	2.3	182
508	880908	1353	326.98	1	21.3	7.2	8.8	171
508	880922	1336	326.54	1	23.2	6.7	4.5	235
510	871008	1139	326.74	1	12.3	7.7	8.8	341
510	871022	1147	326.89	1	9.8	7.8	9.6	358
510	871118	1128	326.84	1	8.1	7.3	8.9	255
510	871223	1053	326.99	1	3.3	7.5	12.2	270
510	880120	1259	330.93	1	5.5	7.0	10.7	142
510	880203	1151	330.95	1	4.8	7.0	11.2	162
510	880224	1121	328.61	1	4.1	7.4	11.9	283
510	880310	1108	329.60	1	8.2	7.8	12.2	278
510	880323	1136	327.80	1	14.2	8.0	13.2	300
510	880421	1130	328.09	1	14.5	7.7	11.5	327
510	880504	1132	331.75	1	13.6	7.1	8.0	114

Concluded on next page

Table 31. Concluded

Station	YrMoDy	Time	Elev. (msl)	TY	Temp (°C)	pH	DO (mg/l)	Cond (µ - MHOS)
510	880518	1157	327.01	1	21.0	7.1	6.7	366
510	880615	1110	326.79	1	24.2	7.4	6.8	354
510	880629	1128	326.65	1	25.2	7.2	6.3	316
510	880713	1106	326.77	1	25.0	7.1	5.3	302
510	880825	1045	326.55	1	25.3	7.2	5.9	307
510	880908	1119	326.50	1	19.8	7.3	6.6	289
510	880922	1108	326.46	1	22.4	7.2	6.5	297
513	871008	1201	320.68	1	11.0	7.0	6.6	453
513	871022	1249	320.00	1	9.3	6.8	5.5	461
513	871118	1206	320.60	1	9.5	6.6	7.6	436
513	871223	1122	320.14	1	4.4	7.1	11.0	257
513	880120	1322	327.33	1	6.1	6.4	10.3	116
513	880203	1258	327.22	1	4.9	6.3	10.9	138
513	880224	1149	321.15	1	5.7	7.0	10.7	272
513	880310	1145	321.15	1	9.4	7.2	10.0	311
513	880323	1200	320.59	1	14.1	7.5	10.9	348
513	880421	1209	320.73	1	15.4	7.2	9.2	343
513	880504	1322	324.27	1	15.5	6.9	7.0	252
513	880518	1327	319.75	1	23.2	7.5	9.6	406
513	880615	1136	319.55	1	24.8	7.5	6.6	436
513	880629	1151	319.43	1	24.9	7.4	6.4	452
513	880713	1130	319.58	1	24.9	7.3	6.0	422
513	880825	1112	319.23	1	24.1	7.3	6.1	314
513	880908	1140	319.85	1	18.6	7.0	6.9	181
513	880922	1131	319.58	1	21.3	7.0	6.3	259

SUMMARY

This report is one of two volumes and summarizes the work related to two of the four major tasks of the Cache River project: review of background information, and data collection and analysis.

The background information segment includes review and identification of the watershed characteristics such as geology, physiology, soils, and drainage. It also contains a discussion of historical developments, including changes in land use patterns and hydraulic projects designed to improve drainage, relieve flooding, and maintain water levels.

The segments on data collection and analysis contain the results of more than three years of data collection and analysis of those data. These segments of the report are subdivided into three major topics: hydrology and hydraulics, erosion and sediment transport, and water quality.

The section on hydrology and hydraulics presents data and analysis on precipitation and streamflow. The precipitation data include historical data from stations in and around the watershed and from a set of raingaging stations in the watershed established especially for this project. The new stations were needed because precipitation is highly variable within the watershed. Also, only one of the historical stations was within the watershed, and even that one was not centrally located. The precipitation data did not show any significant increasing or decreasing trend in rainfall. However, the most recent period (since 1986), which covers most of the data collection period, has been a period of below-normal precipitation in the region.

The streamflow data that are presented include historical data from two stations, one in the Upper Cache River (Cache River at Forman) and the other in the Lower Cache River (Big Creek near Wetaug), and data collected from five new gaging stations. Flood frequency analysis was performed based on the historical data from the two stations and floods of known return periods determined for both stations. This analysis will enable us to determine the severity of floods in the watershed by providing information on the return period.

In terms of current data in the Lower Cache River, streamflows were monitored on Big and Cypress Creeks draining into the Buttonland Swamp area and on the Lower Cache River at Ullin, which represents the outflow from upper portions of the Lower Cache River, Another streamflow station was established for Indian Camp Creek at Ullin to assist in future flood studies for the city of Ullin and the lower portions of the Lower Cache River. The streamflow data clearly show the influence of Buttonland Swamp on floodwater movement. In general, it can be concluded that floodwaters from tributary streams are stored in the Buttonland Swamp area and move out of the swamp slowly. During floods, water elevations at gaging stations on tributary streams rise and fall in a matter of hours, while they remain elevated for days in the swamp and at the outlet.

Another major accomplishment of this study is the understanding of the flow dynamics within the Buttonland Swamp area. Through intensive data collection during flood events, water-elevation changes within the swamp and the frequent change of flow directions were documented several times. It is now well established that water flows in both directions within Buttonland Swamp. The flow direction depends on several factors including initial water levels, the relative amounts of inflows from tributary streams, and the capacities of the outlets on the east and west ends of the area. Among the flood events monitored during the project period was the highest flood ever recorded in the area, during which the water-surface elevation reached 336 feet above mean sea level. The cause of this extreme flood was not high-intensity, short-duration rainfall, as would be expected for a normal stream, but a rainfall of mild intensity for a long duration of several days.

In the Upper Cache River, the purpose of new streamflow data collection was to quantify the flow of water and sediment in the Upper Cache River and its tributaries so that a calibrated mathematical model could be developed to model channel scour in the Post Creek Cutoff and the Upper Cache River. Streamflow data were therefore collected on the Upper Cache River at Route 146 upstream of the Forman gaging station and on Main Ditch at Route 45. In addition to the data from the Forman gaging station, which is maintained by the USGS, the new data set provided adequate information for the development of a calibrated model. The results of the mathematical model are presented in volume 2 of this report.

Since the backwaters of the Mississippi and Ohio Rivers have major influence on flooding and drainage in the Cache River basin, an analysis of river stages on the Mississippi and Ohio Rivers is included in this section of the report. In addition to stage-duration and stage-frequency analyses for each of the stage monitoring stations near the junction of the two rivers, a methodology was developed for determining water-surface elevation on the Mississippi River at the mouth of the Lower Cache River, based on data at other stage monitoring stations on the Mississippi and Ohio Rivers.

The section on erosion and sediment transport presents data and information on channel geometry changes, suspended sediment loads, sedimentation, and streambed and bank material. The information on stream channel changes primarily relates to the channel entrenchment problem in the Post Creek Cutoff and the Upper Cache River. A comparison of the design and recent channel profiles along the Post Creek Cutoff and Upper Cache River is presented to illustrate the magnitude of the problem. Since channel erosion and stability are highly dependent on the characteristics of the material on the streambed and bank, a large number of streambed and bank materials were collected along the Upper Cache River and the

Lower Cache River. The results of the laboratory analysis of the samples and discussions of the types of materials in terms of particle size are presented.

A significant component and one of the main objectives of this project was to collect enough data to determine the amount of sediment being transported by the different streams in the basin. Suspended sediment loads were monitored at six monitoring stations in the Cache River basin. Three of the stations are in the Lower Cache River, and the remaining three are in the Upper Cache River. The stations in the Lower Cache River are located on Big Creek, Cypress Creek, and on the Lower Cache River at Ullin. The data from Big and Cypress Creeks provide information on the amount of sediment being transported into the Buttonland Swamp area by tributary streams, and the data from the Lower Cache River station at Ullin provide information on the amount of sediment leaving the Buttonland Swamp area. For the three complete years of data collection, the annual sediment yield from Big Creek ranged from a low of 16,400 tons in 1987 to a high of 85,300 tons in 1986. For Cypress Creek, the annual sediment yield ranged from a low of 4,000 tons in 1987 to a high of 8,200 tons in 1986. The corresponding numbers for the Lower Cache River measured at Ullin are 8,700 tons in 1987 and 25,700 tons in 1986.

It is interesting to note that not only is the sediment yield of the Lower Cache River at Ullin lower than the combined yield from the two major tributaries, but it is less than the yield from Big Creek alone. This implies that the sediment yield from the Big Creek watershed is very high, and the wetlands and floodplain in the Lower Cache River upstream of Ullin, which include Buttonland Swamp, trap a significant amount of the sediment delivered from the tributary streams. The significance of Big Creek and the sediment-trapping capacity of the Lower Cache River can be further exemplified by comparing the sediment yields in terms of yields per unit area instead of in terms of the total sediment yield. The annual sediment yield per 10 acres ranged from 8.3 to 43.0 tons for Big Creek and from 2.6 to 5.3 tons for Cypress Creek. At the same time the sediment yield per 10 acres for the Lower Cache River at Ullin ranged from only 0.8 to 2.5 tons. The Big Creek watershed yields 2 to 5 times more sediment than the Cypress Creek watershed for the same area. The sediment yield per unit area from the Lower Cache River after it passes through the wetlands and floodplains upstream of Ullin is only 1/6 to 1/17 of that of Big Creek.

The sediment yields from the different watersheds in the Upper Cache River are more uniform than those in the Lower Cache River. The sediment yield per 10 acres ranged from a low of 4.2 tons for the Cache River at Route 146 to a high of 8.4 tons for Main Ditch in Water Year 1986. In Water Year 1987, the sediment yield ranged from a low of 1.5 tons for Main Ditch to a high of 2.4 tons for the Cache River at Route 146. In Water Year 1988, the sediment yield ranged from a low of 1.0 ton for the Cache River at Route 146 to a high of 4.1 tons for the

Cache River at Forman. Therefore the range of sediment yield over the three years at the three stations is only from 1.0 ton to 8.4 tons per 10 acres.

The section on water quality is not as detailed as the previous two sections but presents existing and new water quality data for the Cache River basin. The existing or historical data are from the USGS at two stations, one in the Upper Cache River (Cache River at Forman) and the other in the Lower Cache River (Cache River near Sandusky). Water quality parameters, temperature, pH, dissolved oxygen, and conductivity were measured at nine locations on a regular basis throughout the project duration, using a Hydrolab. The results of the measurements are presented and discussed in the report.

REFERENCES

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1975. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 14th Edition, Washington, D.C.

Bonini, A.P., N.G. Bhowmik, R.L. Allgire, and D.K Davie. May 1983. Statewide Instream Sediment Monitoring Program for Illinois: Annual Report -- Water Year 1981. Illinois State Water Survey Contract Report 318, Champaign, Illinois.

Buchanan, T.J., and W.P. Somers. 1969. Discharge Measurements at Gaging Stations; Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 3, Chapter A8, U.S. U.S. Government Printing office, Washington, D.C.

Cache River Drainage Commission. 1905. Report of Board of Cache River Drainage Commissioners of Illinois. Illinois Printing Company, Danville, Illinois.

Changnon, S. 1987. Droughts in Illinois. Their Physical and Social Dimensions. Illinois State Water Survey, Champaign, Illinois.

Chow, V.T. (editor). 1964. Handbook of Applied Hydrology. McGraw- Hill, New York, New York.

Demissie, M., and N.G. Bhowmik. July 1985. Cache River Basin Study: Progress Report and Project Design. Illinois State Water Survey Contract Report 366, Champaign, Illinois.

Demissie, M., P.B. Makowski, T.W. Soong, and N.G. Bhowmik. 1987. Cache River Basin Project Progress Report. Illinois State Water Survey Contract Report 422, Champaign, Illinois, 28 pp.

Fehrenbacher, J.B. et al., 1984. Soils of Illinois, Bulletin 778, University of Illinois at Urbana-Champaign, College of Agriculture, Agricultural Experiment Station in Cooperation with the Soil Conservation Service. U.S. Department of Agriculture.

Ferguson, R.I., 1986. River Load Underestimated by Rating Curves. Water Resources Research, Vol. 22, No. 1.

Fitzgerald, KK, P.D. Hayes, T.E. Richards, and R.L. Stahl. May 1986. Water Resources Data, Illinois. Water Year 1985. U.S. Geological Survey Water-Data Report IL-85-1, Urbana, Illinois.

Gilchrist, W. 1976. Statistical Forecasting. John Wiley and Sons, London, England.

Graf, W.H. 1971. Hydraulics of Sediment Transport. McGraw-Hill, New York, New York.

Guy, H.P., and V.W. Norman. 1982. Field Methods for Measurement of Fluvial Sediments. Book 3, Chapter C2, in Techniques of Water Resources Investigations of the United States Geological Survey, U.S. Government Printing Office, Washington, D.C.

Huff, F.A 1974. Calculation of 5-minute to 60-minute Rainfall Occurring 1, 2, 3, 4, and 5 Times Per Season. Illinois State Water Survey, Unpublished, Champaign, Illinois.

Huff, F.A., and J.C. Neill. 1970. Rainfall Frequencies. Illinois State Water Survey Technical Letter 13, Champaign, Illinois.

Illinois Department of Agriculture. 1984. Illinois Agricultural Statistics, Annual Summary -- 1983. Illinois Department of Agriculture Bulletin 83-1, Springfield, Illinois.

Illinois Department of Agriculture. 1985. Illinois Agricultural Statistics. Annual Summary -- 1984. Illinois Department of Agriculture Bulletin 84-1, Springfield, Illinois.

Inman, D.L. 1952. Size Frequency of Sediments and the Normal Phi Curve. Journal of Sedimentary Petrology, Volume 15.

Jones, D.M.A., F.A Huff, and S.A Changnon, Jr. 1974. Causes for Precipitation Increases in the Hills of Southern Illinois. Illinois State Water Survey Report of Investigation.

Kite, G.W. 1977. Frequency and Risk Analysis in Hydrology. Water Resources Publications, Fort Collins, Colorado.

Leighton, M.M., G.E. Ekblaw, and L. Horberg. January 1948. Physiographic Divisions of Illinois. Journal of Geology, Volume 56, Number 1.

Linsley, R.K, Jr., M.A Kohler, and J.L.H. Paulhus. 1958. Hydrology for Engineers. McGraw-Hill, New York, New York.

Loganathan, G.V., C.Y. Kuo, and T.C. McCormick. 1985. Methods of Analyzing Instream Flows. Virginia Water Resources Research Center Bulletin 148, Blacksburg, Virginia.

Makowski, P.B., M.T. Lee, and M. Grinter. February 1986. Hydrologic Investigation of the Highland Silver Lake Watershed: 1985 Progress Report. Illinois State Water Survey Contract Report 380, Champaign, Illinois.

Metcalf and Eddy, Inc. 1979. Wastewater Engineering. McGraw-Hill, New York, New York.

Otto, G.H. 1939. A Modified Logarithmic Probability Graph for the Interpretation of Mechanical Analyses of Sediments. Journal of Sedimentary Petrology, Volume 9, No. 2, pp. 62-76.

Parks, W.D., and J.B. Fehrenbacher. 1968. Soil Survey. Pulaski and Alexander Counties, Illinois. Soil Conservation Service, U.S. Department of Agriculture, U.S. Government Printing Office, Washington, D.C.

Pryor, W.A 1956. Groundwater Geology in Southern Illinois. Illinois State Geological Survey Circular 212. Urbana, Illinois.

SAS Institute. 1982. SAS User's Guide: Statistics. SAS Institute Inc., Cary, North Carolina.

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

Singh, K.P., A Durgunoglu, and G.S. Ramamurthy. 1986. Some Solutions to Underestimation of Stream Sediment Yields. Hydrological Science and Technology: Short Papers, Volume 2, **No.** 4, American Institute of Hydrology, pp. 1-7.

Stahl, R.L., R.H. Coupe, T.E. Richards, and P.D. Hays. 1989. Water Resources Data. Illinois, Water Year 1988. U.S. Geological Survey Water-Data Report IL-88-1, Urbana, Illinois.

Stahl, R.L., K.K. Fitzgerald, T.E. Richards, and P.D. Hayes. 1987. Water Resources Data Illinois, Water Year 1986. U.S. Geological Survey Water-Data Report IL-86-1, Urbana, Illinois.

Stahl, R.L., K.K. Fitzgerald, T.E. Richards, and P.D. Hayes. 1988. Water Resources Data Illinois, Water Year 1987. U.S. Geological Survey Water-Data Report IL-87-1, Urbana, Illinois.

U.S. Army Corps of Engineers. 1967. Ohio River Flood Plain, Mound City to Mouth, Kentucky and Illinois, 1966-1967, Maps. U.S. Army Corps of Engineers, St. Louis District, St. Louis, Missouri.

U.S. Army Corps of Engineers. 1983. Missisippi River Hydrographic Survey, Sounded Data 1982-1983, Maps. U.S. Army Corps of Engineers, St. Louis District, St. Louis, Missouri.

University of Illinois. 1982. General Soil Map of Illinois. Agricultural Experiment Station, College of Agriculture, In cooperation with the Soil Conservation Service, U.S. Department of Agriculture, Urbana,

Vanoni, V.A. 1977. Sedimentation Engineering. American Society of Civil Engineers, New York, New York.