The 1993 Flood on the Mississippi River in Illinois

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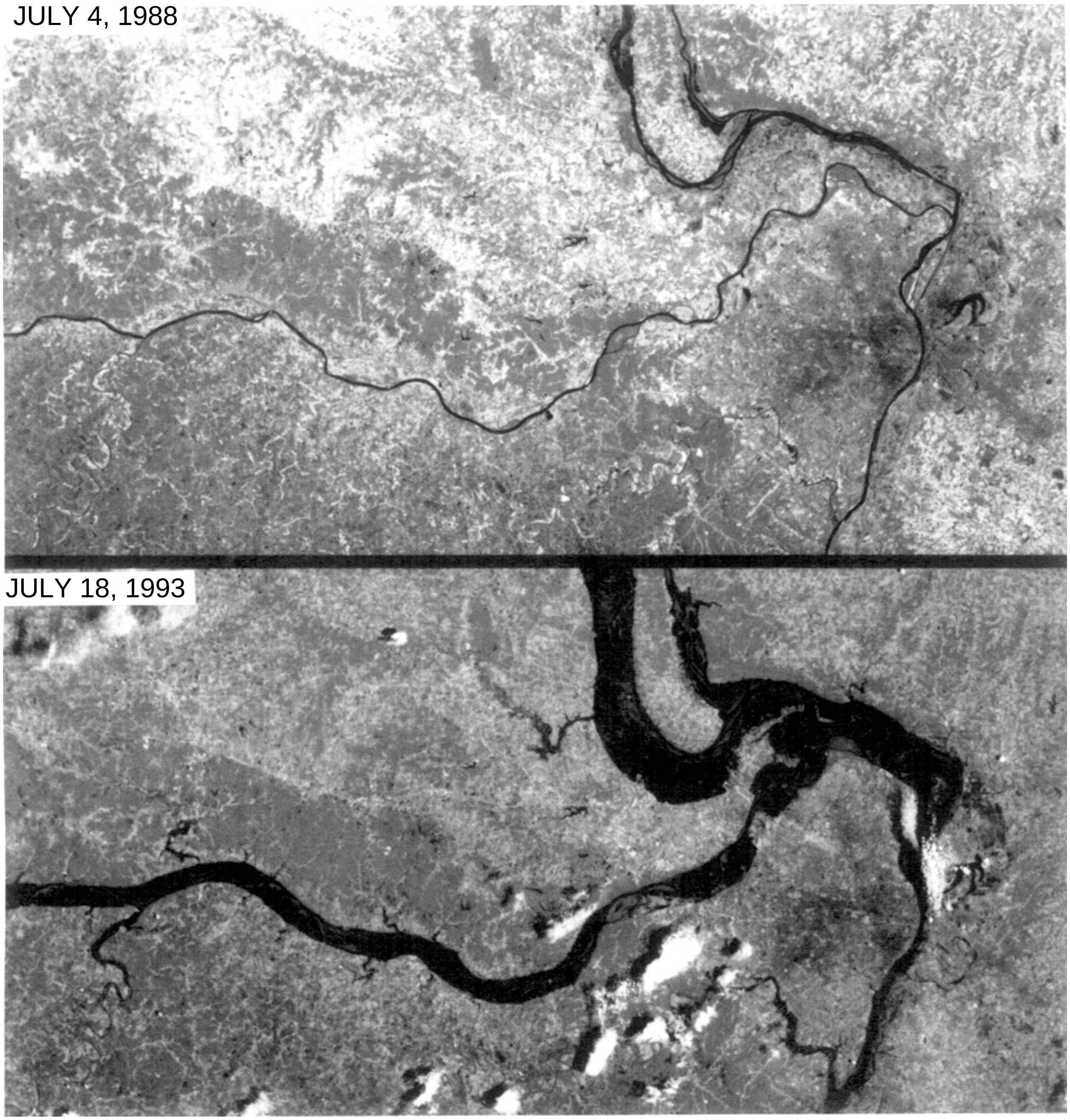

Counterclockwise from top to bottom - Confluence of the Illinois, Mississippi, and Missouri Rivers
(Landsat imagery courtesy of the Earth Observation Satellite Company, Lanham, Maryland)

Metric Conversions

1 foot = 0.305 meter
1 mile = 1.61 kilometers
1 square mile = 2.590 square kilometers
1 cubic foot per second = 28.32 cubic decimeters per second
1 inch = 2.54 centimeters

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Title: The 1993 Flood on the Mississippi River in Illinois.

Abstract: This report on the 1993 flood on the Mississippi River in Illinois and on the lower reaches of the Illinois River was prepared by the Illinois State Water Survey with assistance from the Illinois Department of Transportation/Division of Water Resources and the Illinois Natural History Survey. The report begins with a brief description of the physical setting of the Upper Mississippi River System, including historical facts on climate, precipitation, hydrology, and floods. The 1993 flood is discussed with regard to precipitation, soil moisture, stages, flows, levee breaches, and discharge through levee breaches. Also discussed are impacts of the flood on social, economic, hydraulic and hydrologic, and environmental aspects of the river and its residents. Impacts on water quality, the environment, and public water supplies, including the beneficial and detrimental aspects of the flood, are also included. The lessons learned from this flood focus on the performance of the levees, governmental responses, the effects of flood fighting, change in stages due to levee breaches, flood modeling, and the lack of information dissemination to the public on the technical aspects of the flood. These lessons point out information gaps and the need for research in the areas of hydraulics and hydrology, meteorology, sediment transport and sedimentation, surface and ground-water interactions, water quality, and levees. The report presents a comprehensive summary of the 1993 flood as far as climate, hydrology, and hydraulics are concerned.

Reference: Bhowmik, N.G., et al., The 1993 Flood on the Mississippi River in Illinois, Illinois State Water Survey, Champaign, Miscellaneous Publication 151.

Indexing Terms: Flood, Mississippi River, Illinois River, 1993 flood, levees, flood flow, stages, climate, precipitation, soil moisture, flood damage, ground water.

CONTENTS

Illinois National Guard protect Route 57 along the Mississippi River at Marblehead

CHAPTER 1. INTRODUCTION (Bhowmik)

The 1993 spring, summer, and fall flood on the Mississippi River was a historic event in terms of the time of the year, its magnitude and duration, and its impact on the river and its floodplains. It was also an important event as far as meteorological, hydrological, and hydraulic factors are concerned. The Mississippi, the Missouri, and the lower reaches of the Illinois Rivers reached unprecedented levels of flood inundation and wreaked havoc with rural and urban life and with transportation systems. Never in recorded history has such an event occurred in this part of the river, where its floodplains are used so extensively for agricultural, recreational, and urban purposes.

The Illinois State Water Survey is responsible for conducting data collection, research, and public service activities related to the water and atmospheric issues of the state of Illinois. Thus it was in a unique position to produce a factual and timely report on the events that led to this flood and its impacts on various resources, activities, and hydrologic parameters in Illinois as it moved along the river. Water Survey experts from the fields of meteorology, climatology, hydrology, and hydraulics contributed to this report. Other contributions came from the Illinois Department of Transportation/Division of Water Resources (IDOT/DWR), the U.S. Geological Survey (USGS), the Illinois Department of Agriculture (IDOA), the Illinois Department of Conservation, the Illinois Natural History Survey, and numerous other sources.

This report is not intended to be a complete analysis of all the facts about the great flood. Further research, data collection, and evaluation will be needed for that purpose. However, this report will serve as a starting point for final evaluation of the flood and for planning what could happen if and when such a flood occurs again.

ACKNOWLEDGMENTS

Numerous staff members from the Illinois State Water Survey contributed to this report. Acting Chief Mark Peden of the Water Survey was instrumental in making sure that all necessary support was available for its completion. Significant contributions came from the Illinois District of the U.S. Geological Survey, the Illinois Department of Transportation/Division of Water Resources, the Illinois Department of Agriculture, and the Illinois Natural History Survey.

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The main draft of the report was typed by Lori Nappe, technical editing and formatting were done by Laurie Talkington, final graphics were prepared by Linda Hascall, and the cover was created by Dave Cox. The photographs that appear in the report were taken by Mike Demissie, Linda Hascall, Vern Knapp, Jim Slowikowski, and Adrian Visocky, all from the Illinois State Water Survey; Gary Clark, Division of Water Resources, Illinois Department of Transportation; and the U.S. Army Corps of Engineers. To all of them, the authors and the scientific editor and coordinator express sincere thanks and deepest gratitude for their unfailing cooperation.

The work related to this report was done as part of the regular activities of the Water Survey by the personnel participating in this project.

The Mississippi River
at Alton highway bridges
(new and old) Route 67

CHAPTER 2. BACKGROUND

This chapter describes the Mississippi and Illinois Rivers, including information on their physical settings, climate, previous flooding, and a history of the levees.

Physical Setting (Soong)

Much of this discussion is summarized from reports by the Upper Mississippi River Basin Commission (1981) and the Environmental Work Team (1981).

The Upper Mississippi River System (UMRS) includes major portions of Illinois, Iowa, Minnesota, and Wisconsin, a portion of Missouri, and smaller portions of South Dakota and Indiana. Figure 2.1 shows the drainage basin of the UMRS. The watershed area is 189,100 square miles (sq mi). The Upper Mississippi River (UMR) north of Cairo, Illinois, includes nearly 1,300 commercially navigable miles of river. Downstream from Cairo the UMR meets the Ohio River and flows into the Lower Mississippi River. Major tributaries on the UMRS include the Minnesota River in Minnesota; the St. Croix, Chippewa, Black, and Wisconsin Rivers in Wisconsin; the Cedar, Iowa, and Des Moines Rivers in Iowa; and the Rock, Illinois, and Kaskaskia Rivers in Illinois. The Missouri River, which enters the UMR above St. Louis, is not considered pan of the UMRS, even though it discharges water and sediment drained from 529,350 sq mi to the Mississippi River. Figure 2.2 shows the navigable portion of the UMRS, including some of the major tributaries.

The UMR basin is elongated in shape, lying on a north-northwest to south-southeast axis between latitudes 37° and 48° and longitudes 86° and 97°. It is approximately 550 miles wide by 750 miles long. This region is largely within the Central Lowland physiographic province, except in

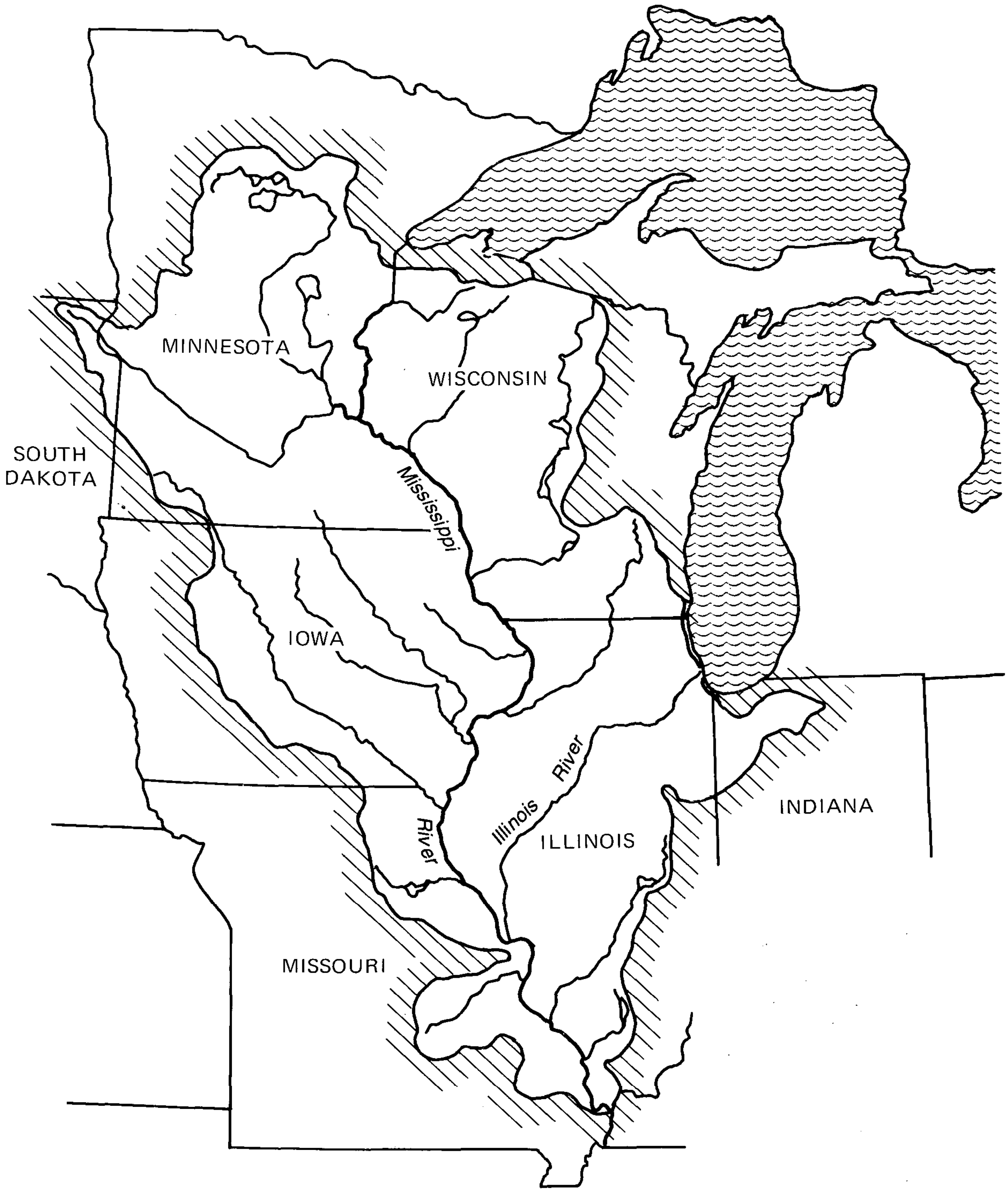


Figure 2.1 The Upper Mississippi River system
(after UMRBC, 1981)

the north where the headwaters drain a portion of the Superior Upland, and in the south where a few streams originate in the Ozark Plateau. The topography has been shaped primarily through glacia tion, except in southwestern Wisconsin and the extreme southern part of the region. These two areas are extensively dissected by streams, creating numerous escarpments and bluffs. The remainder of the basin is gently rolling terrain with no sharply contrasting orthographic features. Elevations rang from 280 to 1,940 feet above mean sea level (msl). The only region with extensively rugged topography is the submountainous Ozark section in Missouri, which is drained by me Meramc

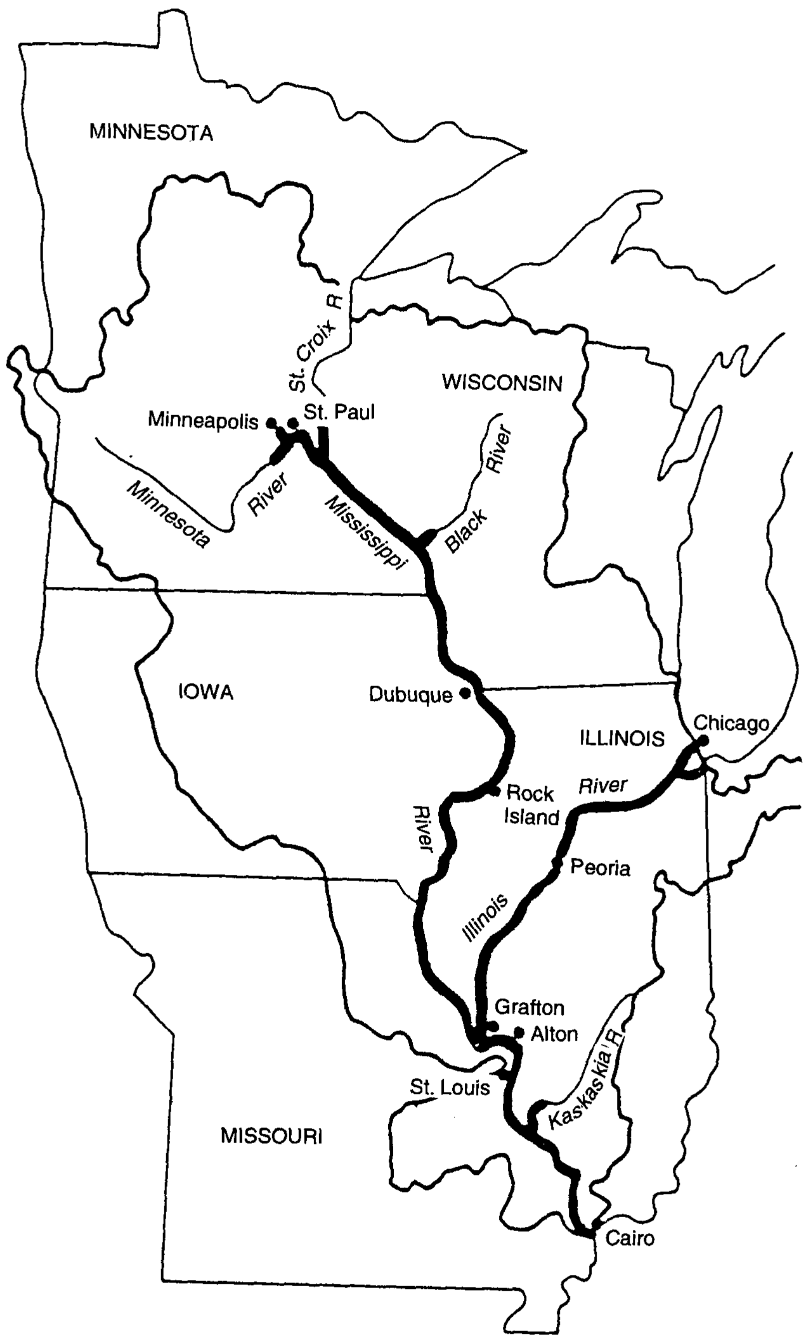


Figure 2.2 The navigable waterway of the Upper Mississippi River system
(after UMRBC, 1981)

River. Natural lakes are prevalent throughout the region but more so in central and northern Minnesota and northwestern Wisconsin, reflecting the glaciated history of the area. Thousands of lakes characterize this drift-covered Precambrian surface.

Prior to navigation development, the Upper Mississippi River channel ran through shallows and pool sections. Natural processes created new backwaters and side channels and filled old ones. This balanced ecosystem supported a diverse array of fish and wildlife. Congress has designated more than 230,000 acres of the UMRS as part of the U.S. Fish and Wildlife Refuge System.

As an important transportation corridor, the UMRS has been subjected to alterations for navigational purposes since 1824. In the 1930s, navigation channel projects were authorized by Congress to ensure a 9-foot depth for both the Mississippi and the Illinois Rivers. The 9-foot channel was developed by the construction of locks and dams, wing dikes, and occasional dredging. Construction of the locks and dams was essentially completed by 1940. Some 700 miles of navigable channel now exist on the main stem of the UMRS (figure 2.2). The locks and dams on the Upper Mississippi from southern Missouri to Upper St. Anthony Falls, Minnesota, essentially create a "stairway of water" consisting of a series of pools from St. Louis to Minneapolis (figure 2.3). The Illinois Waterway connects the St. Lawrence-Great Lakes to the Mississippi-Ohio-Missouri Navigation System. Below lock and dam (L&D) 27 at Granite City, Illinois, the Mississippi River navigation channel is maintained by flow-regulating structures such as wing dikes and dredging.

For purposes of analysis, the UMR has been divided into four reaches (Environmental Work Team, 1981):

UMR 1 — Head of navigation to L&D 10
UMR 2 — L&D 10 to L&D 19
UMR 3 — L&D 19 to 26
UMR 4 — L&D 26 to Cairo

The western border of the state of Illinois includes the portion of the river that extends from L&D 11 through Cairo at the junction of the Mississippi and Ohio Rivers.

UMR 1: Head of Navigation to L&D 10

The present morphology of the river is "island braided," with divided flow around many islands and bars. Numerous side channels and nonchannel areas characterize this reach, which includes areas of high biological productivity. The portion from L&D 4 to L&D 10 includes part of the Upper Mississippi River Wildlife and Fish Refuge, as well as a number of state and wildlife management areas. Thirteen locks and dams on the main stem of the river, as well as numerous wing dams, closing dams, and annual dredging activities, are necessary to maintain the commercial navigation system in this reach.

UMR 2: L&D 10 to L&D 19

This reach is a transition between the upper and lower pooled river reaches. The topography along the river changes from high bluffs near Cassville, Wisconsin, to a more rolling landscape near Keokuk, Iowa. Forests are less prominent in the lower parts of this reach, despite a relatively high distribution of woody vegetation in the floodplain around the Quad Cities along pool 15. Non-

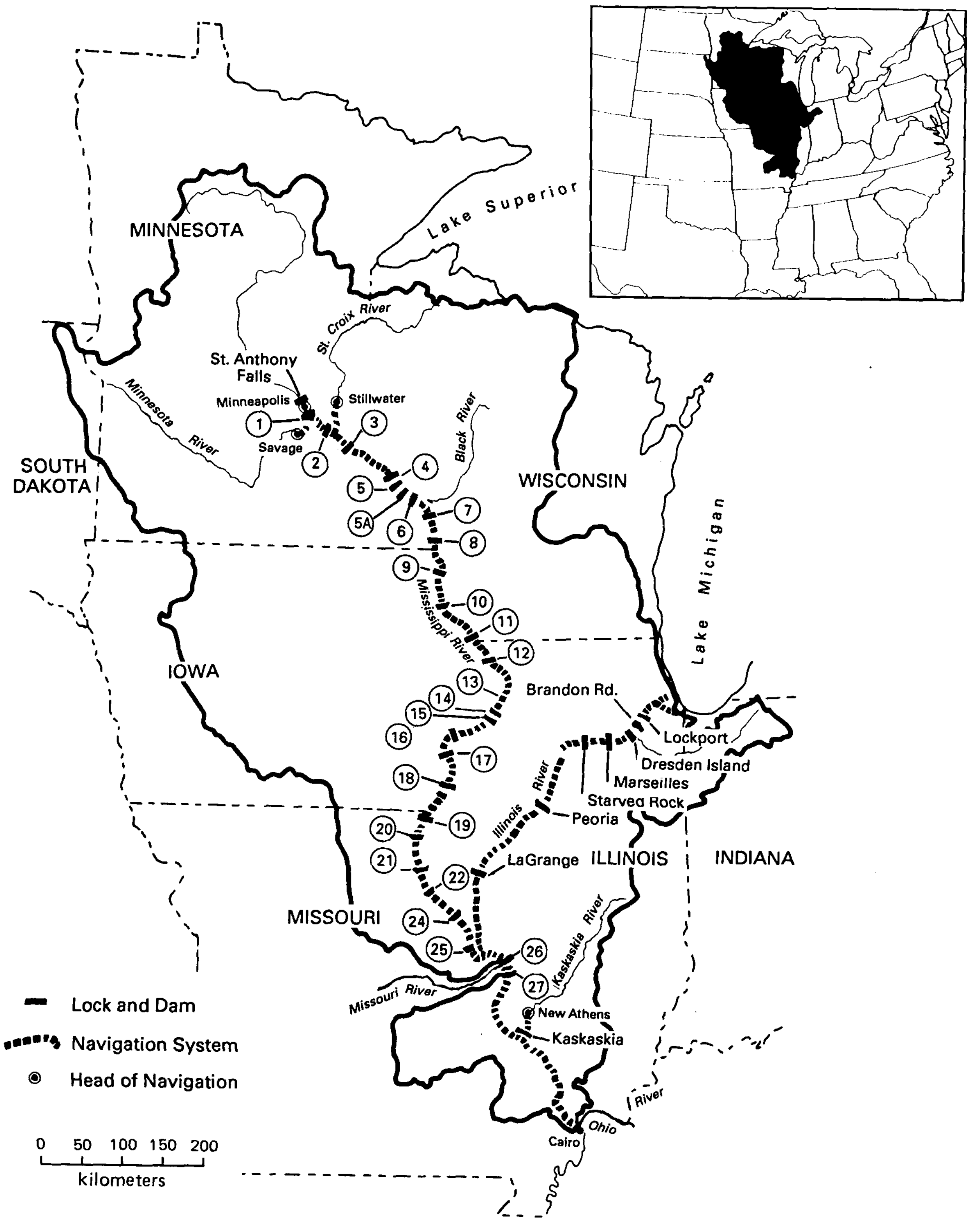


Figure 2.3. The navigation system of the Upper Mississippi River system (after UMRBC, 1981)

channel waters and side channels become less extensive at the lower end of this reach, and are replaced by main-channel border as the dominant water type. Use of the river for commercial navigation increases downstream; tonnage doubles from pool 2 to pool 19. This reach includes pools maintained by locks and dams, wing dams, closing dams, and dredging. More than 100 miles of agricultural levees have been erected along this reach of the river.

UMR 3: L&D 19 to L&D 26

This reach of the UMRS consists of six pools maintained by locks and dams, wing dams, closing dams, and dredging. As the lowest of the pooled reaches of the main stem of the UMR, this area is characterized by a wide floodplain that has been extensively altered by more than 117 miles of levees, behind which lie vast agricultural lands. Side channels and backwaters are relatively small, but the main-channel border waters are extensive.

Commercial navigation is comparatively heavy in this area. It is the only pooled reach of the Mississippi River that regularly accommodates year-round navigation, including that from the Illinois Waterway, which meets the Mississippi River in this reach. The cross-sectional area of this reach has been reduced significantly with construction and maintenance of the navigation channel.

UMR 4: L&D 26 to Cairo, The Middle River

The Middle Mississippi extends from L&D 26 at Alton, Illinois, to the mouth of the Ohio River at Cairo, Illinois, a distance of 202 miles. As opposed to the upper reaches, this reach includes only one lock and dam, L&D 27, which is located in the Chain of Rocks Canal at St. Louis. The dam is similar to a low-level closing dam and cannot be regulated. Therefore, this pool is essentially free flowing. The 9-foot navigation channel is maintained here by closing structures, dikes, and revetments that constrict the flow to the main channel.

Construction work on this segment includes dikes that have constricted the river to 2,500 feet in width, and later to 1,800 feet. Subsequently the U.S. Army Corps of Engineers (USACOE) decided to constrict the channel to 1,500 feet, since it was having trouble maintaining the channel depth. Some test reaches have even been constricted to 1,200 feet. Between 1888 and 1968, the river's surface area has been reduced by approximately one third, the island area by one-half, and the riverbed itself by nearly one-fourth. Most side channels have been entirely blocked off with closing structures.

The floodplain is dominated by agricultural land and woody vegetation, with a comparatively low percentage of water area. Extensive wing dams, revetment (bank protection) structures, and levees have been constructed to maintain the navigation channel and to protect agricultural and urban lands in the floodplain.

Climate of the Mississippi River Watershed (Wendland)

The Mississippi watershed is located in a temperate continental climate zone. It is an area dominated by 1) warm and humid maritime tropical air from the Gulf of Mexico from about April through October; 2) maritime polar air from the Pacific Ocean in spring, fall, and winter; and 3) short-duration incursions of cold and dry continental polar air from Canada several times each winter. Midwinter high temperatures are typically in the low 20s to mid 30s (°F), north to south, whereas summer highs are usually in the low to mid 80s throughout the region. Daily lows are typically about 20°F lower.

Spring and fall are composed of a mix of winter- and summer-like days, and rather large day-to-day temperature fluctuations are common. The greatest day-to-day changes in temperature occur in late fall, winter, and early spring due to strong cold-frontal passages.

Precipitation in the watershed follows a seasonal pattern. Thunderstorms make spring the heaviest season as maritime tropical air from the Gulf moves to its northern limit over the watershed. In summer, the northern limit is typically located over the U.S.-Canadian border, and in fall it slips southward again. In winter, its mean position is over southern Illinois. Day-to-day fronts and storm systems meander from the mean position, but tend to follow the meridional trek with the seasons. Since Gulf air provides the greatest influx of moisture to Illinois, the heaviest precipitation occurs when the northern limit of the air mass is over or to the north of the state.

Winters are usually punctuated with two to eight cold, dry arctic outbreaks, during which daily lows drop to -20 to -40°F in the north, and to -10 to -20°F in the south. Such cold outbreaks generally persist for three to five days. They are often preceded by substantially warmer-than-average temperatures and a winter storm that can reach severe proportions, consisting of 6 or more inches of snow with strong winds, blowing snow, or occasionally freezing precipitation (particularly in the central and southern sections of the watershed).

South of central Wisconsin, summers are distinctly more humid than to the north, with average dew points in the 60s and afternoon relative humidities in the 50 to 60 percent range and 85 percent or higher at night. On average about 40 days per year see temperatures over 90°F in the southern sector of the Upper Mississippi watershed (southern Illinois). This figure decreases to fewer than 10 per year in the northern region. At the northern extreme, about 125 days per year experience temperatures under 32°F, while only about 65 such days occur in the south. Only one or two days per year see temperatures under 0°F in the south on average, but about 15 occur in the north.

Average precipitation (1961-1990) for the watershed varies from about 32 inches in the north to about 45 inches in southern Illinois (with only about 5 to 10 inches of snow). There is great variability from year to year.

On average, 74 days per year experience at least 0.10 inch of precipitation in the southern reaches of the watershed (southern Illinois), and about 45 of these are associated with thunder. In the northern extremes (central Minnesota) precipitation occurs on about 55 days, with only about 15 thunder days. Precipitation is most frequent and abundant during spring and summer throughout the watershed. It accounts for about 57 percent of the annual average in the south, increasing to 90 percent of the annual average in the far north.

In the south, the average frost-free growing season is about 200 days, beginning in early April on average and ending in late October. In the northern reaches of the watershed, the growing season is only about 100 days, beginning in mid-May and ending in early to mid-September.

South of about 38°N latitude (roughly Kansas City to Cincinnati), winters are distinctly milder than in the north. They are characterized primarily by daytime temperatures over 32°F, less snow, fewer days with snow cover, and fewer snowfalls.

Hydrology of the Upper Mississippi River (Knapp)

Sixteen major tributaries drain into the Upper Mississippi River. Their basins are shown in figure 2.4. The profile of the river, including its major tributaries, is given in figure 2.5.

As the Mississippi River flows from the northern to the southern extremes of the state of Illinois, its hydrologic character varies greatly. Where it meets the northern border of the state, the river's drainage area is mostly limited to portions of Minnesota and Wisconsin, and the average flow is approximately 46,000 cubic feet per second (cfs). By the time the Mississippi River reaches the southern tip of the state of Illinois, near Cairo, the river's drainage area is almost nine times as large (717,400 square miles), including major portions of ten states (Montana, North Dakota, South Dakota, Nebraska, Kansas, Missouri, Iowa, Minnesota, Wisconsin, and Illinois), with minor portions of three other states (Wyoming, Colorado, and Indiana), and two Canadian provinces (Alberta and Saskatchewan). At approximately 200,000 cfs, the average flow near Cairo is almost 4.5 times larger than at the northern border of Illinois. By far the largest portion of the watershed area and the additional inflow is contributed by the Missouri River, which enters the Mississippi just north of St. Louis. The drainage areas and average flows along the Mississippi River at various locations in Illinois are shown in table 2.1.

Major tributaries to the Mississippi River along the Illinois border, other than the Missouri River, include the Illinois River with a drainage area of 28,900 sq mi, the Des Moines River (14,500 sq mi), the Iowa River (12,600 sq mi), and the Rock River (10,600 sq mi). Major tributaries to the Mississippi River upstream of Illinois are the Minnesota River, with a drainage area of 17,000 sq mi, the Wisconsin River (11,000 sq mi), and the Chippewa River (9,400 sq mi).

Average Runoff

Average runoff is not uniformly distributed across the Upper Mississippi River watershed. The western and northern portions of the watershed contribute considerably less, relative to their drainage areas, than the southeastern portion of the watershed. For example, the Missouri River drains almost 75 percent of the watershed, yet accounts for less than 40 percent of the total runoff. Figure 2.6 shows the geographical distribution of average annual runoff from the watershed.

Trends in Runoff

The average flow in the Upper Mississippi River varies over time, not just annually, but over decades and multiple decades. Table 2.2 shows the changes in average flow as measured at three long-term gaging stations on the Upper Mississippi River, and figure 2.7 shows the locations of the gaging and stage recording stations in Illinois. The change in average flow over time is also illustrated for the Clinton, Keokuk, and St. Louis gages in figure 2.8, along with the 11-year moving average of the annual values. As illustrated, the average flow has changed over time, and occasionally the 11-year average flow has differed from the long-term average by more than 15 percent. For most locations along the Mississippi River, the 28-year period since 1965 has witnessed the highest average conditions on record. Despite the periodic differences in average streamflow, the long-term average flow has remained remarkably consistent over time. Figure 2.9 shows the cumulative streamflows at Clinton; Keokuk, Iowa; and St. Louis over the respective periods of record.

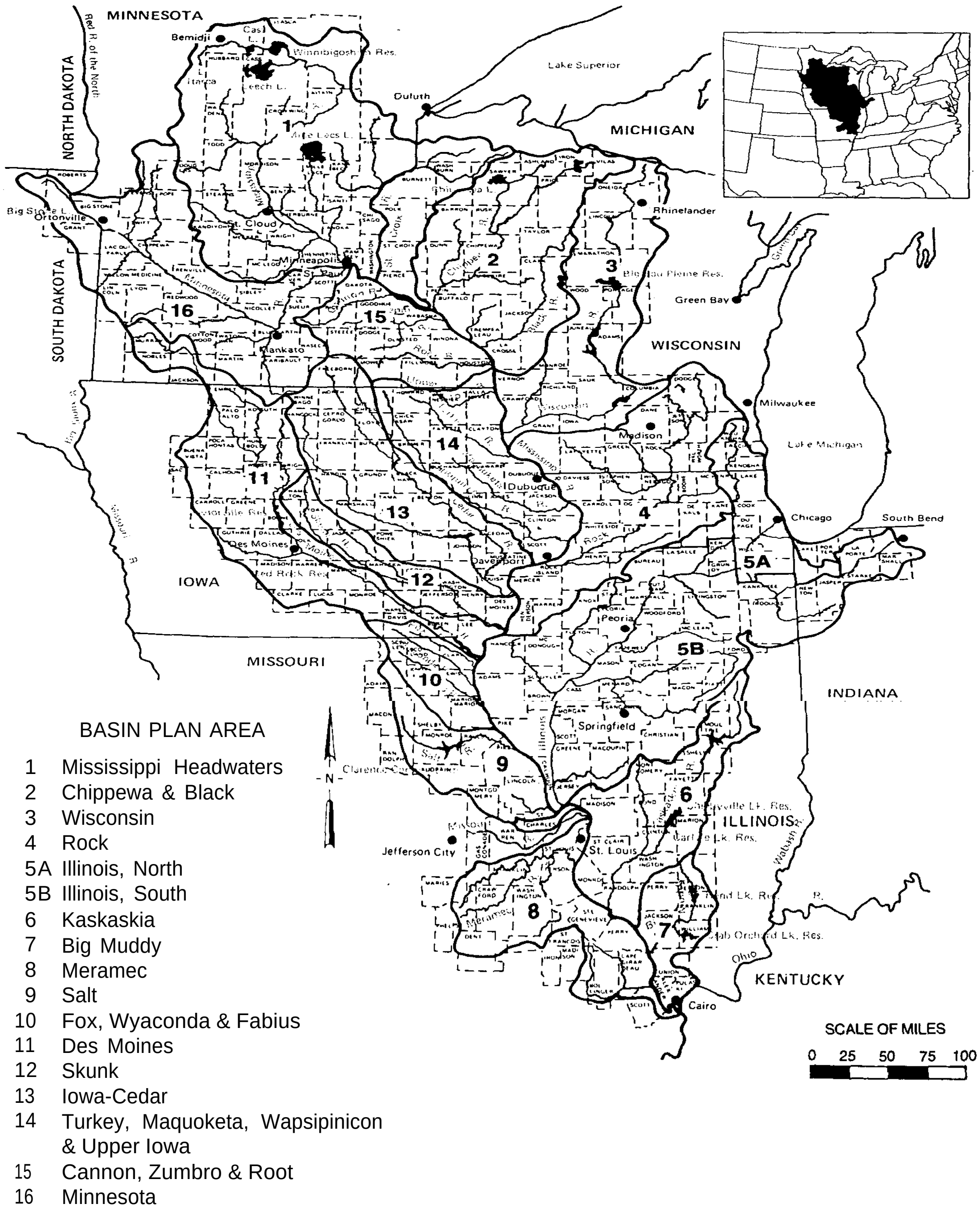


Figure 2.4. The Upper Mississippi River basin with major tributaries (after UMRBC, 1981)

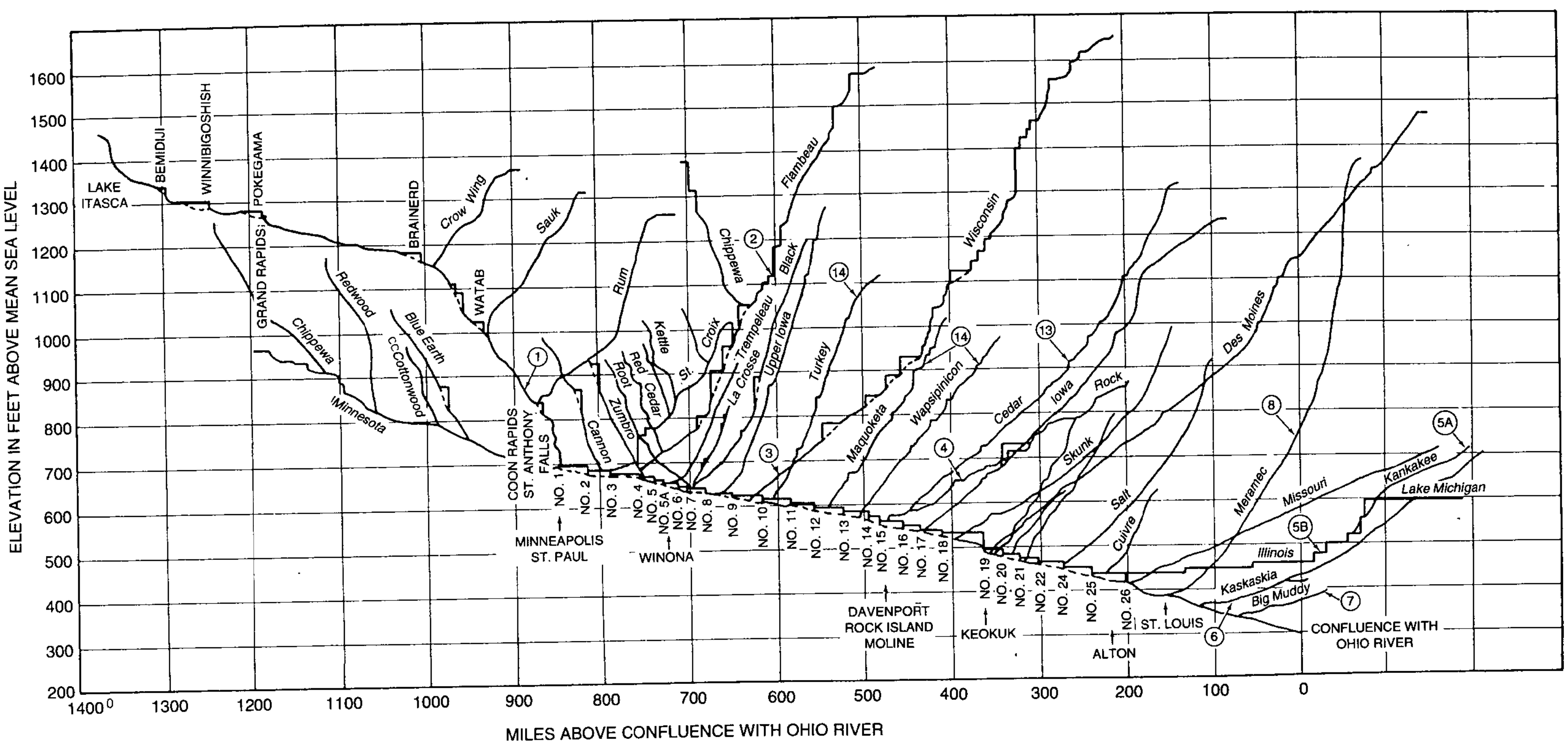


Figure 2.5. River profiles, main stem, and major tributaries of the Mississippi River (after UMRBC, 1981)

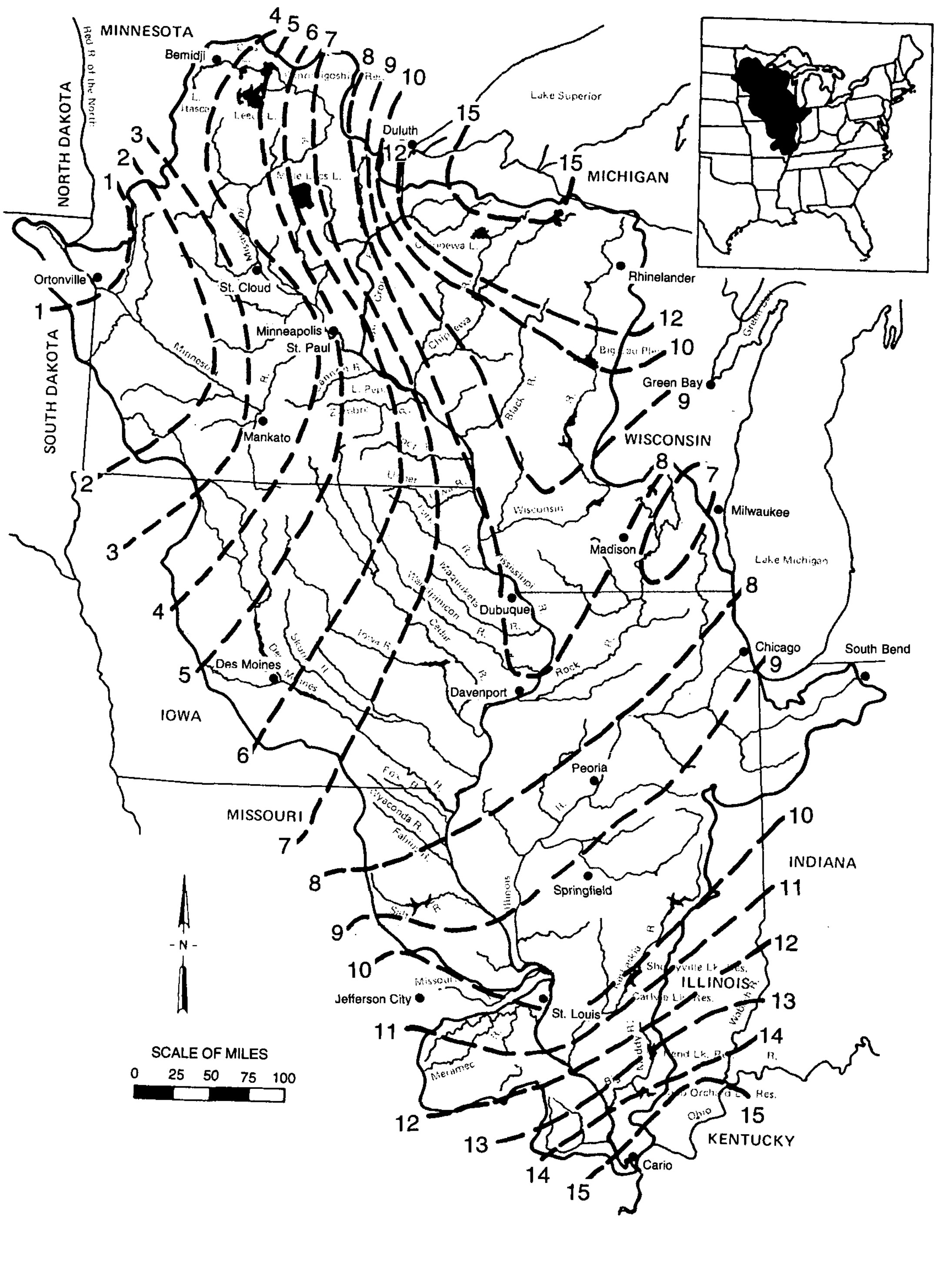


Figure 2.6. Average annual runoff in inches, UMR watershed (after UMRBC, 1981)

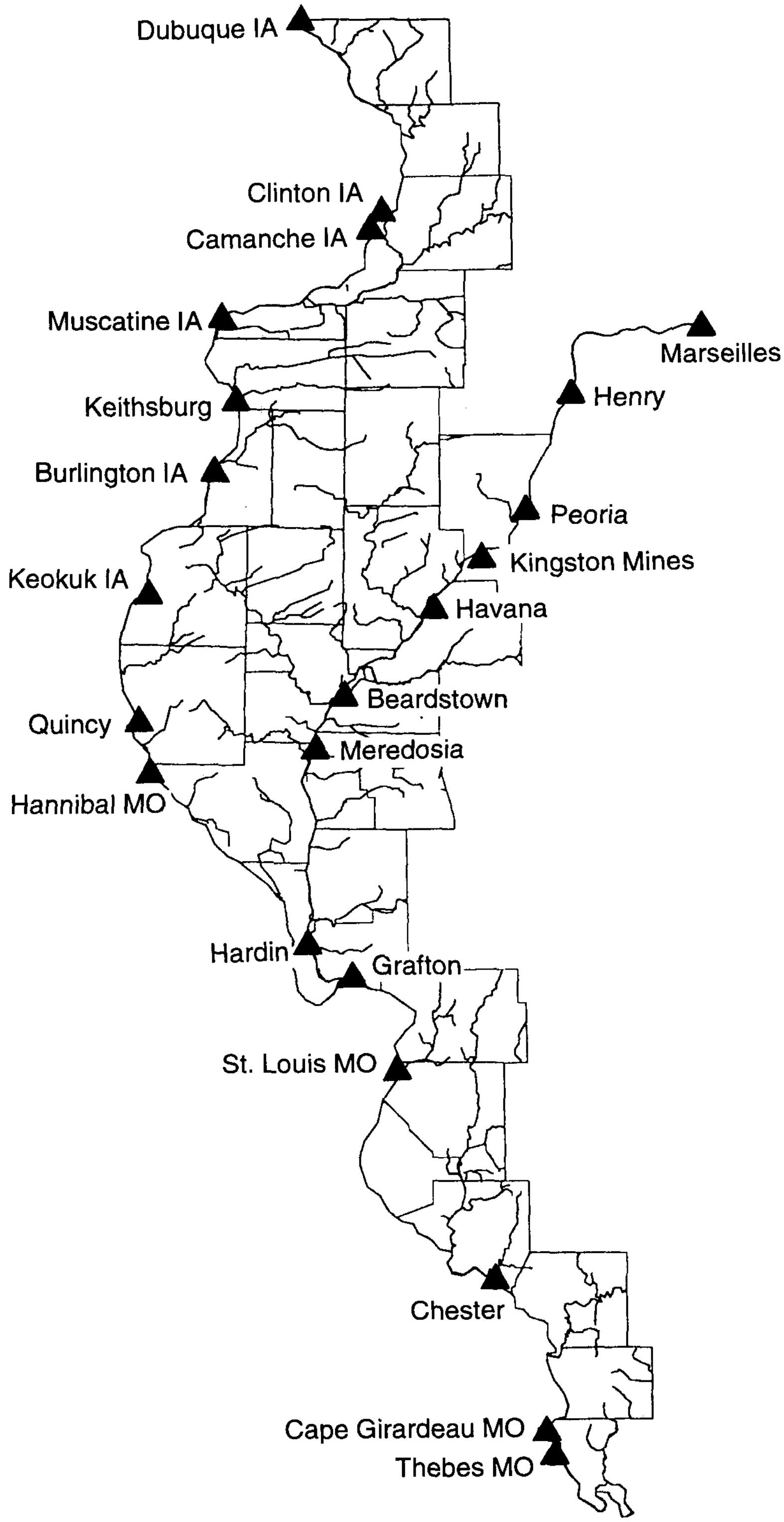


Figure 2.7. Gaging and stage recording stations along the Mississippi and Illinois Rivers

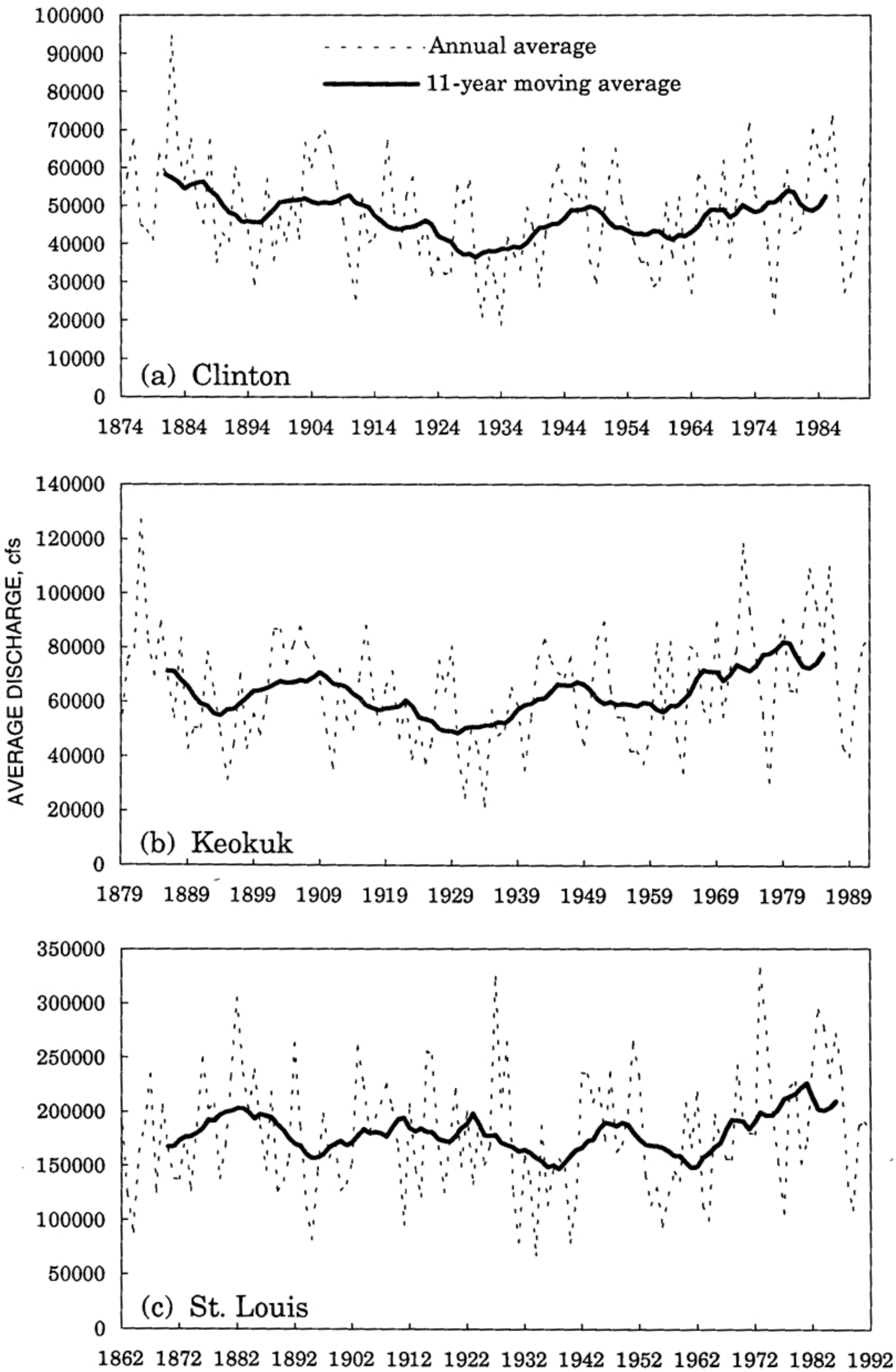


Figure 2.8. Average annual flows and the 11-year moving average flow on the Mississippi River at Clinton (a), Keokuk (b), and St. Louis (c)

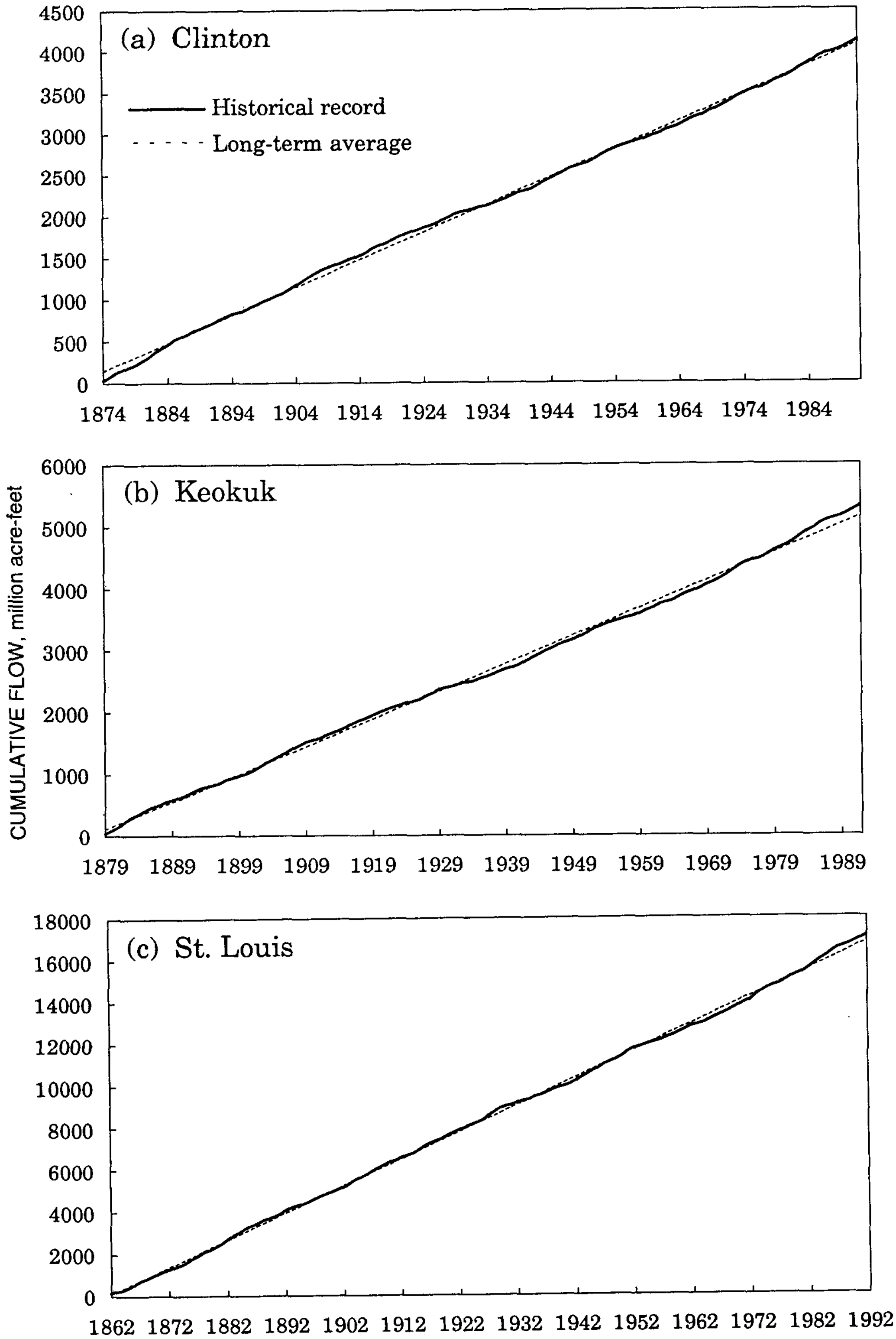


Figure 2.9. Cumulative flow for the period of record for the Mississippi River at Clinton (a), Keokuk (b), and St. Louis (c)

Table 2.1. Drainage Areas and Average Flows at Locations on the Mississippi River

Location	*Drainage area (sq mi)*	*Average flow (cfs)*
Northern border of Illinois	82,500	46,000
Clinton gage	84,600	47,680
Keokuk gage	119,000	64,530
Grafton gage	171,300	101,500
St. Louis gage	701,000	180,050
Chester gage	712,600	198,500
Southern border of Illinois	717,400	203,000

Figure 2.9 and table 2.2 show a noticeable increase in average streamflow at Keokuk and St. Louis between 1965 and 1992. At Clinton the cumulative flow shows little if any deviation from the straight line that represents the long-term average. Streamflow records for Mississippi tributaries between Clinton and Keokuk (the Rock River and the Iowa River) show a significant increase in average flow during the same time period, as do the Des Moines and Illinois Rivers, which enter the Mississippi downstream of Keokuk (figure 2.10). Tributaries of the Mississippi River upstream of Clinton and downstream of St. Louis do not show similar increases.

Possible Causes of Increased Flows

A number of physical modifications in the watershed may have contributed in some degree to streamflow changes over the last 100 years. Among these are various types of land-use changes, including the development of agriculture and modifications in agricultural practices, deforestation, conversion of wetlands to farmlands, stream channelization, and construction of ditches to facilitate drainage. But in general, the greatest changes in streamflow appear to be most strongly related to climate variations, particularly multidecadal precipitation changes. Climatic variation exerts such a strong impact on streamflow that it masks other possible sources of change in streamflow, such as physical modifications to the watershed. It is also difficult to identify major changes in the watershed that might coincide with observed variations in streamflow.

Flooding

Floods on the Mississippi River upstream of the confluence of the Missouri (i.e., upstream of St. Louis) often occur independently of floods at St. Louis and farther downstream. During flood conditions, the origin of flow is relatively evenly spread across the entire watershed, and since the Missouri River represents almost 75 percent of the watershed, it also represents the source of most of the floodwaters. Major floods from St. Louis downstream to Cairo have almost always coincided with major floods on the Missouri River.

Upstream of the Missouri Confluence

The major historic floods on the Mississippi River upstream of the Missouri have almost always occurred during the spring. The reason for this is fairly obvious when one understands the

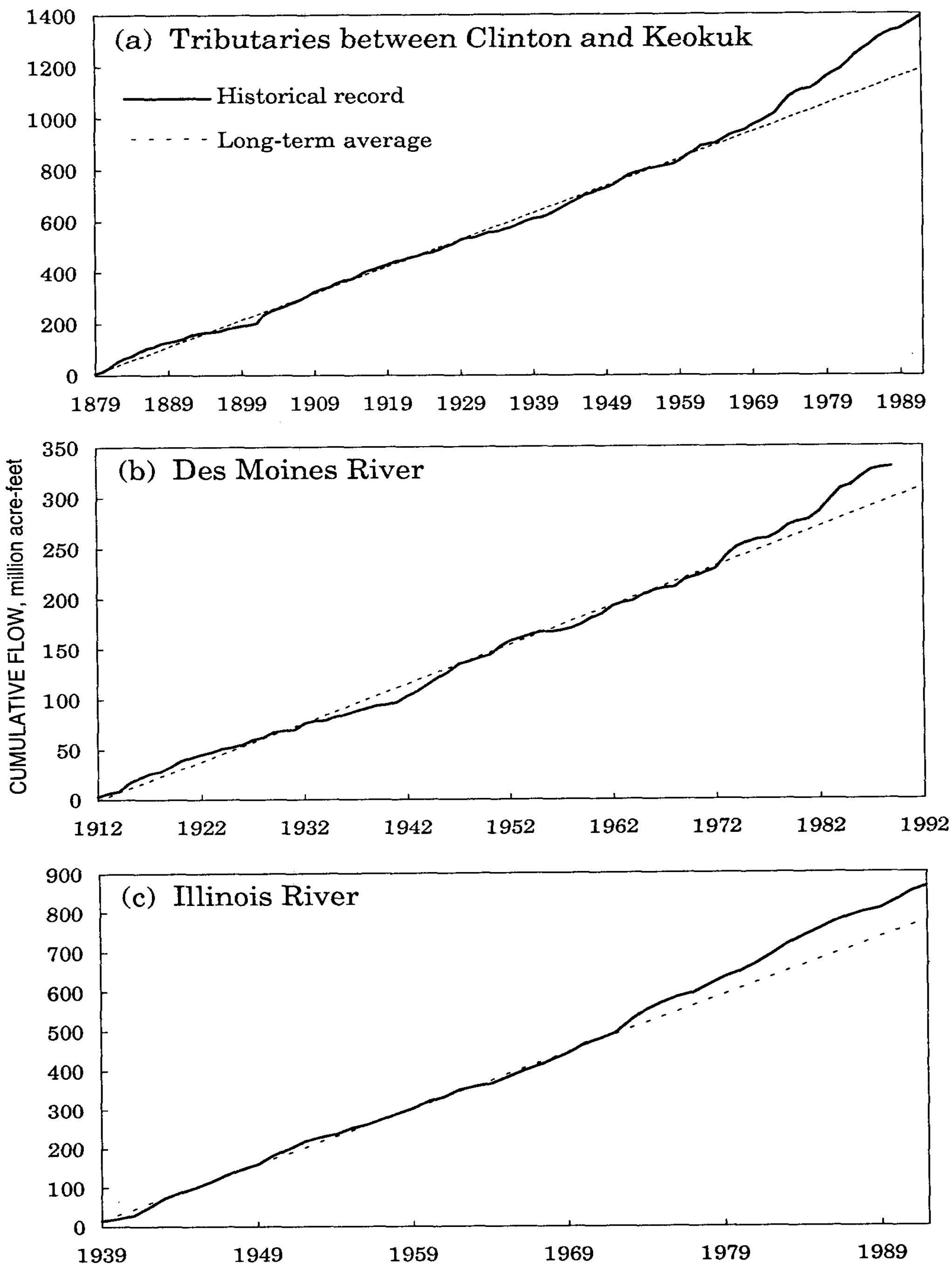


Figure 2.10. Cumulative flow from tributaries of the Mississippi River between Clinton and Keokuk (a), the Des Moines River at Keosauqua, IA (b), and the Illinois River at Valley City

Table 2.2. Variability in Average Streamflow on the Mississippi River (cfs)

Period	*Clinton (1874-1992)*	*Keokuk (1879-1992)*	*St. Louis (1862-1992)*
1862-1893	55,320	71,580	188,830
1894-1920	49,190	63,420	174,380
1921-1940	37,960	49,910	157,210
1941-1964	45,940	63,140	175,360
1965-1992	50,310	75,240	202,910
Total record	47,680	64,530	180,050

seasonal impact on the runoff process in the watershed upstream of St. Louis. Much of the watershed is located in Minnesota and Wisconsin, where the cold winters cause freezing and storage of excess water, thus inhibiting its movement to streams. During the spring thaw, which normally occurs in mid- to late-March, this water is released and regularly causes flooding. Floods may also occur in late spring or early summer when the rivers are still swollen from the spring thaw and rains add to the flow. Flooding in mid-to late summer is infrequent because by this time of year, river levels throughout the watershed have usually dropped. Prior to the 1993 flood, no major historic flood had ever occurred in mid-to late summer in the northem part of the watershed (Minnesota and Wisconsin). In this regard the 1993 flood was unique.

Flooding does not emanate from any common geographical source in the watershed. Each of the major seasonal floods receives inflow from different portions of the watershed. For this reason, the largest flood at one location on the Mississippi River may not be the largest farther upstream or downstream. Table 2.3 lists the largest historical floods for three gaging stations along the Mississippi River. As mentioned, they have no common source. For example, in 1965, streams from the states of Minnesota and Iowa provided almost all of the significant flow. While the 1965 flood was among the most severe on record for most of the upstream locations, it does not rank as one of the top ten floods farther south at Grafton, Illinois. In 1960, the northernmost reaches were not even in flood, even though the Wisconsin, Rock, Iowa, and Des Moines Rivers provided large amounts of inflow. The second worst flood this century at Grafton, 1943, was not a major flood at any other station — most of the inflow originated from the southeastern portion of the watershed, particularly the Illinois River. The 1973 flood, which produced record stages from Keokuk to Cairo, was only the sixth highest stage on record at Clinton. Record flood levels during that event occurred on the Rock River and on smaller tributaries such as the Salt River (northeastem Missouri) and the Skunk River (southeastem Iowa).

Downstream of the Missouri Confluence

Even though gaging of the Mississippi River did not start until 1861, the history of floods at St. Louis goes back several centuries. Estimates of peak discharges for many earlier floods (table 2.3) exceed the discharges of many severe floods measured in this century. Even if the discharges of these earlier events were overestimated by 20 or 30 percent, as suggested by Dyhouse (1993), they indicate that extreme floods such as those of 1973 and 1993 are not new to the Mississippi River. Although the Mississippi River upstream of the Missouri confluence has historically provided sizable volumes to floods farther downstream, most of these major floods on the Mississippi River at St. Louis have coincided with major floods on the Missouri River.

Table 2.3. Top Ten Flood Discharges on Record at Clinton, Keokuk, and St. Louis

Clinton		*Keokuk*		*St. Louis*	
Date	*Peak flow (cfs)*	*Date*	*Peak flow (cfs)*	*Date*	*Peak flow (cfs)*
April 1965	307,000	July 1993	435,000	August 1993	1,030,000
June 1880	250,000	April 1973	344,000	June 1903	1,019,000
May 1888	248,000	May 1965	327,000	May 1892	926,500
July 1993	245,000	May 1888	314,000	April 1927	889,300
June 1892	238,000	June 1892	306,000	June 1883	862,800
Nov. 1881	237,000	Nov. 1881	293,000	July 1909	860,600
April 1969	231,000	April 1960	289,500	April 1973	852,000
April 1952	225,400	June 1880	271,000	June 1908	850,000
April 1920	222,000	June 1903	270,000	April 1944	844,000
April 1951	221,500	Oct. 1986	268,000	May 1943	840,000
Discharge estimates for floods outside the record					
		June 1851	360,000	April 1785	1,350,000
				June 1844	1,300,000
				June 1850	1,054,000
				1855	1,050,000
				June 1851	1,022,000
				1828	1,000,000

Flooding Magnitude

Figure 2.11 shows the cumulative volumes associated with annual high flows along the Mississippi River at Clinton, Keokuk, and St. Louis. During the last 20 years, the 7-day high flows experienced at Keokuk have been, on average, 15 percent greater than the long-term average high flows. This change shows in figure 2.11b as a moderate divergence between the cumulative volume (solid line) and the long-term average (broken line). At both Clinton and St. Louis, the deviation of high flows from the long-term average is insignificant. But the increase in high flows shown by the Keokuk record is not consistent with observed trends in high flows on the tributaries to the Mississippi. Although the Illinois River has shown increases in its high flows (Ramamurthy et al., 1989), none of the other major tributaries in the vicinity of Keokuk shows such increases. The Des Moines and Iowa Rivers have experienced decreases in high flows, likely from the impact of flood control reservoirs.

Historical Floods and Stages (Soong and Knapp)

Abundant tributaries and flows, vast drainage areas, steeper tributary slopes, and mild main-channel gradients all contribute to the complex hydrology of the UMRS. When assessing flood impacts, it is necessary to keep these complex hydrologic conditions in mind before correlating the severity of floods to flood stages. The stretch along the Illinois border, from L&D 11 through L&D 27 to Cairo, suffers flood damage most of the time. This stretch has more than 17 tributaries out of the total 29 major tributaries along the UMR (figure 2.5). While 14 tributaries enter from the Iowa and Missouri side of the river, only three large tributaries enter from the Illinois side. Depending on weather patterns and the amount and distribution of spring thaw and rainfall,

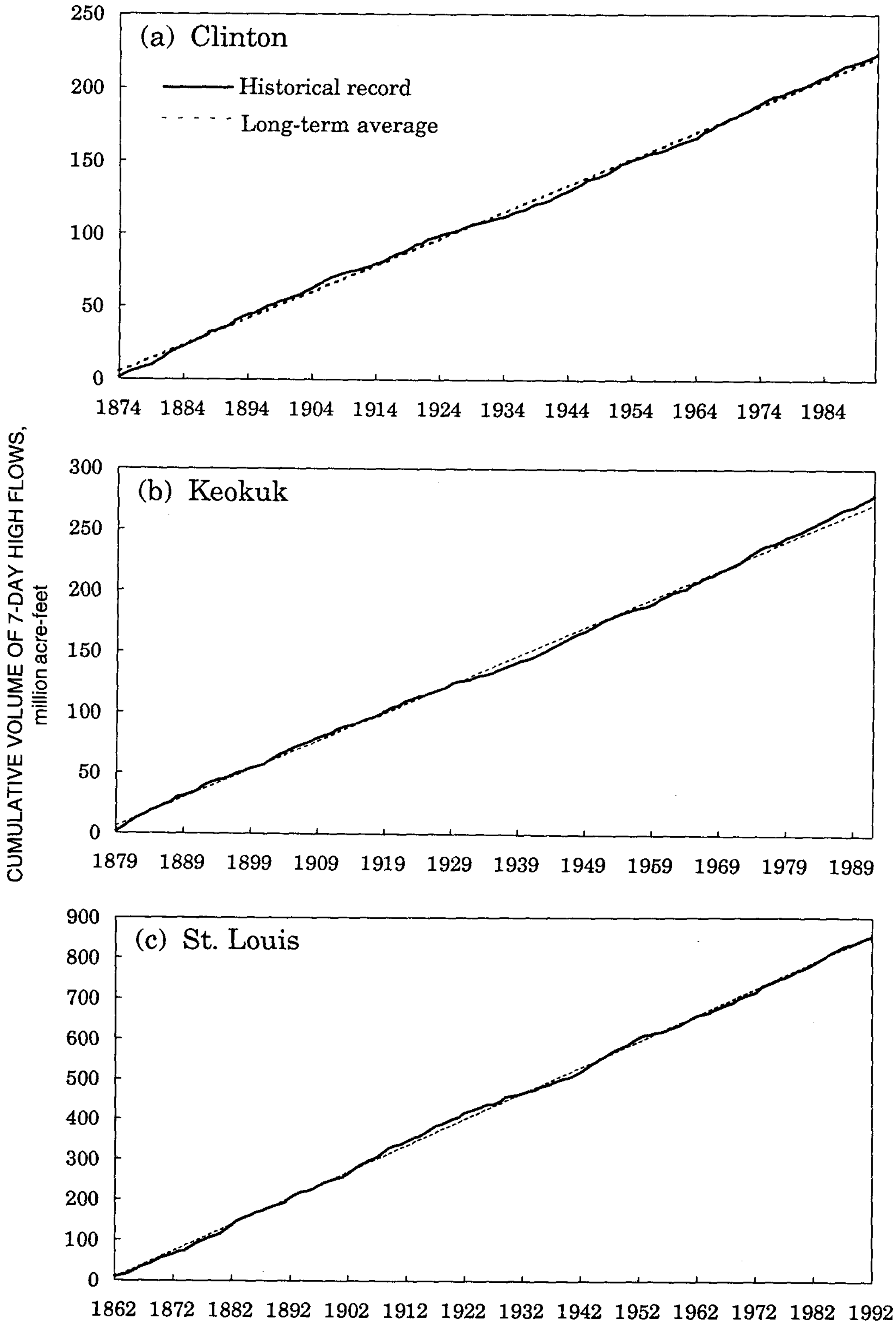


Figure 2.11. Cumulative volume of annual 7-day high flows at Clinton (a), Keokuk (b), and St. Louis (c)

floodwaters significantly affect the stages on the main stream in different times and locations. These features represent the flood characteristics of the UMR.

Historical flood discharges and stages, as shown at five stations along the Illinois border, will help bring the 1993 flood into proper focus: Dubuque (uppermost), Keokuk (middle), Hannibal middle lower), St. Louis, and Chester (lowest). The ten highest historical floods (excluding 1993) at each of these five stations are presented in tables 2.4a-2.4e, along with dates, peak stages, days above flood stages, and discharges. The streamflow records on the main stem of the Mississippi

Table 2.4a. Ten Highest Known Flood Stages at Dubuque, IA, River Mile 579.9

Order	*Date of crest*	*Stages (feet)*	*Days above flood stage*	*Elevations (feet msl)*	*Estimated peak discharge (cfs)*
1	April 26, 1965	26.81	29	612.28	306,500
2	April 23, 1969	23.11	21	608.58	231,000
3	April 22, 1951	22.70	N.A.	608.17	223,000
4	April 25, 1952	22.70	22.5	608.17	223,000
5	March 23, 1973	21.84	14	607.31	214,420
6	April 20, 1870	21.83	N.A.	607.30	N.A.
7	June 23, 1880	21.70	N.A.	607.17	N.A.
8	May 12, 1888	21.40	N.A.	606.87	N.A.
9	April 7, 1920	21.00	N.A.	606.47	N.A.
10	April 21, 1922	21.00	N.A.	606.47	N.A.

Table 2.4b. Ten Highest Known Flood Stages at Keokuk, IA, River Mile 364.1

Order	*Date of crest*	*Stages (feet)*	*Days above flood stage*	*Elevations (feet msl)*	*Estimated peak discharge (cfs)*
1	April 27, 1973	23.35	33	501.18	344,000
2	May 1, 1965	22.14	33	499.97	327,000
3	April 4, 1960	21.83	10	499.66	289,500
4	May 27, 1944	20.85	N.A.	498.68	256,000
5	June 6, 1903	19.60	N.A.	498.43	270,000
6	April 29, 1951	20.30	32	498.13	265,100
7	May 18, 1888	19.60	N.A.	497.43	314,000
8	June 29, 1892	19.25	N.A.	497.08	306,000
9	Oct. 31, 1881	18.90	N.A.	496.73	293,000
10	June 29, 1880	17.50	N.A.	495.33	271,000

Table 2.4c. Ten Highest Known Flood Stages at Hannibal, MO, River Mile 309.9

Order	*Date of crest*	*Stages (feet)*	*Days above flood stage*	*Elevations (feet msl)*	*Estimated peak discharge (cfs)*
1	April 25, 1973	28.6	95	477.9	414,000
2	May 4, 1965	24.5	44	473.8	349,000
3	June 14, 1947	24.1	14	473.4	339,000
4	April 1960	23.4	N.A.	472.7	324,000
5	May 13, 1951	22.6	48	471.9	307,000
6	June 1903	22.5	N.A.	471.8	340,000
7	May 9, 1888	21.8	N.A.	471.1	390,000
8	April 1897	20.8	N.A.	470.1	316,000
9	July 1892	20.8	N.A.	470.1	316,000
10	October 7, 1881	20.6	N.A. (long)	469.9	397,000

Table 2.4d. Ten Highest Known Flood Stages at St. Louis, MO, River Mile 179.6

Order	*Date of crest*	*Stages (feet)*	*Days above flood stage*	*Elevations (feet msl)*	*Estimated peak discharge*
1	April 28, 1973	43.23	77	423.17	852,000
2	June 27,1844	41.32	N.A.	421.26*	1,300,000*
3	July 22, 1951	40.28	N.A.	420.22	782,000
4	July 2, 1947	40.26	N.A.	420.20	783,000
5	April 30, 1944	39.14	N.A.	419.08	844,000
6	May 24, 1943	38.94	N.A.	418.88	840,000
7	June 10, 1903	38.00	N.A.	417.94	1,019,000
8	June 1850	37.12	N.A.	417.06	1,054,000
9	June 1855	37.10	N.A.	417.04	1,050,000
10	June 10, 1851	36.52	N.A.	416.48	1,022,000

*These floods predate the gaging records at St. Louis elevations. Elevations are based on high-water mark(s). Discharges are estimated by extending early rating curves from the gage.

Table 2.4e. Ten Highest Known Flood Stages at Chester, IL, River Mile 109.9

Order	*Date of crest*	*Stages (feet)*	*Days above flood stage*	*Elevations (feet msl)*	*Estimated peak discharge (cfs)*
1	April 30, 1973	43.32	97	384.37	886,000
2	July 22, 1951	39.30	N.A.	380.35	795,000
3	July 3, 1947	38.17	N.A.	379.22	886,000
4	May 24, 1943	38.08	N.A.	379.13	873,000
5	May 2, 1944	37.40	N.A.	378.45	842,000
6	July 15, 1969	35.73	N.A.	376.78	N.A.
7	November 23, 1985	35.14	N.A.	376.19	620,000
8	April 27, 1927	34.40	N.A.	375.45	1,060,000
9	April 2, 1945	34.40	N.A.	375.45	716,000
10	April 30, 1952	34.40	N.A.	375.45	685,000

date back to 1861 when the first continuous gage records started at St. Louis. Recording for other stations began in the late 1800s. These tables show that in general, flood durations at the upstream reaches are shorter than those downstream. Also, floods generally occurred in early spring at upstream reaches, but downstream they occurred in both spring and summer.

Two major tributaries upstream of St. Louis have a significant effect on flood stages at St. Louis. The Missouri River, with a drainage area of 529,350 square miles, enters the Mississippi at river mile 195.2, approximately 15 miles upstream of St. Louis; and the Illinois River, with a drainage area of 28,900 square miles, enters the Mississippi at river mile 218.2, approximately 38 miles upstream of St. Louis. Flood season for this reach is April through July, when 75 percent of the floods occur. The most severe floods are produced by periods of persistent warm, rainy weather.

Over the years several flood control measures have affected flooding on the Mississippi River. These have included levees and floodwalls, channel improvements, and flood control reservoirs. Although there are no flood control reservoirs on the main stem of the Mississippi River, many are located on major tributaries, primarily in the Missouri River basin, and these provide some degree of flood protection. Travel time of flood peaks normally increases significantly from Hannibal to St. Louis and again from St. Louis to Chester and beyond.

Chester is located downstream of the Kaskaskia River (drainage area 5,800 sq mi). Here the flood season is also from April through July, and 75 percent of the maximum annual floods occur during this period. Levees and floodwalls are designed to protect local areas from flooding.

The flood of 1973 produced the highest flood stages on record on the UMRS prior to the flood of 1993. The earlier flood was caused by heavy spring rainfalls, but antecedent conditions also affected the amount of water that entered the river. Winter snow cover was fairly light, but temperature patterns were variable in late December 1972 and early January 1973. This permitted some of the snow cover to melt and also caused some precipitation to fall in the form of rain rather than the usual snow. These factors contributed to increased runoff and streamflow. During March and April 1973, rainfall was generally much above normal throughout the Upper Mississippi basin. New monthly rainfall records were set for March at Moline (7.43 inches) and at Quincy, Illinois (8.65 inches). In April, 9.92 inches were recorded at Rockford and 10.69 inches at Moline, Illinois. Flooding caused some damage throughout various reaches of the Mississippi River. However, the most significant losses were below Burlington, Iowa. At Hannibal, Missouri, the river rose from a low-water stage of 11.6 feet to a peak stage of 28.6 feet in about 53 days, and remained near or above the 16-foot flood stage for approximately 104 days (summarized from U.S. Army Corps of Engineers, 1975, 1977).

Historical Background of the Levees (Singh)

The Mississippi River valley in Illinois and the Illinois River valley from Peoria to Grafton were transformed from permanent, seasonal wetlands to a relatively flood-free agricultural landscape of great productivity (Thompson, 1989) by the construction of levees and the organization of drainage districts, mostly between 1879 and 1916. A levee protects the floodplain from floods equal to or less than the design flood for which the levee was built. Typically, the farmers/owners in an area who desire to be protected by a levee jointly petition the county court to form a drainage and levee district with four main functions: 1) to construct a levee to provide the needed protection against flooding; 2) to dig and maintain drainage ditches to collect ground-water seepage and storm runoff from the floodplain protected by the levee and from directly draining adjacent areas, and to keep the water table sufficiently below ground level for good crop yields; 3) to provide, operate, and maintain a suitable sized pumping plant to remove surplus seepage and ground water; and 4) to maintain the facilities in good condition and equitably charge farmers/owners in the drainage and levee district for annual maintenance and improvement costs. If the court agrees with the petition, then organization of a levee and drainage district is approved.

The concept of drainage district formation for mutual benefit is based on a system of assessments that permits districts to include only lands benefited by the organization of a drainage district. “Drainage districts have played an important role in the development of Illinois — both agriculturally and economically. Through their formation and operation, the fertile wetlands and major floodplains of the state have been developed into prime agricultural lands. Continued operation and improvement of these drainage districts will allow this progress to continuc” (Illinois Department of Business and Economic Development, 1971).

Not all levee and drainage districts organized between 1879 and 1916 still exist today. Some were dissolved because of excessive costs, frequent levee failures, problems with pumping excess water, and so forth. The design floods and stages along the Mississippi and Illinois Rivers have changed over time with construction of more levees (thus reducing valley storage and probably increasing flood stages); with construction of locks and dams to make these rivers navigable year-round; and as agriculture intensified, as urbanization increased, and as some climate changes were ascribed to increasing chlorofluorocarbons and carbon dioxide concentrations in the atmosphere. These changes led the U.S. Army Corps of Engineers to investigate the adequacy and safety of existing levees along the Mississippi River and to make plans for improvements as needed. Many levees have been improved over the years with flatter slopes, higher crown elevations corresponding to a 50-year design flood plus 2 feet of freeboard, provision of berms where foundation conditions so dictated, crushed stone roads atop the levees, and seepage relief wells where deemed necessary.

Illinois Drainage and Levee Districts along the Mississippi River

The following references were used in locating the various existing Illinois drainage and levee districts along the Upper Mississippi River from the Illinois-Wisconsin border (river mile 580.7) to its confluence with the Ohio River. River miles for the UMR are measured from the confluence of the Mississippi and Ohio Rivers.

1. Upper Mississippi River Navigation Charts (U.S. Army Corps of Engineers, 1989).

2. Water Resources Management Plan, Vol. 1, Upper Mississippi Region (Upper Mississippi River Basin Commission, 1980).

3. Inventory of Illinois Drainage and Levee Districts, Volumes I and II (Illinois Department of Business and Economic Development, 1971).

Figures 2.12 and 2.13 show the existing levees along the Illinois and Mississippi Rivers in the state of Illinois. And table 2.5 lists the levees and drainage districts on the Illinois side of the Mississippi River, their locations according to river miles at their extremities, levee crowns in feet above mean sea level as obtained from various Mississippi River Flood Control Project maps, drainage district areas in acres, years of organization, and remarks containing other relevant information. All levees whose crown levels are given in table 2.5 have been improved over the years. The list of levees may not be complete, but it is based on the information presently available.

Drainage and Levee Districts along the Alton Pool of the Illinois River

The following references were used in locating the existing drainage and levee districts along the Alton pool of the Illinois River:

1. Charts of the Illinois Waterway (U.S. Army Corps of Engineers, Chicago, Illinois, 1987).

2. Inventory of Illinois Drainage and Levee Districts, Volumes I and II (Illinois Department of Business and Economic Development, 1971).

The drainage and levee districts along the Illinois River are described in table 2.6. This table also locates the levees according to river miles corresponding to their upstream and downstream extremities. The drainage districts are also described by area in acres with the year of organization. The remarks contain other relevant information. Five drainage and levee districts (South Beardstown, Coon Run, Mauvaise Terre Creek, Keach, and Nutwood) were improved between 1932 and 1941 by the Corps of Engineers. The levee of the McGee Creek Drainage and Levee District (Brown County) was improved recently, and its crown was raised to the level of a 50-year-high backwater from the Mississippi River, which coincides with the 1943 flood of record. According to the U.S. Army Corps of Engineers, many existing levees along the Illinois River are substandard.

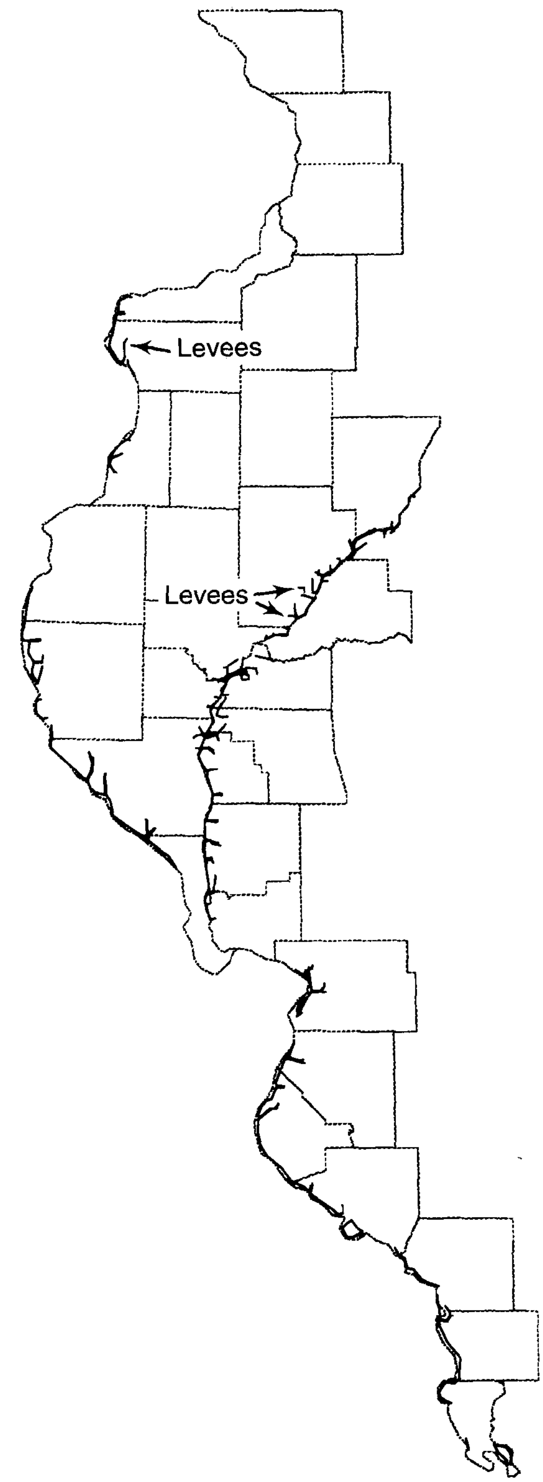
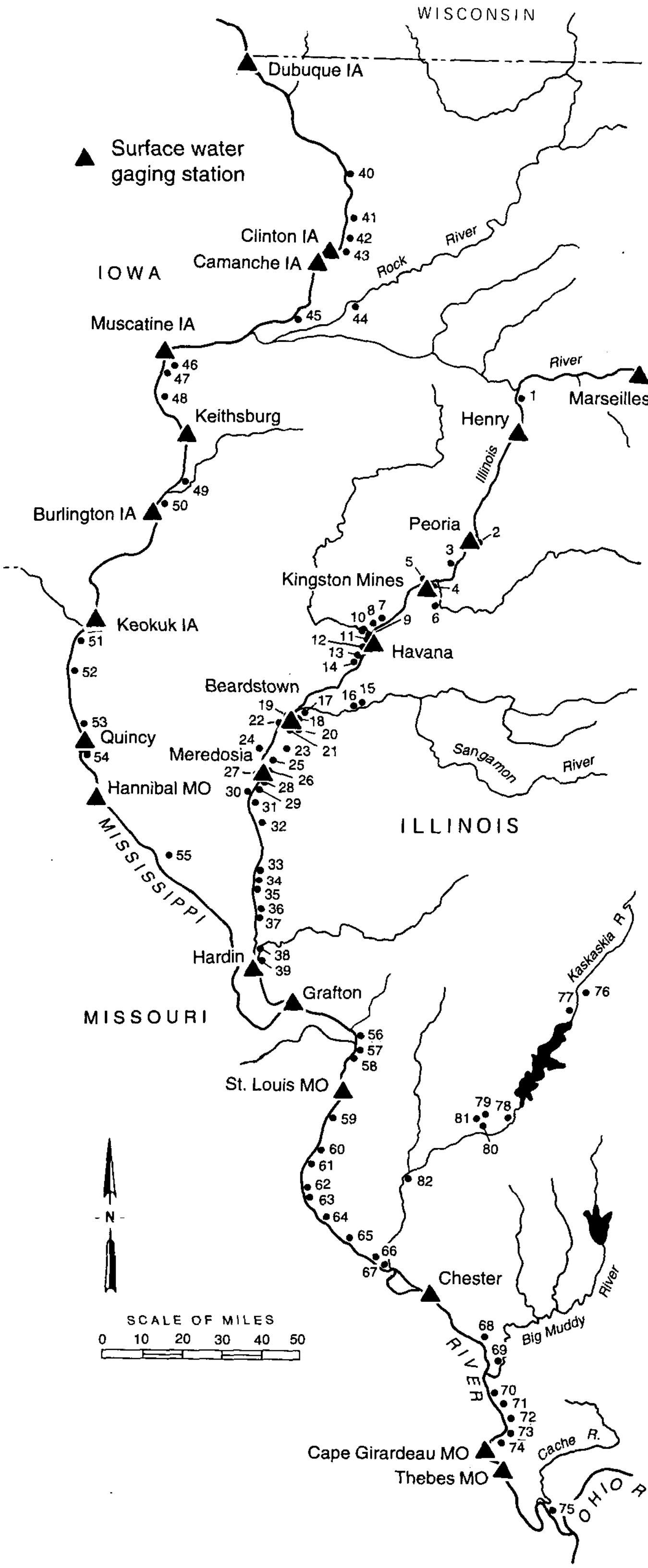


Figure 2.12. Existing levees along the Illinois and Mississippi Rivers within the borders of Illinois



NO.	COUNTY	DRAINAGE AND LEVEE DISTRICT
1	PUTNAM	HENNEPIN
2	TAZEWELL	EAST PEORIA
3	PEORIA	PEKIN & LA MARSH
4	TAZEWELL	SPRING LAKE
5	PEORIA	BANNER SPECIAL
6	TAZEWELL	MACKINAW RIVER
7	FULTON	EAST LIVERPOOL
8	FULTON	LIVERPOOL
9	FULTON	THOMPSON LAKE
10	FULTON	ZEMPEL MUTUAL
11	FULTON	KERTON VALLEY
	FULTON	LACEY
	FULTON	LANGELLIER
	FULTON	WEST MATANZAS
12	FULTON	SEAHORN
13	SCHUYLER	BIG LAKE
14	SCHUYLER	KELLY LAKE
15	MASON	HERGET
16	MASON	FARMERS LEVEE AND RIVER
17	CASS	HAGER SLOUGH
18	CASS	LOST CREEK
19	SCHUYLER	COAL CREEK
20	CASS	VALLEY
21	CASS	SOUTH BEARDSTOWN
22	SCHUYLER	CRANE CREEK
23	CASS	MUD CREEK
24	BROWN	LITTLE CREEK
25	CASS	MEREDOSIA LAKE
26	MORGAN	WILLOW CREEK
27	BROWN	MCGEE CREEK
28	MORGAN	COON RUN
29	SCOTT	MAUVAISE TERRE
30	PIKE	VALLEY CITY
31	SCOTT	SCOTT COUNTY
32	SCOTT	BIG SWAN
33	GREENE	HILLVIEW
34	GREENE	HARTWELL
35	GREENE	KEACH
36	GREENE	SPANKEY
37	GREENE	ELDRED
38	GREENE	MACOUPIN CREEK
39	JERSEY	NUTWOOD
40	CARROLL	CARROLL COUNTY MUTUAL
41	WHITESIDE	JOHNSON CREEK
42	WHITESIDE	CATTAIL
43	WHITESIDE	MEREDOSIA
44	HENRY	PENNY SLOUGH
45	ROCK ISLAND	CAMPBELLS ISLAND
46	ROCK ISLAND	DRURY
47	ROCK ISLAND	SUBDISTRICT #1
48	MERCER	BAY ISLAND
49	HENDERSON	HENDERSON COUNTY #1
50	HENDERSON	HENDERSON COUNTY #2
51	HANCOCK	HUNT
52	ADAMS	LIMA LAKE
53	ADAMS	INDIAN GRAVE
54	ADAMS	SOUTH QUINCY
55	PIKE	SNY ISLAND
56	MADISON	WOOD RIVER
57	MADISON	CHOUTEAU, NAMEOKI, & VENICE
58	MADISON	CHOUTEAU ISLAND
59	ST. CLAIR	PRAIRIE DUPONT
60	MONROE	FISH LAKE
61	MONROE	COLUMBIA
62	MONROE	HARRISONVILLE & IVY LANDING
63	MONROE	MOREDOCK & IVY LANDING
64	MONROE	FORT CHARTRES & IVY LANDING
65	MONROE	STRINGTOWN-FORT CHARTRES & IVY LAND
66	RANDOLPH	PRAIRIE DUROCHER & MODOC
67	RANDOLPH	EDGAR LAKE
68	JACKSON	DEGOGNIA & FOUNTAIN BLUFF
69	JACKSON	GRAND TOWER
70	UNION	PRESTON
71	UNION	MILLER POND
72	UNION	CLEAR CREEK
73	ALEXANDER	NORTH ALEXANDER
74	UNION	EAST CAPE GIRARDEAU & CLEAR CREEK
75	ALEXANDER	CAIRO
76	FAYETTE	DIVELY
77	FAYETTE	VANDALIA
78	CLINTON	SANTA FE
79	CLINTON	GERMANTOWN
80	CLINTON	HANOVER
81	CLINTON	HEIMANN
82	ST. CLAIR	VILLAGE OF NEW ATHENS

Figure 2.13. Streamgaging stations and drainage and levee districts along the Mississippi and Illinois Rivers (after Ramamurthy et al., 1987)

Table 2.5. Active Drainage and Levee Districts along the Mississippi River in Illinois

Name	*Approximate river miles*	*Levee crown (feet msl)*	*Acres*	*Year organized*	*Remarks*
Carroll County					
Carroll Country Drainage and Levee District	536.0-531.6		3,057	1923	Now Spring Lake Wildlife and Fish Refuge
Whiteside County					
Johnson Creek Drainage and Levee District	526.0-523.0		3,211	1905	Has two subdistricts
Cattail Drainage and and Levee District	523.0-518.0		5,964	1907	
Meredosia Drainage and	512.8-510.6		10,413	1896	Also in Rock Island County
Rock Island County					
Campbells Island Drainage and Levee District	491.0-489.9		226	1954	
Drury Drainage and Levee District	459.0-450.8	558.6-556.6	4,358	1906	
Union Drainage and Levee District No. 1 of Rock Island and Mercer (also Union Drainage District No. 1 of Drury and Eliza)	450.8-446.7	555.0	4.370	1905	Also in Mercer County
Mercer County					
Bay Island Drainage and Levee District	446.7-434.0	555.8-553.2	17,705	1906	Continuation of Union Levee in Rock Island County
Keithsburg Drainage and Levee District	431.0-428.0		1,260	1909	Now Upper Mississippi River Wildlife and Fish Refuge
Henderson County					
Henderson County Drainage and Levee District No. 3	414.8-411.5		2,190	1913	
Henderson County Drainage and Levee District No. 1	411.4-403.2	540.5-535.4	6,183	1912	
Henderson County Drainage and Levee District No. 2	403.2-400.7	535.4-534.2	6,642	1911	
Hancock County					
Hunt Drainage and Levee District	358.6-347.3	500.6-495.7	15,294	1879	Also in Adams County
Adams County					
Lima Lake Drainage and Levee District	347.3-341.7	495.7-493.0	13,258	1880	Continuation of Hunt Drainage and Levee District
Indian Grave Drainage and Levee District	341.5-330.0	493.0-488.1	17,889	1880	
South Quincy Drainage and Levee District	325.4-318.0	487.2-481.8	5,515	1913	
Pike County					
Sny Island Drainage and Levee District (includes many subdistricts)	316.0-265.9	475.0-459.0	108,473	1880	Also in Adams and Calhoun Counties and includes 6-mile drainage district

Table 2.5. Continued

Name	*Approximate river miles*	*Levee crown (feet msl)*	*Acres*	*Year organized*	*Remarks*
Calhoun County					
Sand Levee for State Fish and Waterfowl Management Area	265.9-264.3		450		
Madison County					
Wood River Drainage and Levee District	202.7-195.1	445.4-443.4	3,850	1910	
Chouteau Island Drainage and Levee District	193.8-184.2		2,054	1881	
East Side Levee and Sanitary District (also in St. Clair County)	194.9-175.0	446.7-429.8	61,650	1907	Includes Chouteau, Nameoki, and Venice Drainage and Levee Districts
St. Clair County					
Wilson and Wenkel and Prairie Du Pont Drainage and Levee District	175.0-168.8	429.7-425.3	8,191	1885	Also in Monroe County
Monroe County					
Fish Lake Drainage and Levee District No. 8	168.8-166.2	425.3-424.2		1947	
Columbia Drainage and Levee District No. 3	166.1-156.3	419.0-414.2	13,208	1882	Includes many subdistricts
Harrisonville and Ivy Landing Drainage and Levee District	156.1-140.8	414.2-407.4	29,369	1882	Includes Moredock and Ivy Landing Drainage District
Stringtown-Fort Chatres and Ivy Landing Drainage and Levee District (also in Randolph County)	140.8-130.0		12,638	1884	Includes Stringtown Drainage and Levee District
Randolph County					
Prairie du Rocher and Modoc Drainage and Levee District	129.9-117.9	402.5-394.6		1945	
Kaskaskia Island Drainage and Levee District	115.5-111.6		9,362	1916	West of Mississippi River
Jackson County					
Degonia and Fountain Bluff Drainage and Levee District	99.3-84.1	385.6-375.7	29,260	1910	Includes Big Lake, Boone Pond, and Jones Pond Districts
Grand Tower Drainage and Levee District	81.6-76.0	372.8-370.0	2,620	1909	
Union County					
Preston Drainage and Levee District	75.6-66.0	368.4-364.2	20,127	1913	Includes Miller Pond Drainage District
Clear Creek Drainage and Levee District	66.0-56.5	364.2-360.1	20,698	1913	Also in Alexander County and includes North Alexander Drainage District behind it

Table 2.5. Concluded

Name	*Approximate river miles*	*Levee crown (feet msl)*	*Acres*	*Year organized*	*Remarks*
Alexander County					
East Cape Girardcau and Clear Creek Drainage and Levee District	56.5-45.8	360.1-351.0	9,370	1908	
Miller City/Fayville/Len Small Drainage and Levee District	34.3-26.7				
Cairo Drainage and Levee District	12.8-0.8		6,440	1889	

Levee Design, Construction, and Failure (Singh)

Most of the Illinois levees along the Mississippi and Illinois Rivers were originally built from 1879 through 1916 to protect reclaimed floodplains from inundation. They have been improved since then from time to time. Organized levee and drainage districts converted these plains to highly productive agricultural lands. The majority of existing levees, however, fail to provide the degree of protection presently required for the prime farmlands; the mitigatory drainage ditches and pumping equipment; and the farm structures, homes, and ancillary business operations currently located on the floodplains. Construction of the old levees suffered from incomplete knowledge about several relevant topics: 1) levee materials and their compaction, 2) piping failure potential and suitable measures to guard against it, 3) the settling of levees over time due to compaction and ground consolidation, 4) design flood and the corresponding required levee heights, 5) the necessary allowance for levee settling and increased flood stages as other levees were constructed upstream and downstream, 6) clay-core cutoffs to mitigate seepage problems and provision of berms and clay blankets, and 7) foreseeable changes that could affect future levee design and operation (Peter, 1982). Some relevant considerations in levee design, construction, and failure avoidance are described briefly.

Levee Design

Levee height rarely exceeds 30 feet and is usually less than 20 feet. While the older levees were designed for protection against 50-year floods or less, the present consensus favors protection against a 100-year flood. The freeboard should be sufficient and adequate to accommodate some levee settlement and wind-driven water waves. Although 2 feet of freeboard are usually provided, 4 to 5 feet are desirable. The average levee slope (vertical:horizontal) should be 1:2-l/2 or 3 (river side) and 1:3 or 4 (land side), depending on me permeability of the soils constituting me levee.

Berms are desirable with adverse ground conditions or when the subsoil has sand layers sandwiched between relatively impervious clay or silty layers — a combination often found in the floodplains. A relatively impervious soil blanket can minimize the problem of sand boils. A gravel filter toe along the levee on the land side, a drainage ditch close to the levee, or pressure relief wells provide extra protection against piping, liquefaction, and channeling in the subsoil, and against loss of levee slope stability and so forth.

Width at the levee top should be 10 to 20 feet or more, so that major levees can support a crushed stone road to facilitate levee maintenance and repair. Figure 2.14 shows a typical cross

Table 2.6. Active Drainage and Levee Districts along the Illinois River: Alton Pool

Name	*Approximate river miles*	*Levee crown (feet msl)*	*Acres*	*Year organized*	*Remarks*
Cass County					
South Beardstown Drainage and Levee District	87.4-78.9		6,851	1913	
Meredosia Lake and Willow Creek Drainage and Levee District	78.6-72.7		8,044	1903	Also in Morgan County and includes Willow Creek Drainage District
Brown County					
Big Prairie Drainage and Levee District	83.2-80.5		1,807	1916	
Little Creek Drainage and Levee District	78.3-75.1		1,610	1922	
McGee Creek Drainage and Levee District	75.0-67.1		10,780	1905	Also in Pike County
Morgan County					
Coon Run Drainage and Levee District	71.0-65.5		4,361	1899	
Scott County					
Mauvaisterre Creek Drainage and Levee District	65.8-63.4		4,066	1902	Includes Robertson Private Levee District
Scott County Drainage and Levee District	63.1-56.7		10,245	1909	
Big Swan Drainage and Levee District	56.5-50.1		12,749	1903	
Hillview Drainage and Levee District	50.0-43.2		12,323	1906	Also in Greene County
Pike County					
Valley City Drainage and Levee District	66.2-62.5		4,476	1920	
Greene County					
Hartwell Drainage and Levee District	43.1-38.2		8,709	1904	
Keach Drainage and Levee District	38.0-32.8		7,892	1903	
Eldred and Spankey Drainage and Levee District	32.4-23.8		8,348	1909	
Jersey County					
Nutwood Drainage and Levee District	23.6-15.1		10,619	1906	

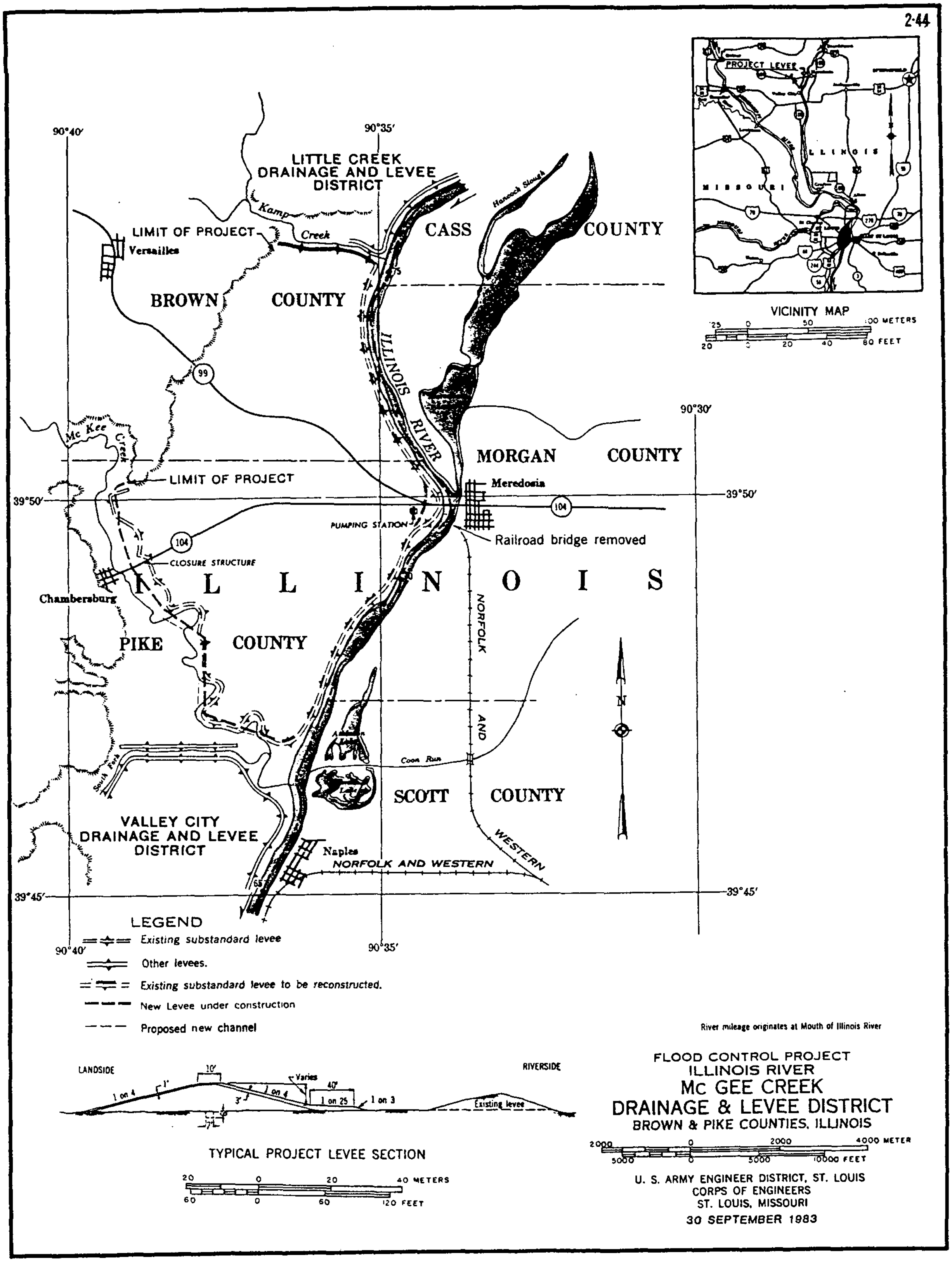


Figure 2.14. McGee Creek Levee and Drainage District along the Illinois River (after USACOE, 1980)

section of an existing levee and a new project levee (lower left corner) completed recently for the McGee Creek Drainage and Levee District along the Illinois River in Brown and Pike Counties. Figure 2.15 shows a typical project levee section (lower left) for the Wilson and Wenkel and Prairie du Pont Drainage and Levee Districts along the Mississippi River in Monroe and St. Clair Counties.

In choosing an embankment section for a levee, Peter (1982 pp. 281-282) notes several factors to consider: "The physical and mechanical properties of materials used in construction; the hydrogeological condition of the subsoil and its physical and mechanical properties, control of seepage in the body of the embankment, and especially in the subsoil; the method of drainage at the downstream foot; and finally the period during which the embankment might be subjected to loading from the design through-flow, and whatever results originate from this (seepage, uplift, drainage of surrounding lands, etc.)."

"The design of antiseepage and control measures is based on a detailed analysis of seepage under given geological conditions. Where high hydraulic gradients exist, there is a possibility that the seepage water may erode channels within the dam or in its subsoil, especially if the soil is loose (sands, sandy soils). The control drain designed as a filter to provide a barrier to soil particles carried out from the dam body and its subsoil is also an interceptor, keeping the downstream slope in an unsaturated state. With the subsoil more permeable, deep compaction and a ditch collecting seepage water can be useful" (Peter, 1982, p. 341-342).

Levee Construction

Levees are among the world's oldest hydraulic engineering embankments. Despite significant improvement in levee construction, neither current knowledge about soil mechanics, hydraulics, hydrology, and hydrogeology, nor current construction technology are adequately considered in their design and construction. Levee construction in a river valley must take into consideration wide fluctuations in flow and even medium to high floods. Most levee problems are caused by alternating soil layers of high and low permeability at some depth below the soil surface.

In Kansas, levee failures "were traceable to numerous causes, among which were poor construction, grades not in conformity with flood profiles, inadequate maintenance, as well as failure to provide sufficient floodway" (Kansas Board of Agriculture, 1947). The weak point in a levee is the interface between the ground surface and the levee. Construction of foundation seepage control and stability features, as per design, must be scrupulously supervised during construction. All organics and other unsuitable material should be removed from the earth foundation, which should be moistened (if necessary) and compacted with tamping rollers to obtain a proper bond with the successive 9- to 12-inch layers of levee materials. These layers should be individually compacted by 8 to 12 passes of tamping rollers under proper moisture control. In the case of cohesionless soils, the most effective method of compaction is by vibrating the materials when they are perfectly dry or when they are saturated with water. Borrow pits should be properly marked, depths of cut determined, and the section of levee to which a particular material is to be delivered should be specified (U.S. Bureau of Reclamation, 1977). The embankment samples should be routinely tested for quality control. Field density tests are necessary for compaction control.

Levee Failure

Failure of a levee by overtopping can occur regardless of any foundation problems. As the floodwaters start flowing over the levee crown toward the land side, soil erosion begins. This is

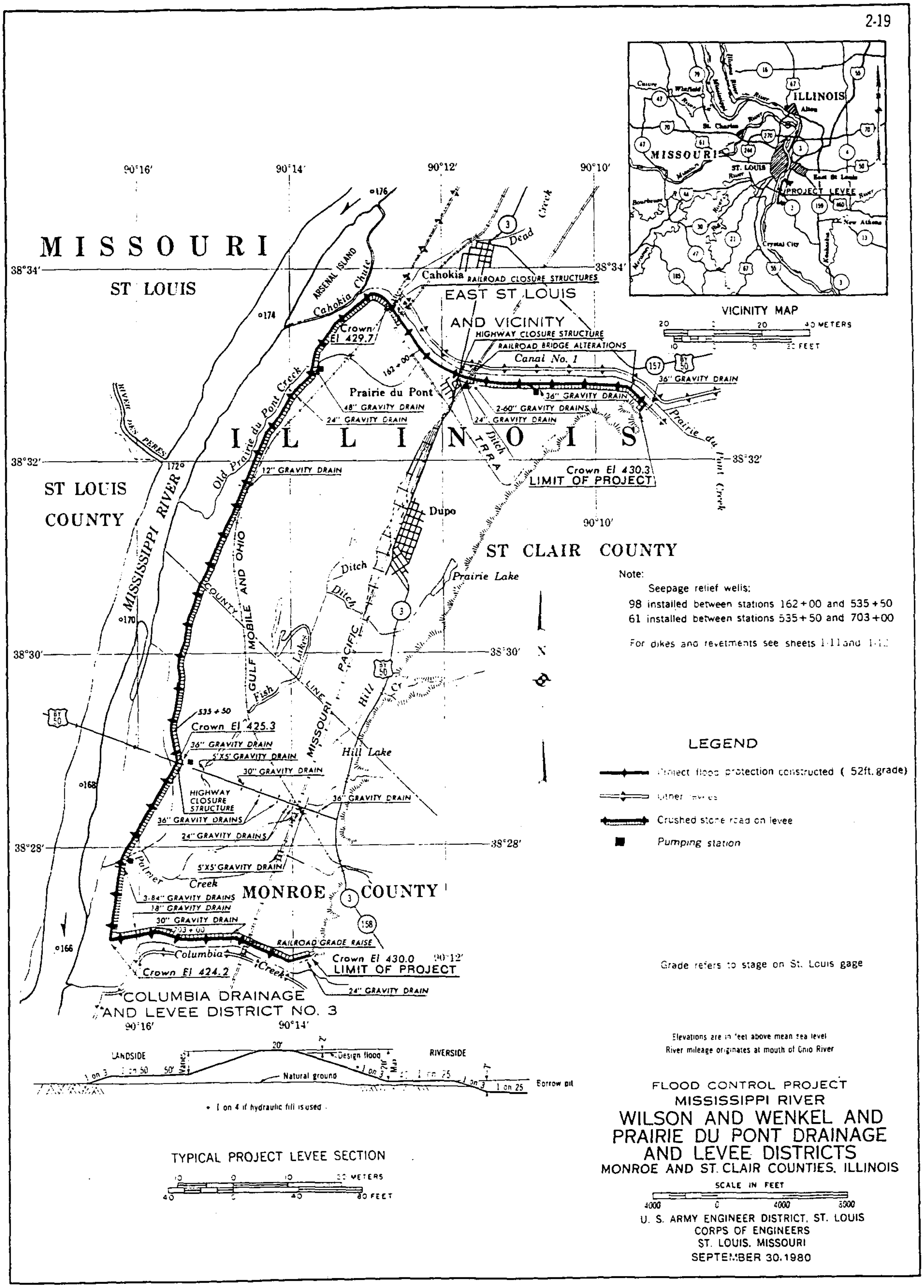


Figure 2.15. Wilson and Wenkel and Prairie du Pont Drainage and Levee Districts along the Mississippi River in Illinois (after USACOE, 1980)

progressively aggravated by several factors: increasing water depths and velocities, rapid erosion of the levee crown, and erosion of the land-side face of the levee. When levee failure or breach eventually occurs, it is typically limited to a few weak and somewhat lower sections (probably because of settling) of the levee.

In the Upper Mississippi and Lower Illinois River floodplains, alluvial deposits are covered by one or more layers of relatively pervious material or by layers of less permeable silty sands and slightly permeable clays. In many cases, conditions favor sand boils, the relatively fast passage of flood waters through pervious layers under the levee base to the area protected by the levee. This in turn leads to the phenomenon of piping.

Piping flows gradually widen the flow channels by removing soil under the levee foundation. Depending on the amount of material removed, the levee may settle unevenly, crack, or even fail by overtopping. Under these conditions, even if floodwaters did not overtop the levee, piping can cause the levee to fail if high-water stages last for several days or weeks. However, the levee will fail by overtopping if the flood stages rise rapidly, without allowing sufficient time for piping failure to develop. The circumstances leading to piping failure are cumulative to a certain extent. For example, flow channels developed in the layers below the levee during one flood event will be vulnerable to further widening if subsequent flood stages are significantly higher. Several measures can guard against piping and sand boils:

1. Lengthen the path of seepage and thus reduce the velocity and the quantity of water movement (e.g., place horizontal, relatively impervious blankets of clay or asphalt in front of the levee).

2. Reduce permeability along the vertical, 20 to 30 feet deep, through depth vibration and vibroflotation, thus creating a relatively impervious and inexpensive cutoff.

3. Reduce uplift and pore pressures and increase levee stability by installing relief wells, ditches, and inverted filter toes on the land side of the levee.

Levee failure can also occur because of saturation of levee materials and loss of soil stability. As the flood level rises, so too does the line or curve of saturation in the levee, although it is usually lower than that occurring at a particular flood level under steady-state conditions. The levee cross section and its materials, and the existence of relief wells, ditches, or levee toe filters on the land side generally determine whether the line or curve of saturation remains well within the levee near the land side toe. When the line or curve of saturation exceeds the ground level at the toes, seepage and sloughing of the slope occur in the affected portion, resulting in loss of slope stability.

Waves, whether they are caused by wind or by commercial or recreational vessels, can also impact the river-side slope of the levee, especially if the levees are close to the navigation channel and the river is in flood stage). To allow for water-level fluctuations caused by waves, about 2 feet of freeboard is provided over and above the river stage corresponding to the design flood. Waves caused by high-speed winds traversing broad rivers, such as on the Mississippi during high flood stages, can also adversely impact the river side of the levee unless it is suitably protected or maintained. Levees can fail from gradual wearing down of the levee top and water flowing over it if the upper portion of the levee is not adequately compacted and maintained and if the freeboard is not adequate for water levels.

Bogardi and Mathe (1968) have considered various phenomena leading to levee failure (figure 2.16), including: 1) overtopping, 2) sand boils and hydraulic soil failure, 3) saturation and

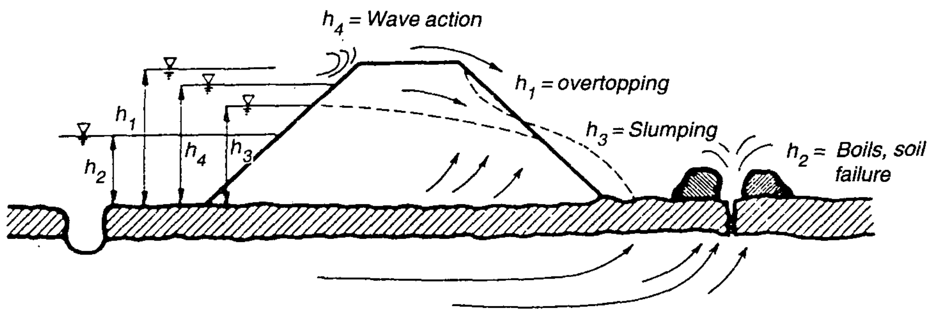


Figure 2.16. Conceptual levee failure mechanisms (after Bogardi and Mathe, 1968)

loss of levee stability, and 4) wave action. The corresponding lowest water levels triggering these phenomena are marked schematically as h_1, h_2, h_3, and h_4 in the figure. The degree of protection critical for the cross section is the lowest of these levels.

The design and construction of levees must consider mitigation of all factors that may contribute to levee failure. Projections of any future increase in design flood stages must also be given due consideration in levee design. Adequate field testing of foundation soil strata and the materials used for levee construction will help in devising protective measures to prevent levee failure from piping, sand boils, and slope instability.

A flooded home
in the upper Quincy area

3. THE 1993 FLOOD (Bhowmik)

The 1993 flood on the Mississippi and Illinois Rivers occurred during the spring, summer, and early fall. This flood has now been recognized as one of the largest on the Mississippi River (Parrett et al., 1993). The peak discharges at various points along the Mississippi bordering the state of Illinois were the result of higher-than-average precipitation through the spring and summer, and the occurrence of this precipitation on a more or less continuous basis. This section will present some of the basic information related to the 1993 flood on the Mississippi and Illinois Rivers. However, it should be noted that the lllinois River flood and the associated levee failures in the lower reaches of the river and in the Alton pool resulted mostly from the backwater effect of the Mississippi River.

Synoptic Basis for the Flood of 1993 (Scott)

Thunderstorms regularly move across the Midwest during the late spring and summer months and bring heavy rainfall to the region. Small localized cloudbursts occur frequently, and larger weather systems provide substantial amounts of precipitation in short periods of time to large sections of the area. These can occur several times during the warm months of the year, and usually do so without raising much widespread attention.

To a great extent, these heavy rain events provide a substantial portion of the annual precipitation required by one of the primary economic resources of the area: agriculture. Some of these heavy showers generate problems over very localized areas, especially to urban interests. Nevertheless, any rain is usually a blessing to agriculture, especially in years of predominantly dry weather, as in the recent devastating drought of 1988 over much of the upper Midwest (Lamb, 1992).

The problems experienced with rainfall over the eastern Great Plains and the western Midwest from May to August 1993 can be blamed primarily on abnormal patterns in the large-scale weather features overlying the region. Simply speaking, summertime weather patterns that are typical for the Midwest occurred only rarely, while those that usually appear only occasionally essentially became the norm. Thus, an atypical summertime weather pattern remained in place for many weeks and thrust the region into an anomalous climate, one in which heavy rains were much more frequent than climatology would suggest.

In average years, one of the dominant meteorological features across central parts of North America is the polar jet stream, a river of faster flowing air located high in the atmosphere. This stream is co-located with a boundary, or dividing line, between warmer air to the south and cooler air to the north. It is a semipermanent feature of the global atmosphere, and is created by meridional circulations between the equator and the Arctic.

One characteristic of the jet is that it acts as a pathway along which low-pressure systems or waves tend to move. As these systems progress, their cyclonic circulation often becomes more intense by "feeding off" the energy associated with contrasting densities of the opposing warm and cold air masses. The wind driven by the pressure gradients within the low pressure cause the opposing warm and cold air masses on either side of the jet to interact. When abundant moisture from the Gulf of Mexico, the Atlantic, or occasionally the eastern Pacific, is added to this mixture, the opportunity for rain formation is typically quite high.

This jet is also associated with intense snowstorms that occur in winter. These storms are followed by massive outbreaks of cold Arctic air that penetrate deep into the United States. In those months, the jet stream is often found as far south as the Gulf Coast, presenting a high amplitudinal loop across the country. The jet stream in summer, however, is usually much weaker and generally flows from west to east across the continent, with only minor north/south undulations. Furthermore, it flows most frequently north of the United States across southern Canada.

A second important feature in a typical summer over North America is a large region of high pressure in the Atlantic, well off the southeastern coast of the United States: the so-called Bermuda High. As with all anticyclones in the Northern Hemisphere, the clockwise circulation of this system provides a constant flow of warm, moist, tropical, westward-moving air over the Caribbean, across the Gulf of Mexico, and northward into the eastern half of the country.

Generally, these two systems remain quite far apart and interact only occasionally. However, they are not "fixed" features over their "average" locations. They can display substantial oscillations in strength and location, often changing positions by several hundred kilometers in a day or two, thus spreading their influences across a much larger area than just their typical climatological location.

If cold air over Canada were to strengthen and move south (causing the jet stream to be displaced south) at the same time as the high in the Atlantic moved west, the flow of air between the two systems would become more pronounced. A likely result would be additional rainfall in regions near the jet, as the warmer, moisture-laden air to the south interacted with the cooler air to the north. Furthermore, if some other mechanism caused these systems to become temporally semifixed in close proximity, heavy precipitation would continue to fall over much of the same area for as long as the weather patterns maintained this position.

This is precisely what occurred during the late spring and summer of 1993 over the eastern United States. As spring progressed, the typical migration of the polar jet to a more northerly location stalled as abnormally cool air from Canada was being advected into the northwestern United States. Figure 3. la shows an early but frequent location of the jet (large arrow) over the Central Plains on May 23, displaying moderate stength for late spring. In addition, an upper-level ridge was beginning to form along the East Coast. On the surface (figure 3.1b), a cyclone was found over the upper Midwest with an associated warm front extending to the east and a cold front stretching to the south. High pressure dominated the East Coast.

This alignment allowed for low-pressure systems to move deep into the United States, only to have their eastward progression blocked by the developing anticyclone along the East Coast. Air masses that were substantially cooler than normal for this time of year were thrust into the north-central part of the country and provided a large thermal contrast to temperatures just to the south. The high pressure, on the other hand, moved westward out of the Atlantic and became entrenched over South Carolina and Georgia. This created a continuous, deep flow of moisture that moved northward out of the western Gulf into the Central Plains and the western Midwest.

The weather patterns for the balance of the summer simply reiterated the features described above. Charts for June 25 (figure 3.2) and July 25 (figure 3.3) both show an alignment of pressure systems that brought copious amounts of precipitation to the flooded areas. That is, high pressure dominated the East Coast, while low pressure overlaid the central part of the country beneath an active jet stream aloft. These occurrences were frequent, with only occasional breaks in the heavy rainfall over the Mississippi and Missouri River basins. It was not until the first week in August that significant breaks in the persistent large-scale pattern appeared.

Why these weather patterns became fixed as they did in June and July is unclear and will likely be debated in the meteorological literature for some time to come. However, events such as these happen in all seasons, and can last for weeks or even a month or two at a time. As witness, remember the drought of 1988 over precisely the same area as this year's flood, or some of the prolonged wintertime cold periods in the late 1970s and early 1980s. Indeed, the persistence of the anticyclone over the Southeast this summer caused severe drought stress to crops and weeks of dangerously high temperatures to the inhabitants of the region. Details in subsequent chapters of this report will document the extent of the rainfall quantitatively, and begin to deal with the severe impacts on the people of the Midwest.

Precipitation Patterns (Wendland)

Precipitation in Early 1993

The flood over the Upper Midwest during spring, summer, and fall 1993 resulted from three conditions: 1) snowmelt in late winter-early spring, 2) very frequent, heavy rainfall from April through August, and 3) high soil moisture levels that yielded high runoff.

Precipitation in January and February was near average for the Upper Midwest, i.e., 2 to 3 inches over the Mississippi watershed. During March, precipitation amounted to less than 1 to 2 inches (about half of average) in southern Minnesota and Wisconsin. The northern sectors of those states realized less than 0.5 inch. Iowa, Illinois, and Indiana recorded near-average levels, i.e., 2 to 4 inches. Flooding began along the lower St. Croix River, which feeds into the Mississippi, and this flooding continued throughout the summer.

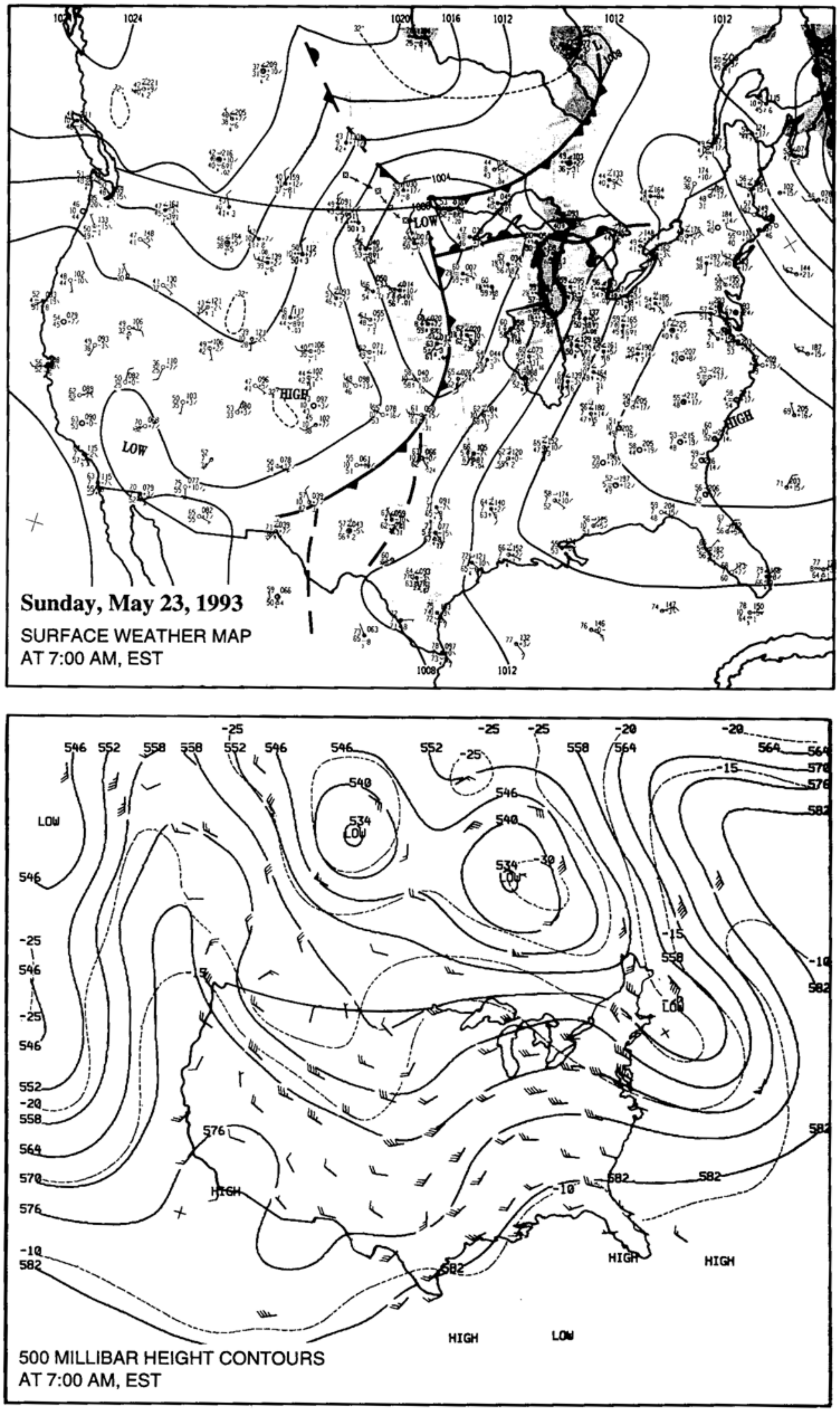


Figure 3.1. Weather map of the United States for May 23, 1993

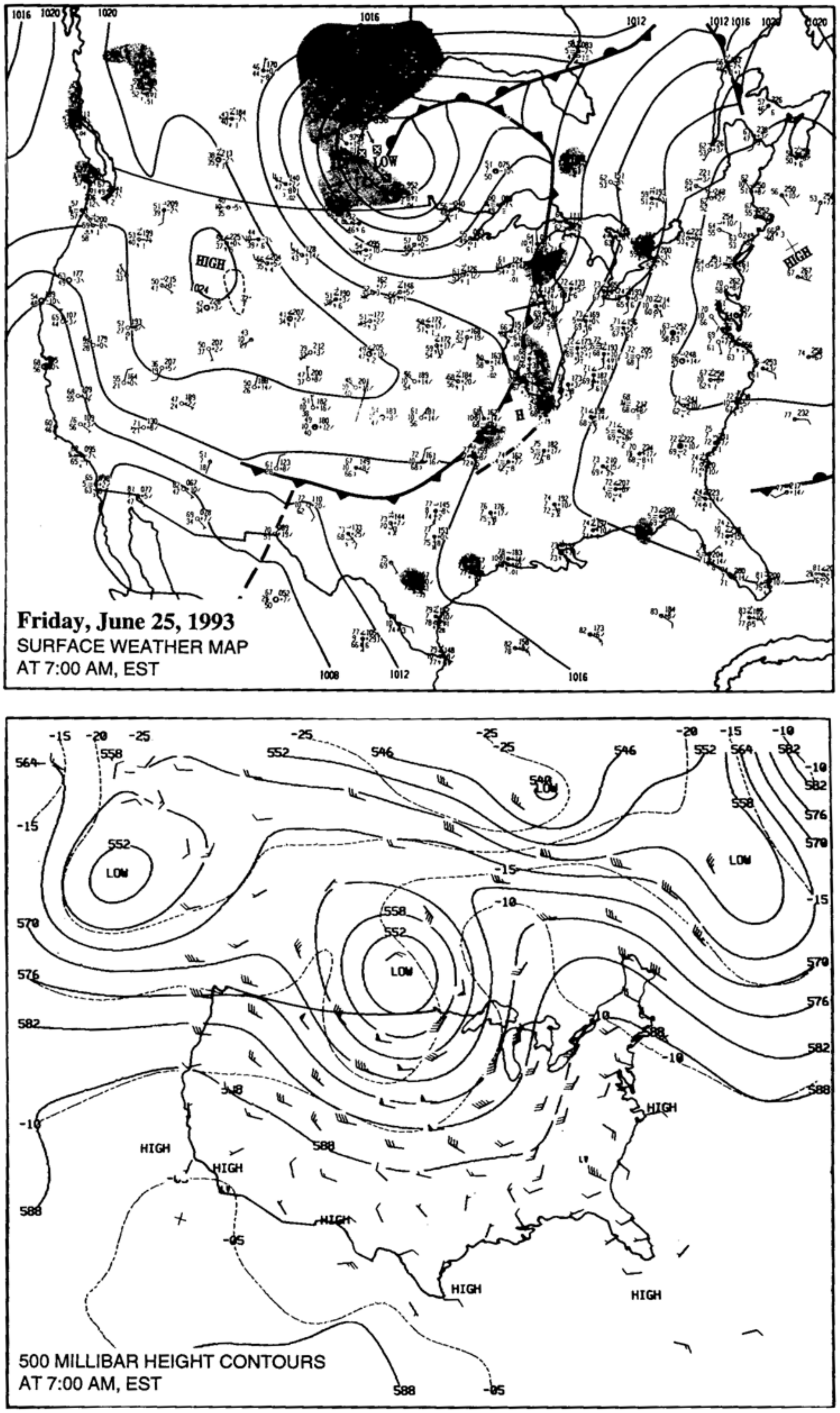


Figure 3.2. Weather map of the United States for June 25, 1993

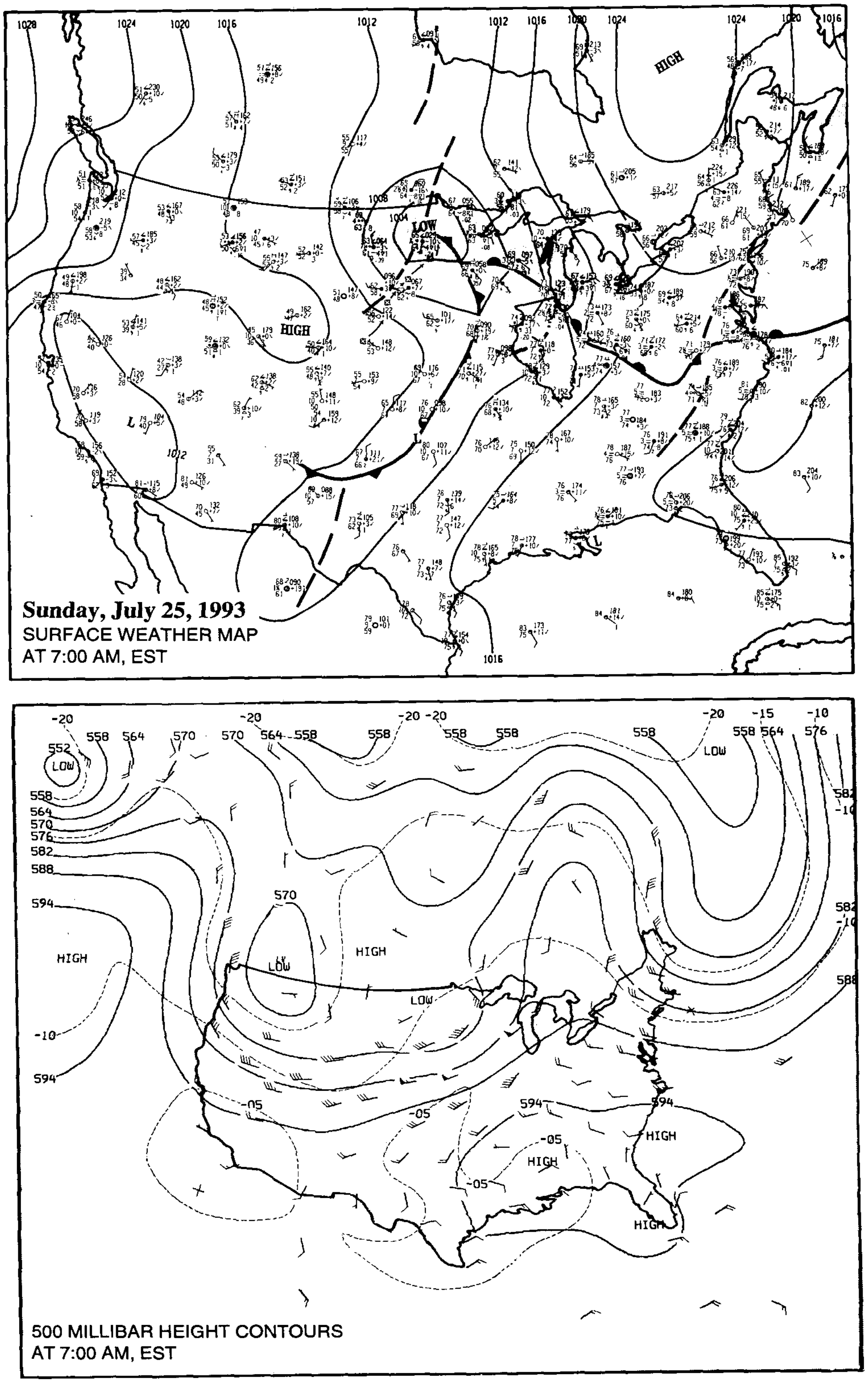


Figure 3.3. Weather map of the United States for July 25, 1993

Precipitation, April through September 1993

Beginning in April, precipitation increased over that of prior months. April precipitation was about twice average in the southern half of Wisconsin, the northern two-thirds of Illinois, and western Indiana. Five inches or more fell over a wide area, including southeastern Minnesota, the southern half of Wisconsin and northern Illinois, and the southern half of Illinois.

May precipitation continued with substantially above-average amounts over the upper Mississippi watershed. From 4 to 6 inches fell over Minnesota and Wisconsin, 6 to 8 inches over Iowa and Missouri, and about 4 inches over Illinois and Indiana. At 1.5 to 2 times the long-term average, it resulted in greater runoff, since the soil was already nearly saturated from the April rains.

During June, rainfall was generally twice or more than average in southern Minnesota and Wisconsin, the northern half of Illinois, and all of Iowa. Precipitation over all of Missouri except the southeastern sector was about 1.5 times average. Actual totals varied from more than 5 to 13 inches over Minnesota and Wisconsin (heaviest in southern counties). Iowa had 7 to 11 inches (about twice average), the northern half of Illinois had 5 to 13 inches (2 to 2-1/2 times the average), and Missouri recorded 3 to 7 inches (about twice average). By this time, flooding had already begun in Minnesota, Iowa, and parts of Missouri.

During July, the distribution of rainfall remained much the same as in June: heaviest in southern Minnesota, all of Iowa and Illinois, and the northwestern two-thirds of Missouri. But some of the heaviest localized amounts were greater than those of June. For example, Iowa recorded 6 to 15 inches, Wisconsin 4 to 9 inches, Illinois generally 6 to 11 inches, and the northwestern half of *Missouri from 6 to as much as 30 inches in July alone! Several counties in northwestern Missouri recorded as much as 8 to 10 times the average rainfall during July. An Agricultural Soil Conservation Service office in Worth County, Missouri, on the Iowa border, recorded 30.30 inches during July alone, 85 percent of the average annual precipitation.* Two nearby sites measured more than 26 inches during July.

Mean statewide precipitation for July in Minnesota, Wisconsin, Iowa, and Missouri was the wettest of any July since 1895, when records began. Indeed, the precipitation for the periods June-July, May-July, and all the way to January-July *for those states and Illinois place them among the five wettest periods in those 99 years.* From a slightly different approach, the precipitation over the Upper Mississippi watershed for July, June-July, and May-July was also the wettest of all one-, two-, and three-month periods since 1895. *June 1993 was the fifth wettest single month on record.* These are formidable records.

A postlude to the very wet June and July in the Upper Midwest occurred overnight on August 1 l-12 over eastern Missouri, Iowa, and Illinois, when a north-south-oriented squall line moved eastward across Illinois. It entered western Illinois at about 2100 on August 11 and exited into Indiana at about 0800 on August 12. Five to six inches and more were reported in Washington and Franklin Counties, Missouri, and in Champaign-Urbana, Illinois, within a few hours.

Return Frequencies of Rainfall Events, Summer 1993

In order to determine how common or uncommon heavy precipitation events may be, they are often characterized by their "recurrence interval," i.e., the average time before such an event occurs again. These are not to be interpreted as regularly recurring events, i.e., cycles, but only as average recurrence intervals based on statistical analyses over a long period of time.

Average statewide precipitation data for the states surrounding the Upper Mississippi for summer 1993 are revealing. Mean statewide precipitation for Minnosota and Iowa for June and July exhibits recurrence frequencies greater than 100 years. The recurrence frequencies for the same period for Illinois, Missouri, and Wisconsin are 85 years, 80 years, and 75 years, respectively. The recurrence frequencies for April through July precipitation are greater than 100 years for Wisconsin and Iowa, 70 years for Minnesota, 45 years for Illinois, and about 13 years for Missouri.

Days with Principal Rainfall Amounts, June and July 1993

Relatively large sections of the region recorded extraordinary amounts of rainfall on more than just a few days, beginning during the first week of June. Indeed, rain fell somewhere in the region on every day of the month. In July, only July 31 saw no precipitation anywhere in the region.

Table 3.1 shows that at least 20 stations recorded precipitation of 2 inches or more in the five-state flood area of Illinois, Iowa, Minnesota, Missouri, and Wisconsin in the 24 hours previous to the date noted. On seven days in June, at least 2 inches of rain fell over a relatively widespread area, and 11 such days occurred in July.

Mean Statewide Precipitation, June 1993

June rainfall over the nine states surrounding the Great Lakes was substantially greater than the long-term average, except in Kentucky and Ohio, which were near average (figure 3.4a). Missouri received only 35 percent more than average, whereas the remaining six states received at least 57 percent more than average. Statewide average precipitation for the last three, six and twelve months showed similar characteristics (see table 3.2).

Table 3.1. Days with at Least 20 Reports of 24-hour Precipitation Greater than 2 Inches

Date	*Number of reports*	*Highest precipitation report (inches)*	*States (at least 2 reports)*
June 7	20	6.0	IA, MN, MO, WI
June 8	66	5.1	IL, IA, WI
June 17	53	6.4	MN, WI
June 20	23	4.4	IA, MO, WI
June 24	27	4.9	IA, MN, MO
June 25	46	4.8	IL, IA, MO
June 30	47	5.8	IL, IA, MN, MO, WI
July 1	65	6.5	IL, IA, MO
July 4	27	4.3	MN, WI
July 5	57	6.6	IA, MO, WI
July 6	49	6.7	IA, MN, MO, WI
July 7	44	7.4	IL, MO
July 9	57	7.9	IL, IA, WI
July 11	30	5.4	IL, IA, MO
July 16	21	6.4	IL, MN
July 18	24	7.8	IL, IA, WI
July 23	29	5.7	IL, IA, MO
July 24	28	6.1	IL, IA, MO

Note: Data are reported as of 0700 of the dates listed.

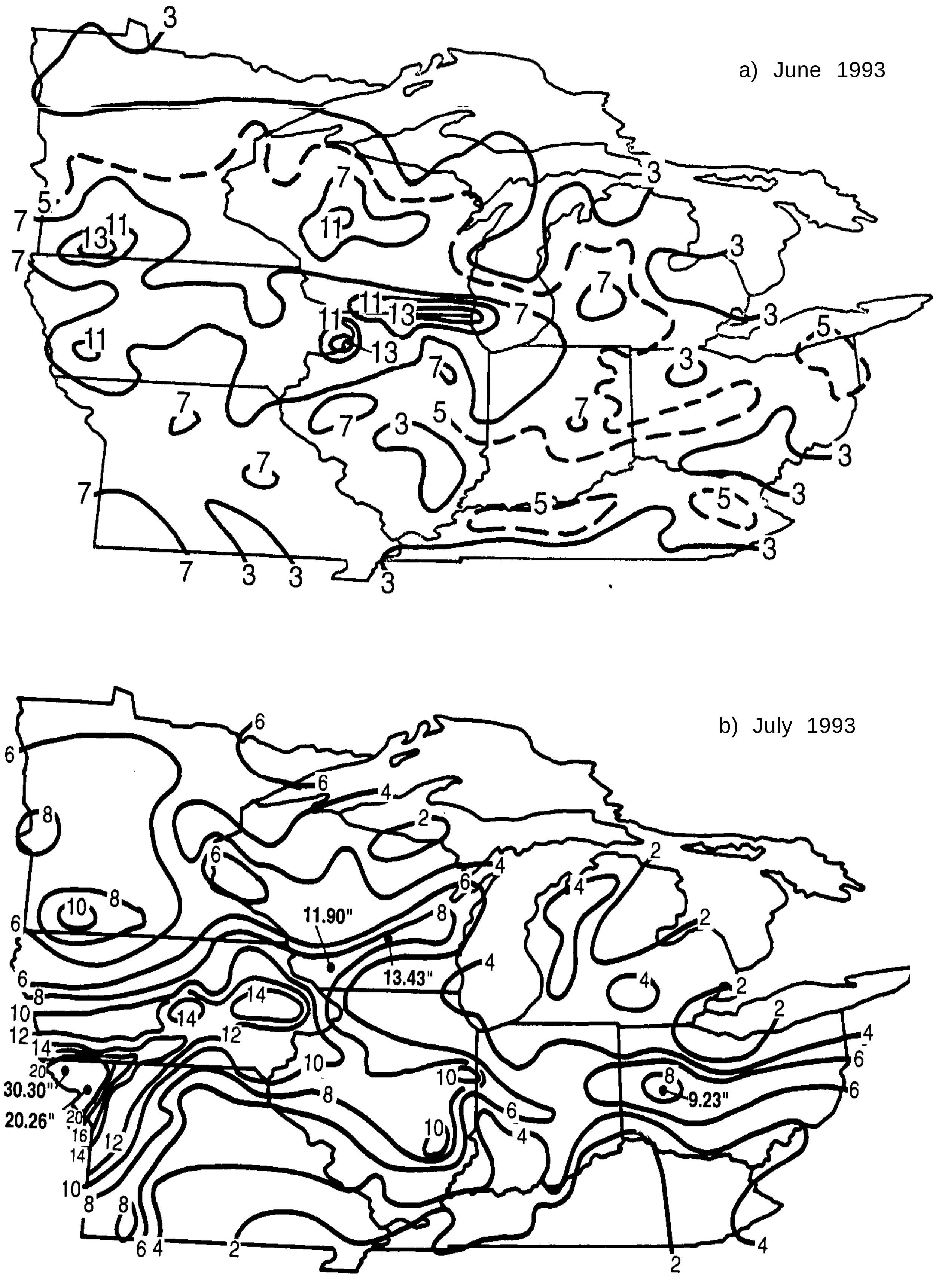


Figure 3.4. Total precipitation for June (a) and July (b) 1993

Table 3.2. Mean Statewide Precipitation for June 1993 and Select Periods of the Previous 12 Months

	Last month		*Last 3 months*		*Last 6 months*		*Last 12 months*	
	Jun 93 (inches)	*% Avg*	*Apr 93- Jun 93 (inches)*	*% Avg*	*Jan 93- Jun 93 (inches)*	*% Avg*	*Jul 92- Jun 93 (inches)*	*% Avg*
Illinois	6.54	163	14.83	125	22.71	120	47.86	124
Indiana	6.31	165	14.07	118	23.47	118	49.08	122
Iowa	8.30	189	17.44	152	22.75	148	47.28	144
Kentucky	3.77	95	9.51	74	20.98	85	42.73	89
Michigan	5.05	157	11.69	133	16.10	114	37.50	117
Minnesota	6.44	160	13.69	147	16.10	133	30.83	116
Missouri	5.65	135	14.78	116	22.88	113	49.82	121
Ohio	4.18	108	9.75	86	19.25	101	43.38	113
Wisconsin	6.88	179	15.31	154	18.73	134	38.78	123

Table 3.3. Mean Statewide Precipitation for July 1993 and Select Periods of the Previous 12 Months

	Last month		*Last 3 months*		*Last 6 months*		*Last 12 months*	
	Jun 93 (inches)	*% Avg*	*Apr 93- Jun 93 (inches)*	*% Avg*	*Jan 93- Jun 93 (inches)*	*% Avg*	*Jul 92- Jun 93 (inches)*	*% Avg*
Illinois	6.70	173	16.48	140	26.41	127	47.50	124
Indiana	4.78	118	14.64	122	24.41	112	45.59	113
Iowa	10.48	260	14.48	199	32.03	172	49.29	151
Kentucky	2.65	59	8.96	68	20.68	80	38.99	82
Michigan	3.30	116	11.30	126	16.88	111	36.10	113
Minnesota	7.08	176	18.81	177	22.55	152	35.00	132
Missouri	7.16	202	17.39	141	26.55	121	50.11	122
Ohio	3.94	102	10.14	87	19.82	96	38.51	100
Wisconsin	4.68	130	15.88	147	21.93	133	39.39	125

Mean Statewide Precipitation, July 1993

Rainfall during July (figure 3.4b) followed a distribution similar to that of June. July rainfall for states within the region for the most recent three, six, and twelve months is shown in table 3.3. Note that Iowa and Missouri show more than 200 percent of average precipitation for July. Minnesota, Wisconsin, and Illinois received much more than average, but Kentucky received only 59 percent of average, representing a substantial shortfall. The remainder of the states show near-average values.

Note that June and July mean statewide precipitation for Iowa was greater than for any of the other eight states. The next wettest states in June were Illinois, Indiana, Minnesota, and Wisconsin. In July, the next wettest states were Illinois, Minnesota, and Missouri.

Table 3.4 presents recurrence frequencies for July mean statewide precipitation, and the table 3.5 shows the same for June and July for the five states directly affecting the Mississippi River. The recurrence frequencies for Iowa and Minnesota are essentially at the limit of their period of observation. Note that the return frequencies are the same or greater for June and July than those for July

Table 3.4. Recurrence Frequencies for July Statewide Precipitation for the Five UMRS States

State	*Recurrence frequency (years)*
Illinois	25
Iowa	>100
Minnesota	>100
Missouri	30
Wisconsin	6

Table 3.5. Recurrence Frequencies for June and July Statewide Precipitation for the Five UMRS States

State	*Recurrence frequency (years)*
Illinois	85
Iowa	>100
Minnesota	~100
Missouri	80
Wisconsin	75

alone. Figure 3.5 plots precipitation versus return frequencies for the months of June and July for the five states.

Mean Statewide Precipitation, August and September 1993

The distribution of August rainfall over the region (figure 3.6a) remained much the same as that of June and July. At two to three times the long-term average, rainfall was heaviest in Iowa, northern Illinois, and western Indiana. Eight inches or more were common in southern Minnesota, Iowa, and northwestern Illinois. September precipitation (figure 3.6b) also exhibited a maximum band of rainfall, but it was now located in Missouri and central and southern Illinois, as opposed to Iowa and northern Illinois. Eight inches were common over most of Missouri, the southern three-quarters of Illinois, and western Indiana.

The continuing heavy rainfall in September renewed flooding within the region, though with less areal coverage and magnitude than during spring and summer.

Rainfall within Major Watersheds of the Region

Rainfall within various watersheds of the Upper Midwest exhibited new maxima, i.e., the greatest monthly mean statewide precipitation since 1895. Put another way, June and July statewide mean rainfall values in 1993 exhibited return frequencies of at least 100 years.

The June-July precipitation for the Mississippi River basin upstream of Quincy, Illinois, totaled 14.24 inches. This represents about twice the 30-year average (normal) and the greatest two-month precipitation over the basin since records began in 1895. Table 3.6 presents the ten greatest

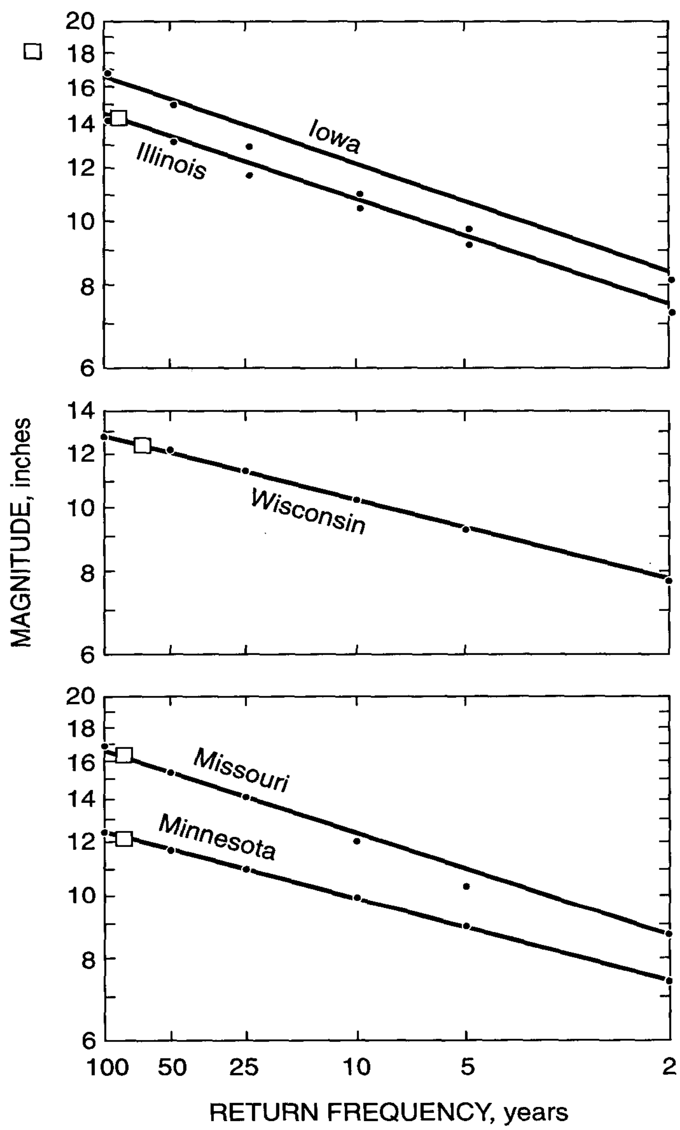


Figure 3.5. Magnitudes of June and July precipitation for various return frequencies (1993 is indicated by the open boxes)

two-month precipitation values for the Upper Mississippi River basin. Notice that they are all summer events, reflecting the fact that the Upper Mississippi is dominated by humid maritime tropical air from the Gulf of Mexico from June through September. Perhaps more importantly, four of the ten extremes occurred within the last 13 of the total 99 years of record, about twice the expected rate, which supports a conclusion of increased climate variability in recent years.

Precipitation from September 1992 through August 1993 over the same watershed was the greatest of any 12-month period since 1895. In fact, the 12-month total of 49.2 inches is fully 7 inches above the previous record set from June 1972 to July 1973 (also a major flood year). Precipitation for June 1993 was the fifth greatest of any single month, and that from July 1993 was the tenth wettest month, again, since 1895.

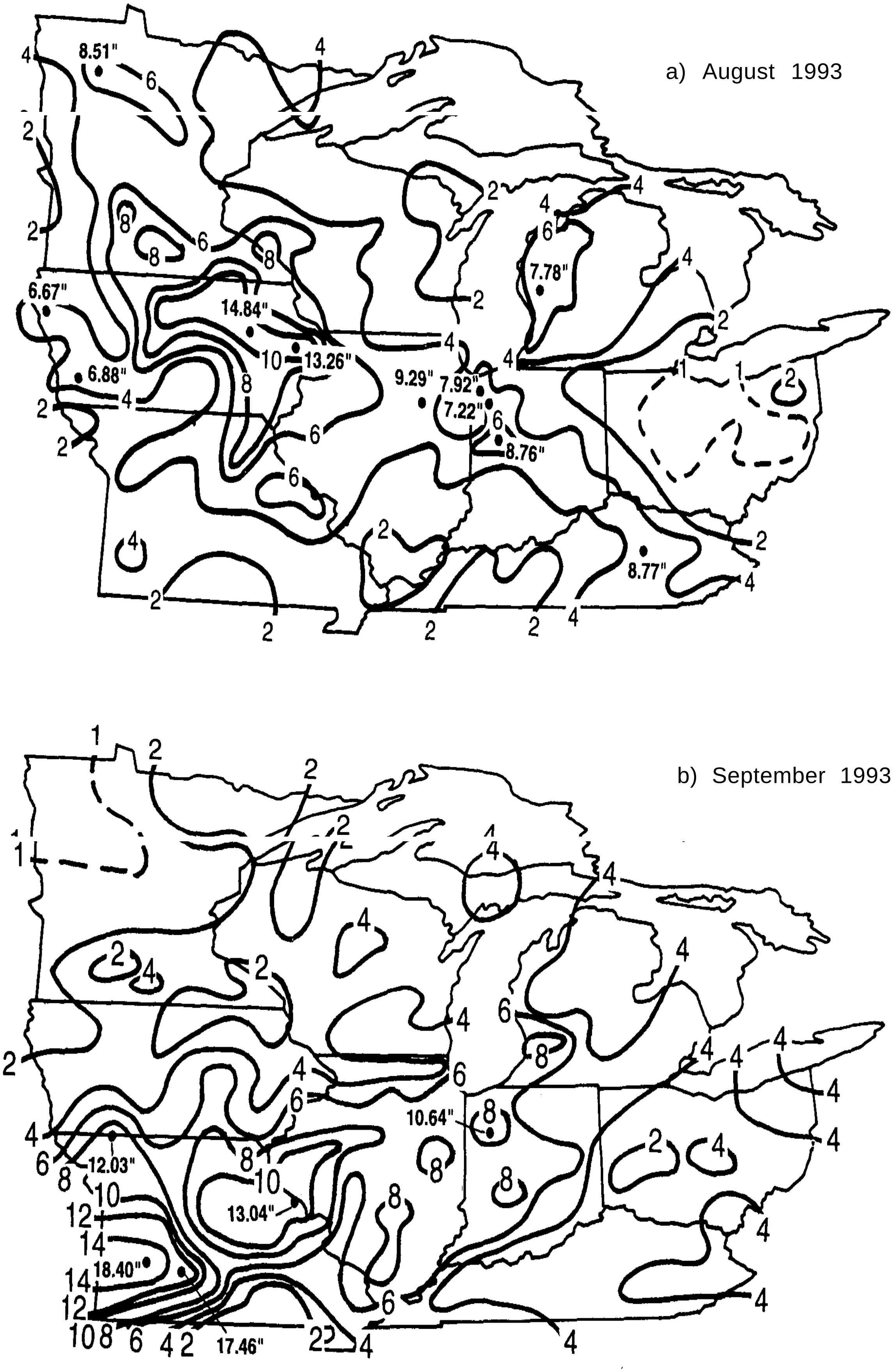


Figure 3.6. Total precipitation for August (a) and September (b) 1993

Table 3.6. The Ten Two-Month Episodes with Greatest Precipitation over the Upper Mississippi River Basin (North of Quincy, IL) since 1895

Rank	*Date*	*Precipitation (inches)*
1	Jun-Jul 1993	15.35
2	Aug-Sep 1980	13.13
3	Aug-Sep 1965	12.68
4	May-Jun 1908	12.32
5	Jun-Jul 1990	12.10
6	Sep-Oct 1941	12.05
7	May-Jun 1905	11.98
8	Jun-Jul 1902	11.95
9	Aug-Sep 1926	11.92
10	Aug-Sep 1986	11.58

Thunderstorms, hail, and tornadoes, all characteristic of March, April, and May in the Upper Midwest, began later than usual this year, only becoming a factor in June. For example, only five tornadoes or funnel clouds were reported in April 1993 throughout the nine states of Minnesota, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana, Kentucky, and Ohio. Eleven more were reported in May 1993, 54 in June, and 23 in July.

Soil Moisture, Summer 1993 (Wendland)

Soil moisture played an important role in the evolution of the 1993 Mississippi flooding. During the first months of the year, soil moisture deviations from normal increased and decreased, essentially in close response to precipitation. Little runoff was produced during this time. In June, precipitation increased dramatically in magnitude and frequency in Minnesota, Wisconsin, Iowa, Missouri, and western Illinois. This increase provided more water to the uppermost layer of soil than it could accommodate. The surplus became runoff to feed creeks, streams, and rivers.

The responses of moisture in the top 6 feet of soil of the Upper Midwest were traced by means of a soil moisture computer program in the Midwestern Climate Center's Climate Information System located at the Illinois State Water Survey. Soil moisture is calculated for various soil layers based on soil type, temperature, and precipitation. Following is a calculation of moisture in the top 6 feet of soil for the Upper Midwest from the beginning of 1993 to early August.

As of January 22, 1993 (figure 3.7a), moisture in the uppermost 6 feet of soil was generally up to 3 inches greater than the period average (1949-1992) for this time of the year, which varies from about 7 inches in northern Minnesota to 12 to 13 inches in Missouri, Illinois, Indiana, Ohio, and Kentucky. The only exceptions were east-central Minnesota and eastern Kentucky, where levels were slightly below average.

Four weeks later, soil moisture had declined by about one inch to near the average of 10 to 12 inches over Missouri, Illinois, Indiana, and Ohio, and to slightly less than the average of 10 to 12 inches in Kentucky (figure 3.7b). As of March 18, with little precipitation in northern sectors and a bit more than average in the south, soil moisture was essentially unchanged, although it increased slightly in Ohio and Kentucky (figure 3.7c).

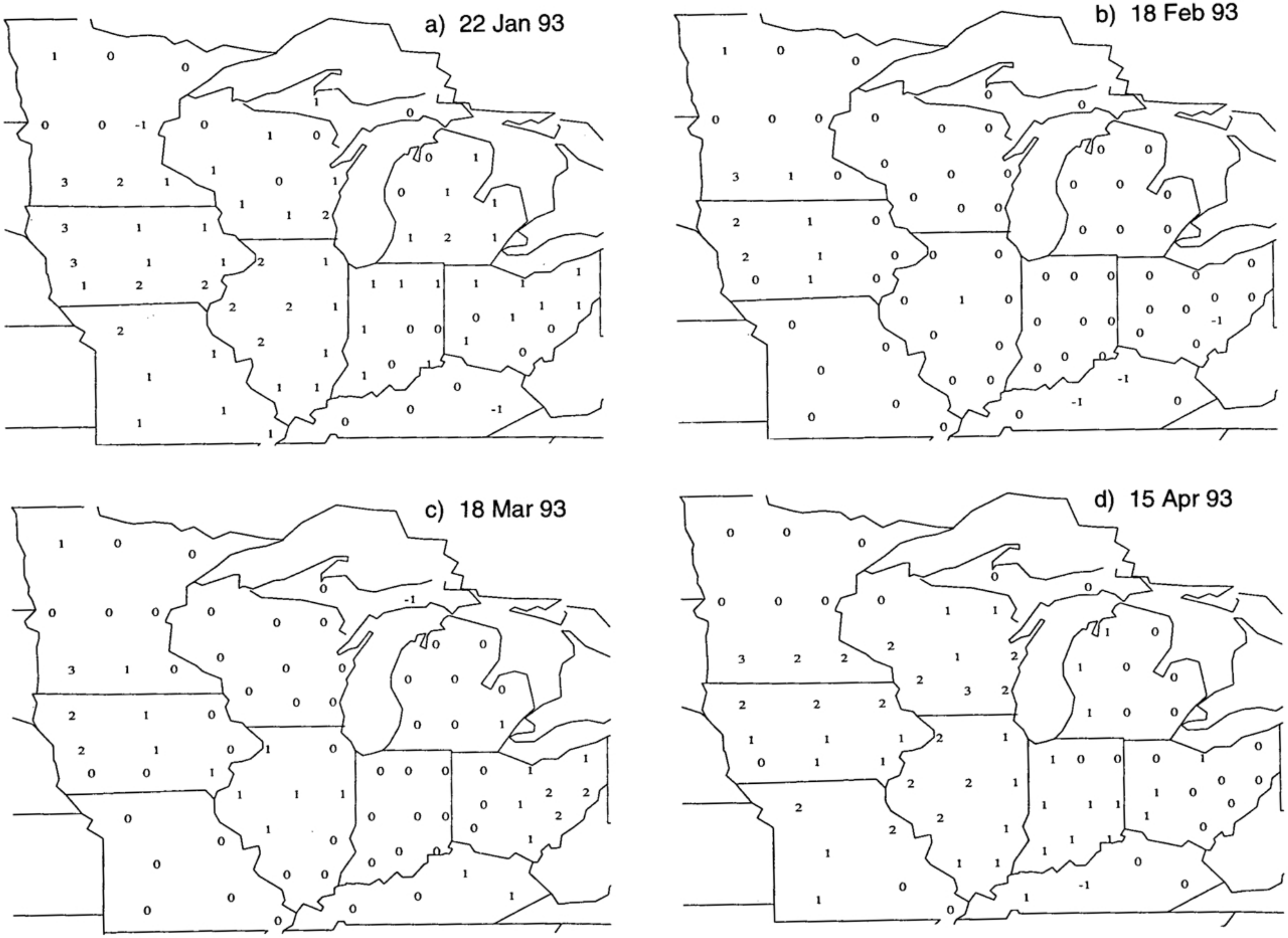


Figure 3.7. Soil moisture deviations from average for January (a), February (b), March (c), and April (d) 1993

As of April 15 (figure 3.7d), with substantial precipitation over Iowa, northern Illinois and western Indiana, soil moisture increased an inch or two in the region, while Ohio and Kentucky lost their March gains. With little precipitation during late April and early May, soil moisture in the uppermost 6 feet (figure 3.7e) had declined by about an inch or so by May 13, approximating March levels, particularly in the southern half of the region. At this time, soil moisture was calculated to be up to 2 to 3 inches above average over all the states except Ohio and Kentucky, where levels were either average or one inch below.

During the ensuing four weeks, soil moisture either remained constant or increased throughout the region, so that by June 10 (figure 3.7f), only eastern Ohio and Kentucky were at the period average, while all other locations registered 1 to 3 inches above average. Substantial and consistent rainfall during the following four weeks added moisture to the uppermost 6 feet everywhere in the region. By July 8 (figure 3.7g), levels in the region varied from average in much of Kentucky and northeastern Ohio to 3 to 6 inches over average in the remaining seven states of the region.

Although moderate to heavy rainfall continued in the region (again, except in Kentucky and Ohio) throughout July and into early August, soil moisture by August 5 (figure 3.7h) remained unchanged or declined by up to one inch, indicating that saturation had been reached in spite of the needs of maturing crops.

Soil Moisture Outlook for Fall and Winter Conditions (Kunkel)

Heavy rains continued to plague flood-ravaged areas of the Midwest into early fall, maintaining much-above-average soil moisture levels. Figure 3.8 shows the departure from normal soil moisture conditions as of September 28, 1993, in the top 5 feet, based on an operational computer model of the Midwestern Climate Center. (This model uses constantly updated temperature and precipitation data and other data to estimate soil moisture conditions.) In the western part of the U.S. Corn Belt, soil moisture was 4 to 7 inches above the seasonal normal. In many of these very wet areas, soil moisture was at record high levels for late September (based on 1949-1992 data). Normal values are 6 to 7 inches of plant available water in Iowa, 6 to 7 inches in Missouri, and 6 to 7 inches in Illinois. Thus in many of these areas, the amount of water available for plants was nearly double the normal value.

This soil moisture model was used in a series of forward-looking analyses to estimate the probability for future moisture problems related to the current high soil moisture levels. Soil moisture conditions estimated by the model on September 28, 1993, were used as the initial conditions. The model was then run forward in time using historical weather data as possible scenarios for future weather conditions. This generated soil moisture estimates from September 29, 1993, through May 1, 1994. Each year of historical weather data (from the year September 29, 1949-May 1, 1950 through August 28, 1992-May 1, 1993) was used to form 44 possible scenarios. The results for early March 1994 were analyzed to simulate the possible conditions at the start of spring, when many floods occur and when the snowpack begins to melt.

Figure 3.9 shows the probability that soil moisture levels will be above normal on March 1, 1994, the meteorological beginning of spring. The probabilities are greater than 60 percent throughout the western half of the Corn Belt. In western Minnesota and northwestern Iowa, probabilities are 90 percent or greater. Therefore, it is highly likely that spring runoff will be greater than normal and that the soil will have a very limited ability to absorb spring rains or snowmelt. The size of the

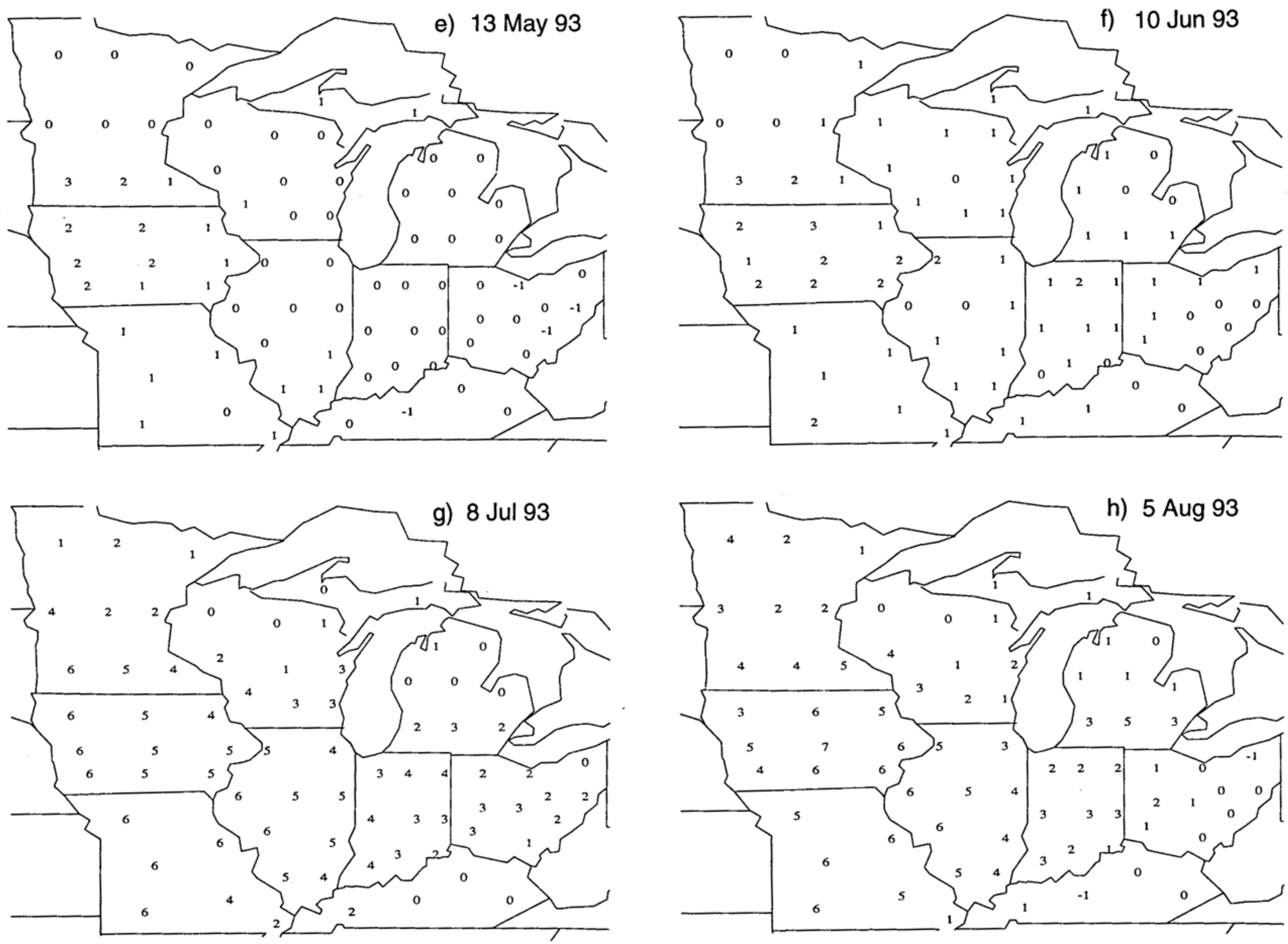


Figure 3.7. (Continued) Soil moisture deviations from average for May (e), June (f), July (g), and August (h) 1993

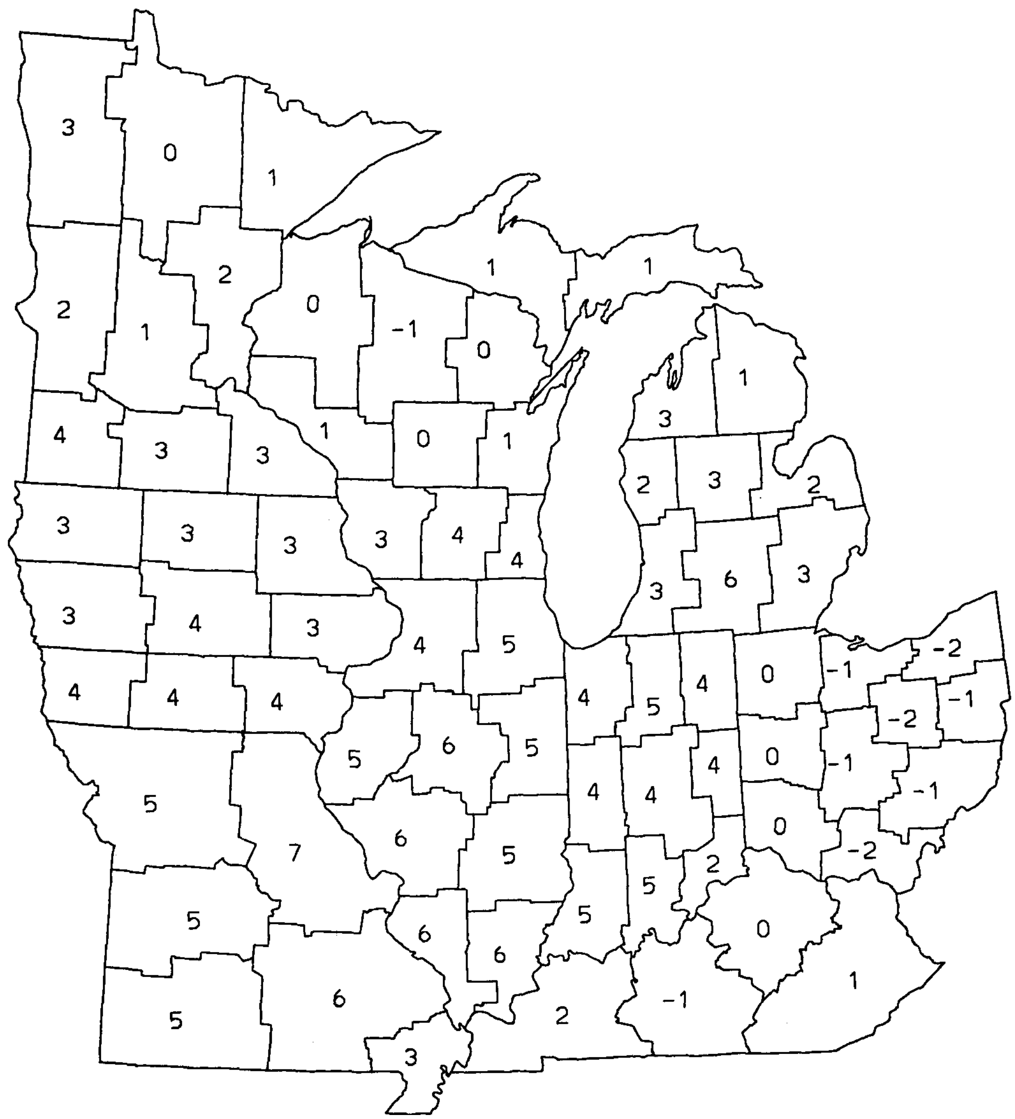


Figure 3.8. Deviations from late August long-term average soil moisture in the top 5 feet in inches (5=5 inches above)

snowpack entering spring and the amount of spring rainfall will be critical for determining the possibility of spring flooding.

The soil moisture model was also used to assess more quantitatively the potential for additional flooding in the Mississippi basin. The model keeps track of "excess water," that is, water that cannot be held by the topsoil and must go elsewhere. This is precipitation that either runs off into streams and rivers or percolates to become shallow ground water. Much of the latter ultimately percolates into streams and rivers as well. Excess water was calculated for the future period September 28, 1993-April 30, 1994, using the 44 yearly weather scenarios. The area of this calculation was the Upper Mississippi River basin upstream of Quincy, Illinois.

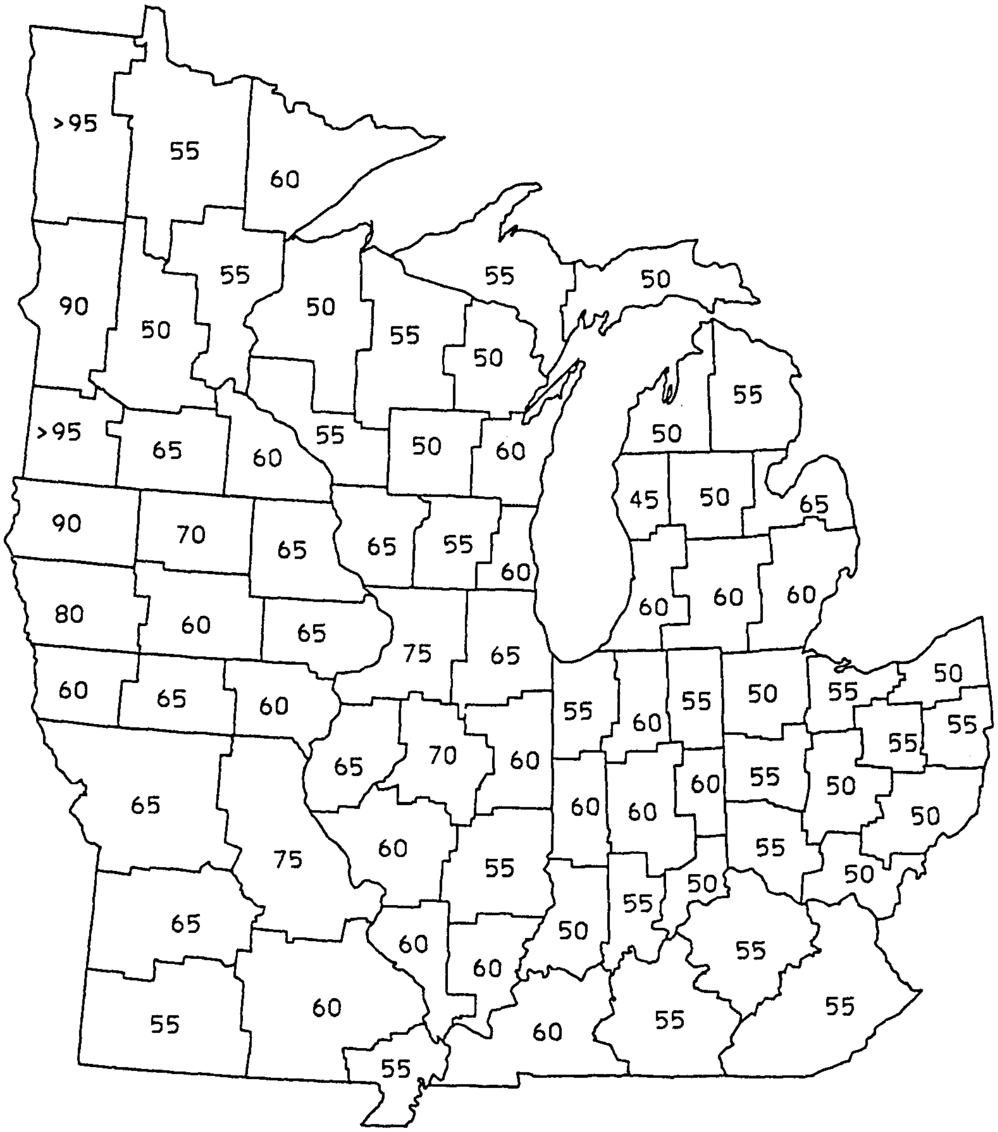


Figure 3.9. Percentage of probability of above-average soil moisture on March 1, 1994

Table 3.7 shows the distribution of potential excess water for these scenarios. Also shown is the climatological distribution of excess water based on calculations using the 44 historical years, 1949-1992. These values are not directly equivalent to runoff into the Mississippi River system for the following reasons:

1. The model is appropriate only for the flatter prime agricultural areas. In hillier areas, runoff will be higher.
2. The value used for precipitation in the model is an average of all available stations. It does not account for the localized heavy rainstorms that produce disproportionate amounts of runoff.

Table 3.7. Estimated Excess Precipitation, Upper Mississippi River Basin (inches)

	Probability of Exceedence						
Period	*100%*	*90%*	*70%*	*50%*	*30%*	*10%*	*0%*
9/28/93-5/1/94	3.1	3.4	4.9	7.0	7.8	10.2	13.1
Average	0.2	0.4	1.8	3.7	5.8	7.2	10.0

3. The model does not account for runoff occurring because the topmost layer of the soil is frozen. In this case, runoff will occur even if the soil is relatively dry. This obviously occurs frequently in the spring.

For the above reasons, actual runoff may be higher than "excess water." For instance, the long-term average flow volume at Keokuk, Iowa, for October through April is equivalent to a value of "excess water" of 4.5 inches, which is higher than the median value of excess water of 3.7 inches shown in table 3.7. Nevertheless, the model provides a tool to assess the flood potential in a relative fashion.

With the above qualifications in mind, these calculations are nevertheless revealing. The probability is 50 percent that excess water will exceed 7.0 inches, a value that is expected to be exceeded in only 1 of 10 years. The probability is nearly a 90 percent that the average value of 3.7 inches will be exceeded. In the worst-case scenario, the excess water across the basin could be as high as 13.1 inches, 30 percent higher than that of any previous year since 1948.

This situation exists because soil moisture was at its highest late-September level on record, when averaged over the entire basin. Usually, soil moisture is rather low around late September. This year, soil moisture was at springtime levels, usually its highest point. In most of these areas, there was little or no capacity for absorption of water. In addition, little warm weather remained to dry out soils.

Whether flooding occurs during the next seven months will depend on the distribution (in time and space) of future precipitation, the size of the winter snowpack, and the rate of spring snowmelt. However, at this point, it is safe to say that the **potential** for flooding during the next eight months is at its highest level in at least 40 years because the capacity for soil absorption of precipitation was at its lowest late-September value on record.

Chronology of the Flood (Knapp)

Hydrologic Conditions Preceding the 1993 Flood

Most accounts of the 1993 Mississippi River flood indicate that it began in the latter half of June. However, the circumstances leading to the flood began as much as a year earlier.

In most years, rainfall in the fall and early winter replenishes the soil moisture that was depleted over the summer. But in 1992, the soil moisture in Iowa, Minnesota, and eastern Nebraska was hardly depleted — July 1992 was the second wettest on record in Iowa (Fuson, 1993). Some areas of eastern Nebraska experienced record flooding in July. Heavy rainfall in September also produced record flooding in southern Iowa. The November rainfall total for Iowa was among the greatest of this century. Instead of replenishing soil moisture, the rainfall was causing streams to flow full.

Heavy snowfall in February 1993 covered much of the northern portion of the Mississippi River watershed. In early March the snowbank across much of Iowa was more than 2 feet deep. The snowpack alone meant that normal spring flooding would be greater than usual.

The snowmelt began at the end of March and with it came the runoff. The ground throughout much of the watershed was saturated, and all of the tributaries were flowing full or overflowing. Record flooding was now occurring in central Iowa, and as a result several counties were declared disaster areas. The Mississippi River reached flood stage in the first week of April, and by mid-April it was reaching flood peaks that were the highest in seven years. The U.S. Army Corps of Engineers began closing the locks and dams along the river, and by April 26, all but one of the ten locks and dams between Muscatine, Iowa, and Winfield, Missouri, were closed to navigation. This effectively stopped river traffic for 216 miles. In general, this flooding caused little damage to communities along the river, although in Grafton, 118 of the town's 386 families were displaced.

The river stage started to recede, but continued rains in late April and early May slowed this recession. Up to 4 inches of rain fell in eastern Iowa in the first week of May, and the river stage rose again, close to the April maximum. Only in the last week of May did the river Finally fall below flood stage.

But rainfall in the second week of June caused the river level to rise again. The rise was not great, but it was enough to push the river above flood stage. This was the condition before the great flood began.

June Flooding in Minnesota and Wisconsin

The start of the great flood was marked with heavy rains during a four-day period, June 16 to June 19, over southern Minnesota, northern Iowa, and western Wisconsin. On June 17 (according to Table 3.1 more than 6 inches of rain fell at Marshall, Minnesota. Other one-day rainfall totals included 4.5 inches at St. George, 3.5 inches at Wanamingo and Brighton, and 3 inches at Faribault, Minnesota (AP, 1993a). By June 21, the Minnesota River was cresting at Mankato at a record stage of 30.13 feet, more than 11 feet above flood stage. The peak discharge at Mankato was estimated to be 75,800 cfs, according to Parrett et al. (1993), the fourth highest in more than 100 years of record. None of the Upper Mississippi River basin was spared. Many locations experienced heavy showers and thunderstorms, with 2 to 3 inches of rain in less than one hour at numerous locations throughout central Iowa. Record flooding on the Black River in western Wisconsin caused a 50-foot section of a dam along the river to break, while another dam was overtopped.

Despite all this, the flooding was only receiving moderate press coverage, and conditions in Wisconsin and Minnesota were considered just some of the many flooding problems affecting the nation. More newsworthy was the heavy flooding affecting East Texas and Louisiana as a result of tropical storm Arlene. But others could see that this was just the beginning:

> Some of the worst flooding in recent memory is brewing for communities along the Minnesota and Mississippi Rivers. On the Minnesota River, in particular, it could be as bad as it was in 1965. This is what happens when two to three months of rain falls in less than two weeks. The ground across southern Minnesota is hopelessly saturated and unable to soak up any additional rainwater. Rain immediately runs off into streets and storm sewers, eventually flowing into streams and rivers. It is a scenario more likely to play out in April, when snow is melting and topsoil is still partly frozen. The possibility of additional heavy rain is present, especially from late tonight into Thursday. Another slow-moving

> storm approaching from the northern Rockies will push scattered thunderstorms into Minnesota, and a few could bring an inch or two of rain. This is another in a seemingly endless series of storms that have hammered northern-tier states in recent weeks. Cold air is sagging unusually far south out of Canada (it could snow in Montana by Wednesday). This in turn has led to ripe conditions for storms to cut off from the main belt of westerlies, slowing down, even stalling. The result will be a significant episode of flooding. For many this promises to be a very long week. (Paul Douglas, *Minneapolis Star Tribune*, June 22, 1993)

Heavy rain on June 24 brought 5 inches of rain to Minneapolis within a 90-minute period. As much as 10 inches of rain fell over two days in southeastern Iowa. On June 26 the Mississippi River at St. Paul had crested at its fifth highest level in more than 100 years, and the highest since the 1965 flood of record. A large portion of the floodwater on the Mississippi River had been contributed by the Minnesota River.

Two days earlier, the flooding in Minnesota had not been a major concern downstream. But now forecasts were predicting that the Mississippi River down to St. Louis would experience the second or third highest flood on record. Within a day, virtually all the locks and dams along the Mississippi from St. Paul to St. Louis were closed to navigation, effectively shutting down the river. The shutdown was expected to last two weeks (AP, 1993b).

On June 27, new storms dumped an additional 5 inches in southern Wisconsin, Minnesota, and Iowa. The National Guard was called out to aid in sandbagging operations in Davenport, Iowa. On the night of June 30,6 inches of rain fell in Quincy, Illinois. South of Davenport the river was now forecasted to reach record stages, surpassing those set by the 1973 flood. There was now concern that as many as 70 percent of the levees along this reach of the Mississippi River were in danger of collapse because of saturation, and sandbagging operations began in full force along the levees between Davenport and Grafton.

The river crested on July 3, almost a foot lower than the forecasted stage, and lower than the record stage set in 1973. Many people were now looking to the end of the flood. But Lee Larson, hydrologist with the National Weather Service, indicated that he did not see an immediate end to the flooding problems: “The big concern right now is the Mississippi, the Missouri, and the Minnesota, but we have flooding in just about all 14 states in the region” (AP, 1993c). The mood of the impending situation was aptly described in the following:

> By the Fourth of July weekend, Iowa had received eight straight months of above-normal rainfall and below-normal sunshine, 15 straight months of below-normal temperatures and evaporation, and four straight months of major flooding. Then the unimaginable happened. It got worse. (Ken Fuson, *Des Moines Register,* August 22, 1993)

July Flooding in Iowa and the Mississippi River Upstream of St. Louis

On July 5, up to 5 inches of rain fell over much of Iowa and southwestern Wisconsin. By this time most flood control reservoirs were full. The emergency spillway of the Coralville dam near Iowa City was being used for the first time in its 35-year history. The Corps of Engineers was withholding water because they did not want to add to the flooding just downstream at Iowa City. Despite the storage provided by the flood control reservoirs, the Iowa River registered a record flow of 107,000 cfs, estimated to be greater than a 100-year flood event (Parrett et al., 1993).

But three days later, on July 8, another 3 to 8 inches fell in central Iowa. The Des Moines, Raccoon, and Skunk Rivers were now experiencing their floods of record, again with recurrence intervals estimated to exceed 100 years. All of these rivers were now emptying into the Mississippi between Davenport and Quincy, coinciding with the new peak that was occurring on the Mississippi River caused by additional rainfall in Minnesota, Wisconsin, and northeastern Iowa.

Up to this time, the flooding had been much worse on the lower-lying Missouri side of the river, and several levees had already broken by July 5. On the Illinois side, however, most of the problems were confined to riverside towns such as Grafton, where flooding is common. But as the Mississippi prepared to reach record levels, many Illinois communities and levee districts were stepping up their flood defenses. Intense sandbagging operations were shoring up threatened levees north of Quincy, Illinois, in the towns of Niota and Meyer, and south near Hull. Hundreds of residents were evacuated from levee districts. More than 600 National Guard troops were employed to sandbag and patrol Illinois levees. The number of troops would swell to 1,800 by July 8 and to 3,500 by July 13.

By July 8 the rising river broke through levees near Pleasant Hill and Keithsburg, Illinois, and LaGrange and Gregory Landing, Missouri, flooding more than 40,000 acres. On July 9 the Lima Lake levee broke north of Quincy, flooding 30,000 acres.

By July 10, most levees had been built up 3 to 4 feet above their original height, along with the additional 3 feet of freeboard designed into the levee. But even this was not enough when faced with the record stages. In a five-day period, July 10 to 15, as the river near Quincy was reaching its peak of 32 feet, a number of major levees broke near Quincy, including those at Niota and Indian Graves, Illinois, and at South River and West Quincy, Missouri. A complete list of levee breaches and acres flooded is provided later in this report. After each of these breaks, the river stage would fall a foot or two, only to rise again to higher levels within a day or two.

Meanwhile, the rains kept coming. In July, there were rarely more than three consecutive days on which major rainfall did not occur. Total rainfall by the end of July set records for Iowa and Minnesota, and ranked among the highest on record for Illinois and Missouri.

Near Keokuk and Quincy, the peak river stage was reached on July 10-13, but the river level remained high. At some locations, such as at Hannibal, Missouri, the river reached peak stage on July 27. Thus the Mississippi was still near its peak at the end of the month, when the Missouri and Illinois Rivers reached their peaks.

Flooding in the Missouri River Watershed and the Mississippi River at St. Louis

Much of the rainfall that caused flooding in Iowa in the first week of July also caused flooding in the Missouri River watershed. The James and Big Sioux Rivers in South Dakota and the Little Sioux River in western Iowa all experienced severe flooding July 6 to 8 (Parrett et al., 1993). On July 13 the Missouri River at Nebraska City, Nebraska, rose to its highest flood levels since 1952, just before the major flood control reservoirs were built in the Missouri watershed.

Up to 13 inches of rain fell in Nebraska, Kansas, and Missouri during the three-day period, July 22-24. The Platte, Kansas, and Grand (Missouri) Rivers all experienced flood magnitudes near or in excess of the 100-year flood level. This flooding moved downstream, bringing the Missouri River to record or near-record levels as it progressed (Parret. et al., 1993). The flood crest on the Missouri reached the Mississippi River on July 31-August 1.

The July 22-24 rainfall also affected western Illinois, causing flooding on the Spoon and Illinois Rivers. The Illinois River peaked at Valley City on August 1, coinciding with the arrival of the peak on the Missouri River. The peak discharge at Valley City was 97,500 cfs, the fifth highest on record, which was roughly equivalent to a 10-year flood discharge. But peak stages on the Illinois River were greatly influenced by backwater from the Mississippi River, and record stages were observed at Hardin and Kampsville.

The Mississippi River at St. Louis reached a record peak stage of 49.47 feet on August 1, exceeding the previous high of 43.23 feet, which occurred in 1973. The discharge of 1,030,000 cfs was the highest measured in the 130-year record at St. Louis, although the discharge of the 1844 flood is estimated to have been greater. As the peak was being reached, and shortly thereafter, a number of levees in the St. Louis area began to fail. Levee failures during the period July 31-August 3 included the Columbia, Harrisonville, and Prairie du Rocher levees, located south of St. Louis; the Hillview, Hartwell, and Eldred levees, located on the Illinois River; and the Alton levee. The Alton levee failure led to the inundation of the Alton water treatment facility, and caused a three-week interruption in the supply of potable drinking water to 70,000 people.

The Mississippi River at St. Louis started falling quickly shortly after it reached its peak in early August. It is unlikely that the levee failures that occurred near the time of the peak had anything mom than a small influence on that recession. The crest of the flood hydrograph then proceeded downstream, passing Cairo on August 8, becoming part of history. From St. Louis to Cairo, the flood remained one of the largest historical events ever. But below Cairo, where the Mississippi River meets the Ohio River, the channel capacity of the river increases considerably and the impacts of the floodwaters became minimal.

Nevertheless, continued rains in late August and September caused the river to remain above flood stage for another two months. With rainfall in southern Missouri and Illinois, the river peaked again in late September and early October. At St. Louis, this final peak was 39.0 feet, which was not only higher than the spring peak in April, but was the fifth highest flood peak ever recorded at the gage. The river finally fell below flood stage at St. Louis on October 10 and near Cairo on October 14. At many locations, the river had remained above or near flood stage for more than 6 continuous months.

Summary

Iowa state climatologist Harry Hillaker described the chain of events leading to the flooding in the *Des Moines Register* (Fuson, 1993): “If you’re writing a disaster script, you probably wouldn’t write statistics as ridiculous as what happened. It would seem too incredible.”

The timing, location, and persistence of rainfall over the Mississippi River watershed provided optimal conditions for record flooding. Continual rains throughout the spring provided wet soil moisture conditions and reduced the natural storage available for excess water. Heavy rainfall began in the northern portion of the basin, and over a period of weeks it slowly moved to the south, allowing the heaviest rainfall to coincide with the arrival of runoff that had originated upstream. For example, peak flows on major tributaries to the upper Mississippi, such as the Iowa and Des Moines Rivers, entered the Mississippi River at the same time that the Mississippi was cresting. The Mississippi River was still near its crest when the maximum runoff from the Missouri River entered. To a lesser extent, the Illinois River contributed in the same manner.

River Stages and Flood Peaks (McConkey)

The flood of 1993 set new record peak stages at virtually every station along the Mississippi downstream of Camanche, Iowa. The unprecedented peak river levels at stations along the Illinois border between July 1 and August 8 were preceded by an extended period of high river levels, that had exceeded flood stage for the greater part of four months. The summer flood of 1993 was in fact a series of three flood waves that progressed down the river. Tributary inflows and levee breaks show as undulations in the flood stages recorded at river gaging stations. Figures 3.10-3.13 show the daily stages of the Mississippi River at ten river gaging stations along the Illinois border. The geographic location of these stations is depicted in figure 2.7 and 2.13. The plots of river stage versus time in figures 3.10-3.13 show the numerous flood peaks resulting from the repeated heavy precipitation in the watershed and the progress of the flood downstream.

Flood stage is typically defined as the level at which the river goes out of its banks and is not necessarily related to damage. Flood stages referred to herein are from *River Stages in Illinois: Flood and Damage Data* (IDOT/DWR, 1991). Observations of river stages at gaging stations are reported in terms of the height of the water surface, registered in feet above the datum of the gage. The stage of a river is *not* the same as the depth of the flow. The stage may be converted to a commonly used vertical datum, by adding the stage (measured in feet) to the gaging station datum. The datum in common use is the National Geodetic Vertical Datum (NGVD) established in 1929, which is analogous to mean sea level. The stage at one station may vary considerably from the stage at another station for the same event, depending on the gage installation. Stages should be converted to the standard vertical datum to compare water surface elevations and/or to determine slope. The datum of each of the ten Mississippi stations is noted on the plots near the 0 stage point. Elevations shown in figures 3.10-3.13 and table 3.8 are relative to NGVD 1929. Peak stages recorded at each station during previous significant flood events and the 1993 peaks are shown along the vertical axes of the plots. The legends identify the dates of the peak stages. Due to changing river conditions, the historical peak stages may or may not coincide with the historical peak discharges.

Spring Flooding

The record-setting peak stages in July and August along the Mississippi were preceded by several months of high flows with stages repeatedly exceeding flood stage. The Dubuque and Camanche station data (figures 3.10a and 3.10b) clearly show the two major flood waves, the first rise occurring in mid-April. The pattern of the stages recorded at these two stations differs from the pattern recorded at stations downstream, where flood stage was exceeded in March. Several major tributaries join the Mississippi between Camanche and Keithsburg, the next station downstream (figure 3.10c): the Rock and Edwards Rivers enter from the east; and the Maquoketa, Wasipinicon, and Iowa Rivers from the west. The contribution of these tributaries is indicated by the elevated river stages in early March at the stations downstream of Camanche (figures 3.10c and 3.11). Between the Keithsburg and St. Louis stations, the Missouri and Illinois Rivers join the Mississippi. The impact of flow contributions from these major tributaries can be seen in the undulations in the stage data, i.e., multiple peaks superimposed on the flood wave, in the plots for St. Louis (figure 3.12a) and stations farther downstream.

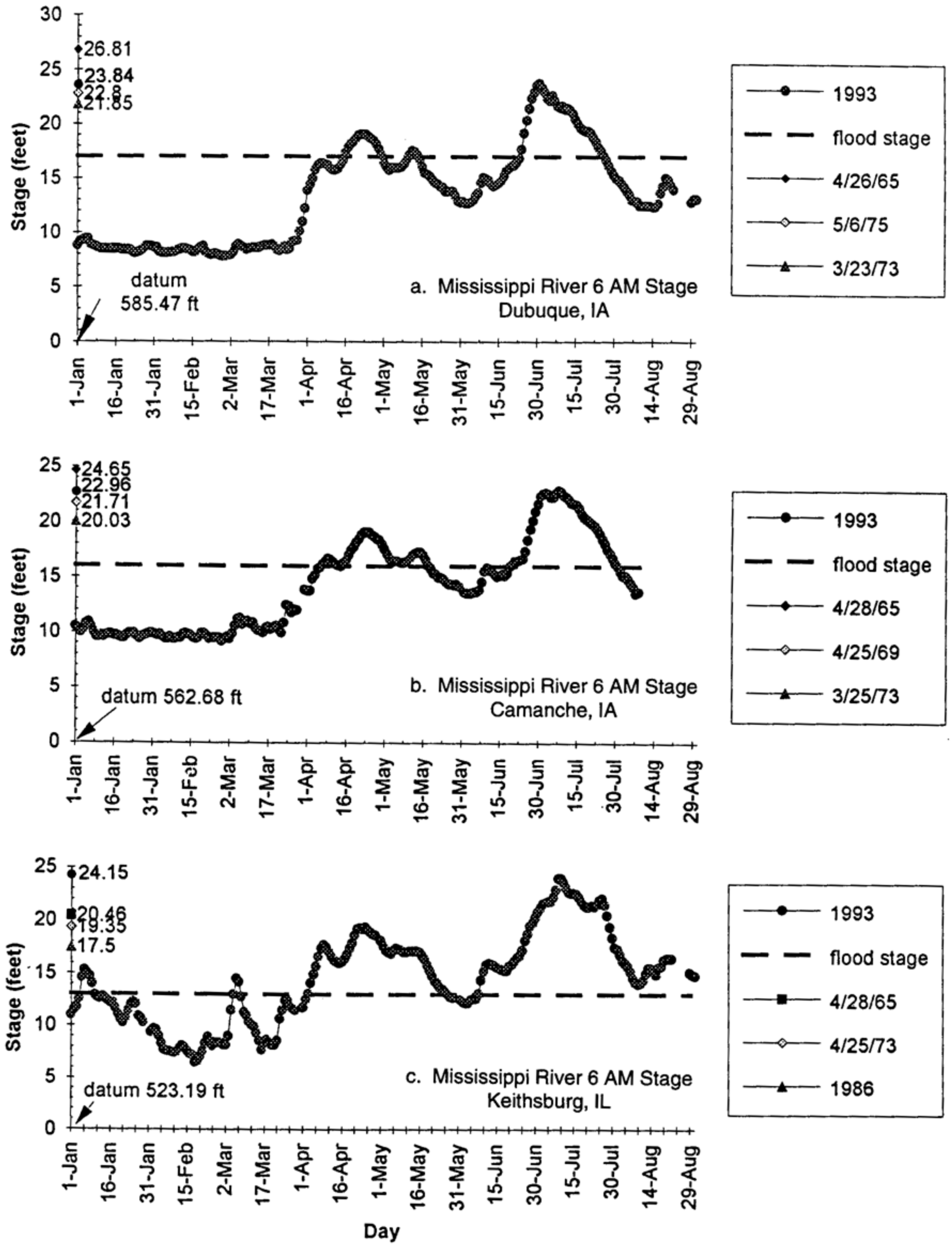


Figure 3.10. Mississippi River stages from January 1 through August 29, 1993, at Dubuque (a), Camanche, IA (b), and Keithsburg (c)

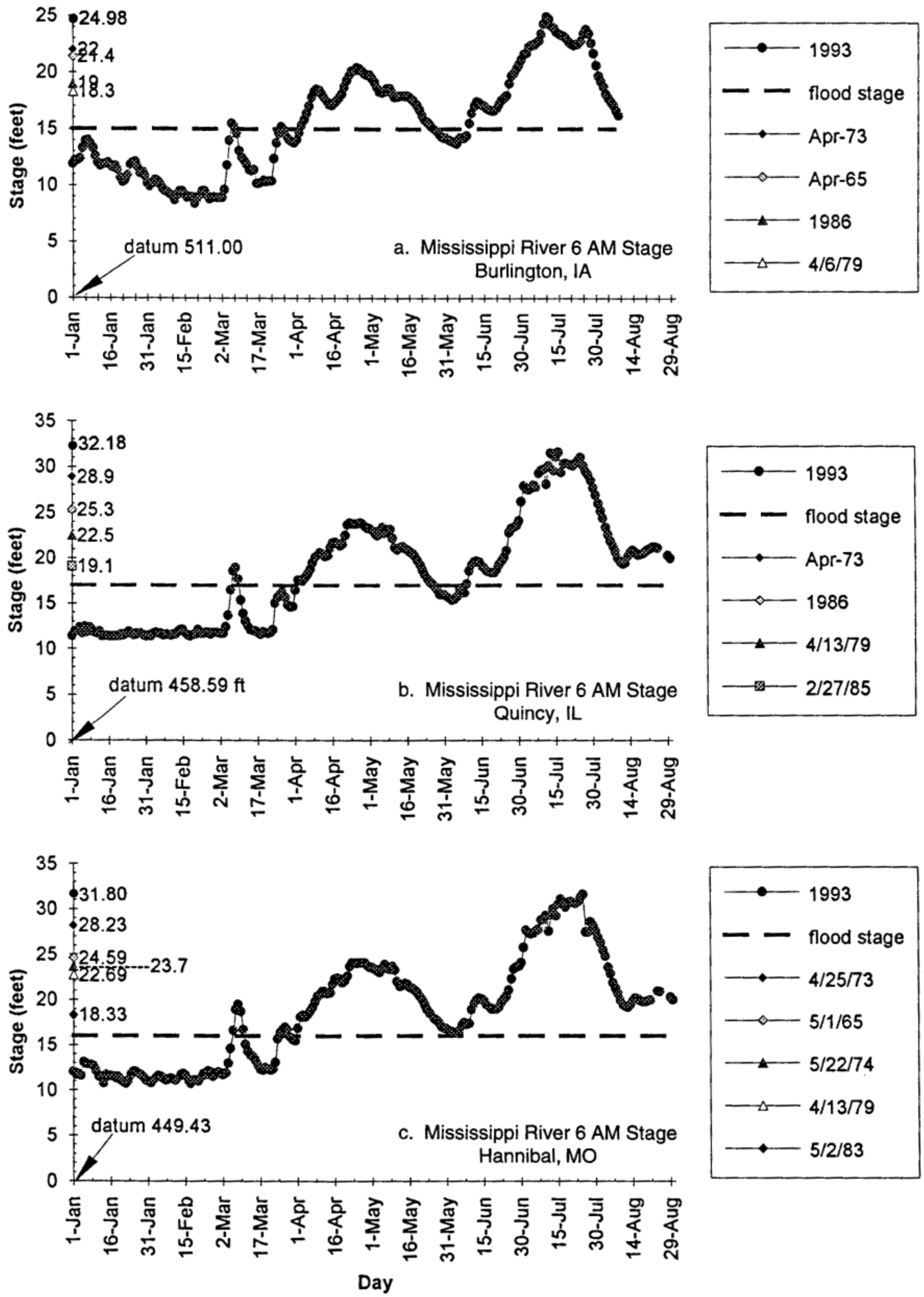


Figure 3.11. Mississippi River stages from January 1 through August 29, 1993, at Burlington, IA (a), Quincy (b), and Hannibal, MO (c)

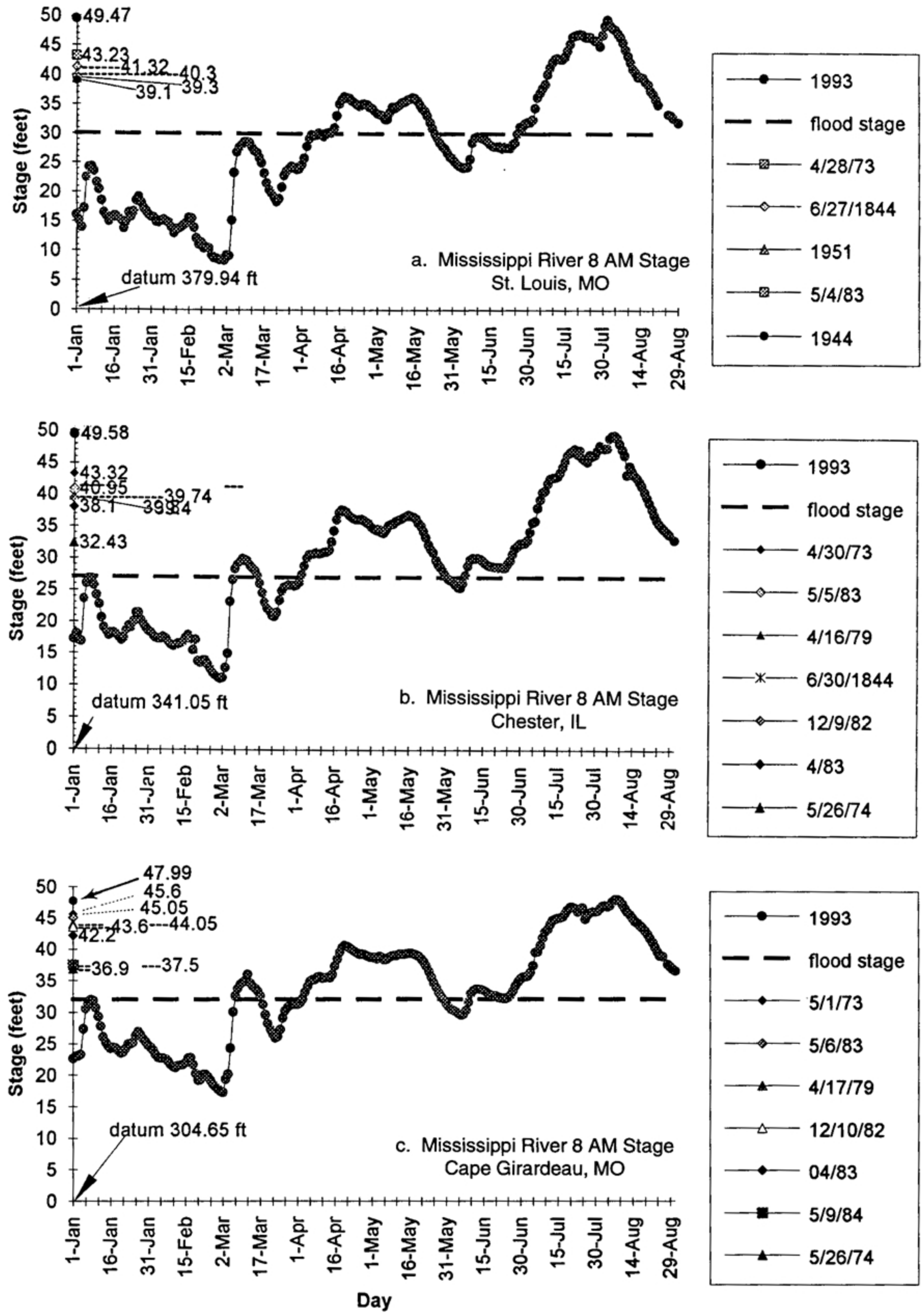


Figure 3.12. Mississippi River stages from January 1 through August 29, 1993, at St. Louis, MO (a), Chester (b), and Cape Girardeau, MO (c)

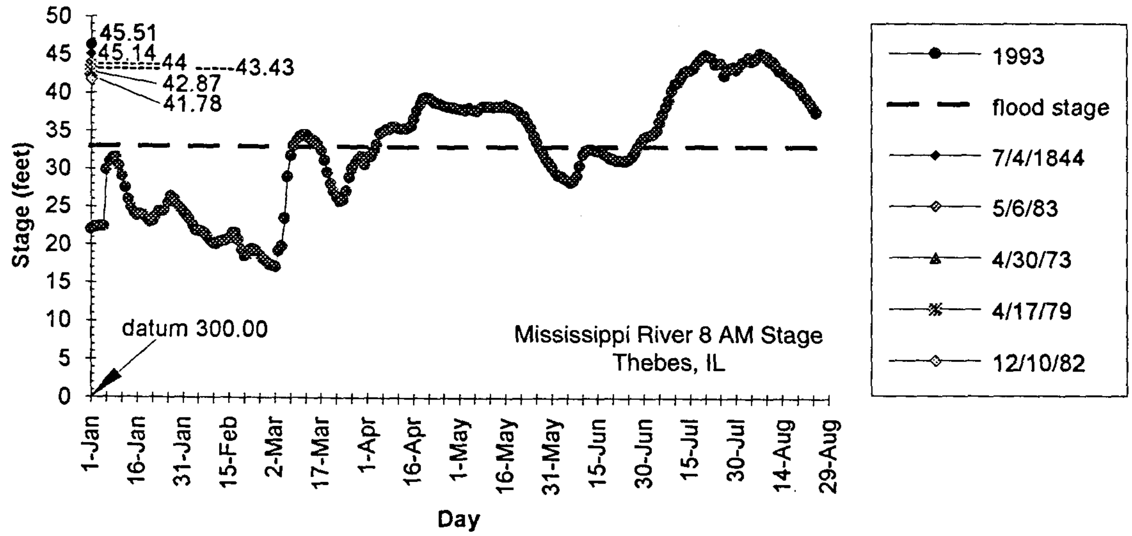


Figure 3.13. Mississippi River stages from January 1 through August 29, 1993, at Thebes

Below Dubuque and Camanche, the Mississippi River spiked above flood stage at Keithsburg, Quincy, and Hannibal on March 6, 7, and 8, respectively (figures 3.10c, 3.11b, and 3.11c). The St. Louis gage shows the rise, but levels did not exceed flood stage at this time (figure 3.12a and 3.13). Designated "flood stage" at St. Louis may correspond to a less frequent flood event (i.e., a longer return interval), made possible by the extensive levee system designed to protect the urban area. Below St. Louis, river levels recorded during early March peaked above flood stage at Chester on March 10 (figure 3.12b) and at Cape Girardeau and Thebes (figures 3.12c and 3.13, respectively) on March 12, approximately six days after the peak passed Keithsburg. Although it exceeded flood stage, the March flood wave was not statistically significant. Stages were less than anticipated for an event with a 5-year return period (USACOE, 1979). Along the Illinois shore, Mississippi River levels fell below flood stage after the March flood wave, only to rise again at the onset of the history-making part of the 1993 flood.

After the early March flood wave passed, river stages began to rise again in late March. Flooding in the Rock River basin resulted in levee failures and damage along the southern portion of the Rock and its tributaries in Illinois, and produced peaks at stations in the river basin between March 25 and 28. This flooding contributed to the rise in stage on the Mississippi between March 24 and 26, which is most readily evident at Keithsburg, Quincy, and Hannibal (figures 3.10c, 3.11b, and 3.11c). After a brief decline, the Mississippi River again rose above flood stage at most stations between April 1 and 4. The multiple intermediate peaks superimposed on the April flood wave at Keithsburg were attenuated as the flood moved downstream to Quincy and then to Hannibal.

Twin peaks can be observed on the major flood wave in the stage plots for April and May for St. Louis, Chester, Cape Girardeau, and Thebes (figures 3.12a, 3.12b, 3.12c, and 3.13, respectively). The first peak occurred on April 18 at St. Louis, April 19 at Chester, and April 20 at Cape Girardeau and Thebes. After a slight decline, the second peak occurred in mid-May. The Illinois River gaging station at Meredosia recorded monthly peak stages in excess of flood stage every month from November 1992 to July 1993. Peak stages were highest in April and second highest in May at 12 and 9 feet above flood stage, respectively. The Illinois River flow was a significant contributor to flooding along the Mississippi in April and May.

At its peak in April, the Mississippi River was 6 or more feet over flood stage. However, the peak stages recorded at the Mississippi River stations during April were considerably less than those recorded during the 1973 flood, which had held the record at the stations below Keithsburg. Recorded stages show that the river level was declining toward the end of May, and for a short period of time it dropped below flood stage at most stations. At the end of May the soil was saturated, and channel and bank storage were filled. Driven by heavy precipitation, river stages began rising again in early June for the onset of the third and most devastating flood wave.

Record Stages and Comparisons to Historical Data

The third flood wave peaked July 1 at Dubuque at 23.84 feet (figure 3.10a), below the historical peak of 26.84 feet set in 1965. The reporting station at Dubuque first exceeded flood stage on April 17. By July 27, when it finally dropped and remained below flood stage, the river had exceeded flood stage for 52 of 71 days. The stages recorded at Camanche, similar to those at the Dubuque station, did not exceed the 1965 flood stage record (figure 3. 10b). Below Camanche, new record peak stages were set at every station. Peak stages and other pertinent data for the Mississippi River stations are reported in table 3.8; they include river mile, gage datum, flood stage, the current flood and historical peak stages, and the stage as of September 30, 1993. The difference between the 1993 peak and flood stage, and between the 1993 peak and the historical record stage are also provided in the table.

Several days lapsed between the occurrence of the highest stage recorded at each succeeding station moving downstream. After the maximum peak was recorded at Dubuque, the river peaked eight days later at Keithsburg (figure 3.10c) on July 9 at 24.15 feet (11.15 above flood stage). The peak reached Quincy on July 13 (figure 3.11b), four days after Keithsburg, reaching 32.18 feet (15.18 feet above flood stage). At Hannibal, peak stage occurred on July 16 (figure 3.11c), three days after Quincy, at 31.80 feet (15.80 feet above flood stage). This flood wave reached St. Louis on July 21 and set a temporary new record high, only to be surpassed (figure 3.12a) by the maximum peak, 49.47 feet recorded on August 1 (19.47 feet over flood stage). The pattern of twin peaks during August was apparent at the St. Louis station, and can also be observed in the stage plots for Chester, Cape Girardeau, and Thebes (figures 3.12b, 3.12c, and 3.13, respectively). The maximum peak recorded at Chester was 49.58 feet (22.68 feet above flood stage) on August 7. The river also peaked on August 7 at Cape Girardeau at 47.99 feet (15.99 feet above flood stage). The maximum stage recorded at Thebes was 45.51 feet (12.51 feet above flood stage), also on August 7.

Measured flood stages may be compared to estimated flood stages for statistically calculated flood events. Estimated flood stages for the 5-, 10-, 50-, 100-, and 500-year return intervals were constructed for the Mississippi River by the U.S. Army Corps of Engineers and reported in *Upper Mississippi River Water Surface Profiles River Mile 0.0 to River Mile 847.5,* (USACOE, 1979), along with the 1951, 1965, and 1973 flood profiles. Below St. Louis (river miles 48 to 167) the urban design flood was used to estimate the 500-year event profile. Agricultural levees below

Table 3.8. Mississippi and Illinois River Stations Historical and 1993 Peak Stages

Gaging station	River mile[1] (feet}	Gage datum (feet)	Flood stage (feet)	Peak stage from July 1-Aug 31,1993 (feet)	Peak stage from July 1-Aug 31,1993 (date)	Feet over flood stage	Historical peak stage (feet)	Historical peak stage (date)	Difference from record	September 30 stage[2]
Mississippi										
Dubuque	579.9	585.47	17.0	23.8	7/1	6.8	26.81	4/26/65	-3.0	I0.0
Camanche	511.8	562.68	16.0	23.0	7/8	7.0	24.65	4/28/65	-1.7	N/A
Muscatine	455.2	530.74	16.0	25.6	7/9	9.6	24.81	4/29/65	0.8	11.4
Keithsburg	427.7	523.19	13.0	24.2	7/9	11.2	20.46	4/28/65	3.7	12.0
Burlington	403.1	511.45	15.0	25.0	7/10	10.0	22.0	4/1/73	3.0	13.9
Quincy	325.0	458.59	17.0	32.1	7/13	15.2	28.9	4/1/73	3.3	15.6
Hannibal	309.7	449.43	16.0	31.8	7/16	15.8	28.23	4/25/73	3.6	16.1
Grafion	218.0	403.79	18.0	38.0	8/1	20.0	33.2	4/28/73	4.8	27.1
St. Louis	180.0	379.94	30.0	49.5	8/1	19.5	43.23	4/28/73	6.2	39.0
Chester	109.9	341.05	26.9	49.6	8/7	22.7	43.32	4/30/73	6.3	41.4
Cape Girardeau	52.1	304.65	32.0	48.0	8/7	16.0	45.6	5/1/73	2.4	42.3
Thebes	43.7	300.00	33.0	45.5	8/7	12.5	45.14	7/4/44	0.4	40.4
Illinois										
Henry	96.0	425.88	19.0	21.1	7/93	2.1	32.67	3/22/79	-11.6	18.6
Kingston	144.4	428.00	20.0	20.3	7/30[3]	0.3	26.02	5/25/43	-5.7	N/A
Havana	119.6	424.40	14.0	23.4	7/30	9.4	27.3	5/25/43	-3.9	N/A
Beardstown	88.6	419.90	14.0	26.6	7/28	12.6	29.7	5/25/43	-3.1	21.9
Meredosia	61.4	418.00	14.0	26.9	7/27	12.9	28.61	5/26/43	-1.7	N/A

Notes:

Stage data for Mississippi River obtained from Army Corps of Engineers, Rock Island, and St. Louis Districts; Illinois River data and some Mississippi River data obtained from remote access to National Weather Service forecast computer.

[1]River mile from mouth.

[2]No data July 1-9.

[3]Not peak, time of reading varies.

St. Louis were designed for a 50-year recurrence interval event. Profiles for events exceeding the 50-year interval are uncertain, depending on the number and severity of levee breaches. The constructed stages corresponding to 100- and 500-year events serve as a point of reference to compare the 1993 stages where discharge data are not available.

The profile elevations for the 100-year event from the 1979 USACOE study are the basis for the floodplain boundaries depicted on most of the current flood insurance rate maps for Illinois riverside counties and communities. Flood insurance is required for structures within the 100-year floodplain. The anticipated elevations of the 100-year event thus indicate levels of preparedness for catastrophic flood events.

Comparison of the peak stages recorded in 1993 to flood profiles estimated for the upper Mississippi by the U.S. Army Corps of Engineers (1979) is quite revealing. Records set at the stations from Keithsburg to St. Louis during this flood event were 2 or more feet over estimated peak stages for a flood with a one percent chance of occurrence during any given year (commonly referred to as the 100-year flood). The records were at or above elevations predicted for an event with a 0.2 percent chance of occurrence during any given year (commonly referred to as a 500-year flood). The peak recorded at Chester was slightly greater than the elevation estimated for a 100-year event. At Cape Girardeau and Thebes, the peak did not exceed the 100-year profile elevation as a consequence of the multiple levee failures before the peak passed.

Duration of Stages over Flood Stage

The magnitude of the peak stages was not the only distinctive feature of the 1993 flood. The duration of the flood was also significant. The daily station data show that from Keithsburg to Thebes, the Mississippi River was above flood stage almost continuously since the first week of April. Many stations were still above flood stage at the close of September, and some stations did not drop below flood stage until October. At Keithsburg the river was above flood stage for 138 out of 151 days between April 3 and August 31. Even at that date it was still above flood stage, but declining. Similarly, at Quincy the river rose above flood stage on April 2 and remained there for 139 out of 152 days until August 31, when it was still above flood stage. The gage at Hannibal recorded levels above flood stage continuously since April 1 and was still above flood stage at the close of August. At Chester and Cape Girardeau, flood stage was exceeded on April 3 and remained there for 144 and 140 days out of 151, respectively (to August 31).

Between Dubuque and Keithsburg, the river fell below flood stage in August, and at the end of September recorded stages were well below flood stage (table 3.8). However, flooding lingered from Keithsburg to Thebes. While river stages declined from the record peaks in July, each precipitation event in August and September was reflected in resurgent rising stages and flooding. The Keithsburg and Quincy stations recorded river levels below flood stage at the end of September, but stations from Hannibal to Thebes showed levels still over flood stage. September flooding was significant, as indicated by the September 30 stages shown in table 3.8. The Mississippi River at Grafton and at St. Louis was reported at more than 8 feet over flood stage at the close of September, and conditions below St. Louis at the end of September forced evacuations. The river at Chester was still 14.5 feet over flood stage on September 30.

The impact of the 1993 flood on Illinois tributaries is evidenced in the continued flooding recorded at stations near the confluence of these tributaries with the Mississippi. Along the Illinois River, flooding overtopped levees and caused significant damage, although recorded stages at stations along the Illinois did not surpass historical floods of record, as shown in table 3.8. Recording stations near the mouths of the Illinois, Kaskaskia, and Big Muddy Rivers in Illinois showed these rivers well above flood stage through me end of September.

Impact of Levee Failures on River Stages

The multiple levee failures in July and August imprinted a distinctive signature on the stage records at stations downstream. The Mississippi River levees along the Illinois border are identified in figures 2.12 and 2.13, and the gaging station locations are given in figures 2.7 and 2.13. Successive levee failures occurred during the month of July. Figures 3.10c, 3.11b, and 3.11c show the stages recorded at 6-hour intervals at Keithsburg, Quincy, and Hannibal, respectively, from July 1 through July 31. The levees in the Rock Island area above Keithsburg held, and the 6-hour data from the Keithsburg station, plotted in figure 3.14a, show a fairly smooth transition in river stage for the month of July. However, the numerous levee failures during July led to the flooding of large levee districts just upstream of Quincy and Hannibal. The jagged appearance of the stage plots for these two stations in July (figures 3.14b and 3.14c) illustrates the sudden and significant drops in river levels that are coincident with levee failures. The levee district name and the date of the levee failure for those on the Illinois side of the Mississippi are labeled on the stage plots in the figures. The immediate drop in river level at the time of the various levee failures was followed by a rapid rise in river level once the floodplain storage of the levee district was occupied. The flooding of the levee districts caused only temporary declines in river stage. However, me attenuation of the flood wave as the districts flooded served to lower the peak stage of the concurrent flood wave.

Main Channel Discharges (Juhl and Knapp)

It has already been pointed out that the flood of 1993 resulted in several new record stages along the Mississippi and the lower Illinois Rivers. The Illinois Department of Transportation/ Division of Water Resources contracted with the Illinois District of the USGS to obtain discharge measurements on the Mississippi and Illinois Rivers and several of the principal tributaries during the flood event. These discharge measurements were requested to 1) assess the magnitude of the flood peaks, and 2) to define the upper end of the rating curve at gaged stations. The Missouri and Iowa USGS districts were also making discharge measurements.

Significant riverbed scour was occurring in some locations where measurements were taken, which necessitated the use of fathometers to give better estimates of the channel bed, or the use of Doppler meters to more readily track bed movement during a discharge measurement. A Doppler meter was rented from the U.S. Army Corps of Engineers in New Orleans, and the Doppler meter owned by the Illinois District USGS was also used. Many other measurements were made by the USGS and the Corps of Engineers as part of normal ongoing gaging programs. These discharge measurements were useful in monitoring river stages and in understanding stage forecasts and rates of rise or fall in the rivers.

Table 3.9 lists peak discharges for selected locations on the Mississippi River, its major tributaries, and the Illinois streams that experienced significant flooding. These discharges were provided by the USGS, and most of these values were published in Parrett et al. (1993). The period of record for the gaging stations listed in this table range from 49 years to 132 years, with most stations having a record greater than 70 years. The historical peaks and flood ranks are based on

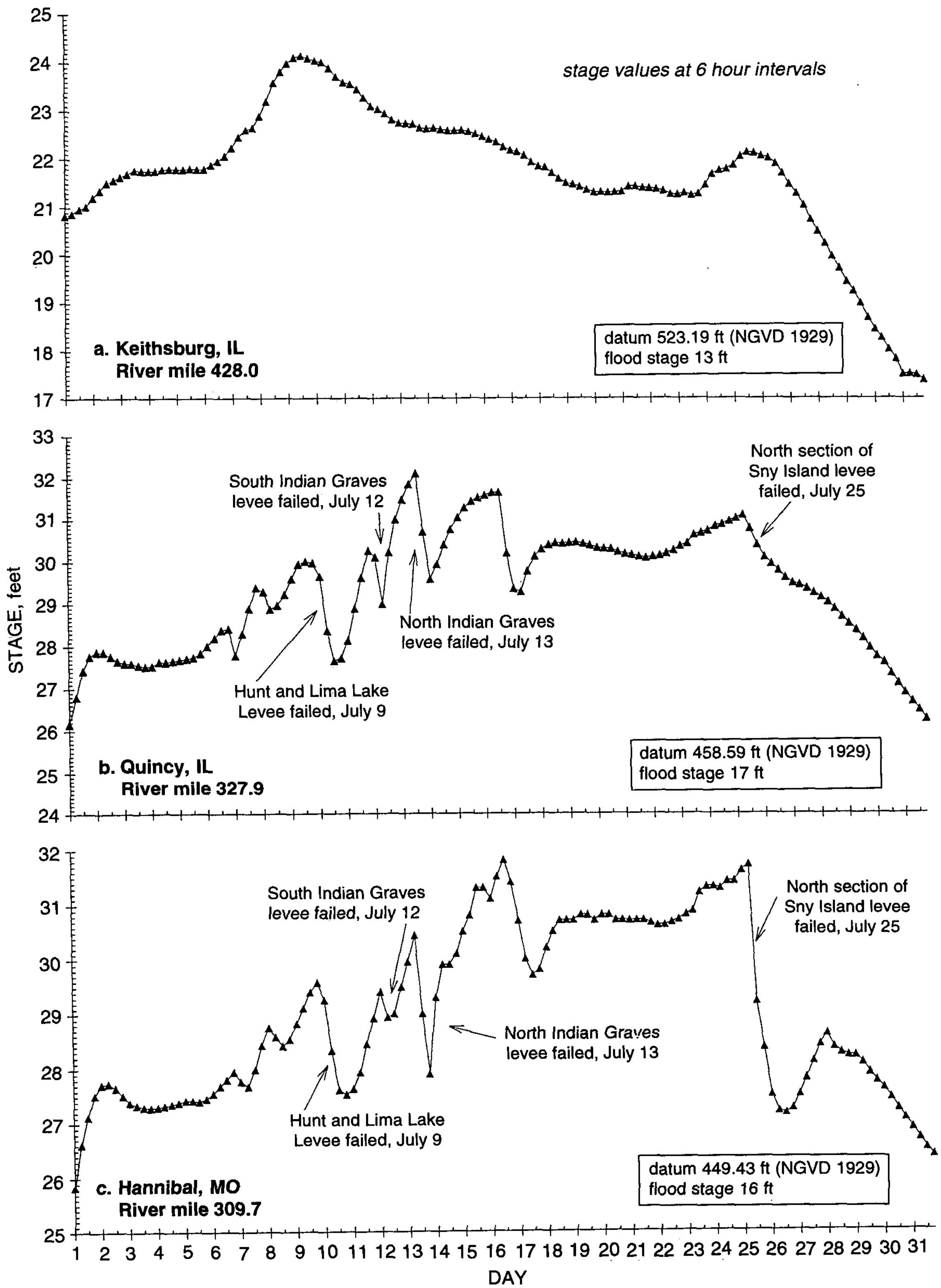


Figure 3.14. Mississippi River stages for July 1993
at Keithsburg (a), Quincy (b), and Hannibal, MO (c)

Table 3.9. Peak Discharges for the 1993 Flood on the Mississippi River and Major Tributaries

Location	*Historical peak flow through 1992 (cfs)*	*Peak flow in 1993 (cfs)*	*Date*	Historical rank
Minnesota River at Mankato, MN	94,100	75,800	6/21	3
Mississippi River at St. Paul, MN	171,000	104,000	6/26	5
Chippewa River at Durand, WI	123,000	90,100	6/23	5
Black River near Galesville, WI	65,500	64,000	6/21	2
Wisconsin River at Muscoda, WI	80,800	59,600	6/25	8
Maquoketa River near Maquoketa, IA	48,000	38,000	7/6	3
Mississippi River at Clinton, IA	307,000	245,000	7/5	4
Rock River at Joslin, IL*	41,600	34,000	6/11	12
Mill Creek at Milan, IL	9,300	7,680	6/25	3
Iowa River at Wapello, IA	94,000	107,000	7/7	1
Edwards River near New Boston, IL	18,000	5,250	7/24	19
Pope Creek near Keithsburg, IL	8,900	6,860	7/24	3
Henderson Creek near Oquawka, IL	34,600	30,100	7/25	2
Skunk River at Augusta, IA	66,800	54,400	7/10	2
Mississippi River at Keokuk, IA	344,000	435,000	7/10	1
Des Moines River at Keosauqua, IA	146,000	108,000	7/13	4
Bear Creek near Marcelline, IL	39,500	12,700	7/1	14
Spoon River at Seville, IL	37,300	34,400	7/26	3
LaMoine River at Ripley, IL	28,000	15,800	7/27	16
Illinois River at Valley City, IL	123,000	97,500	8/1	10
Missouri River at Hermann, MO	618,000	748,000	7/31	1
Mississippi River at St. Louis, MO	1,013,000	1,030,000	8/1	1
Mississippi River at Chester, IL	1,060,000	950,000	8/6	2
Mississippi River at Thebes, IL	893,000	975,000	8/7	1

The 1993 annual peak discharge for the Rock River at Joslin was 48,000 cfs on March 26, 1993. This was the flood of record for the Joslin gage.

each gage's period of record, and do not use discharges estimated according to flood marks from prior years.

Most of the major tributaries in the Upper Mississippi River watershed experienced severe flooding, ranking 1993 as one of the top five on record. Peak discharges estimated to be in excess of the 100-year flood flow occurred on the Mississippi River at Keokuk and St. Louis, and on the Missouri, Iowa, Des Moines, Skunk, and Black Rivers, as well as many other unlisted smaller tributaries.

A large number of smaller streams not shown in table 3.9 also experienced severe flooding, with recurrence intervals in excess of 10 years and frequently in excess of 50 years. Streams in Iowa and eastern Nebraska, in particular, experienced extreme floods. But most streams in Illinois did not exceed 10-year event levels, with the exception of the Spoon River and Henderson Creek in west-central Illinois.

Peak discharges on the Illinois and Rock Rivers had recurrence intervals in the range of 5 to 10 years. However, both rivers contributed sizable amounts of water to the 1993 flood and were above flood stage most of the five months from April through August. The flow during these five months on the Rock River averaged more than 20,000 cfs, making it the greatest five-month flow volume on record. The record peak discharge on the Rock River, 48,000 cfs, occurred on March 26, 1993, and greatly contributed to the high spring flows on the Mississippi.

Carrying Capacity of Floodplains (Bhowmik)

The floodplains of the Mississippi and Illinois Rivers are protected against inundation by levees. Water is essentially confined to the leveed river unless the levees fail due to seepage or overtopping. In a natural system, where the floodplains are unprotected against the flood flow and the river is expected to flood these areas, it is reasonable to expect the floodplain to carry a portion of the flood flow. Questions may be asked as to the quantity of the flood flow that could be carried by the floodplains for different stages and flood frequencies if the floodplains were kept unobstructed. Actual field data on flood flow distribution between the main channel and the floodplains are hard to come by, and not much is available in the open literature. As far as the Illinois and Mississippi Rivers are concerned, very little data have been collected or are available on this specific question.

Some research in this area was conducted by Bhowmik and Stall (1979) and Bhowmik and Demissie (1982). They gathered data from various sources to show the variability of flow distribution between the main channel and the floodplains at various stages and flow frequencies. This research has shown that for medium to small streams, the average velocity increases as the river stage rises up to the bankful stages. However, once the water spills over the bank, the average velocity within the river decreases before it again starts to increase with rising stages. The average velocity in the floodplain also starts to increase as the stage rises. But beyond a certain flow and stage, average velocities on both the main channel and the floodplains become asymptotically equal before they more or less follow the trend line of the river's velocity before it reached bankful stage.

These data and observations indicate that at certain flow frequencies and also for certain stages, the floodplain acts partially as a storage reservoir and partially as a conveyance channel. However, after certain flood stages and flow frequencies, the floodplain and the main channel behave as a single entity, carrying proportional amounts of flow, Data that were analyzed by Bhowmik and Stall (1979) and Bhowmik and Demissie (1982) have shown that this occurs at a flow frequency of about 40 years' recurrence (figure 3.15).

Data were also analyzed to determine the distribution of flow between the floodplain and the main river. Some of the data analyzed for Tuxachanie Creek in Mississippi, the Big Black River near Way, Mississippi, and for the Minnesota River near Jordon are shown in figure 3.16 and 3.17. They show that, in general, as the flow frequency increases, the floodplains start to convey more and more water. The exception is the Big Black River near Way, Mississippi, where the floodplain is the dominant feature of the system.

It is not known how much water would have been conveyed by the floodplains of the Mississippi River if the levees had not been built and the floodplains were not constricted. Answers to such questions can only be obtained through mathematical modeling exercises. The plots and discussion presented here show that an unobstructed floodplain could be expected to carry some of the flows during extreme flooding events.

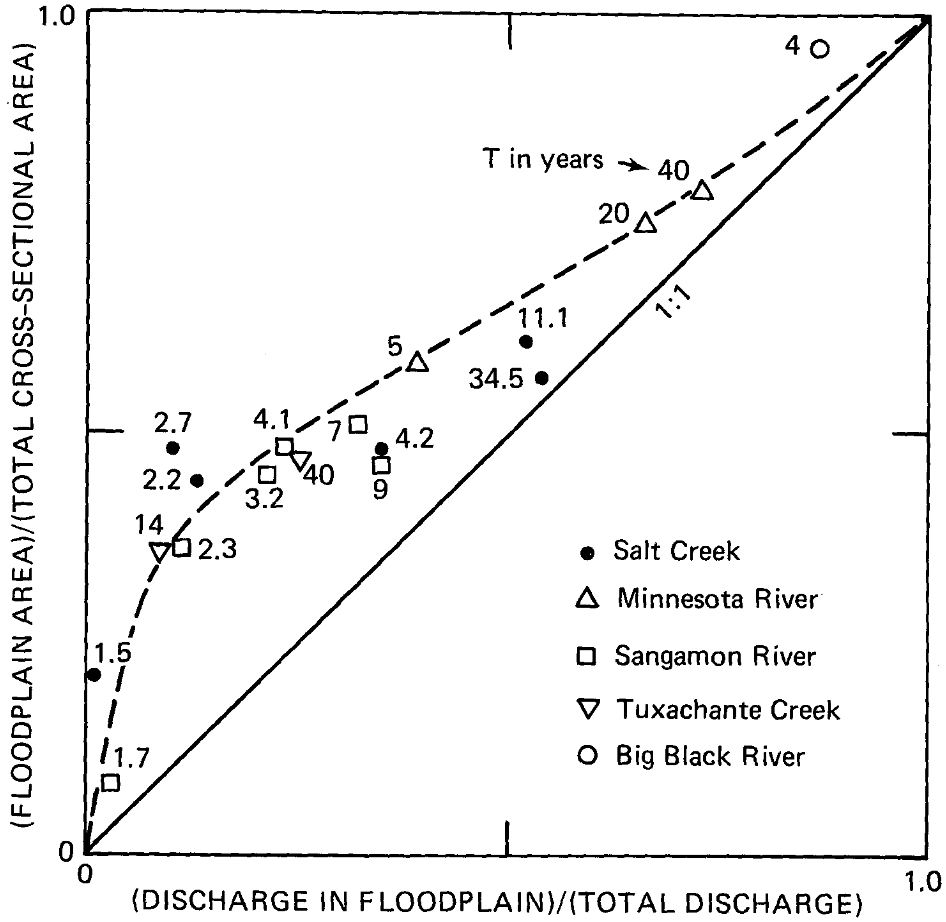


Figure 3.15. Relationship between the ratio of the floodplain area to the total cross-sectional area and the ratio of discharge in the floodplain to total discharge (after Bhowmik and Stall, 1979)

Levee Breaks (Durgunoglu)

Levee breaks were probably the most dramatic and heartbreaking part of the flood of 1993. After nearly three months with the Mississippi River at or above flood stages, levees in Illinois started to fail in early July. These levee breaks are listed in table 3.10, and the locations of the failed levees am given in figure 3.18.

The first Illinois levee was breached on July 7 at Pope Creek near Keithsburg, which protected 1,260 acres. The levee of the Lima Lake Drainage District, near the small town of Meyer, failed two days later (July 9). This break also caused flooding at the Hunt Levee and Drainage District, where 28,600 acres were inundated. The three levees in Henderson County near Gulfport failed the same day, flooding an additional 15,000 acres. The flooding of Niota on July 10-11 and the subsequent oil spill raised the fear of floodwaters contaminated with hazardous materials.

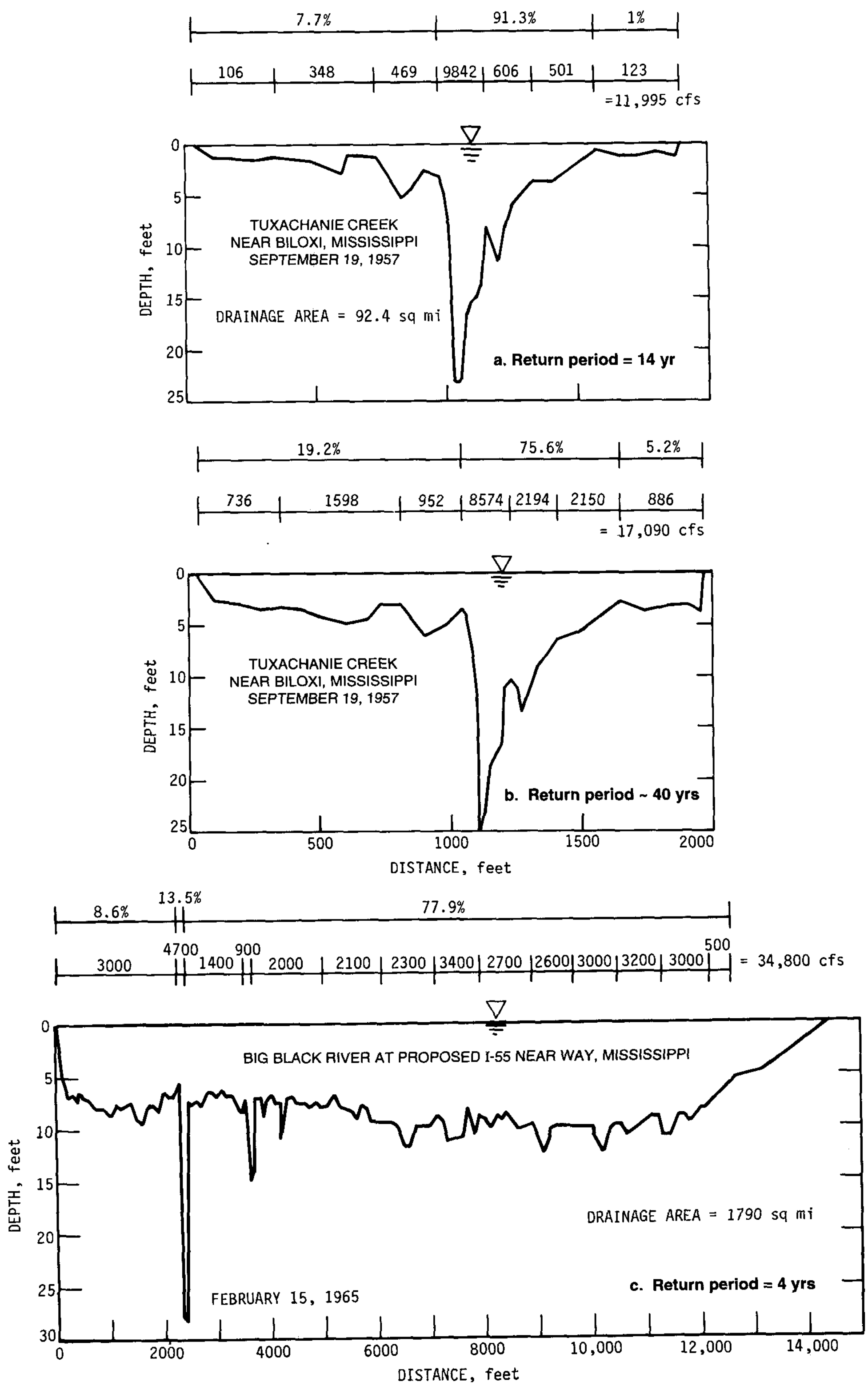


Figure 3.16. Flow distribution in the Tuxachanie Creek near Biloxi, MS (a,b), and in the Big Black River near Way, MS (c) (after Bhowmik and Stall, 1979)

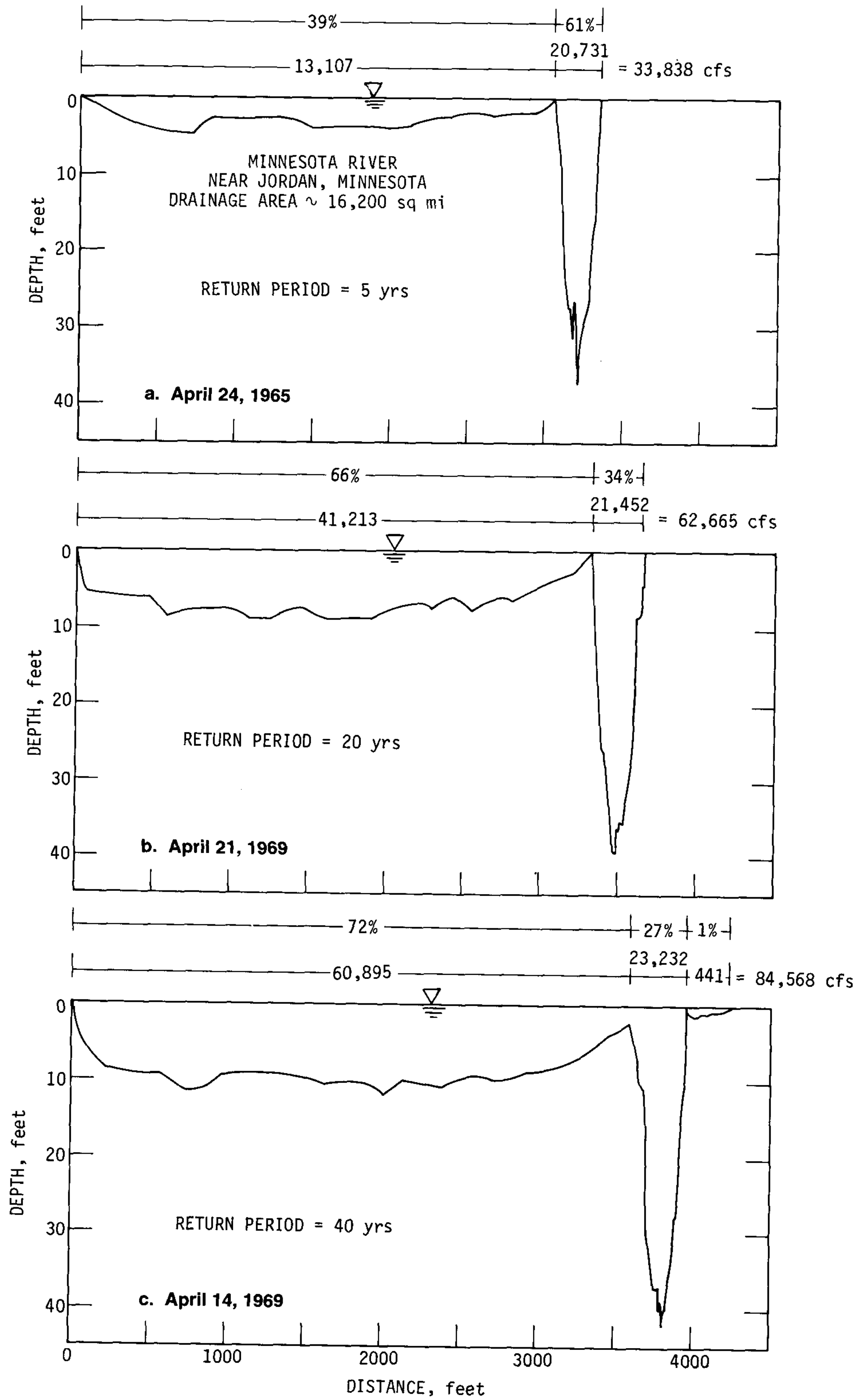


Figure 3.17. Flow distribution in the Minnesota River near Jordan for three different return periods (after Bhowmik and Stall, 1979)

Figure 3.18. Failed levees in Illinois

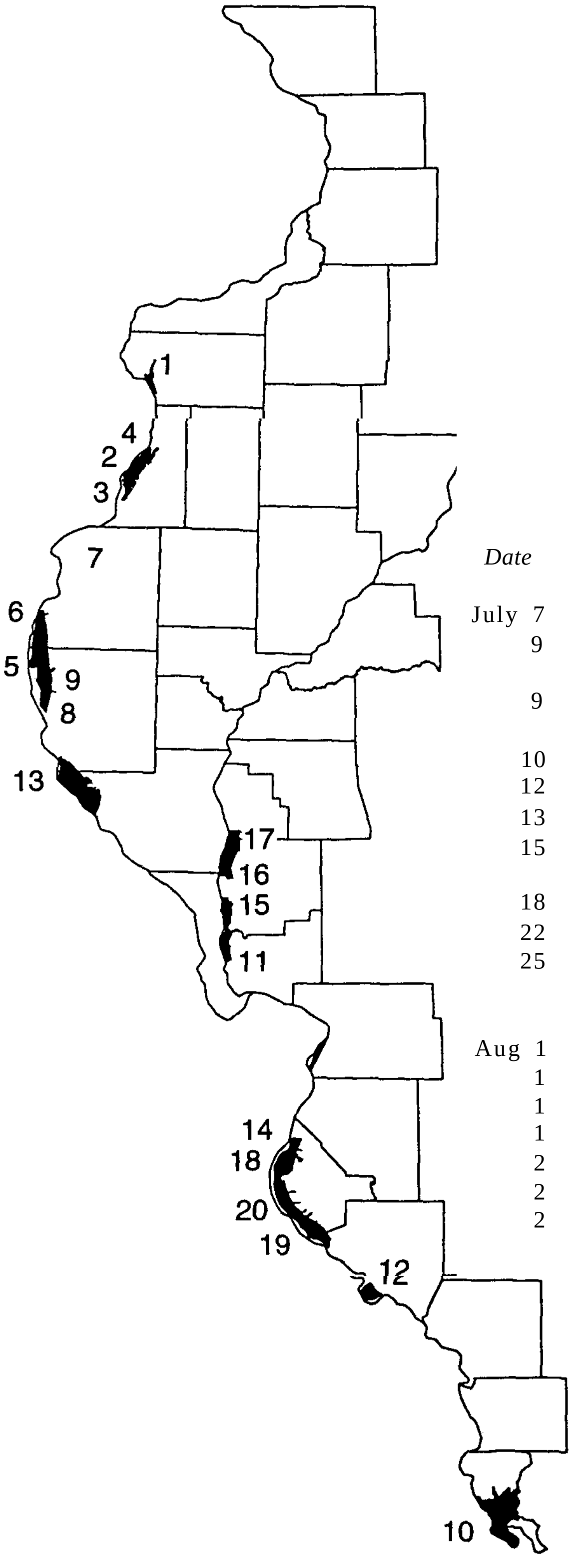


Table 3.10. Levee Breaches in Illinois

Date	*Name of levee district(s)*	*Acres flooded*	*Location in figure 3.18*
July 7	Keithsburg	1,260	1
9	Henderson County Levees #l, #2, and #3 (near Gulfport)	15,000	2, 3, 4
9	Lima Lake (near Meyer) and Hunt Districts	28,600	5, 6
10	Niota	1,000	7
12	Indian Grave (southern portion)	8,000	8
13	Indian Grave (northern portion)	10,000	9
15	Len Small (near Miller City and Fayville)	20.000	10
18	Nutwood (near Hardin)	11,000	11
22	Kaskaskia Island	14,000	12
25	Sny Island (northern portion) and Fall Creek	44,000	13
Aug 1	Columbia	13,000	14
1	Eldred (near Kampsville)	8,400	15
1	Hartwell (Greene County)	8,700	16
1	Hillview (Greene and Scott Counties)	12,300	17
2	Harrisonville and Ivy Landing	30,000	18
2	Stringtown	2,500	19
2	Fort Chartres and Ivy Landing	10,100	20

Note: This list does not include small levees or the breach of temporary levees built during the flood to protect a particular structure. None of the breaches in Iowa or Missouri are reported.

By that time the Illinois National Guard had been activated to help reinforce the levees and organize evacuations if needed. In the early morning of July 12 the southern section of the Indian Graves Levee (north of Quincy) broke, flooding 8,000 acres of farmland. The northern section of the Indian Graves Levee broke the next day and flooded an additional 10,000 acres. The failure of the West Quincy Levee (in Missouri) on July 16 closed the Bayview Bridge, leaving no open Mississippi River bridges between Keokuk and St. Louis.

More news of levee failures came from southern Illinois on July 15 when the Len Small Levee on the Mississippi River broke near Miller City in Alexander County, flooding about 20,000 acres, including the Horseshoe Lake Conservation Area.

On July 18, the Nutwood Levee on the Illinois River near Hardin broke. This failure inundated about 11,000 acres and practically isolated Calhoun County.

The levee system protecting Kaskaskia, the only town in Illinois located west of the Mississippi, followed on July 25. The town and 14,000 acres of surrounding farmland were flooded.

The worst of the levee breaks was yet to come. On July 25, the northern part of one of the largest levee districts on the Mississippi River broke. The failure of the Sny Island Levee (south of Quincy), including the Fall Creek Levee, flooded about 44,000 acres and prompted the evacuation of Fall Creek, Hull, and East Hannibal. This failure caused temporary relief for downstream river stages, even though the southern section of the Sny Island Levee held.

The northern part of the flood wall protecting St. Louis was almost breached in late July, but the Corps of Engineers promptly plugged the hole and reinforced the foundation. In the meantime, the crest of the Mississippi River tolled downstream and caused a new chain of levee breaks on August 1. The Columbia Levee in Monroe County failed, and the Mississippi River flooded more than 13,000 acres. That same day the backwater from the Mississippi River caused three more levee failures on the Illinois River. Eldred Levee in Calhoun County near Kampsville broke and flooded 8,400 acres; Hartwell Levee in Greene County failed and flooded 8,700 acres; and Hillview Levee in Greene and Scott Counties also failed and inundated another 12,300 acres.

The following day (August 2) another levee on the Mississippi River broke near Valmeyer in Monroe County. This levee break would cause the inundation of almost 43,000 acres in three drainage districts: Harrisonville and Ivy Landing, Stringtown, and Fort Chartres and Ivy Landing.

On August 3, the Corps of Engineers intentionally broke another section of the same levee, at a point 30 miles downstream of the original breach. The manmade break caused more rapid flooding of the Fort Chartres and Ivy Landing district, but also relieved pressure on another levee that protects the town of Prairie du Rocher. The strategy was successful, as the Prairie du Rocher levee held. By this time the floodwaters on the Mississippi River had started to recede, with no further danger to the remaining levee districts.

The flood of 1993 broke through 1,082 of the 1,576 levees in the Missouri and Upper Mississippi River basins. These levees sustained hundreds of millions of dollars in damage, although the exact amount can only be determined after the floodwaters recede. A preliminary survey by the Corps of Engineers found that only 203 of the damaged levees were eligible for help under a program that gives top priority to repairing levees protecting metropolitan areas. Most of the remaining 879 damaged levees, ineligible for aid from the Corps of Engineers, protected farmland. Other programs may be offered by the U.S. Department of Agriculture for levee repairs.

Of the 1,576 levees, 229 were federal levees built by the Corps to protect farms and river towns. Only 39 of the federal levees failed, whereas 1,043 non-federal levees failed. Although the first impression is that the rate of failure of non-federal levees was much higher than for the federal levees, no information is available now on the design specifications (design flood frequency) of these levees. Therefore a meaningful comparison of failure rates cannot be made. Still remaining are the questions regarding the future of most of the flooded levee districts.

Discharge and Stages at the Len Small Levee Breach (Knapp, McConkey, and Dalton)

When a levee is breached, in most cases the water that flows into the levee district is stored there. Once the levee district is completely inundated, the flow rate through the levee breach becomes fairly small and is controlled by the rise and fall of the river. But in a few cases, the breach provides a separate path for the conveyance of floodwaters downriver. On July 15, the Len Small Levee in Alexander County was breached by the Mississippi near river mile 34 (figure 3.19). The communities of Miller City and Willard, as well as scattered homes, were located behind the levee. Over the following few days, as water passed through the breach, a portion of the water started flowing northeast toward the lowland area near Horseshoe Lake. Then the floodwaters moved through the lake, over the dam, and south along Lake Creek to the Cache River diversion outlet to the Mississippi River. Another portion traveled south and southeast of Willard, following the downstream direction of the Mississippi River. This distribution provided alternate paths for some of the flows of the Mississippi River. The Cache River diversion joins the Mississippi River 21 river miles downstream of the location of the levee failure, while the overland route is approximately 10 miles. By July 27, the breach had expanded to a width of 1,550 feet and was starting to accept a significant portion of the Mississippi River's flow.

The U.S. Geological Survey, with partial support from IDOT/DWR, measured the flow passing through the Len Small Levee breach. On July 28, it was measured at 178,000 cfs, equivalent to more than 20 percent of the flow in the river. Within a few days, the flow had increased to almost 200,000 cfs and was scouring a channel into the levee district and in the farmland side of the levee. By August 8 the width of the breach had expanded to 2,429 feet (table 3.11). The depth of flow along the levee breach varied from 30 to 70 feet, exceeding 70 feet at its centerline. From July 31 to August 2, a large amount of riprap had been placed along the riverward toe of the levee near Mississippi River mile 39. This portion of the levee, near Fayville and Olive Branch, was also beginning to erode.

Water elevations were also measured by IDOT/DWR and the USGS at five temporary stations. These stations were located: 1) on the Mississippi near the levee breach, 2) at the north end of Horseshoe Lake (to monitor lake levels), 3) at the intersection of Routes 3 and 127 (the northern extent of the flooding), 4) on Lake Creek at Route 3, and 5) on the Cache River diversion channel at Route 3 (figure 3.19). Measurements were made from July 17 through August 18.

Water elevations were measured at these stations as well as at the Thebes station on the Mississippi (figures 3.20 and 3.21). The data were plotted according to measurements made around 7:00 a.m. each day, and missing data points were interpolated. As the levee breach widened, water levels rose at the temporary stations. By the beginning of August, the water-level fluctuations on Lake Creek and at the Cache River diversion were mimicking the fluctuations in stage of the Mississippi River recorded at Thebes.

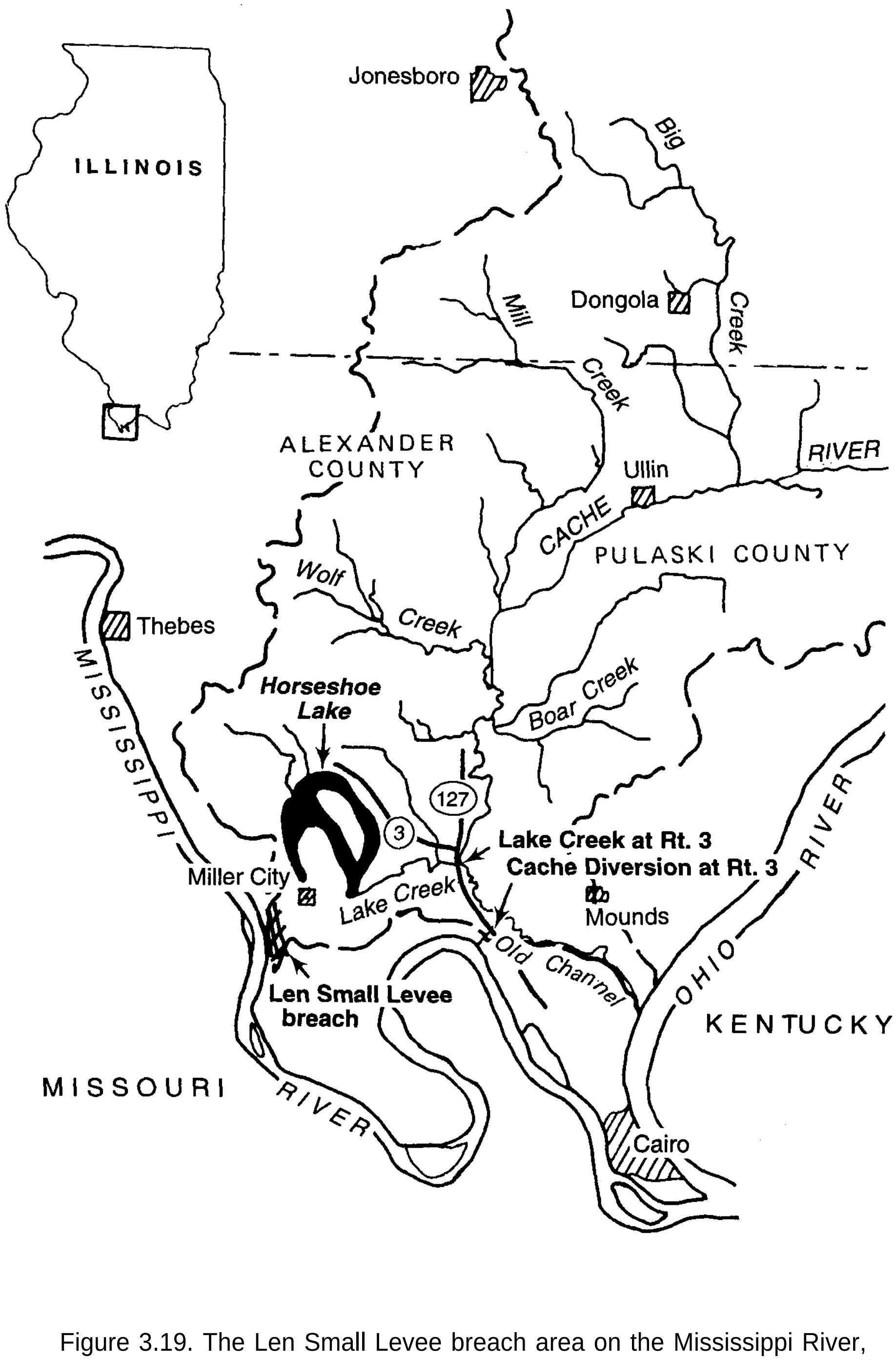


Figure 3.19. The Len Small Levee breach area on the Mississippi River, including the locations of the stage measuring stations

Table 3.11. Dimensions of the Len Small (Miller City) Levee Breach and Discharges through the Breach

Date	*Width (feet)*	*Center line depth (feet*	*Discharge (cfs)*
July 15	0	0	0
July 27	1,550	40	–
July 28	1,860	71	178,000
July 29	1,924	71	193,000
July 31	2,180	73	<200,000
Aug 2	2,164	–	–
Aug 8	2,429	–	–

Source: Illinois Department of Transportation, Division of Water Resources

On August 25, an aerial tour of the area indicated that much of the water moving through the breach was now bypassing the Horseshoe Lake area, spreading out along the former farmland and moving more directly toward the downstream portion of the Mississippi River. Speculation rose that the river might cut a new channel for the Mississippi, bypassing a 10-mile meander of the river known as "Dogtooth Bend." The extent of the channel scour and modifications to the land will not be known until water levels subside.

Levee Protection (Knapp)

Among the most emotional aspects of the flood were the efforts spent trying to save the levees. Those efforts in western Illinois near Quincy are described in the following. Most of the material was gathered from local accounts printed in the *Quincy Herald-Whig QHW*). River stages at Quincy for the period described here are shown in figures 3.11b and 3.14b.

The fight to protect levees in the Quincy area actually began in early spring 1993, when the river was approaching its spring peak stage of 24 feet. This was the highest stage experienced on the river in the seven years since 1986. In mid-April, a weak spot was noticed in the Lima Lake Levee near Meyer, which protects 13,189 acres of farmland. This weakness, caused by lateral erosion of the Mississippi River running alongside the levee was reported to be a half-mile long. A major effort was launched to reinforce the levee and reduce the erosive impact of waves with heavy plastic and wooden fencing and sandbags. Most residents of the district moved their farm machinery and other belongings to higher ground, and many evacuated the area. Meanwhile, the district's pumping station kept operating nonstop to clear the district of the increased seepage caused by the levee weakness (*QHW*, April 25, 1993). On April 23, a team from the U.S. Army Corps of Engineers came to inspect the levee, which was found to be in critical condition, structurally weakened by years of erosion.

The spring flooding and the observed weakness in the Lima Lake Levee created significant concern that many of the levees along the Mississippi needed to be repaired and improved. The Upper Mississippi River Flood Control Association, which represents 25 levee and drainage districts in Illinois, Iowa, and Missouri brought this concern to Washington DC, and on June 18 the

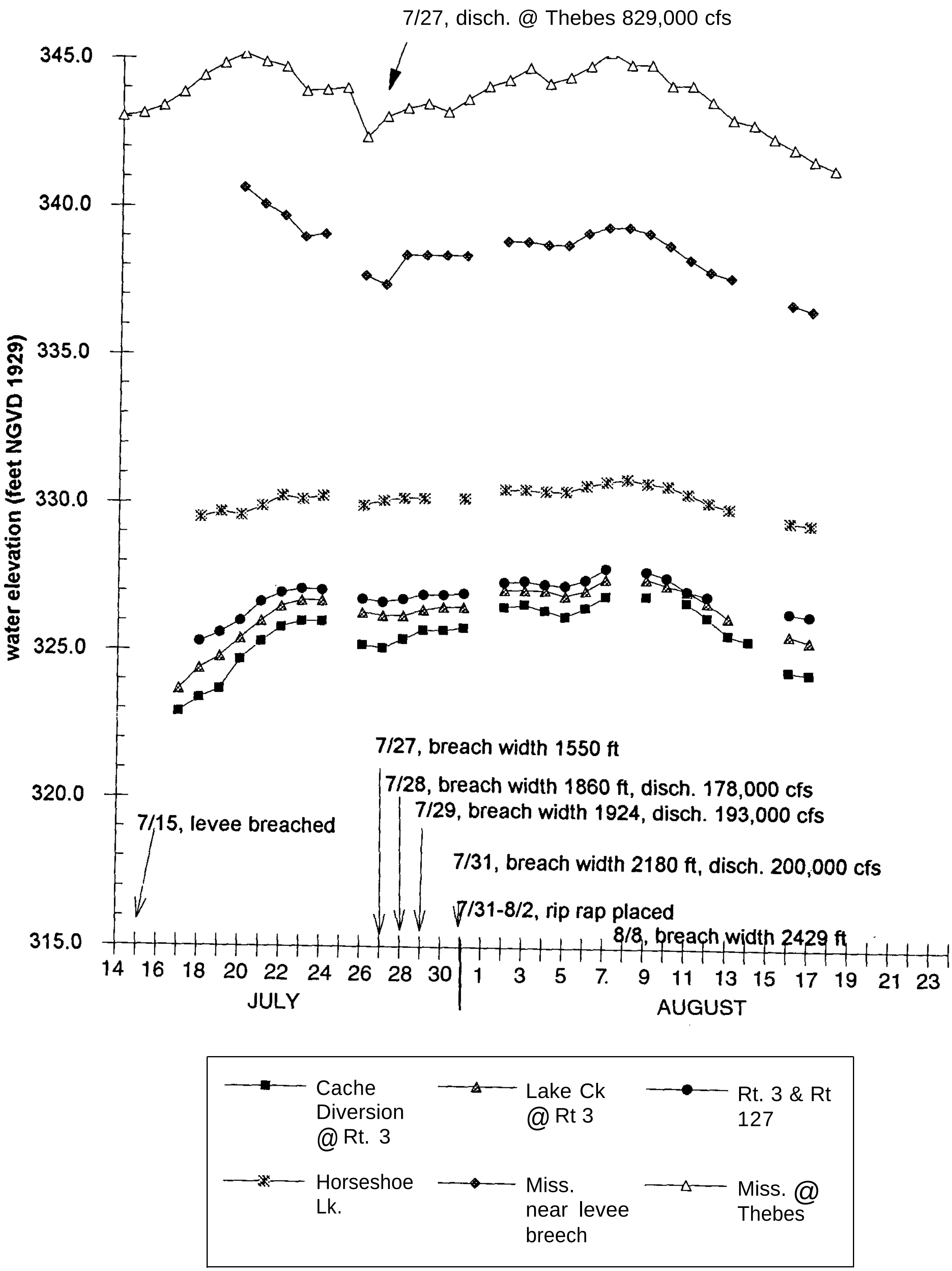


Figure 3.20. Stage variability on the Mississippi River at locations close to the Len Small Levee breach

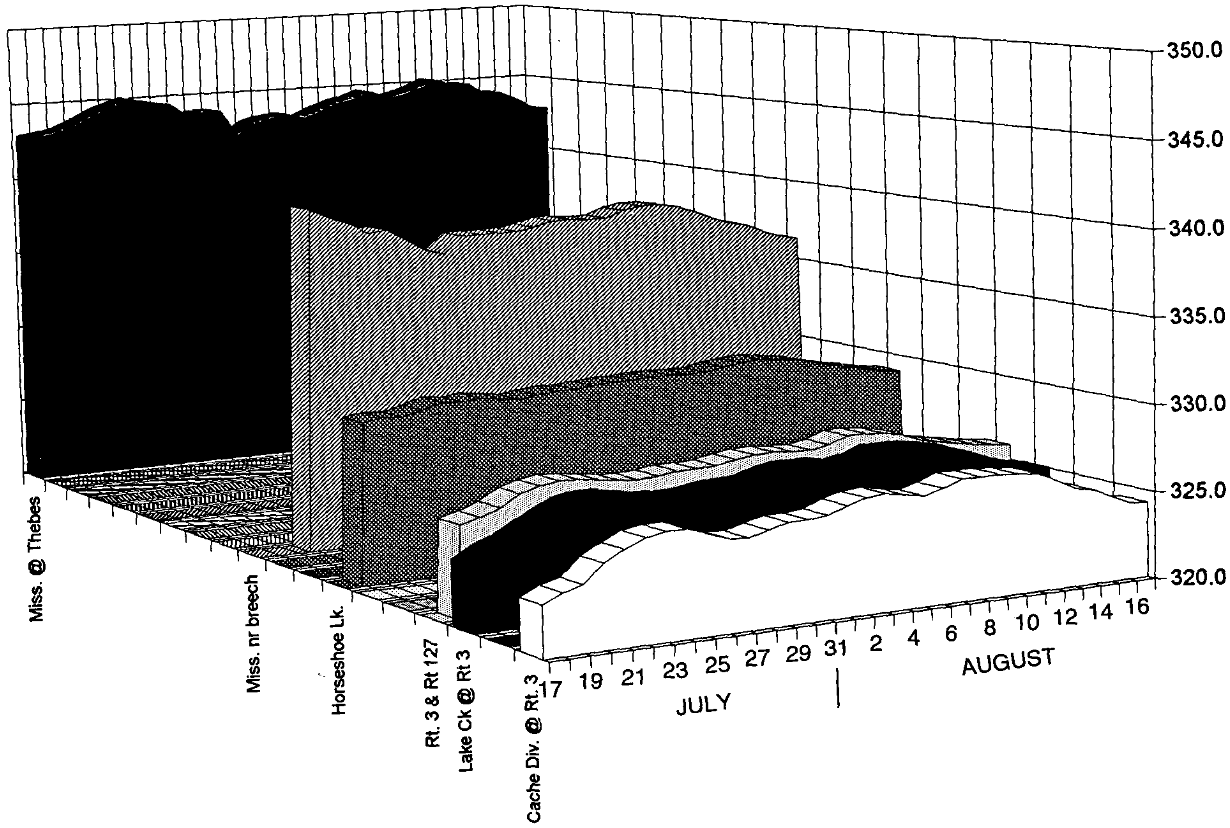


Figure 3.21. Three-dimensional model of stage variability on the Mississippi River near the Len Small levee breach

U.S. House of Representatives approved $250,000 to study whether these Mississippi River levees needed fixing (*QHW*, June 19, 1993).

At about this time, June 17-20, major flooding began on the Upper Mississippi River in Minnesota. Interestingly, the flooding problems upstream on the Mississippi were largely ignored in the Quincy area until June 24. The National Weather Service had forecast that the river would rise to 21.9 feet at Quincy, 2 feet short of the spring peak. Officials at the Lima Lake Levee District were not particularly concerned because many of the weak spots in the levee had been shored up with sandbags and fencing. However, within 24 hours the flooding potential changed. Overnight rains caused the river to rise 1.4 feet in one day, and the National Weather Service was now forecasting a crest of 24.5 feet (table 3.12). The state of the Lima Lake Levee at Meyer was now a concern, and many residents in the levee district wondered if they would have to evacuate again, as they had in April.

Most area levees were designed to protect against a flood stage of 26 feet, with an additional 3 or 4 feet of freeboard. Sandbagging operations began along many of the area's levees on June 30, when the river stage forecast was revised up to 26.5 feet. Workers at the Sny Island Drainage District near New Canton started using bulldozers to raise the top of the levees, along with installing flashboards and sandbags. Seepage water was already beginning to inundate some of the cropland within the district, and at some locations it was up to 3 feet deep.

Table 3.12. Updates in the National Weather Service Forecast for Quincy

Date	*Forecasted peak stage*
6/24	21.9
6/25	24.5
6/30	26.5
7/1	30.0
7/2	28.4
7/3	27.6
7/5	31.5
7/7	32.5
7/10	32.0

On the night of June 30 a thunderstorm dropped large amounts of rain along the Mississippi River valley near Quincy, including a record-high 6.06 inches at Quincy. The river was forecast to reach a record stage of 30 feet as a result of these rains. Officials of the Lima Lake Levee District ordered residents to evacuate at 5:00 a.m. the next morning, and the Corps of Engineers warned that the levee was in imminent danger of failing. The pump operator at the district, Floyd Penn, saw no way the levee could hold the predicted stages: "The levee is completely saturated and has been eroded to the point there's nothing we can do." (*QHW,* July 1, 1993).

The National Weather Service lowered the forecasted crest on July 2, and one day later the Quincy area breathed a sigh of relief when the river crested at 27.6 feet, significantly lower than the revised forecast. Levee districts were still fighting sand boils and were greatly concerned about levee stability because of the extended period of seepage that they had already endured and were yet to endure before the floodwaters receded. However, officials were now looking forward to the end of the flood and recovery (*QHW,* July 4, 1993).

But on July 5, a new round of heavy thunderstorms dropped more than 4 inches of rain over much of Iowa, drowning any hopes of receding flows along the Mississippi River. The new forecast put the expected river crest at Quincy at 31.5 feet, an increase of 4 feet, and 2.6 feet higher than the record stage experienced in 1973. This meant that the expected flood peak would be several feet above the original tops of most of the area's levees. The levees had already served their function and protected against the 50-year flood level. But now more was expected of them. Residents of many of the levee districts were all being asked to leave—and most people already had.

About 480 troops from the Illinois National Guard were called out by Governor Edgar to provide security on closed bridges, to patrol levees, to sandbag sand boils, and to help with evacuations. They started arriving on July 4. By July 7, National Guard troops in the area numbered 1,140, many of whom were being put to work on the levees. Guard troops were deployed from Bloomington, Peoria, Decatur, East St. Louis, and Champaign-Urbana.

On July 6 and 7, three levees failed upstream of Quincy on the Missouri side of the river: LaGrange, Alexandria, and Gregory Landing. In Quincy, officials organized a central location where volunteers could fill sandbags for the endangered levees throughout the area. Urgent appeals were issued for more volunteers to help sandbag the levees. Many people had already been sandbagging for over a week with little sleep.

The Lima Lake (Meyer) Levee broke on July 9, ending an intense ten-day struggle to keep the water out. The river stage had risen above 30 feet, and water had been pushing over the top of the levee in several locations throughout that day. Ironically, the levee broke at one of the assumed "strong" spots, while workers were busy shoring up what they thought was a weak spot. The Hunt Levee District, north of Lima Lake, was also being inundated because no levee separated them from the Lima Lake District. It took little more than 24 hours to inundate the 28,600 acres belonging to both levee districts.

More Illinois National Guard troops arrived, bringing the number in the Quincy area to about 2,000. The 3,500 troops deployed throughout Illinois accounted for almost half of those used in the entire Midwest to fight the flood. The Chief of the National Guard Bureau in Washington DC, Lt. General John B. Conway, estimated that the total cost to the National Guard units from all states was between $1.5 and $3 million per day (UPI, July 13, 1993). An unofficial estimate of costs for the Illinois National Guard's efforts by the end of the summer was $40 million.

The troops and other volunteers continued to work on other levees — nonstop, 24 hours a day, many times in steady rain. By July 11 most area levees had been built up an additional 3 to 4 feet above their original heights. "We've got gobs of very, very exhausted, tired volunteers. Everyone's just so tired from working so many days. It's been around-the-clock since it started. Now everybody's just hoping it's going to hold" (*QHW*, July 11, 1933).

After the Lima Lake and Hunt districts had been fully flooded, the level of the Mississippi River started to rise quickly — more than 2 feet on July 11. Early in the morning on July 12 the levee protecting the southern portion of the Indian Graves District failed. Within 12 hours that half of the district was inundated. The northern portion of the district was now surrounded by water on three sides: the Mississippi River, and the inundated areas of the Lima Lake and South Indian Graves Districts. The river stage surpassed 32 feet by the evening of July 13, when the North Indian Graves Levee finally failed. Within hours the South River Levee, located just south of Quincy on the Missouri side of the river, also failed.

By July 13, nine of the twelve major drainage districts in the Quincy area (including those on the Missouri side of the river) had failed, flooding 120,000 acres. Only three levee systems had not been breached: Sny Island, South Quincy, and South Fabius, Missouri. Of these, only the South Quincy Levee, which had been built by the Corps of Engineers in 1987, was not considered in imminent danger. At this point, the levees had been pushed up as high as possible, and workers were settling in for a lengthy "siege," patrolling and repairing the levees wherever weaknesses and sand boils were found. Although the river had fallen on July 13 after the levee breaks, it was expected to crest again three days later at 32 feet. This gave the South Fabius (West Quincy) Levee just 6 inches of breathing room — the top of the levee was at 32.5 feet (*QHW*, July 16, 1993).

The South Fabius Levee broke on July 16. Of all the levee failures, this one was perhaps me most disheartening, because it forced the closure of the Quincy Bayview Bridge, which for the previous two weeks had stood as the only bridge open along the 200-mile stretch between Keokuk and St. Louis. The levee break occurred without warning at a location that hadn't experienced seepage and gave no signs of weakness. The suddenness of the break gave rise to speculation that the levee had been sabotaged (*QHW*, July 18, 1993).

Attention now turned to the Sny Island Levee District, where for weeks the levee had been considered to be in danger of failure. The district was described as "totally saturated," but still holding. Crews continued patrolling the levee and working on sand boils. For the next week, river levels remained high, above 30 feet, and then they slowly started rising closer to the peak stages that had been experienced in mid-month.

Finally, on July 25, a northern section of the Sny Levee “blew out,” causing the inundation of 44,000 acres. As with other area levees, the breach occurred in an area that workers thought was secure. Less than an hour after the levee broke, the river had opened a breach 1,000 yards wide. The break forced about 2,000 people from their homes. Levee workers moved first to safety and then to lateral levees to start work needed to hold back the water from the remaining southern portion of the Sny District (*QHW*, July 26, 1993). These latter efforts succeeded. The flooding of the northern part of the district resulted in a local 4-foot drop in the flood stage, and the peak of the flood was now past the Quincy area. Amazingly, throughout all of the levee failures, no casualties were caused by the floodwaters.

The Mississippi River
at Alton looking south

CHAPTER 4. IMPACTS

Overview (Changnon)

An assessment of the impacts of a catastrophic event like the flood of 1993, while the floodwaters were still receding, can at best be only a qualitative exercise. Careful impact analyses require good quantitative data carefully collected and analyzed. It is impossible to have all such data at this time.

Another factor that limits analyses done before the event ends relates to the fact that impacts of a catastrophic event occur in a three-tiered sequence.

1. First are the **direct** or initial impacts, such as the flood inundating 0.68 percent of the Hardin residential district.

2. The **secondary** impacts evolve from the direct impacts; for example, a water treatment system ruined by chemicals released by a flood-related accident elsewhere.

3. The **tertiary** impacts are those that occur last, usually months or years after the direct impacts. Examples might be the collapse of a structure a year after the flood because its foundation was undermined by excessive wetness. Other tertiary impacts could include pollution of aquifers, weakening of bridge foundations, instability of roadbeds, or the loss of family income because a manufacturing plant had to close and could not obtain a loan adequate to restore operations — or because it lost its market share to another plant that was not flooded.

Given this complex hierarchy of impacts, it is important to realize that as of September 1993, few of the direct impacts of the flood had been measured adequately; many of the secondary impacts of the flood had not occurred; and few of the tertiary ones have developed. At this time, it is only meaningful to identify the **types of direct impacts** that have occurred and not try to be too specific about the **amounts** of loss or benefit.

Another important aspect of "impact analysis" relates to the difference between **impacts** and **responses.** Impacts of an event have physical, emotional, or socioeconomic implications or effects. Those from a storm, a drought, or a flood are typically behavioral changes or damage losses. Responses are what people and institutions **do to address impacts.** A flood impact to a railroad is washed-out trackage; the rebuilding of the track is the response. Both are interrelated, and both can be measured as a cost to the railroad. At the same time, those employed to rebuild the structures are the beneficiaries of the flood.

Benefits occur in certain sectors because of flood losses elsewhere. For example, the floods of 1993 caused the loss of floodplain crops representing a reported 3 percent of the state's corn and soybeans; however, these losses are credited for helping to increase the market prices for both crops, producing benefits to Illinois farmers who were not flooded. In the end, weather-caused disasters produce both "winners and losers."

A broad national economic view of the 1993 flood is that losses from damages to business productivity, commercial sales, housing, failed transportation systems, and drowned crops will be regained by later expenditures to **respond,** that is to rebuild most systems. The national economy and the cost of living in the United States will be little affected by the midwestern flood of 1993.

The flood of 1993 produced three major classes of impacts in Illinois and in the other eight heavily flooded states. These broad classes include: 1) social disruption, 2) economic effects (both losses and gains), and 3) environmental impacts. The effects on governmental entities at the local, state, and federal levels are largely in the form of responses.

Social Disruption (Changnon)

A catastrophic event like the flood of 1993 produces a myriad of societal impacts, including effects on human health and safety. Those in Illinois have included:

- Six deaths, many illnesses, and untold anxiety over loss and displacement of activities.
- Displacement of individuals and families from homes or from employment. More than 16,000 persons in Illinois were displaced.
- Damage to homes and household furnishings. More than 6,000 homes were lost or severely damaged.
- Loss of income due to flooded employment places or inability to reach the place of employ ment for prolonged periods. More than 10,000 people lost their jobs.
- Evacuation of communities and loss of service support systems. A total of 18 Illinois communities were severely flooded, and 17 communities either lost supplies or suffered damaged systems.
- Loss of power, water, or sewage treatment facilities.
- Delays in education due to flooded schools.

Public Water Supplies (Singh)

Protection for water supply facilities in Illinois is designed for flood stages corresponding to a 100-year flood or the flood of record, whichever is higher. The unexpected flood levels during summer 1993 were significantly higher than the 100-year flood. Consequently, several supplies were rendered inoperative for days or weeks, and some maintained operation under “don’t drink” or “boil order” conditions.

Bacteriological testing was badly needed for determining the potable quality of drinking water. But because of limited staff and services available at state laboratories, private laboratories had to be contracted to do the necessary testing. The Illinois Environmental Protection Agency (IEPA) plans to visit and offer technical assistance to all affected water supply facilities after the floodwaters recede.

Some of the affected communities and their water supplies are briefly described below, based on communications with Roger Selburg, manager of the IEPA Division of Public Water Supplies. The information is current up to August 26, 1993. Alton’s water supply is the largest, while the other plants serve 5,000 people or less.

Alton: Illinois American Water Company, Madison County. The plant serves a population of 72,335 covering the city of Alton and nearby villages, townships, and water districts. The plant treats water from the Mississippi River and has a capacity of 14.95 million gallons per day (mgd). Because of rising river stages and the potential for contamination, a precautionary “boil order” was issued on July 18 and bottled water was provided in Alton. Restorative work allowed water delivery into the distribution system for sanitary purposes only on August 5. A “don’t drink” advisory was also issued. The plant was then dewatered and prepared for operation. Service was restored to 95 percent of the customers by August 10. Filters and clear wells were disinfected, and chlorine residuals were maintained at 10 milligrams per liter (mg/L) throughout the distribution system. The “don’t drink” order was rescinded on August 15 and replaced with a “boil order.”

Baldwin: Randolph County. The plant provides water to about 675 people. A “boil order” was issued on July 13. The wells are under water but have been operated by extending casing vents and power lines above flood level. Bottled water is being distributed and is in good supply. Plans were being made on August 16 to start disinfecting wells and the distribution system. A “boil order” is still in effect as of this writing, i.e., August 26.

Central Alexander County Water District: Alexander County. The treatment plant is located near Olive Branch. The levee broke on July 15 so the district resorted to intensive sandbagging of the plant. Part of the distribution system went underwater, though the plant remained dry and the system remained operating. A “boil order” was issued for part of the system and is still in effect as of this writing.

Evansville: Randolph County. Floodwaters surrounded the intake structure on the Kaskaskia River. The treatment plant is at a higher elevation. Much of the distribution system was underwater and a precautionary “boil order” was issued.

Gorham: Jackson County. The plant gets water from Kincaid-Reeds Creek Intercity Water Commission, and the facility was not affected by the Mississippi flooding. Though water rose to the top of the village levee on August 6, it subsided thereafter. The levee did not fail. A “boil order” was issued and is still in effect as of this writing.

Grafton: Jersey County. The treatment plant facility obtains water from two wells and supplies 1,040 people with potable water. The well pumps were pulled out and the wells were sealed on July 31 as water levels kept rising. The plant was sandbagged, but there were numerous leaks. Bottled water was in good supply. Well pumps were resinstalled on August 10 and the leaks were repaired. Chlorine was being maintained at levels as high as possible. The “don’t drink” order is still in effect as of this writing.

Ground Tower: Jackson County. Two wells used for water supply are adjacent to the levee, but ground storage tanks are on a hill. As the floodwater levels rose, a precautionary “boil order” was issued on July 30. Floodwaters almost rose to the top of the levee on August 6. A few rows of sandbags were added, and the levee held. The system is operating normally. The “boil order” is still in effect as of this writing.

Hardin: Calhoun County. Water from two wells supplies about 1,100 people. With the failure of the levee, the water plant was flooded on July 31. Potable water was brought into the area in 100-gallon tanks on pickup trucks. Water service was restored on August 2, but a “boil order” was in effect. The plant has been rewired and now operates automatically.

Hillview: Greene County. After iron removal, water from two wells supplies about 375 people. The town was under floodwaters, the power to the treatment plant was turned off, and the water tank floated with rising water levels. The plant was still under 2 to 3 feet of water on August 16. The plant may have to be moved to a higher location.

Hull: Pike County. The plant provides water to 529 people. On July 25, the north portion of the Sny Levee broke, and the plant was sandbagged to a height of 12 feet. Because of the electric power cutoff, the pumps and other equipment had to be rewired over the next two days. An emergency generator operated the sump pump. Chlorine residuals were maintained at 0.3 mg/L. Bacteriological samples are being collected and tested. The “boil order” is still in effect as of this writing.

Jerseyville: Jersey County. Casings of all wells were raised above the 100-year flood level by July 13. The levee failed on July 18. Although wells were covered by 5 to 10 feet of water, the raised vents were not. Bacteriological testing on samples collected from the wells was done on July 23, and the results were satisfactory. The plant now operates normally.

Kampsville: Calhoun County. By July 13, part of the distribution system was flooded, and a precautionary “boil order” was issued. Well casings were raised above the expected flood levels, and treatment plant operation was not affected. Even on August 10, several feet of water remained over the hydrants, so flushing and disinfecting the system would have to wait. Otherwise, plant operation was normal. The “boil order” is still in effect and plenty of bottled water is available as of this writing.

Keithsburg: Mercer County. Failure of the levee along Pope Creek on July 7 led to flooding and evacuation of the village. Wells and the water plant were under 13 feet of water or more. A new well was drilled and started operating on July 19. A new pump house and water treatment plant were completed on August 4. As of this writing, the “boil order” was soon to be rescinded if bacteriological samples tests were satisfactory.

Menard Correctional Center: Randolph County. Water from the Mississippi River is treated by conventional clarification/purification methods at this 1.5-mgd capacity plant, which flooded on July 20. Bottled water was provided. The plant resumed operation on July 23, but a “don’t drink” order remained in effect. The rock levee installed by the Illinois Department of Transportation allowed sump pumps to cope with the seepage water.

Nutwood Water District: Jersey County. A “boil order” was issued on July 13 because part of the distribution system was flooded. Potable water was purchased from Jerseyville. Water use in the system increased because many houses floated off their foundations, severing water pipes. On August 5, with only seven houses occupied, daily use was 200,000 gallons. On August 9, water was shut off for all but two hours a day for flushing toilets and showers.

Prairie du Rocher: Randolph County. The treatment plant and its two wells are protected by levees. On August 4 both became flowing artesian wells, with 30 gallons per minute (gpm) from one well and 50 gpm from the other. Levees together with sandbags protected the treatment plant and wells. The wells have stopped flowing and plant operation has returned to normal.

Valmeyer: Monroe County. After iron removal and zeolite softening, water from two well supplies about 400 people. With the levee break on August 1-2, the plant was under 8 to 10 feet of water. It was still under water as of this writing.

A numerical summary of public water supplies with flooding problems, according to information from Roger Selburg, IEPA, is given below:

- Three facilities inoperable: the Hillview, Valmeyer, and Nutwood Water Districts.
- Nine facilities partially damaged: Central Alexander County Water District, Evansville, Evergreen Mobile Home Park, Grafton, Hardin, Hull, Kampsville, Menard Correctional Facility, and Prairie du Rocher.
- Eleven facilities reported inoperable or partially damaged but now operable: Baldwin, Doyle’s 1st Addition Subdivision, Eldred, Illinois American Water Company-Alton, Illinois American Water Company-Granite City, Keithsburg, London Mills, Maeystown, Pearl, Warsaw, and Winslow.
- Thirty-nine facilities being monitored.
- Thirty-four facilities issued “boil orders” due to flooding. Of these, 13 were still in effect as of August 26: Evansville, Evergreen Mobile Home Park, Grafton, Grand Tower, Gorham, Hardin, Hillview, Hull, Kampsville, Menard Correctional Facility, Nutwood Water District, Royal Lakes, and Valmeyer.
- Twenty-six Illinois counties affected: Adams, Alexander, Calhoun, Carroll, Cass, DeKalb, Fulton, Greene, Hancock, Henderson, Jackson, Jersey, JoDaviess, Knox, Macoupin, Madison, Mercer, Monroe, Morgan, Pike, Randolph, Rock Island, Stephenson, St. Clair, Union, and Whiteside.

Residential Damage and Evacuations (Knapp)

Most of the property damage occurred in towns located within inundated levee districts, such as Keithsburg, Hull, Niota, Valmeyer, and Prairie du Rocher. Considerable damage also occurred to riverside towns, such as Grafton, Hardin, and Kampsville. Following is a list of the towns (and their populations) that were inundated and suffered major flood damage:

Grafton (918)	Valmeyer (900)
Keithsburg (747)	Hull (550)
Niota	East Hardin
Kampsville (400)	Hardin (1,071)
Hillview (271)	Meyer (80)
Prairie du Rocher (700)	Harrisonville
Holt	East Carondelet (630)
Pontoosuc (264)	Fults
Evansville (700)	Gulfport

Larger cities located on the river, such as Quincy and Alton, also sustained property damage, either along the waterfront or in low-lying places. But the relative amount of damage, compared with the city size, was small because most of these cities are built on hills situated well above the river.

Keithsburg, a community of 750 in Mercer County, was evacuated July 7 when a levee gave way. Two-thirds of the town was inundated in less than two hours. About 2,000 people were evacuated from the Columbia and Harrisonville Levee Districts on July 31 and their levees broke on August 2. Valmeyer, a town of 900, was almost totally inundated when that levee broke. All but four of the town's 350 homes were damaged, and 75 percent sustained damages in excess of 50 percent of the value of the home. Eight of 12 businesses in Valmeyer also experienced damages.

In Grafton, a town frequently exposed to flooding, about 80 percent of the town's 386 families were displaced. The town also lost about 80 percent of its 1993 revenue, most of which originates from river-based recreation. Residents of the town were seeking aid to rebuild much of the town on higher ground.

Typical building damage sustained during the flood included warped walls and floors, collapsed or weakened structures, damaged equipment and appliances, soggy furniture, and water stains. Cleanup requires shoveling mud and cleaning muddy surfaces with high-powered hoses and detergents. The Illinois Department of Transportation deployed an industrial shredder to chop up damaged furniture, wallboard, and other debris. During the cleanup process, landfills have seen up to a 50 percent increase in business. In many cases, limitations were waived on the type of material that landfills could accept.

Economic Effects

The economic impacts of the floods of 1993 involved losses to individuals in and near flooded communities, to floodplain farmers, and to business and industry in the region. Notable among the business losses were those to regional sales, agricultural production, utilities, manufacturing, transportation, and recreation. Some estimates indicate that flood losses in Illinois amount to $1 to $2 billion. Some winners and some losers, however, can be identified in the agriculture, business, and transportation sectors.

Agriculture (Durgunoglu and Changnon)

As of July 15, the U.S. Department of Agriculture (USDA) reported that lands lost to crop production due to flooding in Illinois included 312,000 acres of corn and 276,000 acres of soybeans. The total flooded farmland grew to 873,000 acres, representing about 3 to 4 percent of the state's planted acreage. Some losses of farm animals were also reported. Continuation of wet conditions into the fall and winter of 1993-1994 was expected to greatly limit fall field work and to potentially limit planting of 1994 crops in many floodplains. Drainage districts that had built drainage systems and levees to protect croplands were severely impacted when the levees were damaged. The intrusion of floodwaters in the high-quality floodplain soils brought mud and sands that could, in the short term, hurt existing soils and affect future farming.

Field Crops

In the aftermath of the flood, the government, public, and farmers will try to determine the economic impacts of the flooded farmland and the crop losses. Although it may be difficult to disaggregate certain components of agricultural losses (crop damage, loss of farm property, loss of planting time), two possible methods have been proposed by James Endress of the University of Illinois (UI) Cooperative Extension Service (Personal communication, August 1993).

One method is to calculate the economic losses attributable to the flooded cropland by totaling the out-of-pocket expenses that have been incurred per acre. According to University of Illinois crop budgets, farmers growing corn had invested approximately $85 per acre in spring input costs. The comparable figure for soybeans was about $51 per acre (UI, 1993). In addition to the spring input expenses, the land costs, either through ownership costs or rental, must be considered. These were in the range of $100 to $140 per acre. No return will be realized from the flooded acres.

The second method is to estimate the returns per acre that the growing crop would have produced. If we assume that the corn would have yielded 130 bushels per acre at $2.25 per bushel, the corn would have generated an income of $292.50 per acre. Similarly, a soybean crop of 45 bushels per acre at a price of $6 per bushel would have earned $225 per acre (Personal communication with James Endress, UI Cooperative Extension Service, August 1993). That income potential was eliminated for the flooded acres.

The Illinois Department of Agriculture (IDOA) estimated that 873,000 acres in Illinois were inundated by the 1993 flood (Personal communication with Patrick Hogan, IDOA, August 1993). This amounts to about 4 percent of the total cropland in Illinois. The primary crops affected in Illinois were corn, soybeans, wheat, hay, oats, and vegetables. According to the IDOA, damages to crops and unplanted lands totaled about $425 million, and damages to buildings and farm equipment were about $110 million. The damages to crops were estimated based on $375 of crop loss per acre, plus $100 per acre for land and grain lost in farm and commercial storage facilities. The estimate was then rounded to the nearest quarter million. Damages to buildings and equipment were estimated by assuming that about 1,500 to 1,800 farms were affected, with $15,000 in damages to equipment and $50,000 in damages to buildings.

Other states in the region also had considerable agricultural damages. The Cooperative Extension Service estimated farm damages and crop losses at about $125 million in Wisconsin (Communication with Charles M. Morgan, U.S. Department of Agriculture, Communication and Information Technology, Internet Gopher Service, July 16, 1993). The Soil Conservation Service had estimated an additional $200 million in crop losses earlier in the year, partly due to the winter kill of alfalfa. The Soil Conservation Service also reported severe land erosion on 7 percent of Wisconsin's cropland, which will cost $10.8 million to repair. In Iowa agricultural losses were estimated to exceed $1.7 billion (USDA, 1993). Even with insurance coverage, losses will be about $1.37 billion. The losses could increase by $154 million with an early frost.

Flooding also causes special weed problems. Many broadleaf and grassy weed seeds are spread by floodwaters and deposited on flooded lands. And deposited silt provides an excellent seedbed for weed seed germination, while warm temperatures and moist soils stimulate germination. In addition, crop stands thinned by flooding provide little competition for weed seedlings (Internet Gopher Service, 1993).

Livestock

Once the floodwaters recede from pastures, livestock producers must be aware of potential hazards from toxic plant regrowth and disease. According to Dr. Gavin Meerdink at the UI College of Veterinary Medicine (Personal communications, August 1993), stress from displacement, change in management schemes, confinement, and feed changes can affect livestock. Infectious diseases may follow due to lack of observation and treatment facilities. In addition, heat, humidity, and standing water will encourage mosquitoes and other disease-transmitting insect populations. Soil disruption and decaying organic matter will expose livestock to clostridial (bacterial) organisms that can lead to diseases such as botulism, tetanus, blackleg, and malignant edema. Anthrax has also occurred in livestock herds following floods.

A variety of weeds also pose threats as they sprout quickly in the croplands and pastures after floodwaters recede. Cocklebur and pigweed, for example, are common and potentially toxic. Cocklebur is most toxic in the young, two-leaf stage. Other plant-related problems can be traced to altered forage supplies and nitrate poisoning, which occurs when new plants sprout in nitrate-rich sediment and are subsequently eaten by animals.

Dr. Meerdink recommends that producers maintain continuity in management and feeding practices to reduce problems. He suggests that producers move livestock to unaffected areas, if at all possible, pending re-establishment of their home environments. Producers should consult with their veterinarians about preventive measures such as vaccination programs for clostridial diseases, leptospirosis, equine encephalitis, and diseases specific to their areas.

Transportation

One of the major problems caused by the flooding was the curtailment of transportation following excessive damage to transportation systems. The flood became an absolute barrier to cross-river rail and vehicular traffic, paralyzing transportation along the Mississippi River.

Navigation (Soong)

The flood on the Upper Mississippi River became sufficiently high by June 25 to stop all barge traffic from Minneapolis to St. Louis. As the flood crest moved south in July, the river was closed to commercial and recreational boating to Cairo, effectively preventing all river traffic for more than 800 miles. Flooding problems in the southern portions of the Illinois River stopped barge traffic there by early July. The flood stalled some 3,100 barges on the Mississippi, many of which were still anchored in mid-August. On the Illinois River north of Grafton, 1,075 barges could not move. Estimates of losses to barge companies ranged from $1 to $2 million per day. This problem also affected industries dependent on en-route shipments of bulk commodities such as coal for Illinois utilities, grain for mills, and petroleum products. Illinois power plants dependent on coal either shifted to expensive truck deliveries or to equally expensive gas-coal fuel mixes, while many grain companies had to ship summer grain by rail.

The barge industry accounts for 15 percent of all the freight moved in the United States, including much of the nation's grain, coal, and chemicals. The industry employees 32,000 people, earning a total of $1 billion per year in the Upper Mississippi River basin.

Increasing stages and flow velocity forced the Corps of Engineers to close four locks and dams (numbers 16, 17, 20, and 22) as early as April 19. Navigation was completely shut down for the 830 miles between Minneapolis and Cairo, Illinois, beginning July 11. It was not until August 22 that Coast Guard officials began permitting barges to move downriver along the UMRS — after test runs by some towboats showed that their wakes didn't endanger the weakened levees protecting riverside towns.

Officials from the Maritime Administration and the Federal Department of Transportation projected that the economies of Illinois and Missouri combined would lose more than $100 million during every month that barge traffic was halted on the Mississippi, Missouri, and other rivers, with the Illinois economy accounting for $92 million of that. The estimates were based on 1992 levels of cargo and employment. According to the Maritime Administration, losses in the barge industry were much worse in Illinois than in Missouri. They included 1,775 barge-related jobs a month in Illinois, including towboat crews, cargo handlers, and people who service barges.

Despite the receding waters, traffic along the river will have difficulty moving for several months because the flooding destroyed many navigation aids such as buoys and changed the navigation channel of the river in many areas. Barge-dependent industries such as agriculture, electric utilities, and chemical manufacturing face more months of supply disruptions. The standing barges loaded with everything from corn to fuel have forced many companies to use trains and trucks instead — costing the ailing barge industry millions of dollar in revenue. Meanwhile, the land traffic had to be routed through bridges that were not closed by high waters.

Railroads (Changnon)

The flooded areas of Illinois, Iowa, and Missouri are crossed by the nation's major east-west railroads, connecting Chicago and East St. Louis to Kansas City and West Coast ports. The railroads most severely impacted include the Santa Fe, Burlington Northern, Norfolk Southern, and Gateway Western. All had bridges across the Mississippi closed for extended periods, and all suffered major washouts of track in Illinois or adjacent states. Many trains could not operate for several weeks; some were detoured on longer, more circuitous routes (some Santa Fe trains operated between Chicago and Memphis on the Illinois Central, before heading west to their mainline in Oklahoma); and all east-west trains operated on delayed schedules for more than a month, incurring enormous financial losses. Some Amtrak trains were cancelled, some were run over different routes, and most operating through the flood zones were routinely delayed by several hours. The delays and losses of shipments had a major ripple effect, hurting those industries dependent on rail such as auto manufacturers, coal users, and the grain industry.

Some railroads benefited, however, such as the Illinois Central. Grain shipments normally sent to New Orleans by barge were sent by rail, doubling the grain train frequency during July and August. The costs of reconstructing damaged roadbeds, bridges, and other rail structures in Illinois is not known, but the Santa Fe Railroad estimates reconstruction costs through the flooded areas of Illinois, Missouri, and Kansas at $80 million. The flood losses in the Midwest were defined as the worst single-event losses in U.S. railroading history.

Bridges and Highways (Soong)

Twenty-eight bridges, carrying both highways and railroads, cross the Mississippi between Illinois and Missouri or Iowa. (Those impacted by the flood are listed below.) Eleven of the highway bridges across the Mississippi and one across the Illinois River were closed during some portion of the flood; and for three weeks in July, all the Mississippi River bridges between St. Louis and Rock Island were closed. Five remained closed as late as mid-August. Many bridges are known to have sustained damage due to erosion and washouts, and there is concern about long-term damage to bridge foundations.

Illinois

Ill. 57, Jefferson Street south to R.J. Peters Drive
Ill. 57 Marblehead to Fall Creek
U.S. 366 (CIE) closed at Ill. 57 and at Payson exit (Ill. 96)
U.S. 24 at the Quincy Memorial and Bayview Bridges
Ill. 96 Bridge to Fort Madison, IA
Ill. 106 near Hull
Meyer blacktop south of Meyer
Bonansinga Drive from Quincy north to Bear Creek Access
Hamilton-Warsaw blacktop
Bluff Road south of Warsaw
Carmen Road in Henderson County
Ill. 9 and 96 Niota to Dallas city, detour in place
Ill.96 Nauvoo to Niota, open to local traffic only
Ill. 96 at Mozier, Kampsville
Ill. 164 Gladstone to Oquawka, open to emergy vehicles only
Ill. 100 at Kampsville, Hardin, and south of Pearl (detour in place), and Grafton
Chambersburg-Valley City blacktop
Nebo-Pittsfield blacktop at Bay Creek; bridge closed for repairs
LaGrange Lock and Dam Road in Brown County
Ill. 106 at Alsey detoured to Ill. 267
U.S. 54 Champ Clark bridge at Pike Station to Louisiana, MO
Fort Madison, IA, bridge
Many secondary roads
Ill. 78, Mason County, 3 miles south of Bath
Ill. 3, Randolph County, in Chester, Prison Road, from Mary's River Bridge to Cora Levee, all the way to Jackson County

Missouri

U.S. 36 at Hannibal Bridge
U.S. 61 at Alexandria
U.S. 61 at Taylor
U.S. 24 west of and at Brunswick
Route B north and south of Canton and at LaGrange
MO 79 two miles south of Hannibal
MO 168 east of Palmyra
Route E south of Hannibal
Route F to Gregory Landing
Route P north of Gregory Landing
Route K west of Colony
Route EE south of MO 79
Many secondary roads

As a result of the bridge closings, cross-country truck traffic had to be rerouted, which was very costly. Also adversely affected were commutets actoss the river, while business sales along the river incurred higher shipping costs. The amount of monetary loss to Illinois' individuals, area businesses, and trucking companies is as yet unknown, but can be expected to be sizable.

Road closings during the flood were mainly concentrated along Illinois' Mississippi shoreline. At one time, 140 miles of Illinois highways were closed at 64 locations, and travel along the flooded Mississippi was drastically curtailed. Certain highways sustained damage due to erosion and washouts, so their foundations will have to be replaced at a cost of millions of dollars.

In addition, two Mississippi River ferry operations in Calhoun County, Illinois, and two on the Illinois River in Greene and Calhoun Counties were also closed during the high flows.

Business and Industry (Knapp and Changnon)

Several floodplain businesses and industries were flooded, or their operations were impeded by the flood. Facilities were damaged, and production was either stopped or greatly slowed. The limitations to transportation interrupted incoming and outgoing raw or manufactured products and created business stoppages. Adding to these woes were the many perishable goods lost to flood damage in stores or warehouses. Banks feared that Illinois farm losses would not allow farmers to repay loans, a problem that could continue into 1994.

Most of the industrial and commercial flood impacts were associated with lost income opportunities, and will never be included in damage estimates. For example, it is estimated that more than a third of the local commerce in Quincy depends upon traffic across the river to and from Missouri. Retail stores in Quincy have annual sales of more than $400 million, of which $160 million is estimated to come from Missouri customem. Quincy's bridges were closed for 73 days between July 15 and September 26, costing the community an estimated $30 million in lost income. Similar commercial losses occurred along the entire reach of the river. Overall reductions in commercial sales were estimated between 15 and 50 percent along the flood area, totaling hundreds of millions of dollars.

About 860 businesses reported closings due to flooding, and most of these businesses incurred flood damage. As a result of the closures, about 6,500 persons were temporarily unemployed. Payments for unemployment insurance may cost these businesses an additional $40 million, though legislation has been presented to have the state cover this expense.

Several industries were also inundated or saw partial damage due to the flood, and many more faced reductions or closures in operations. Among those inundated in the Quincy area were the Celotex factory and the Knapheide Manufacturing Company. Both factories had closed operations earlier and assigned employees to sandbag duty. Employees of the Knapheide Manufacturing Company, which makes custom truck bodies, spent two weeks leading the efforts to sandbag the West Quincy levee. When the levee failed on July 16, the business was under several feet of water. Within ten days the company had leased a building in Quincy and resumed operation, using machinery taken from the West Quincy plant. The company received a 45-day variance from the Illinois Pollution Control Board in obtaining permits for volatile organic materials emissions. But the resumption in operations kept over 400 people employed.

Those industries that rely on barge traffic for transporting grain, chemicals, or coal were forced to slow production. Electric utilities dependent on coal shipments had to substitute a gasand-coal mix to generate power. When the floodgates were closed in East St. Louis, access to a number of riverfront industries, such as Peabody Coal and Con Agra, was entirely blocked, effectively forcing them to close down operations. The ConAgra plant at Alton was closed down when the plant's loading dock was flooded.

In many other cases, industries had to reduce production so that employees could help protect their workplace from the flooding. The American Cyanamid pesticide factory, located south of Quincy in Palmyra, Missouri, shifted most of its work force to shoring up levees surrounding the South River Drainage District. About 300 employees, along with other workers and volunteers, built up the height of the levees in an effort to maintain access to their plant. The plant itself was in little danger because it was surrounded by a 35-foot levee, designed to protect it from a 500-year flood. In mid-July, when the South River levee failed, the company began shuttling its employees to the plant by pontoon boat in order to begin the annual maintenance shutdown, which normally occurs in late August. All dangerous chemicals were removed from the plant by helicopter.

Recreation (Changnon)

The flood losses and extensive media coverage effectively scared many potential tourists away from visiting riverside recreation areas in Illinois. Estimates ranged from 15 to 30 percent losses in business due to the lack of tourists. The flood also halted recreational boating on the Mississippi River for two months.

Environmental Impacts Overview (Changnon)

Flood impacts on the environment from flooding are difficult to measure, and many will take months and years to be realized. At this point, we can only speculate at their possible extent. The natural environments of the Mississippi River and its floodplain have been sizably altered, with many conditions changed forever. Certainly the flooding and related excessive erosion have brought both silting and erosion to floodplains and wetlands. Too much silt smothers vegetation and threatens productive farmland, and the lack of removal of sandbags and other temporary dirt containment structures represents an environmental problem of considerable proportions. The ecosystem of the Mississippi River and its environs have indeed been put under great stress.

Although the flood will drive some species toward extincition, it will be a windfall for some others. We do not know yet which ones will be winners and losers. Alterations in river flow, river water quality, and wetlands will be helpful to certain fish species and to other life in and along the river. Prolonged immersion of the nonfarmed portions of the floodplains could have detrimental effects on certain tree and plant species. Wildlife were isolated and drowned when levee breaks suddenly inundated vast areas. The number of insect pests in future years may be drastically altered. The annual migration of waterfowl along the Mississippi Flyway may also change, as some traditional feeding grounds have been destroyed and new ones created by the flood. The Mark Twain National Wildlife Refuge, 275 miles long, was largely submerged by the flood. Ground-water quality and quantities along the river will certainly be altered. Still, one can envision some environmental benefits from the flood, particularly if additional wetlands are developed along the river.

Floodplains (Bhowmik)

It is impossible to summarize the impacts of the 1993 flood on various aspects of land, water, urban, rural, agricultural, and human resources of the state when the flood impacts are still being assessed, and some will not be until spring 1994. However, some facts available as of August 31,1993, can be summarized and described.

The initial impact of a major flood is the flooding of the floodplains. As of now, the flood expanse on the floodplain has been assessed, but the theoretical extent of the 100-year and 500-year floodplains have not been assessed, nor have they been compared to those for the 1993 flood. Since detailed information on the full extent of the 1993 flood has not yet been determined, some information on the theoretically estimated 100-year and 500-year Illinois floodplains for the Mississippi and Illinois Rivers and their tributaries is shown in figure 4.1

This figure amply illustrates the bluffs located close to the main river, which reduce the lateral extent of the floodplains. Areas where significant amounts of surrounding lands are expected to be covered by 100- or 500-year floods can also be seen in this figure. The 1993 flood, especially along the lower Illinois River and below Quincy on the Mississippi River, showed a pattern of flooding similar to that in this figure, especially where the levees failed.

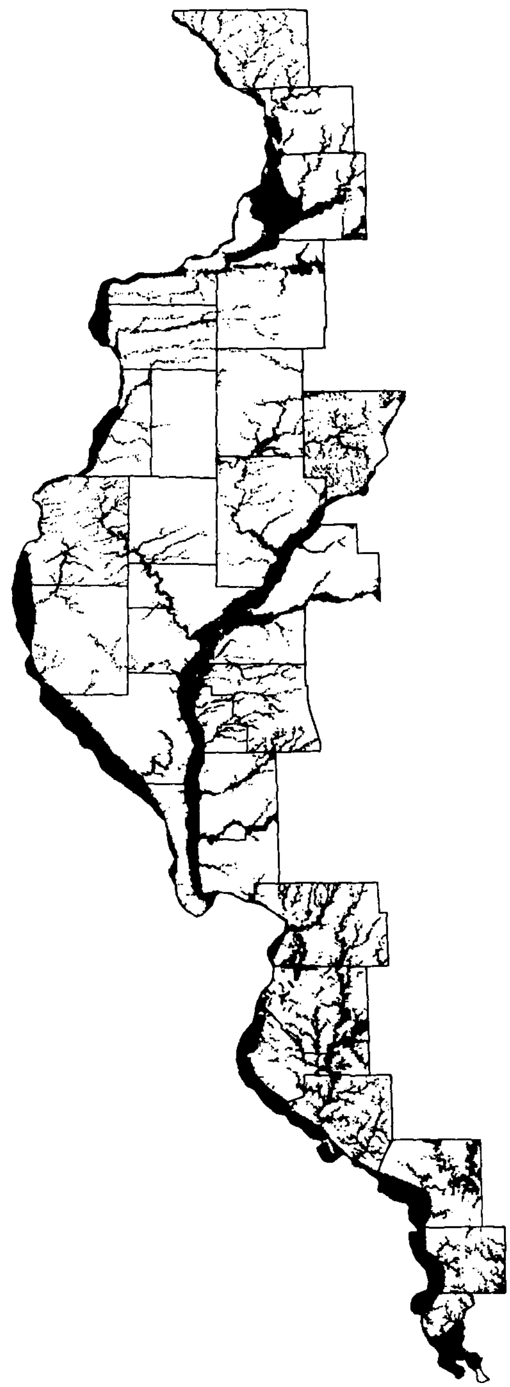


Figure 4.1. Estimated 100-year and 500-year floodplains in Illinois along the Mississippi and Illinois Rivers

Water Quality (Knapp)

The floodwaters of the Mississippi contained much-above-normal amounts of sediments and agricultural chemicals. The increase in the total amount of sediments is to be expected — higher flow rates and the associated increases in flow velocity typically allow the river to carry higher concentrations of sediments. But the impact of flooding on other components of water quality are starting to be understood, and the 1993 flood provides an opportunity for further learning.

During the flood, the U.S. Geological Survey measured water quality at many points along the Mississippi River and its major tributaries. Their measurements of agricultural chemicals are presented in the release, *Agricultural Chemicals Reported in Mississippi Floodwaters* (USGS, 1993). Following is an abbreviated presentation of those results. Similar findings were determined by University of Iowa Researchers (Rajagopal, 1993).

Agricultural Chemicals

The concentration of atrazine is a good indicator of pesticide runoff because it is the most commonly used chemical in midwestern watersheds. Figure 4.2 shows discharge data and atrazine measured by the USGS on the Mississippi River at Clinton, Iowa, and Thebes, Illinois, in 1991 and 1992 and during the 1993 flood. The concentration of atrazine in streams is typically low during the winter months and highest during late spring and summer, when it is generally washed from fields by rainstorms. The concentration during 1993 ranged between 2 to 3 parts per billion, and is not significantly higher than that during lesser floods, such as in 1991.

But there was some expectation that concentrations would actually be less during an extreme flood. Philip Cohen, chief hydrologist with the USGS, stated: "We thought that concentra-

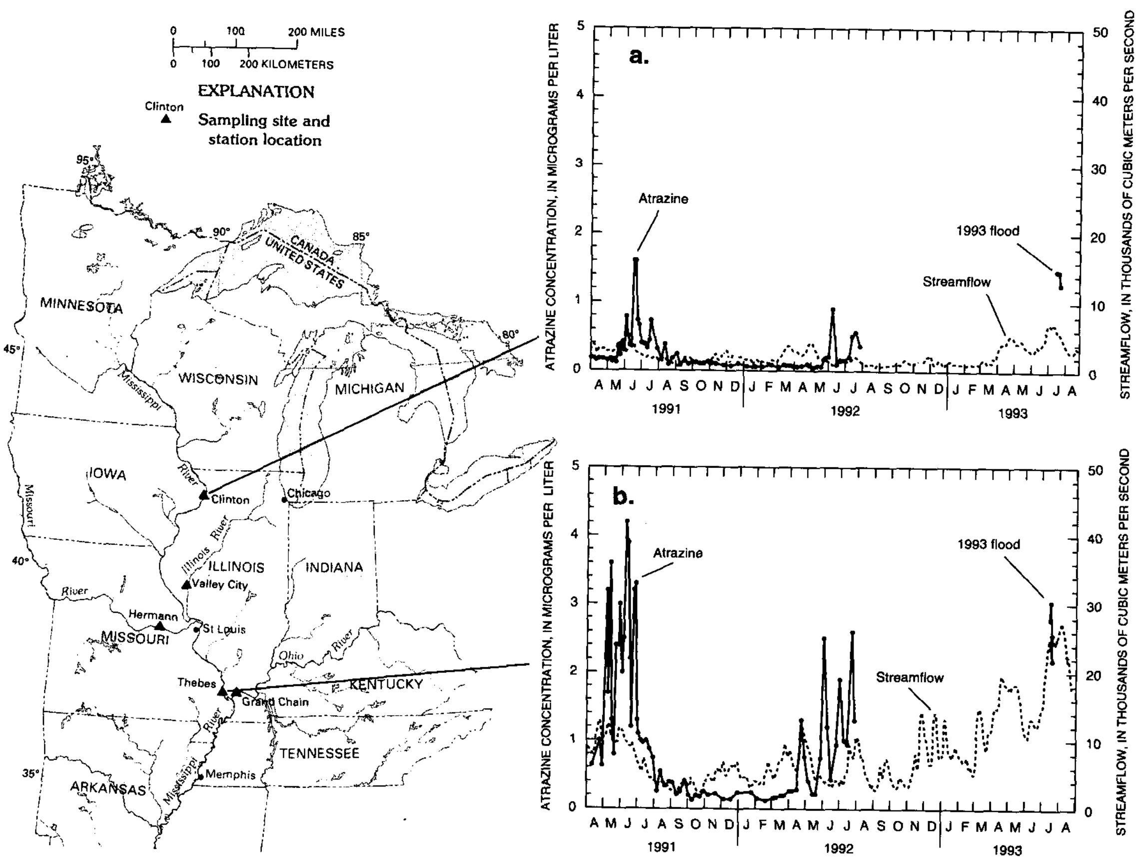


Figure 4.2. Streamflow and temporal distribution in the concentrations of atrazine in the Mississippi River at Clinton, IA (a) and Thebes (b) from April 1991 through August 1993 (from Goolsby et al, 1993b)

tions would be diluted by the record-high flows, but this did not turn out to be the case. Instead, herbicide concentrations were at or near the maximum levels that were found in our previous studies" (USGS, 1993).

The concentration of other herbicides, including cyanazine, alachor, and metolachlor, were also measured at Thebes, and the results are presented in table 4.1. The concentrations listed in this table are fairly typical of those measured at other locations on the Mississippi River and its major tributaries.

Though the concentration of atrazine measured during the 1993 flood was within the normal range of expectations, its total amount per day by weight, as shown in figure 4.2, was much greater because the river's flow rate was so large. The daily load of atrazine in the Mississippi River at Thebes was estimated to be as great as 12,000 pounds per day. Nevertheless, this daily load of atrazine and other herbicides was still a very small percentage of the 200 to 300 million pounds of herbicides that are applied to midwestern fields each year.

Other Health Risks

Another water quality concern along the Mississippi River was the amount of raw sewage, bacteria, viruses, and parasites being carried by the floodwaters. Raw sewage was discharged into the river and its tributaries from overflowing wastewater treatment plants and failed septic systems. Health officials were concerned that the organisms in the water could cause hepatitis, cholera, typhoid, or gastrointestinal illnesses, and warned people against ingesting any floodwaters. Exposure to open wounds could lead to tetanus, hepatitis A, or dysentery. During sandbagging activities in early July, the Red Cross dispensed tetanus shots as a precaution for people working along the river.

At this time it is not known how many cases of sickness have been caused by the flood. It is possible that the large amounts of flow in the river diluted some of the contaminants and their impacts. But the health risks will continue for months as falling floodwaters fester and cleanup operations continue (*Quincy Herald-Whig,* August 8, 1993).

Sediment (Bhowmik)

The great flood of 1993 not only carried a tremendous amount of water from June through September, it also carried a substantial amount of sediment, both as suspended load and as bed load.

Table 4.1. Concentrations of Agricultural Herbicides in the Mississippi River at Thebes, IL, after USGS (1993).

Date	*Streamflow (cfs)*	*Alachlor (µg/L)**	*Atrazine (µg/L)**	*Cyanazine (µg/L)**	*Metolachlor (µg/L)**
7/16/93	830,000	0.32	2.79	0.83	1.03
7/18/93	838,000	0.38	3.04	1.82	1.17
7/20/93	893,000	0.26	2.18	1.27	0.81
7/20/93	893,000	0.32	2.56	1.91	0.98

*µg/L = parts per billion

Unfortunately, equipment and instrumentation are not available to measure bed load during a flood event or when the river simply transports sand and silt as bed load. No data on bed load were collected by any agency for the flood of 1993. Although some preliminary data on suspended load were collected by the Illinois State Water Survey, they have not yet been analyzed.

Almost all of the major rivers in the world carry a tremendous amount of sediment load during flood flows. Research conducted in Illinois by Bhowmik et al. (1980, 1986) and Demissie et al. (1983) has shown that almost all the rivers in Illinois could carry about 60 to 90 percent of their annual suspended loads in a period of about 20 to 90 days during storm periods. This has been shown to be true even for small streams. Since no data are now available for the entire duration of the 1993 flood, it is suspected that the Mississippi may have carried 60 to 70 percent of its annual sediment load during the flood.

During the last major flood on the Mississippi River in 1973, all the gates on all the locks on the UMRS were completely open, creating an open river system. This was also true for the 1993 flood. Research conducted in Illinois on the Illinois and Mississippi Rivers as pan of the Long-Term Ecological Research project supported by the National Science Foundation has shown that in Pool 19 near Hamilton, Illinois, about one year's equivalent of sediment load was washed away when all the gates on Lock and Dam 19 were kept completely open in 1973. Over the years, approximately 30 to 33 feet of sediment had been deposited upstream of this lock. Even though no data are now available for any pool, it is suspected that tremendous amounts of sediment must have been scoured away from Pool 19 and others during the 1993 flood.

Sediment also moved in massive quantities as many of the major levees failed in Illinois. Data collected by the U.S. Geological Survey on the Len Small levee breach shows that a scour hole reached about 73 feet deep on July 31 at the center of the 2,180-foot wide breach (table 3.11). Scour holes were certainly also present at other failed levees. Moreover, numerous aerial photographs taken by the Water Survey and others have shown that when the levees failed, turbid and sediment-laden water moved out of the river into the newly opened floodplains. However, when the stages in the river started to drop, almost crystal-clear water was found to be moving back to the river. This indicates that most of the sediments carried by the floodwaters were deposited behind the failed levees before relatively clear water started to move back to the river. Recent aerial photographs and news reports have also shown dunes of substantial sizes within the floodplains, indicating the deposition of sediment in these areas. Research and sediment deposition data must be collected from these areas in order to quantify the actual volumes of sediment that moved out of the river during the flood.

Floods not only carry sediment, but they also impact the riverbanks, especially the outside bank because it takes the impact of the high-velocity flow. These high velocities could scour away erodible bank materials. Bank erosion is also accelerated due to the presence of secondary circulation, which intensifies during flood flows. Bank erosion is also expected to be severe not only for the Mississippi but also for many of its tributaries that were also at flood stages. A quantification of bank erosion can only be done after the water recedes from the floodplains.

Before the 1993 flood, many of the backwater lakes along the Illinois River were found to have lost 70 to 100 percent of their capacities (Bhowmik and Demissie, 1989). Some of those same backwater lakes, especially those located within the Alton pool along the Illinois River and others on the Mississippi River, must have received relatively large quantities of additional sediment during the flood.

Ground-Water Supplies and Quality (Buck)

The flooding has already caused and has the potential to cause serious impacts on ground-water quality and quantity. Some of the known ground-water quality and quantity impacts include bacterial contamination of wells; contamination of aquifer systems with nitrates, pesticides, herbicides, and other hazardous materials; underground utility damage; and flooded basements.

Large supplies of ground water for domestic, municipal, and industrial development are withdrawn from permeable sand and gravel in unconsolidated valley fill in the bottomlands adjacent to the Mississippi River. The valley fill is composed of recent alluvium and glacial valley-train material. Typically, the valley fill ranges in thickness from near zero close to the bluff boundaries to more than 175 feet near the river. The thickness of the valley fill is generally greatest and exceeds the average near the centers of any buried bedrock valleys that may bisect some of these low-lying areas. In addition, these sand-and-gravel deposits commonly become progressively coarser with depth. The coarsest deposits most favorable for development of a water well are commonly encountered near the bedrock surface.

Ground water in the bottomland areas commonly occurs under leaky artesian and water-table conditions. Water levels in wells generally recede in late spring, summer, and early fall when discharge from the ground-water reservoir by evapotranspiration, ground-water discharge to streams, and pumpage combine to exceed recharge from precipitation and infiltration induced from surface water bodies. Ground-water levels generally begin to recover in early winter when conditions are favorable for recharge from precipitation. The recovery of ground-water levels is especially pronounced in early spring when precipitation recharge exceeds evapotranspiration and discharge to streams, resulting in most of the annual recharge to the aquifer,

The water level measured in a well at a particular time reflects not only seasonal variation but also factors such as recent climatic conditions, nearby pumpage, and the water levels of nearby surface water bodies. Figure 4.3a shows the observed monthly ground-water elevations of the Olin Mathieson observation well near Alton, Illinois. The hydrograph depicts the fluctuating nature of ground-water levels in this sand-and-gravel aquifer system. Noted in the hydrograph are near record-low ground-water levels during the drought of 1988-1989 and record-setting high ground-water levels during the flood of 1993. Figure 4.3b shows the average monthly high and low water levels, historic highs and lows, and the 1993 water levels observed at this same well. This graph shows that ground-water levels were at record-high levels from April through August 1993.

Under normal conditions, ground water typically flows from the bluff areas on the eastern edge of the Mississippi River bottomlands to the west, where it then discharges into the river. Recharge within the area is from precipitation, induced infiltration of surface water from the Mississippi River and lesser water bodies in the area, and subsurface flow from the bluffs bordering the area. A fraction of the annual precipitation seeps downward through surface materials and into the valley fill material. Recharge by induced infiltration can occur at places where pumpage from wells has lowered the elevation of the potentiometric surface below the water-level elevation of a surface water body. This is more common near urban areas where large cones of depression have been established.

Bacterial contamination of individual domestic and municipal wells will become a problem where surface water has entered a well. Proper remedial steps such as chlorination of the well and plumbing systems can alleviate this condition. Because of the extent and nature of the bacterial

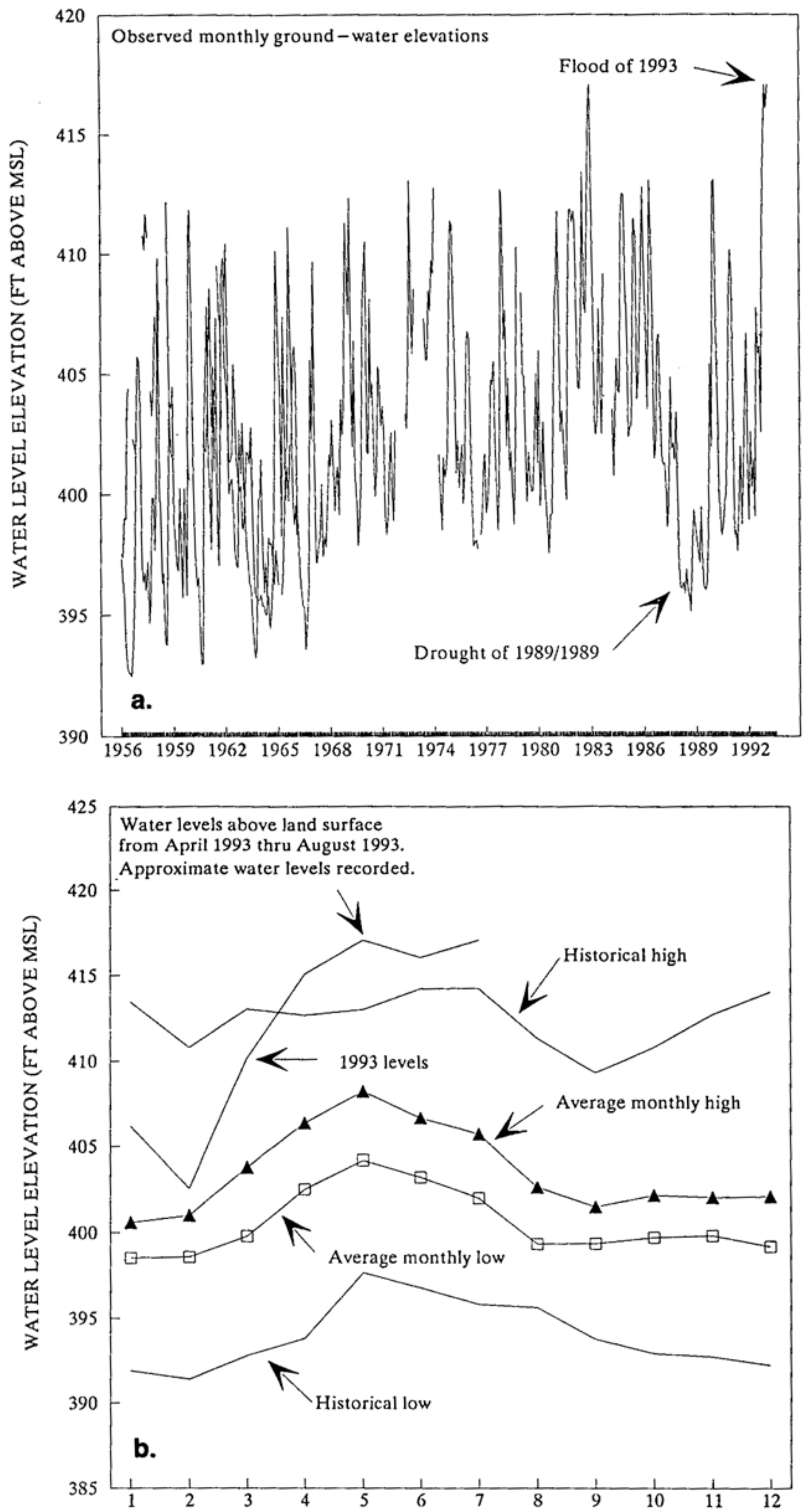


Figure 4.3. Observed ground-water elevations and historical high and low levels at the Olin Mathieson observation well near Alton

contamination, two to three chlorinations are recommended to disinfect the well and to ensure that bacteria do not return.

Additional ground-water contamination problems can exist where floodwaters entering a well contain materials that may have washed off or out of areas such as landfills, road salt storage areas, and hazardous materials storage sites (e.g., petroleum and pesticide storage sites). The extent of this problem will depend on the kind and amount of contaminated material in the floodwaters, the proximity of these waters to flooded wells, and the period these wells remain underwater. Concerns have also been raised about the effect of high ground-water levels on existing contaminated areas. Under normal hydrologic conditions, ground-water usually discharges from the aquifer to the river. To date, ground-water levels at a "nest" of observation wells in Granite City, Illinois, indicate that this is still the case in the MetroEast region. However, prolonged flooding along the Mississippi River valley could reverse this ground-water flow gradient. These above-normal ground-water levels have the potential to change ground-water flow patterns, thus changing concentrations and characteristics of plumes of contamination. If this situation does occur, areas previously not contaminated could become so.

In addition to the potential for ground-water quality problems, high ground-water levels in the Mississippi River valley lowlands have the potential to cause additional levee failures, widespread sewer and underground utility damage, and flooded basements. Most of the bottomland area along the Mississippi River is protected from floodwaters by a series of levees, and much effort was exerted to contain floodwater by raising their height with sandbags. Sandbagging did help contain surface water from spilling over the tops of levees, but it may not help maintain the structural integrity of the levees with regard to controlling hydraulic pressure from ground water. Failure of levees for this reason is the cause of most of the flood-related damage. Aside from overtopping, a principal cause of levee failure is the flow of ground water through and/or beneath the levees, causing the formation of "sand boils," which ultimately lead to structural collapse and flooding. The hydrogeological properties of the levees, the underlying geologic material, and the interface between the two control how the hydraulic pressure on the levees is dissipated and how sand boils are formed. In some levee districts, relief wells have been constructed to allow ground water to freely discharge into drainage ditches along the levee. From the ditches, the water is pumped back over the levee and into the river. Allowing ground water to discharge from the sand-and-gravel aquifer underlying the levee helps prevent "sand boils."

Granite City, Cahokia, Venice, and East St. Louis are a few cities now experiencing problems with sewer failure. Granite City has reportedly experienced 16 such sewer failures to date. Some of these breaks have occurred on major sanitary sewer lines, leaving residents without this vital public utility. Fluctuations seen in the hydrograph for U.S. Army Corps of Engineers relief wells 18 and 70 (figures 4.4a and b) located along the Chain of Rocks Canal near Granite City, Illinois, show ground-water levels at all-time highs since the Illinois State Water Survey started collecting data from them in the early 1950s. These ground-water levels correlate closely to Mississippi River stages because of the hydraulic connection between the river and the sand-and-gravel aquifer. The hydrograph for LaClede Steel Company Well No. 1 near Granite City (figure 4.5) shows that at the end of August 1993, the second highest ground-water level ever was recorded at this well. Continued high ground-water levels in the Mississippi River bottomland regions may persist well after river stages have receded.

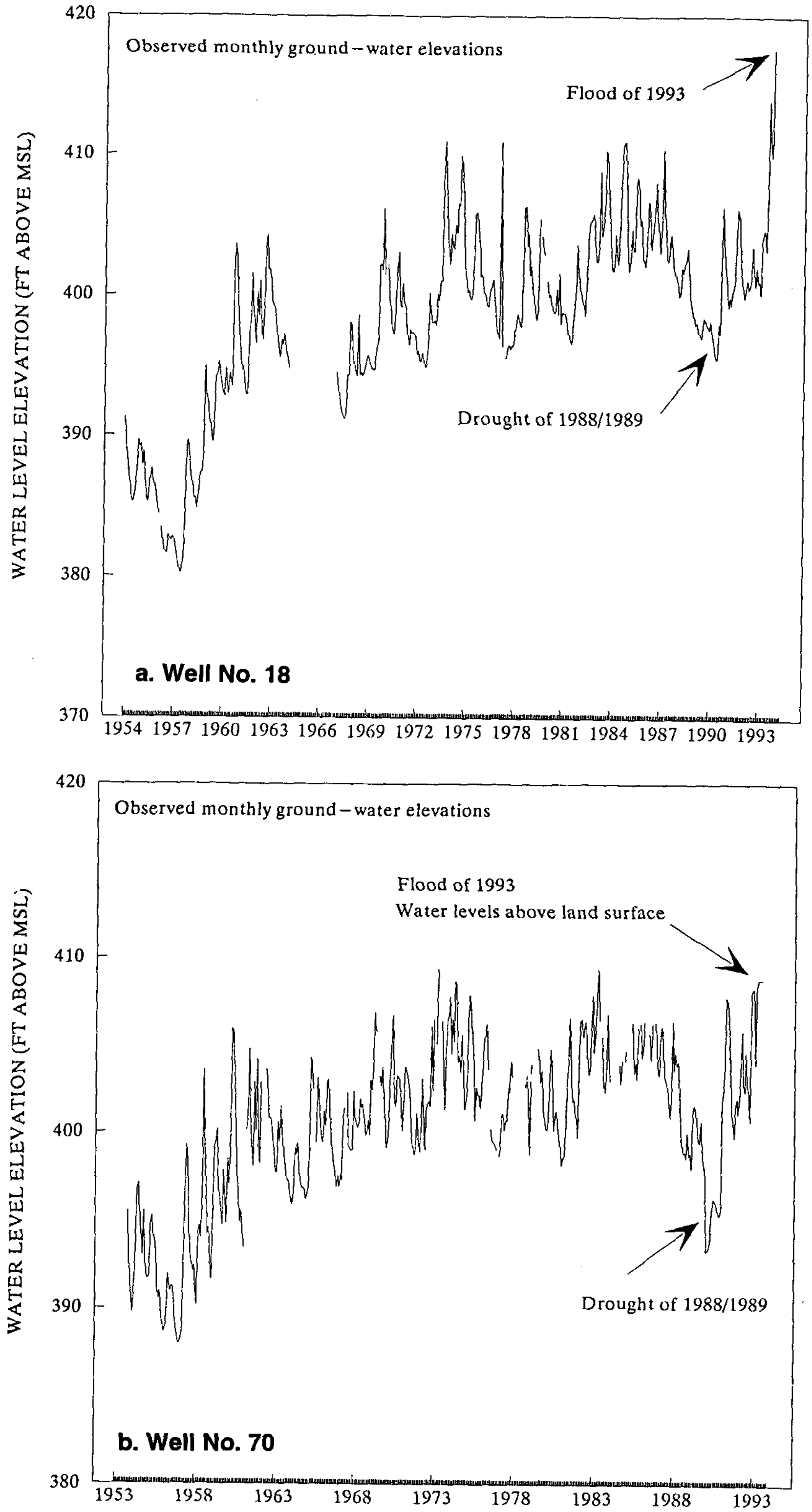


Figure 4.4. Ground-water levels in USACOE relief wells 18 (a) and 70 (b) along the Chain of Rocks Canal near Granite City

Ground-Water Flooding in the Havana Lowland Area (Visocky)

The Mason County area is a wide, low, rolling, roughly triangular sandy plain, bordered on the west by the Illinois River, on the south by the Sangamon River, and on the east by glaciated uplands. Thick deposits of Pleistocene-age sand and gravel (Sankoty sand) underlie the area and provide large quantities of water to municipalities, irrigators, and homes. Normally the water table in the area is well below the land surface, except around large depressions. Occasionally, in its normal fluctuations, the water table will rise high enough to reach the bottoms of some depressions, and small ponds will temporarily form until the water table again drops. However, nearly continuous rises in the water table, beginning in summer 1992, culminated in September 1993 in serious local flooding in the Havana area. Since summer 1992, water levels rose more than 5.5 feet at a shallow observation well near Snicarte. Water levels were comparable to those observed in summer 1974, as shown in the hydrograph in figure 4.6.

Between July 1992 and June 1993 rainfall at Havana was 151 percent of normal, and in July 1993, another 9 inches of rain fell at that station. Although August rainfall was closer to normal (3.5 inches), rainfall over the Labor Day weekend apparently caused the already high water table to rise to a level that created lakes in depressed areas around Havana. Still another 3 to 4 inches of rain fell the following week, complicating the already flooded conditions. In addition, the Illinois River had been at flood stage for about a month and had just recently dropped below that level. Moreover, irrigators had not used their wells much during the summer because of the heavy rainfall.

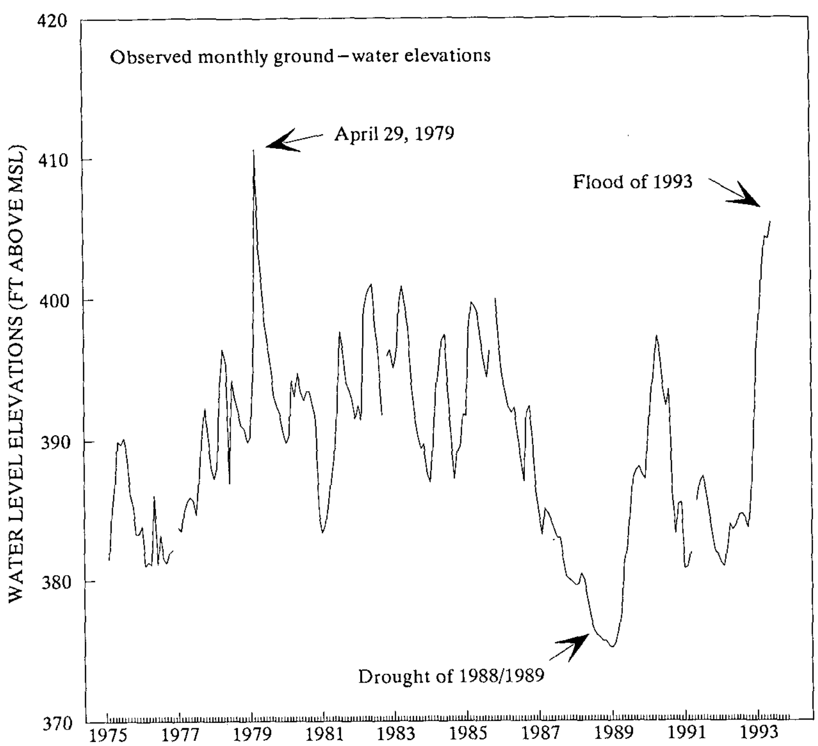


Figure 4.5. Ground-water levels for LaClede Steel Company well no. 1 near Granite City

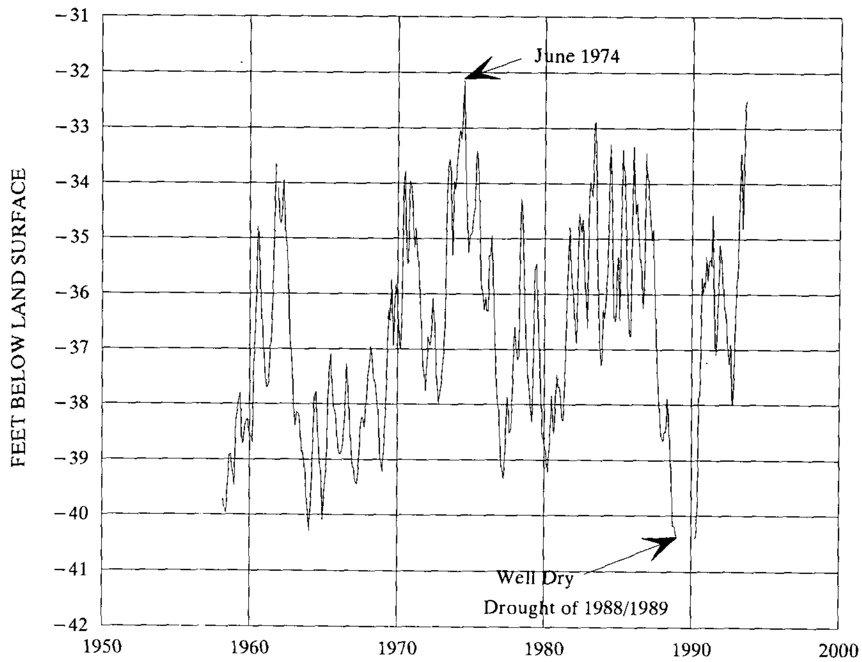


Figure 4.6. Ground-water levels at the Snicarte observation well in the Havana Lowlands area near the Illinois River

As a result of all of these influences, many portions of State Routes 78 and 97 and U.S. Route 136 were covered by as much as 3 feet of water, forcing them to be closed. In addition, residents on the east side of Havana experienced flooded basements, which could not be dewatered for fear of basement wall collapse. Emergency Services and Disaster Agency staff and local officials recruited workers, including correctional inmates, to sandbag the roads and critical areas of town. Large-capacity pumps and pipelines were procured through federal grants, and dewatering operations continued through mid-November, with no end in sight. Additionally, roadways were raised at least temporarily with gravel.

A mass measurement of ground-water levels in the Havana Lowlands area was made in late September 1993 in response to the flooding caused by the above-normal precipitation. As part of an ongoing project in that area, sponsored by the Imperial Valley Water Authority and IDOT/DWR, a network of about 300 wells was established in the irrigated area of Mason and southern Tazewell Counties (about 500 square miles), and mass measurements were made in fall 1992 and spring 1993 to determine the impact of seasonal irrigation pumpage and recovery of ground-water levels. The latest measurements were made for the purpose of documenting this period of unusually high ground-water levels for future use in resource and land-use planning. These data have not yet been analyzed.

Fish, Wildlife, and Vegetation (Sparks)

The flood of 1993 was an economic disaster, but it was probably a boon to most of the native plants and animals in and around the Missouri, Illinois, and Upper Mississippi rivers. Even the few species that appear to have been harmed by the flood may benefit in the long term. The harm that did occur may have been caused more by human factors than by the flood itself: catastrophic failure of levees, storage or disposal of hazardous materials on the floodplains, and dispersal of introduced pests. The midwestern rivers affected belong to a world class of large river-floodplain ecosystems, including the Nile, the Amazon, and the Mekong, where the organisms are adapted to seasonal flooding (Junk et al., 1989).

Beneficial Effects

Judging by the numbers of young fish captured on the floodplain of the lower Illinois River, at least 36 species of fish from seven families used the inundated floodplains and the expanded backwaters for spawning areas and nurseries (USFWS, 1993). These include important commercial species such as the introduced common carp, two species of native buffalofishes, and channel catfish; and sport fish such as largemouth bass, white bass, bluegill sunfish, black crappie, and white crappie.

The nest-building bowfin, black bullhead, crappies, sunfishes, and largemouth bass have trouble excavating nests and keeping watery sediments from smothering their young in areas where sediments have never dried and compacted. But the flood provided access to newly-flooded firm soil, sand, gravel, or plant roots that provided good nest sites. The channel catfish probably found nest cavities among inundated tree roots and abandoned bank dens of muskrats and beavers.

The blackstripe topminnow, shortnose gar, grass pickerel, and brook silverside often spawn over vegetation. Truly aquatic vegetation is usually lacking in the middle and lower reaches of the Illinois, where excessive turbidity limits light penetration and plant growth, but the flood inundated terrestrial grasses, forbs, and shrubs that probably made good substitutes.

Other species simply scatter eggs: some species have floating eggs, while others have eggs that sink. Sinking eggs usually survive better if they land on firm, rather than flocculent substrate. These eggs benefited from landing on firm, newly-flooded soils that may have been anchored by terrestrial vegetation. The spawning habits of several species, including the mud darter, skipjack herring, spottail shiner, and pirate perch, are not known, but the young of these species also were found on the floodplain.

In the inundated floodplain, nutrients and organic matter can be released from the newly flooded soils, stimulating microbial activity and the production of microcrustaceans and aquatic insects, just at the time they are needed as food by larval fishes. Very small organisms, including larval fish, do not interest predatory wading birds such as herons and egrets, and may escape some fish predators by hiding in flooded terrestrial vegetation or staying in water too shallow for large fish.

The beneficial effects of the slow retreat of the flood could occur in either the flooded levee district or the natural floodplain. Some of the fish production that occurred during the flood grew to edible size and was eaten by predatory fish and birds. This benefits not only the predators, but also the prey, by preventing overpopulation and stunting, which sometimes occur in ponds and reservoirs with relatively constant water levels.

Some of the beneficial effects of a natural floodpulse do not occur when levees fail and water suddenly rushes onto the old floodplain. But a slow, natural rise allows terrestrial animals to vacate to higher ground, and creates a moving, nutrient-rich littoral zone that advances across the floodplain, thereby benefiting small invertebrates and fish, as described above.

Detrimental Effects

Several pest species, including some mosquitoes that are vectors of human disease and the newly introduced European zebra mussel, were aided by the flood. The larvae of several species of mosquitoes do well in temporary pools, water-filled containers, abandoned tires, and tree holes where their predators (primarily other insects and fish) cannot enter or survive. Thus, it may be fairer to say that mosquitoes were aided by the excessive rain more than the flood, which can often bring an influx of predators as well as water.

The zebra mussels were introduced to North America in ballast water taken on by ships in European rivers and subsequently discharged in the Great Lakes. The mussels entered the Illinois River from Lake Michigan via the canal system in Chicago and established themselves in the middle and upper Illinois River during the past two years. These mussels released their larvae as the flood was occurring. The larvae then settled in the lower Illinois River, where densities now range from 28,000 to 94,000 per square meter. Larvae presumably were carried downstream into the Mississippi, laterally into many floodplain lakes and industrial and municipal treatment ponds, and perhaps even “upstream” in tributaries that were backed up by the big mainstem rivers. Zebra mussels use byssal threads to attach themselves to any solid substrate, including water intakes and pipes, boat hulls, navigation locks, and the shells of native mussels, clams, and snails.

This introduced pest has already cost industries and municipalities in the Great Lakes region millions of dollars to treat, kill, and remove the mussels from intakes, piping, and equipment within the plants. Zebra mussels have also literally smothered all 12 species of native mussels that once occurred in the western basin of Lake Erie, so the prognosis for the 22 species of native mussels in the Illinois and 37 in the Upper Mississippi River is not good.

Legacies

The overwinter survival of the fish produced during the flood of 1993 is likely to be good. With water levels still relatively high, fish will have access to backwater wintering areas that will be too deep to freeze solid if temperatures are within normal winter ranges. Many of these fish will grow and survive for several years, thereby increasing the sport and commercial catch. The unwelcome zebra mussel will prosper in its newly colonized habitats, adding to the cost of water treatment and plant maintenance, jeopardizing the survival of the native mollusks, and perhaps even altering river food webs by filtering detritus, suspended sediment, and the contaminants associated with these particles. The dense populations of zebra mussels carpeting the bottom may consume enough oxygen to lower dissolved oxygen concentrations in the overlaying water, thereby affecting other forms of aquatic life.

The understory of the floodplain forests has been temporarily eliminated by the protracted flood, and gaps may even open in the canopy as some weakened trees succumb to insects or disease. In compensation, the absence of shading and other competition will enable cottonwoods and other species to germinate and grow, thereby rejuvenating mature plant communities. In some places along the Missouri River, the river itself was rejuvenated where it broke levees that are unlikely to be rebuilt (at least in the same place) and scoured new basins and channels to replace those that had been lost to sediment accretion. The greatest legacy of all may be new attitudes and policies regarding flood and floodplain management, transforming what has long been regarded only as a threat and a detriment back into the essential and beneficial floodpulse (Johnston, 1989; National Research Council 1992).

Levee repair

CHAPTER 5. LESSONS

National Policy Issues (Changnon)

The massive midwestem floods of 1993 have raised questions about fundamental policy issues that pertain to flood control and floodplain management. What should we as a nation do in the aftermath of the flood of 1993, and how can society most wisely use flood-prone lands? Another issue raised by the flood relates to “gambling with nature,” and a related theme that “nature is all-powerful and we should respect it.”

The flood also raises problems of short-term responses versus long-term solutions. Was the flood an “Act of God?” And should the philosophy of response be to provide all the relief needed at government expense (and in the public interest) because the system of structures and insurance could not be expected to deal with a 100-year event?

Questions also surround the issue of whether or not to correct many ills in the nation’s floodplain management program based on the failures of many of the current approaches.

The major issues that appear most in need of future consideration are: 1) the inadequacy of flood control structures, 2) the lack of floodplain insurance, 3) the inadequacy of the nation’s crop insurance program, 4) the wisdom of continuing loss payments to those who failed to use precautions or purchase insurance, and 5) the shift to environmental uses of flood-prone lands.

Floodplain management has traditionally involved two approaches: structural solutions and nonstructural solutions. The inability of the dam and levee structures to control the 1993 flood and the failure of the flood insurance program (fewer than 30 percent of those affected by the 1993 flooding were insured) raise fundamental questions about the dimensions of the nation's future policy on floodplain management. Some of the questions under this broad topic include:

1. What should be done about structural control of floods? Clearly the $25 billion spent for dams and 10,000 miles of levees were unable to protect us from the 1993 flood. However, it must be pointed out that most levees that failed were designed to withstand a flood frequency of 50 years or less. All the federal levees in Illinois remained stable during this flood. One consideration is that the 1993 flood was a record setter, beyond the 100-year design level, and a system capable of handling such an extreme event should not be designed or built. In essence, accept the losses as the result of an **extreme event.** The existing system worked to control lesser floods, but the sizable ones of 1965, 1973, and 1993 have overwhelmed all or parts of the control system. Further, the ever-increasing use of levees ultimately is self-defeating for managing the truly excessive floods. How should we rebuild the current system? Should there be fewer levees? Should there be larger levees?

2. Should we let nature have more control and devote more floodplains to natural uses such as wetlands? The shift of floodplains into agricultural lands through drainage of wetlands and the erection of levees since the 1860s has removed many natural areas from use as wetlands or from less critical uses such as recreation.

3. Should we have a more definitive, enforceable, and realistic floodplain insurance program? It was apparent 30 years ago that the structural approach to flood control was not effective. The nation then launched a "nonstructural approach," based heavily on incentives to use the floodplains for various purposes and to employ flood insurance to both protect and discourage development in the floodplains. The floods of 1993 indicate that the nonstructural approach has not worked because the flood insurance program has not been adequately implemented.

Governmental Viewpoint (Vonnahme)

Plans and Policies

Governmental plans and policies on occupancy, use, and protection of the Mississippi and Illinois River floodplains should be evaluated according to these questions:

1. Did flood protection systems perform as designed?
2. Did any areas flood that are not shown on flood hazard maps?
3. Did flood protection systems, i.e., levees, significantly increase flood damage potential so that the impact of the flood was worse than foreseeable?
4. Do floodplain regulations allow or encourage restoration of flood damage potential?
5. Are any changes indicated for flood protection plans or regulatory policies to mitigate damages in future floods?

Levee Performance

The first two questions can be answered immediately. Only one federal levee failed to perform as designed: the Kaskaskia Island levee, an agricultural levee that protects 9,460 acres of farmland. Thirteen federal agricultural levees protecting 195,100 acres of farmland did not fail until flood stages rose 3 to 4 feet above the design protection gradeline. No federal urban levee failed. Thus performance of the flood protection system was nearly perfect. No leveed area flooded that was not shown as a special flood hazard on federal flood insurance maps.

It should be noted that levees are classed as "agricultural" and "urban" to distinguish the design standards regarding level of protection, erosion protection, freeboard, seepage control, etc. "Urban" levees are designed to higher standards and usually protect against the 200-year flood or greater. "Agricultural" levees usually protect against the 50-year flood or lesser.

The remaining questions are complicated and will be addressed next.

Effects of Levees on Floods

Simulation of flood wave movement through a leveed floodplain is very difficult for two reasons. First, the flood routing model must be able to accurately move flood storage in and out of leveed areas, as well as down the floodway. Second, assumptions regarding levee overtopping must be realistic. Neither of these problems has been addressed on the Mississippi River. Suitable flood routing models were not available until recently. Assumptions regarding levee overtopping, as shall be seen, must confront the unpredictability of flood-fighting success. As a result, the 1979 flood profiles (UMRBC, 1979) which are the technical basis for levee design and flood hazard maps, were not generated by a flood routing model. They are the product of judgmentally extrapolated discharge-frequency relations combined with steady-flow water surface profiles in a "fully confined" floodway. These are very conservative assumptions, and it seems that actual stages cannot be higher than those predicted. After all, many levees were overtopped when large volumes of floodwater moved to storage. Therefore, the answer to the third question is that the flood protection system did not make the flood worse than was projected by the 1979 profiles.

Effects of Flood Fighting

While flood stages did not exceed the "fully confined" profiles developed in 1979, they were raised considerably by flood fighting. Flood fighting effectively raised the level of protection of agricultural levees to the top of the freeboard or slightly higher. The overtopping stage corresponded to the 200-year profile or higher, while the design level of protection is the 50-year profile. The flood fighting was exceptionally effective, because available manpower was unusually plentiful and deployment was rapid. Normally the annual maximum flood on the Mississippi above Grafton occurs more slowly, and the effectiveness of flood fighting is too unpredictable to be counted on.

Regulation of Reconstruction

Existing regulatory policies authorize levees to be rebuilt to restore the preflood alignment and grade. Any adjustment of alignment or grade that would increase flood damage must be compensated for by design or by flood easement. These policies adequately prevent increased flood damages due to encroachment on flood storage and conveyance.

Reconstruction of insurable homes and businesses is regulated by local ordinances that conform to federal requirements for participating in the National Flood Insurance Program (NFIP). It should be noted that Alexander County is the only county covered by state and federal disaster declarations that is not participating in NFIP. Therefore it does not qualify for federal disaster assistance. The regulatory requirements turn on the "substantially damaged rule." If damage is less than 50 percent of market (or replacement) value, the structure may be repaired to preflood conditions. If damage is more than 50 percent, the structure must be elevated above the 100-year flood. While the rule does not prevent restoration of some flood damage potential, the long-term effect is to phase out the most vulnerable homes and businesses.

Buying Out Flood-Prone Homes and Businesses

The Federal Emergency Management Agency and the Illinois Department of Transportation/Division of Water Resources are providing technical and planning assistance to flooded communities to determine the feasibility of purchasing homes and businesses and permanently relocating occupants outside the floodplain. Federal and state financial assistance will be offered for property purchase, relocation, demolition, and conversion of land to public open-space use.

Levee Degrading

State and federal agencies are interested in pursuing opportunities for degrading some agricultural levees. Notching can restore flood storage. Embankment removal can restore floodway conveyance. Flood stages can thus be reduced over long reaches of the river, effectively increasing the level of protection of the remaining levees. Purchased land can be converted to wetlands and wildlife habitat. Federal legislation is needed to authorize federal financial participation.

Flood Modeling

When the 1979 flood profiles were prepared, the federal-state task force recommended development of a better flood routing model for the Mississippi River. The technology is now available to accurately model a leveed river with much less reliance on assumptions regarding levee overtopping. Such a model would permit 1) realistic appraisal of levee degrading proposals, 2) delineation of a regulatory floodway for the first-time, and 3) reassessment of the level of protection of levees for flood control planning, floodplain regulation, and flood insurance purposes.

Information Dissemination (Demissie)

This disaster ranks as the greatest flood in modern history in North America. But what have we learned from it? As scientists and engineers collect and analyze mounds of data, from flood elevations to satellite images, the general public is force-fed by the news media and selected "experts." But too often, media information is wrong, incomplete, or misleading. Unfortunately, it will have significant impact on government response to the flood.

As the debate heats up on who or what to blame, it becomes clear that the scientific and engineering community has not adequately educated the public and policy makers on how our natural environment and our flood control structures operate. Sadly, people seem more knowledgeable about the odds of a lottery win (let's say one in a million) than about the chances of a 100-year flood (one in 100) or the chances of a flood control levee designed for a 50-year flood being overtopped in any year (two in 100).

Most people thought they would never see a 100-year flood in their lifetimes, simply because we don't live that long. Or the problem could be that the TV "experts" don't understand engineering concepts and communicate the wrong messages, albeit wrapped in confidence and elegance: "A 100-year flood occurs only once in 100 years," or "We'll never see this again." Such misinformation has led to a total disregard for the laws of nature when it comes to flooding and flood control.

Often heard along the flood route has been, "After the '73 flood, they said this wouldn't happen again for 100 to 500 years." And when told that the 1993 flood is the greatest on record, they say that they heard the same thing in '65 and '73. They could have been supplied with misinformation or they could have misinterpreted accurate information. Either way, the problem is ineffective communication.

Athletic records are routinely broken, which the public accepts. But when flood records fall, so too does the public's trust in "experts." It's a trust that's hard to relinquish. We want to believe in experts. We want to believe we're knowledgeable. We want to believe in flood control and feel secure about flood control structures.

We as scientists must admit that we do not totally understand how our natural environment behaves, and we haven't done an adequate job in communicating that uncertainty. Now is the time to begin promulgating clear and concise explanations of the major topics of the day: how flood frequency works; how often rivers can be expected to overtop their banks and reach their floodplains; what a design flood is; the functions and limitations of levees; how constructions such as bridges, flood walls, and levees affect flood elevations; and how locks and dams control a river and impact flooding. We must respond to questions and concerns such as:

- Why are we surprised when a major flood occurs?
- Why are many "experts" saying that a flood of this magnitude will not recur for a long time?
- Why am we surprised that levees designed for a 50-year flood fail in a flood that surpasses the 100-year level?
- Why do people risk their lives sandbagging atop levees that were designed to fail weeks earlier?
- Why do we spend money and emotion protecting cornfields that are expected to be flooded an average of once every 50 years?
- Why do many feel that the levees caused this flood?

The answers touch on social, political, economic, scientific, environmental, and basic survival issues. As scientists, it is our responsibility to communicate effectively—to provide those answers, or at least to explain when there are no answers. The key is that we must respond — accurately, directly, and honestly. Some basic concepts about the flood and its aftermath are outlined below.

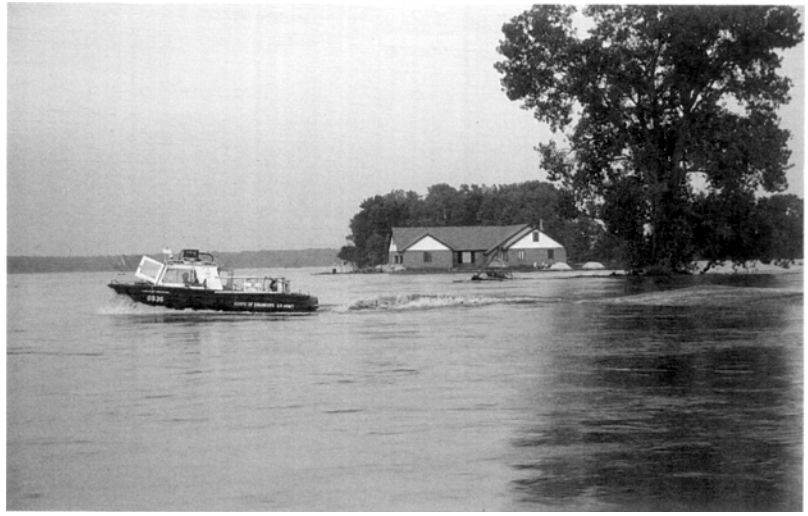
Flood Frequency. This statistical term expresses the chance that a flood of a particular magnitude could occur in any year, or how frequently certain floods are expected to occur on a *long-term basis.* For example, a 100-year flood has a *1* percent chance of occurring in any year, a 500-year flood has a 0.2 percent chance, and so on. The occurrence of the major flood in 1993 does not reduce the chances of another major flood in 1994. When we say a 100-year flood occurs on the average of once in 100 years, we don't mean that it occurs only once every 100 years. We mean that on a long-term basis, it will average out as once in 100 years. Perhaps the terminology is to blame for the confusion, and "chance of occurrence" might be a more appropriate term.

Flood of Record. The 1993 event is now the flood of record for most of the Mississippi River, superseding the 1973 flood, which was identified at that time as the flood of record for some segments. This does not mean that the 1993 flood will not be exceeded in the future. Records are made to be broken, and the record goes back only about 100 years.

Floodplains. The floodplain is the area adjoining a river or stream that is inundated by floodwaters whenever the capacity of the stream is exceeded and water overflows the streambanks. This is a natural process of river systems. The extent of the floodplain is defined to correspond to the magnitude of floods: the 100-year floodplain is inundated by a 100-year flood, and so on. It is important to realize that most of the damage from the current flood is confined to structures and farms that am *within* the Mississippi's floodplain.

Levees. It is true that levees and flood walls channelize a river, confining the floodway and increasing the water's elevation. But it is very unlikely that levees change the discharge in a large river such as the Mississippi. Most of the agricultural levees along the Mississippi were designed only for a 50-year flood, and this level was surpassed early on. Thus, they performed *beyond* what they were designed to do. Have we "oversold" the levees? Probably. Have we encouraged an unwarranted sense of security among those who rely on them? Very likely. We must learn to accept the risk that extreme floods will overcome levees designed to withstand lesser floods of greater frequency. It is economically infeasible, if not technically impossible, to design levees that will never fail.

Floodwaters at Miller City



CHAPTER 6. INFORMATION GAPS AND RESEARCH NEEDS (Bhowmik)

The flood of 1993 has pointed out very clearly that our knowledge of major floods, their progression, and their distribution, including hydrodynamic features, are not well known or understood. It has also shown where data and information are not available or have not been collected, and where further analyses are needed. Some of these gaps in our knowledge on extreme flood events were identified in a report by Changnon et al. (1983), produced as part of a project sponsored by the National Science Foundation on the need for research on floods and their mitigation in the United States.

Information gaps and some specific research needs applicable mainly to floods of the Mississippi and Illinois Rivers can be listed under seven categories: 1) hydraulics and hydrology, 2) meteorology, 3) sediment transport and sedimentation, 4) surface and ground water, 5) water quality, 6) levees, and 7) general.

Hydraulics and Hydrology

- Determine flood frequency and flood probability at various locations along the main stem of the Mississippi River and its major tributaries.
- Improve real-time forecasting of flood flows for various stages along the river.
- Determine the impacts of land-use changes on flood flows, duration, and timing. Changes include wetland conversion, stream alteration, and hydraulic structures along streams.

- Determine the impacts of levees on flood stages. Utilize unsteady flow routing models to determine flood heights and time of travel of floods, as well as a quantification of the effects of river training works, such as levees, closing dams, dikes, etc.
- Determine the impacts of levee breaks on flood dynamics.
- Determine the source areas of the floods and thus the sources of the sediments.
- Determine the distribution of flow between the main channel and the floodplain for different flow frequencies in the absence of any obstruction. Flood-flow distribution on the main channel and the floodplain should also be measured to calibrate mathematical model(s).
- Analyze and conduct mathematical modeling to determine the flows that could or would pass through a levee breach at typical locations along the river.
- Determine the time of travel of hazardous materials during flood flows.
- Sample water, sediment, and other parameters at and below the confluences of major rivers such as the Illinois and Mississippi and the Mississippi and Missouri during flood events. This sampling should be followed by mathematical modeling to determine the mixing characteristics of these large rivers.
- Collect hydrographic data for the calibration of mathematical model(s) before, during, and after the flood at selected reaches.
- Quantify the distribution, rate of movement, and heights of sand dunes that move as bed load during extreme floods on these large rivers.

Meteorology

- Develop improved methods of remotely sensing precipitation (radar, satellite) and quantitatively interpreting it for integration into conventional networks, river flow models, and forecast and warning systems.
- Develop reliable quantitative precipitation prediction methods for large amounts, including numerical mesoscale models and scales relevant to river flow routing models.
- Study snowpack release as a major contributor to flood conditions, including the antecedent history of rain in the watershed.
- Re-examine statistical procedures for estimating maximal rainfall values for different time and space dimensions.
- Reanalyze historical floods, including flash floods, the synoptic patterns that caused them, and the effect of antecedent ram.

Sediment Transport and Sedimentation

- Collect data on sediment transport during flood events. These data are currently either nonexistent or not available. Attempts should also be made to collect these data before, during, and after the flood events. Other data that need to be collected include the grada tions of bed materials.

- Sediment transport during flood events needs to be mathematically modeled and made available. These models should also determine the relative magnitudes of suspended sediment loads and bed loads during extreme flooding events.
- Quantify the sediment deposition patterns behind failed levees.
- Measure the scour holes and sediment transport from levee breaches followed by unsteady flow modeling. This is needed to predict what could happen if such an event takes place in the future.
- Determine the effects of sediment, turbidity, and organic matters on the aquatic, palustrine, and terrestrial habitats along and within the floodplains of the river.
- Quantify the sediments that have been deposited in backwater lakes, side channels, and sloughs. This also should include a determination of the quality of the deposited sediment.
- Perform surveys to determine bank erosion due to this flood to determine the volume of material that was scoured away.
- Evaluate sediment loads during flood events to determine the changes in sediment concentrations at different river stages.
- Quantify and evaluate surface erosion due to intense rainfall.
- Utilize Landsat and other data to evaluate turbidity and suspended sediment transport during flood events.
- Use remotely sensed data to estimate sediment deposition behind levee breaks and other areas. This should be done with ground truth data.

Surface and Ground Water

- Determine the impacts of flood flows on ground-water levels, including the rates of infiltration between the riverbed and the aquifer.
- Determine the movement of nutrients, organices, trace metals, and other pollutants from surface to ground waters and estimate their ultimate fate in the ground-water environment.
- Evaluate and determine the effects of river flooding on the flooding of lowlands by ground water, similar to the occurrences in the American Bottoms near East St. Louis and the Havana Lowlands along the Illinois River during the 1993 flooding.
- Determine and evaluate contamination in ground-water wells that were submerged under floodwaters.

Water Quality

- Collect water quality data during flood events. Compare these data with samples taken during nonflood events. Continue monitoring surface and ground waters after the flood to determine any long-term impacts on surface and ground water.
- Determine the effects of farm chemicals on the surface and ground waters that were either washed away or transported during the flood event.

Levees

- Determine the hydraulic and geotechnical characteristics of constructed levees.
- Evaluate the failure mechanisms of levees, including the effects of seepage, sand boiling, and overtopping.
- Determine the heights to which the failed levees should be reconstructed.

General

- Determine the feasibility of building levees with gated control structures that could be opened during a flood event when it becomes apparent that the levee will fail. Also determine the locations along the levees where these control structures should be built.
- Determine the economic viability of utilizing some of the leveed areas as floodplains, wetlands, and farmland.
- Determine the impacts of various management scenarios on the biological habitats of the river and its floodplains through mathematical modeling and real data.

Confluence of the Mississippi and Illinois Rivers

7.0 Summary (Bhowmik)

This report was prepared by staff members of the Illinois State Water Survey with contributions by senior and administrative staff from the Illinois Department of Transportation/Division of Water Resources. This report is not intended to be an analysis and evaluation of all the facts that led to or relate to the 1993 flood. Rather, it is a compilation and review of the facts on hand at a specific point in time. The report incorporates available information on precipitation, soil moisture, and surface and ground water; and it explores the flood's progress and impacts, as well as gaps in information and research that require further investigation. Following is a brief review of the substantive chapters.

Chapter 2: Background

The Upper Mississippi River basin is approximately 550 miles wide and 750 miles long. The UMRS includes not only the Mississippi River, but 16 major tributaries as well. Together they provide about 1,300 miles of navigable waterway. The Mississippi itself now consists of a series of pools defined by locks and dams constructed in the 1930s to maintain a 9-foot navigation channel during low flows.

The UMRS drains 189,100 sq mi. But with the inclusion of the Missouri River basin, the drainage area of the Mississippi at its confluence with the Ohio River is 718,450 sq mi. The average discharge of the Mississippi River at Cairo, Illinois, is about 200,000 cfs.

The UMRS is located within the temperate continental climate zone. Average precipitation varies from 32 inches in the north to about 45 inches in the south.

Average runoff over the basin varies both in time and space. But for the 28-year period since 1965, the Mississippi River has experienced the highest average runoff conditions on record. Analysis of streamflow between 1965 and 1992 has shown a noticeable average increase at Keokuk and St. Louis. And analysis of the top ten floods on record since discharges have been measured indicates that as of August, the flood of 1993 was the highest ever at St. Louis at 1,030,000 cfs. This was followed by the June 1903 flood at 1,013,000 cfs. Other "estimated" record floods at St. Louis occurred in April 1785 (1,350,000 cfs), June 1844 (1,300,000 cfs), June 1850 (1,060,000 cfs), and in 1855 (1,050,000 cfs).

Levees were constructed along the Illinois and Mississippi Rivers to protect urban areas against floods and to allow the agricultural use of the highly productive floodplains, Most of these levees were constructed between 1879 to 1916. Today, 34 active levee and drainage districts line the Mississippi River in Illinois, and 15 levee and drainage districts line the lower 80 miles of the Illinois River in the Alton pool.

Chapter 3: The Flood

The data available for the 1993 flood on the Mississippi and Illinois Rivers include climate and weather, soil moisture, hydrologic conditions, stages and discharge, levee failures, and preliminary information on measured discharges.

Climate, Weather, and Soil Moisture

The flood of 1993 was the result of a combination of many factors, including an abnormal weather pattern, heavy precipitation in 1992 and 1993, extremely high soil moisture conditions, and increased runoff. Many of these conditions can be traced to the "polar jet stream," a river of fast-flowing air that dominates the central part of North America. The jet stream normally stays close to the U.S.-Canadian border in the spring and summer months. However, it dropped below the border in 1993 and occupied the midwestern states. The mixing of cold and warm air at this junction resulted in abnormal precipitation for a prolonged period of time over the entire UMRS and portions of the Missouri River.

Precipitation for June, July, and August 1993 was either record-breaking or close to the record. For the five states of Minnesota, Wisconsin, Iowa, Missouri, and Illinois, July precipitation was the greatest of any July since 1895. For the entire January-through-July period, precipitation in all five states ranked among the five highest in the last 99 years.

Soil moisture played an important role in the 1993 flooding. By January 1993, soil moisture in the uppermost 6 feet ranged from average to 3 inches above average for the period of record. This high soil moisture continued through June, July, and early September 1992, and became one of the contributing factors to the 1993 flood. Mathematical modeling of the excess soil moisture over the entire Midwest indicates a very good probability that precipitation, soil moisture, and hence runoff could be high during spring 1994.

Hydrologic Conditions and Flood Stages

The 1993 flood was, in fact, a series of three flood waves that traveled down the river. The stage at Dubuque was 23.84 feet, which is lower than the record stage set in 1965 (26.84 feet).

Flood stage at Camanche, Iowa, also did not exceed the 1965 flood stage, but below Camanche, new record peak stages were set at every station. At Keithsburg, the 1993 stage of 23.17 feet was set on July 9. It exceeded the April 1965 record by 3.69 feet. Similarly at Hannibal, St. Louis, Chester, and Thebes, the flood stages were 31.80, 49.47, 49.58, and 45.51 feet, respectively. These values were 3.57 feet, 6.24 feet, 6.26 feet, and 0.37 feet higher, respectively, than the stages set in the 1973 flood. None of the stations along the Illinois River surpassed the historical stage records set in 1943 and 1979, although only the stages at Meredosia (10 miles upstream of Valley City) came within 1.7 feet of the record, which was set on May 26, 1943.

Comparison of the peak stages with the historical data through frequency analyses indicates that for all the Mississippi River stations from Keithsburg to St. Louis, the 1993 flood stages were at least 2 feet over the stage for a flood with a 1 percent chance of occurrence during any given year. This is commonly referred to as a 100-year flood event. Similarly, peak stages at these stations were also either at or above the elevations for a flood with a probability of occurrence of only 0.2 percent, i.e., a 500-year flood event. The peak stage at Chester was slightly greater than the elevation estimated for a 100-year event, although at Cape Girardeau it did not exceed the 100-year peak stage.

Ever since the first week of April, the river was at flood stage almost continuously from Keithsburg to Thebes and many stations were still at or above flood stages at the end of September. At Keithsburg the river was at flood stage or above for 138 days between April 3 and August 31, and it remained at flood stage at the end of August. At Quincy, the river was at flood stage for 139 days from April 2 to August 31. And at Hannibal the river was at flood stage from April 1 through at least the end of August. At Chester and Cape Girardeau similar situations were observed.

Stage data recorded at various locations also showed the impacts of levee failure. Data from Quincy and Hannibal for the month of July showed that as soon as a levee failed, the river stages dropped precipitously until the leveed area was full of floodwater. Then the stages on the river started to rise until another levee failed, and the cycle repeated itself.

Discharge

Discharge data through the end of August indicate that most tributaries on the UMRS experienced floods that ranked among the top five for the period of record. Peak discharges in excess of 100-year flows occurred on the Mississippi River at Keokuk and St. Louis; and on the Missouri, Iowa, Des Moines, Skunk, and Black Rivers, as well as on many other smaller tributaries.

It is not known how much discharge would have been carried by the Mississippi River's floodplains if there had been no levees. Previous research has shown that after a certain flow and stage, the river and its floodplain may act as a single unit carrying proportional amounts of water.

From July 7 through August 3, a total of 19 Illinois levees failed along the Mississippi and the lower reaches of the Illinois River. The greatest number occurred on August 1 and 2 when eight levees failed.

Discharge data collected at the Len Small Levee break near Horseshoe Lake in Alexander County indicated that a discharge of more than 200,000 cfs passed through this breach on July 31. The breach was 2,180 feet wide, and the rushing waters created a scour hole 73 feet deep at its center. The discharge on the Mississippi River at this location was estimated to be more than 1,000,000 cfs, indicating that about 20 to 25 percent of the Mississippi River flow passed through this breach on July 31.

Chapter 4: Flood Impacts

The 1993 flood exerted massive impacts on local water supplies, on residents and their homes and businesses, on water quality, and on ground water. Although most of the impacts were overwhelmingly detrimental, a few can be considered positive.

Human and Commercial

The flood displaced at least 16,000 people. More than 10,000 jobs were lost, more than 6,000 homes were lost or severely damaged, and 18 Illinois communities were severely flooded. Seventeen public water supply entities were either damaged or destroyed. Approximately 873,000 acres of Illinois farmland were flooded, including 312,000 acres of corn and 276,000 of soybeans. Total flooded farmland was about 3 percent of the state's planted acreage. Damage to cropland and unplanted land in Illinois was about $425 million, with an additional $110 million in damages to buildings and farm equipment. In Iowa the agricultural losses are estimated to be $1.7 billion.

This flood, at one time or another, impacted more than 550 miles of the navigable waterway and forced the stoppage of commercial and recreational traffic. Approximately 3,100 barges on the Mississippi and 1,075 barges on the Illinois River north of Grafton were halted. Nine highway bridges across the Mississippi River and two across the Illinois River were closed during the flooding. At one time, about 140 miles of highways were also closed in Illinois. Many industries located in the floodplains of the river were also impacted.

Water Quality

The ecosystem of the Mississippi River was also put under great stress during the flood, as natural areas such as the Mark Twain National Wildlife refuge were submerged. Although the floodwaters carried farm chemicals such as atrazine, concentrations were more or less the same as in previous years without major floods. This indicates that the 1993 flood transported much higher volumes of atrazine because of the tremendous amount of water it carried. In July it was estimated that the Mississippi River at Thebes carried as much as 12,000 pounds of atrazine per day.

No suspended sediment data during the flood are available. However, research conducted in other Illinois basins has shown that during storm periods, the river could transport as much as 60 to 90 percent of its annual sediment load in 20 to 90 days. It is suspected that the flood of 1993 transported a vast amount of sediment, both as suspended load and as bed load. This was confirmed during the receding stages of the flood when about 17 barge-tows were stranded on the Mississippi River at L&D 25 along Calhoun County. The deposition of tremendous amounts of sediment grounded the barges and forced the closure of the lock on October 13.

In ground-water wells along the Illinois and Mississippi Rivers where data were available, significant rises were recorded during the flood. Ground-water level data from the American Bottoms area showed near-record high water levels. Ground water along the Chain of Rocks Canal near Granite City experienced its highest levels since the early 1950s, correlating well with Mississippi River stages. Through the end of August, ground-water from nested wells near Granite City was still discharging to the river. Prolonged flooding could reverse this movement, so that groundwater could be contaminated by the floodwater. Bacterial and chemical contamination of groundwater will be a problem on those areas where floodwaters entered domestic or municipal wells.

Similar high ground-water levels have been measured at wells in the Havana Lowland areas along the Illinois River. As it did during the 1973 flood, this area again experienced ground-water flooding. At places up to 2 to 3 feet of water covered the land surface.

Aquatic Habitat and Biota

The flood of 1993 has also had some beneficial impacts on the aquatic habitats and fisheries of the river. The inundated floodplain of the lower Illinois River was used for spawning and nurseries by 36 species of fish, including many commercial and sport fish. The soft substrates of the newly inundated farmland were particularly desirable. Moreover, the fish produced during the flood of 1993 are likely to have excellent chances for overwintering, since the river and the floodplain still have plenty of water.

The flood also destroyed some of the understory of the floodplain forests. This loss, however, makes it easier for cottonwood and other species to grow, thus rejuvenating mature plant communities.

The failure of the levees forced high-velocity water into the floodplain, as opposed to the situation in an unregulated large river, where water levels would rise gradually to flood stages with increased flow. Gradual rises allow 1) terrestrial species to move out of the floodplain, and 2) a slow increase in microbial activity and microcrustacean and aquatic insect production. But neither of these took place in 1993.

On the other hand, pests such as mosquitos, which are vectors of human disease, and zebra mussels may have been aided by the flood. The zebra mussels released their larvae as the flood was occurring, invariably transporting the species to the Mississippi River and the backwater lakes — and probably up some of the smaller tributary streams due to the backwater flows caused by high water levels. The zebra mussels, which smothered 12 species of native mussels in Lake Erie, may have equally detrimental impacts on the 22 species in the Illinois River and the 37 species in the Upper Mississippi River.

Chapter 5: Lessons

The lessons learned from the 1993 flood point to the questions that need to be addressed. They include the structural and nonstructural control of floods, the restoration of the floodplains and their use as wetlands, enforcement of a realistic floodplain insurance program, and the evaluation of crop insurance programs and payments to those who either failed to protect themselves with adequate insurance or did not take appropriate precautions.

Levee Performance

State and federal agencies have had to evaluate and answer questions on the performance of flood protection systems, flooding outside of flood-prone areas, the effects of levees on flood stages, the effects of floodplain regulation on damage potential, and on future directions in all of these areas.

Almost all the levees performed as designed. The federal urban levees are normally designed for 200-year flooding events, while 50-year flooding events are used for agricultural levee design. One federal agricultural levee failed to perform as designed, but the others failed only when stages were 3 to 4 feet above the design level. None of the federal urban levees failed.

The flood fighting raised many of the levees' heights considerably, effectively enhancing the protection of agricultural lands. In many cases sandbagging increased levee heights to the equivalent of 200-year stages, even though the levees were originally designed against 50-year flood stages.

The 1979 flood profile for the Upper Mississippi River was based on discharge-frequency relations combined with steady-flow water surface profiles within a fully confined floodway. Better quantification of the flood profiles through unsteady-state modeling will be needed, even though it appears that the 1993 flood filled large storage volumes behind failed levees and still forced many other levees to fail.

Existing regulation authorizes the levees to be rebuilt to restore the preflood alignment and grade. Reconstruction of insurable homes and businesses is regulated by local ordinances.

Alternatives

Levees could, however, be lowered or removed to increase wetland habitats and floodplain conveyance, and to reduce flood stages. This would be most effective with the restoration of floodplains over a long reach of the river, which will require federal legislation and financial participation. Better mathematical models calibrated with real data are needed to implement any of these alternatives.

Regardless of which course of action is followed, the general public and the various governmental agencies must be educated on the meaning of l00-, 200- or 500-year floods, on the bases for the design heights of the levees and how they performed, on the efficacy of levee repair to protect agricultural land when the levee is almost certain to fail, and on the unwarranted security that people perceive when they are protected by a levee designed for a 50-year flood event. Public education should concentrate on the frequency of the occurrence of floods, the level of protection expected from flood control measures, the wisdom of sandbagging, and practical methods to partially offset seepage and sand-silt boiling, the main mechanisms of levee failure in 1993.

Chapter 6: Information and Research Needs

Information gaps and research needs exist in all areas related to the flood: hydraulics and hydrology, meteorology, sediment transport and sedimentation, surface and ground water, water quality, levees, and more.

Of particular concern are the lack of data on flow distribution in floodplains and main channels; flood discharges; hydrographic variability during a flood event; quantification of sand dunes that move during flood events; sediment movement during floods; sediment and water quality; remotely sensed information on precipitation, turbidity, sediment concentration, flow mixing, and water movement; sediment deposition in backwater lakes, side channels, and areas behind failed levees; and movement of water and other dissolved and particulate matters between surface and ground waters.

Research is needed on areas of flood frequency and flood probability; the effects of land-use changes on flood flows; the impacts of wetlands on flood flows; the impacts of levees on flood stages; the movement of sediment, water, and organic matters through breached levees and within the floodplains; the development of reliable quantitative precipitation prediction models; mathematical modeling of sediment transport during flood and nonflood events; bank erosion due to floods and surface erosion due to intense rainfall; quantification of ground-water flooding; and innovative concepts in levee design.

Research is also needed on the mathematical modeling of complex river-floodplain systems to address flows of varying frequencies in connection with all the hydraulic, hydrologic, and sediment parameters. The end product of the hydraulic and hydrologic modeling should be combined with biological modeling to determine the impacts of various management scenarios on the biological habitats and species that are dependent on the large river-floodplain system.

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ADDENDUM

Introduction (Bhowmik and Demissie)

The *Great Flood on the Mississippi River in Illinois* was originally published by the Water Survey in February 1994, but the demand was significantly higher than expected, and the Water Survey had almost exhausted its supply of reports by July 1994. Since then Water Survey researchers have reviewed and analyzed additional data on the flood event. Thus it became clear that a reprint of the original report was necessary to meet the increased demand and also to include additional analyses on stages and discharges on the Mississippi River.

In the meantime, many other reports have been published on the 1993 flood (Wahl et al., 1993; Green and Lillie, 1994; Illinois Department of Energy and Natural Resources, 1994; International Erosion Control Association, 1993; Chrzastowski et al., 1994; Interagency Floodplain Management Review Committee, 1994; Interagency Floodplain Management Review Committee, Part V, 1994; U.S. Army Corps of Engineers, 1994a, 1994b, 1994c; M.J. Dowgiallo, ed., 1994; and Zimmerman, 1994). So many articles in newspapers, journals, and popular magazines have been written about the flood that it would be almost impossible to cite all of them.

The International Water Resources Association published a special issue of *Water International* in December 1994 on "The Great Flood of 1993" that includes seven articles prepared by various experts. An excerpt from the editorial prepared by Bhowmik and Demissie (1994) for this issue appears here.

> The Great Mississippi Flood of 1993 was truly the greatest hydrologic event of the century in North America. The flooding was historic in many respects. Miles and miles of flooded streams and rivers affected large portions of nine midwestern states and resulted in the federal government declaring disaster areas in more than 420 counties. Costs for damage attributed to the flood reached about $20 billion. Flood stage records were broken at many monitoring stations in the Upper Mississippi and Missouri River basins. Weather forecasters continuously reminded the nation that precipitation records were being broken throughout the Midwest. The news media vividly presented homes being flooded or actually being washed away from their foundations and even showed coffins floating down the Mississippi River.
>
> Most of the levees along the Mississippi and Missouri Rivers were either breached or overtopped, flooding millions of acres of fertile floodplain croplands. Interstate highways and bridges were impassable throughout the region. Thousands of volunteers risked their lives to repair and raise levees that were not designed to provide protection for floods of this nature and magnitude.
>
> Massive flooding over such a large area was due to a combination of unanticipated climatic and hydrologic conditions that have never before been observed. Record-breaking precipitation over a region that was fully saturated from a wet spring resulted in rapid and repetitive rising flood stages over a six-month period. Most hydraulic structures along the major rivers and other infrastructures were not designed for a flood of such magnitude and duration. Consequently, media reports gave the impression that everything was collapsing, when in reality most of what occurred *should* have been expected.

With such a major catastrophe in terms of damage and interruption of economic activity, it is amazing that only 48 deaths were attributed to the flood. In other parts of the world, a similar flood would have resulted in many more fatalities. Several factors were responsible for the low number of deaths. Although not quite perfect, the capabilities of state, federal, and local agencies in forecasting, disseminating data, and supervising evacuations from risky areas were still major factors in keeping fatalities to a minimum. Moreover, most flood control structures on the Mississippi and Missouri River basins prevented about $19 billion of damage.

The Great Flood has brought many water resources issues to the forefront and resulted in great debates on river and floodplain management, disaster assistance, impacts of land use changes on flooding, impacts of flood control structures, the role of state and federal agencies, and so on. Issues raised by the flood are not just limited to technical issues; many social, economic, and political issues am also being debated. This broad and inclusive event has led to discussions having a national perspective, rather than being limited only to the Mississippi and Missouri River basins. In a landmark report, the Interagency Floodplain Management Review Committee (1994) recommended significant changes in the floodplain management policies of the United States. The report's subtitles almost summarize its main message: *A Blueprint for Change, Sharing the Challenge: Floodplain Management into the 21st Century*. The most important message is that floodplain management in the United States is going to change.

Issues discussed in the United States and related to the flood as a major hydrologic event or natural disaster also have relevance for other parts of the world. There are great lessons to be learned from the U.S. experience. Are flood control structures the best way to manage our rivers? When do we categorize disasters as natural disasters? What is the responsibility of government agencies in "bailing out" people practicing risky business? How good is our scientific know-how in predicting floods? Can our hydrologic and hydraulic models accurately model flood flows in large rivers with complex floodplains? And there are also many other questions that require answers.

The 1993 flood of the Mississippi and Missouri Rivers can truly be classified as one of the greatest natural disasters in North America. This reprinted report will be made available to many more managers, scientists, engineers, and members of the public who are interested in knowing about this flood and how to manage such an event in the future. The following material prepared by Water Survey hydrologist Vern Knapp includes additional analyses on precipitation trends, streamflows, discharges, and peak stages for stations along the Mississippi River.

Trends and Distributions of Stream Discharges and Stages (Knapp)

The 1993 flood on the Mississippi River has generated intense scientific and public debate about the impact of human intervention on the flood's severity. It is *popularly* accepted that human-induced modifications of the Mississippi River and its watersheds have increased the amount of flow in the river, particularly during flooding events. It is not merely speculation to suggest that such impacts have occurred; numerous hydrologic investigations indicate that most land-use modifications, similar to those occurring in the Mississippi River watershed, can cause significant changes to streamflows on a local scale. But we know relatively little about the aggregate impact of these modifications on flows in large rivers such as the Mississippi, particularly as these modifications impact flood conditions.

The Interagency Floodplain Management Review Committee (IFMRC) report (1994), often referred to as the Galloway report, summarizes selected studies dealing with impacts of human intervention, including investigations conducted prior to the 1993 flood and those studies completed within six months after the flood. The Galloway report found that information to determine the effect of wetland storage on peak flows on large rivers was inconclusive, especially for large floods such as the 1993 flood. The report also indicates that flood-storage reservoirs have provided substantial reductions in flood discharge on the Missouri River, and that levees have minor overall effects on flood stage but may have significant local effects. Meanwhile, numerous technical studies are continuing in an attempt to better define the impacts of specific modifications on flooding, as well as to verify previous findings such as those presented in the Galloway report.

Many of these modeling efforts are long overdue and are crucial to the evaluation of flooding impacts because they can provide a direct, quantitative comparison of alternative watershed conditions. Such analyses too often ignore the role of history, however. Each year, federal, state, and local agencies spend millions of dollars to measure streamflows in the Upper Mississippi River basin (UMRB), and a great emphasis is placed on maintaining streamgages with long periods of record. And yet there has been little examination of these historical records to document the hydrologic changes that have occurred on the Mississippi River. This is odd because significant trends in the streamgage record would arguably provide the most definitive evidence that the watershed hydrology *is being modified* by either natural or human influences. The following evaluation of the historical records for the UMRB provides a starting point for identifying trends in the watershed's hydrology and their possible causes.

Modifications to the Watershed, Floodplain, and Channel

The UMRB has experienced considerable hydrologic change over the last two centuries as a result of land development. This development includes removal of wetland areas, deforestation and subsequent reforestation, changes in agricultural practices, and urbanization. Table 1 shows changes in the watershed's wetland and forest areas since pre-settlement times. Many of the changes described occurred between 1850 and 1900. By 1900, logging had denuded much of the land still considered to be forest. Although the total amount of forested area has continued to decrease somewhat since the first part of the twentieth century, significant regrowth has occurred in the remaining forest area since the 1930s.

Table 1. Wetland and Forest Areas in the Upper Mississippi River Basin

	Total area (percent)			
	Illinois	*Iowa*	*Minnesota*	*Wisconsin*
Wetlands				
1780	23	11	28	27
1980	4	1	16	15
Forests				
1800	38	19	58	83
1930	8	----	36	46
1990	12	6	31	41

Sources: Dahl (1990), Brand and Walkowiak (1991), Miles and Chen (1991), Wisconsin Department of Natural Resources (1994), and Illinois Department of Energy and Natural Resources (1994)

Additional modifications have changed the manner in which the Mississippi River and its tributaries convey their water. These modifications include the construction of drainage ditches in upland areas of the watershed and channelization of many streams. Navigation projects have modified the channel of the Upper Mississippi River north of St. Louis, MO, including the installation of 27 locks and dams, as well as the construction of underwater wing dams, revetments, and other diversion structures to deter the navigation channel from meandering. Construction of levees has further restricted the flow of the river during flood and high flow conditions. Figure 1 shows a cross section of the Mississippi River 20 miles upstream of Keokuk, IA, in Pool 19. This cross section is typical of many locations on the river between St. Louis, MO, and Clinton, IA. As shown in the figure, the water level during low and normal flows is high (above the surrounding floodplain) so that the 9-foot-deep navigation channel is maintained in the pool upstream of the lock and dam.

Hydrologic Data Trends

Several streamgages on the Mississippi and its tributaries have been maintained since the late 1800s, including the 131-year streamflow record on the Mississippi River at St. Louis, MO, which is the longest continuous gage record in the United States. For this study, preference was given to gaging records longer than 90 years. When long-term records were not available for some of the larger tributaries to the Mississippi River, shorter records were also examined. Some shorter records were also used to verify trends observed in the longer records. Table 2 lists 13 selected gages for which long-term records are available and the drainage area at each gage. Slack and Landwehr (1992) indicate that only four of these records represent relatively unimpaired watershed conditions: the Mississippi River at Clinton and Keokuk, IA, the St. Croix River at St. Croix Falls, WI, and the Cedar River at Cedar Rapids, IA.

The oldest known precipitation record for the UMRB at St. Louis dates back to 1837. Numerous other precipitation records date back to the mid-1800s but most of these gages were sparsely located. Precipitation records from 1895 to the present were used for the current study in order to have a representative network of gages throughout the watershed.

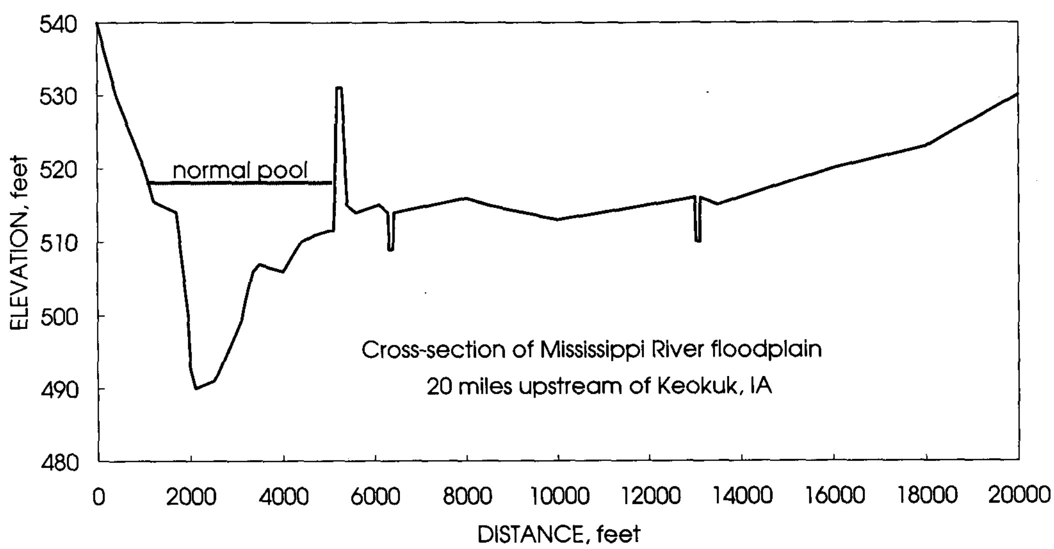

Figure 1. Typical cross section of the Mississippi River floodplain, 20 miles upstream of Keokuk, IA, in Pool 19

Table 2. Gaging Station Records Used in the Analysis of Long-term Trends

Gage number	*Location*	*Watershed area (sq mi)*	*Period of record*
05211000	Mississippi River at Grand Rapids, MN	3,370	1883-1992
05325000	Minnesota River at Mankato, MN	14,900	1929-1992
05331000	Mississippi River at St. Paul, MN	36,800	1892-1992
05340500	St. Croix River at St. Croix Falls, WI	6,240	1902-1992
05365500	Chippewa River at Chippewa Falls, WI	5,650	1888-1992
05395000	Wisconsin River at Merrill, WI	2,760	1902-1992
05420500	Mississippi River at Clinton, IA	85,600	1873-1992
05464500	Cedar River at Cedar Rapids, IA	6,510	1902-1992
05474500	Mississippi River at Keokuk, IA	119,000	1878-1992
05490500	Des Moines River at Keosauqua, IA	14,040	1911-1992
05586100	Illinois River at Valley City	26,740	1939-1992
06934500	Missouri River at Hermann, MO	528,000	1898-1992
07010000	Mississippi River at St. Louis, MO	697,000	1861-1992

A Kendall trend analysis was one of the procedures used to identify significant trends in the records. This analysis produces a rank correlation coefficient indicating the strength of the trend relative to the overall variability of the flow parameter being analyzed. Alley (1988) provides equations to estimate the Kendall coefficient. The trend analysis was performed using the annual series of four flow parameters: mean flow, peak discharge, 7-day high flow, and the maximum monthly flow.

Table 3 presents the correlation coefficients developed in this analysis for the 13 selected gages. A Kendall coefficient of zero indicates that there is absolutely no trend. Negative values indicate a decreasing trend, and positive values indicate an increasing trend. The strength of the trend increases as the absolute value of the coefficient approaches 1.0 (the maximum correlation). If the natural variability of the flow parameter is particularly great, as with high flows and floods, it may be more difficult to identify a significant trend. Coefficients are highlighted in table 3 when they identify a trend that is significant at a 90 percent level of confidence. Individual trends are discussed later.

The great annual variability in the hydrologic data often obstructs both the ability to observe relatively small trends in the data and the ability to identify such trends by means of statistical tests, such as Kendall trend analysis. One useful method to identify small trends in a time series is to examine the cumulative departure from an established normal condition represented simply by the long-term average or, as in this study, by relating the hydrologic variable of interest to changes in a basic hydrologic process, such as precipitation. Plots of cumulative departure, also referred to as the sum of the residual series, were used to identify most of the trends described in subsequent sections.

Much of the residual series analysis employs an 11-year moving average of streamflow and precipitation conditions. There are two reasons for this:

- Averaging conditions over a number of years eliminates much of the record's short-term variability that masks the relationships between hydrologic parameters.

Table 3. Coefficients of the Kendall Trend Analysis

Location	*Years of record*	*Annual flow parameter* *Mean flow*	*Peak discharge*	*7-day high flow*	*Maximum month*
Mississippi River at Grand Rapids, MN	109	0.0954	0.0190	--------	0.0032
Minnesota River at Mankato, MN	85	--------	0.1227	--------	***0.1770***
Mississippi River at St. Paul, MN	92	***0.1776***	***0.1724***	***0.2020***	***0.1808***
St. Croix River at St. Croix Falls, WI	90	***0.2173***	***0.2274***	--------	***0.2280***
Chippewa River at Chippewa Falls, WI	101	-0.0116	-0.0150	-0.0516	-0.1281
Wisconsin River at Merrill, WI	90	-0.114	-0.0412	***-0.1751***	***-0.2350***
Mississippi River at Clinton, IA	119	-0.0624	-0.0232	-0.0624	-0.0343
Cedar River at Cedar Rapids, IA	90	0.0981	0.0244	0.0436	0.0949
Mississippi River at Keokuk, IA	114	0.0696	0.0735	0.0322	0.0195
Des Moines River at Keosauqua, IA	81	0.0430	-0.0444	0.0175	0.0442
Illinois River at Valley City, IL	55	***0.1576***	***0.1900***	0.1420	***0.1592***
Missouri River at Hermann, MO	95	0.0037	--------	--------	-0.0813
Mississippi River at St. Louis, MO	131	0.0591	0.0328	---------	-0.0155

Notes: Coefficients in bold italics indicate significance at the 90 percent level of confidence. Missing values indicate that the available data did not permit computation of the flow parameter for the entire period of record.

- Most hydrologic records contain a mild 11-year cycle, believed to be associated with sunspot activity. The choice of an 11-year period for averaging removes the impact of this cycle from the results.

Precipitation

There has been a general increase in precipitation over the UMRB during the 20th century, particularly since 1965. Figure 2 indicates those portions of the watershed that have experienced statistically significant increases in average precipitation. Areas with the greatest increase in average precipitation since 1965 include southern Minnesota (7 to 10 percent increase), southeastern Iowa, (6 to 7 percent), and northeastern Illinois (9 percent). Most of Iowa has had an increase in average precipitation of more than 5 percent over the last 25 years. Most portions of Wisconsin, Missouri, and western Illinois show little if any increase in precipitation, however.

Average Streamflow

There is a very strong relationship between long-term average precipitation and streamflow. For example, figure 3 illustrates the relationship between the 11-year moving averages for watershed precipitation and streamflow for the Mississippi River at Keokuk, IA. That same type of relationship was present for all streamgages that were analyzed. The coefficient of correlation between the 11-year moving average of precipitation and streamflow normally exceeds 0.95. Consequently, trends observed in average precipitation were also reflected in the streamflow.

Table 4 lists the average flow measured at four Mississippi River gages (St. Paul, MN; Clinton, IA; Keokuk, IA; and St. Louis, MO) for five periods over the last 130 years: 1862-1893, 1894-1920, 1921-1940, 1941-1964, and 1965-1992. The values indicate that flow conditions over the UMRB have varied considerably. Most streamflow records from the UMRB began in the early 1900s (coincident with the precipitation records); and for these records the recent 1965-1992 period

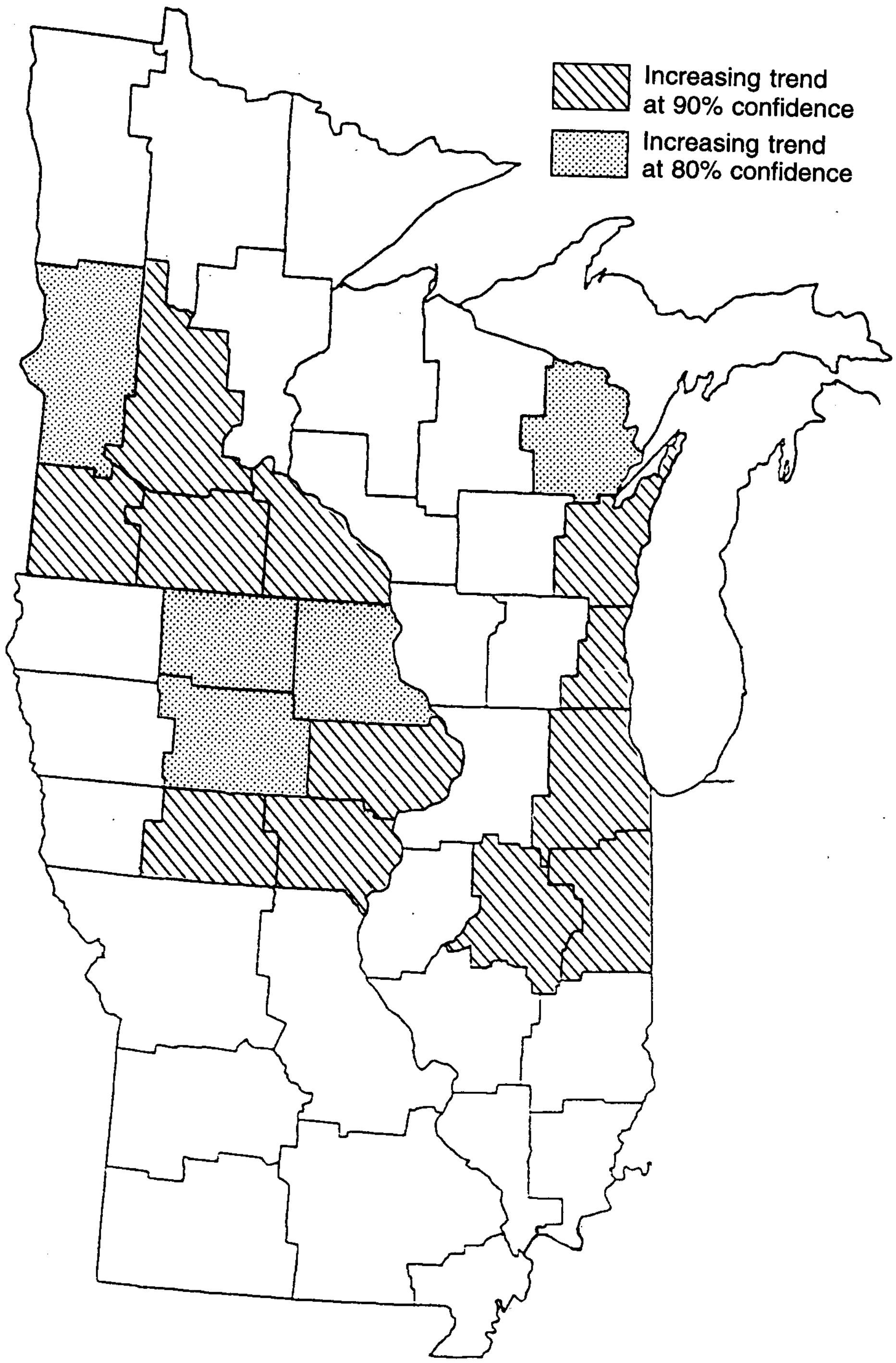

Figure 2. Precipitation trends in the Upper Mississippi River basin

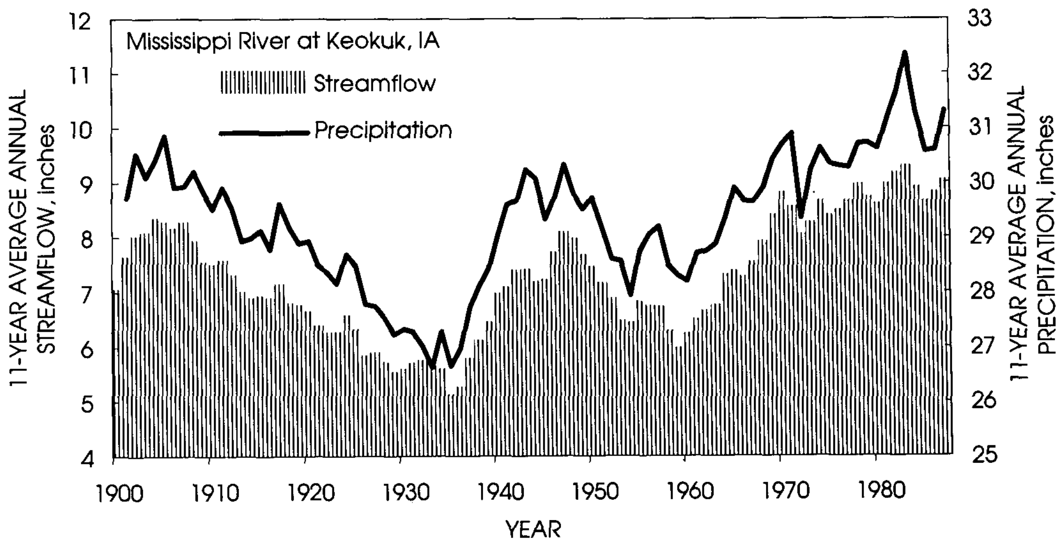

Figure 3. Comparison of 11-year moving average streamflow and watershed precipitation, Mississippi River at Keokuk, IA, 1900-1990

Table 4. Variability in Average Streamflow on the Mississippi River (cfs)

	St. Paul, MN	Clinton, IA	Keokuk, IA	St. Louis, MO
Period				
1862-1893	———	55,320	71,580	188,830
1894-1920	11,113	49,190	63,420	174,380
1921-1940	5,569	37,960	49,910	157,210
1941-1964	11,504	45,940	63,140	175,360
1965-1992	14,267	50,310	75,240	202,910
Total Record	*10,948*	*47,680*	*64,530*	*180,050*

Note: Streamflow values are based on the period of record (through 1992) for each gage, which may not cover the entire period of 1862-1893. Each gage's period of record is listed in Table 2.

of above-normal flows is unique. The increase in average streamflow for Iowa and southern Minnesota has been particularly great, ranging from 12 to 35 percent. These changes are directly attributable to the concurrent increase in precipitation. Trend statistics computed for many of the shorter gage records frequently indicate the presence of trends, as shown in table 3 for the Illinois River at Valley City. But for the longer flow records, there exists an additional period of above-normal flow, from 1862 to 1893, and trend statistics for these longer gage records (table 3) usually fail to identify any significant trends. The length of the gage record therefore plays a substantial role in the visualization of hydrologic trends.

Because the correlation between precipitation and streamflow is strong, we can hypothesize that precipitation in the late 1800s was also significantly above normal, comparable to that of recent years. With the presence of these two above-normal periods (1862-1893 and 1965-1992) and an intermediate period of significantly below-average precipitation and streamflow (1920-1940), one may speculate whether there exists a long-term cycle of 80 to 120 years in the hydrologic record. Without longer hydrologic records, however, such a long-term cycle cannot be verified.

To analyze the possible impacts of physical modifications on flow in the Upper Mississippi River and its tributaries, it is necessary to remove the dominating influence of climatic variability. Figure 4 illustrates how the 11-year average watershed precipitation and streamflow are related for the Mississippi River at Keokuk, IA. Under relatively wet climatic conditions, the relationship between average precipitation and streamflow is approximately linear with a slope of one. But under drier conditions, reductions in available soil moisture can limit watershed evapotranspiration, thereby causing an increase in streamflow relative to the linear relationship established under wetter conditions. Figure 4 shows that curvature in the precipitation-streamflow relationship occurs when average watershed precipitation is less than 29 inches. Two separate lines are used to represent the nonlinear relationship. The composite regression line shown in the figure can be used to compute an expected streamflow given the concurrent amount of watershed precipitation.

Differences between the observed and expected streamflow were examined to detect trends in the flow record not associated with precipitation variability. Figure 5 shows the cumulative difference between the observed and expected flows for the Mississippi River at Clinton, IA. The differences between the expected flows and the observed flows are generally positive for the 1900-1933 period and negative from 1952 to the present. This indicates a nonstationary relationship between precipitation and streamflow, and also a general decrease in streamflow between the two periods. The average difference between the two periods was estimated to be 0.5 inches per year (equivalent water depth over the entire watershed), or a reduction of about 6 percent in average flow. Similar differences between observed and expected flow are also detected for most long-term gaging records from central and northern Wisconsin. Streamflows from these Wisconsin watersheds contribute more than 40 percent of the average flow at the Clinton gage, and it is believed that the reductions in flow may be related to hydrologic changes as a result of forest regrowth in central and northern Wisconsin since the mid- 1930s.

A similar analysis of gage records from Iowa and southern Minnesota indicates that average flows in these regions since 1945 are 5 to 10 percent higher (relative to precipitation) than those from 1915 to 1945. It is not clear whether the flow increases were due to changes in land use or agricultural practices, or some other unknown variable within the hydrologic record. This regional trend had a minor impact on the downstream flows measured on the Mississippi River gage at Keokuk: than 2 percent change in average flow relative to watershed precipitation.

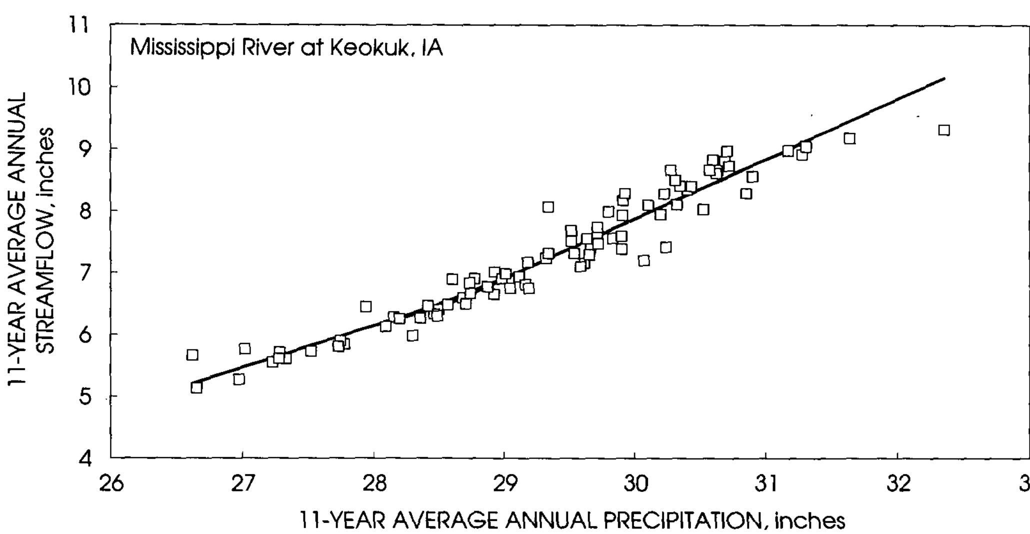

Figure 4. Scatter diagram relating 11-year average streamflow and watershed precipitation, Mississippi River at Keokuk, IA, 1900-1990

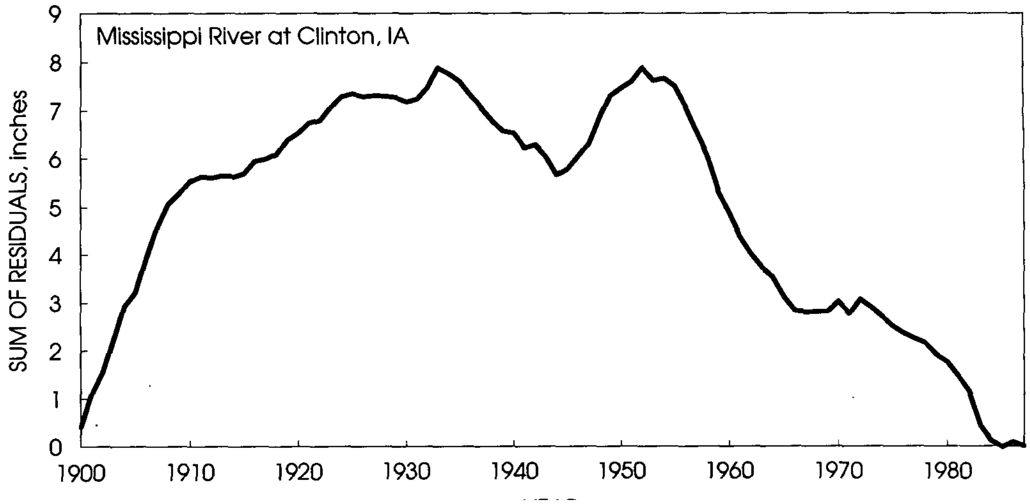

Figure 5. Cumulative difference between observed and expected streamflow at Clinton, IA (based on watershed precipitation)

Peak Discharge and Flood Volume

Trend analysis was also used to examine annual peak discharge and annual high flows (the volume of flood or high flow for a specified duration, ranging from 7 days to 1 month). The trend statistics for flow parameters are given in table 3. Though the high flow statistics are not a direct measurement of flood volume, the two parameters will reflect similar trends over a long period.

Several flooding trends were noted for many tributaries to the Mississippi River. The Minnesota, St. Croix, and Illinois Rivers experienced noticeable increases in both annual peak discharges and high flows since 1965. In all three cases the increases were proportional to coincident increases in precipitation and mean streamflow. Peak flows in the Wisconsin watersheds show little change over time, but high flows have decreased slightly, and this decrease may be consistent with the hypothesis that reforestation has altered surface runoff in these watersheds.

The watersheds of a few major tributaries, such as the Des Moines River, contain flood control reservoirs that substantially decrease both high flows and peak discharges. Other Iowa watersheds display a 10 to 25 percent increase in high flows for long durations (31 days or more) since 1965, which is consistent with the increase in average streamflow. However, these watersheds have not experienced a corresponding increase in either peak discharge or high flows over short durations (7 days). Thus, while much of Iowa is experiencing a wetter hydrologic regime, it appears that the magnitude and frequency of flood-producing precipitation has not changed substantially.

Figure 6 displays the historical peak discharge series for the Clinton, Keokuk, and St. Louis gages on the Mississippi River. The figure accentuates and identifies major flood events. Neither statistical testing nor an examination of this figure indicates substantial trends in these series.

Peak discharges and high flows at the Keokuk gage are somewhat higher over the last 25 years, and are closely correlated to the higher amount of precipitation and average streamflow that has also occurred over that period. Expected high flow values were estimated for the Mississippi River gages using long-term precipitation as the independent variable, For the Clinton and Keokuk records, the differences between the expected and observed high flows have no trend. Therefore, all observed changes in high flows and peak discharges at these two stations appear to be related to climate variability.

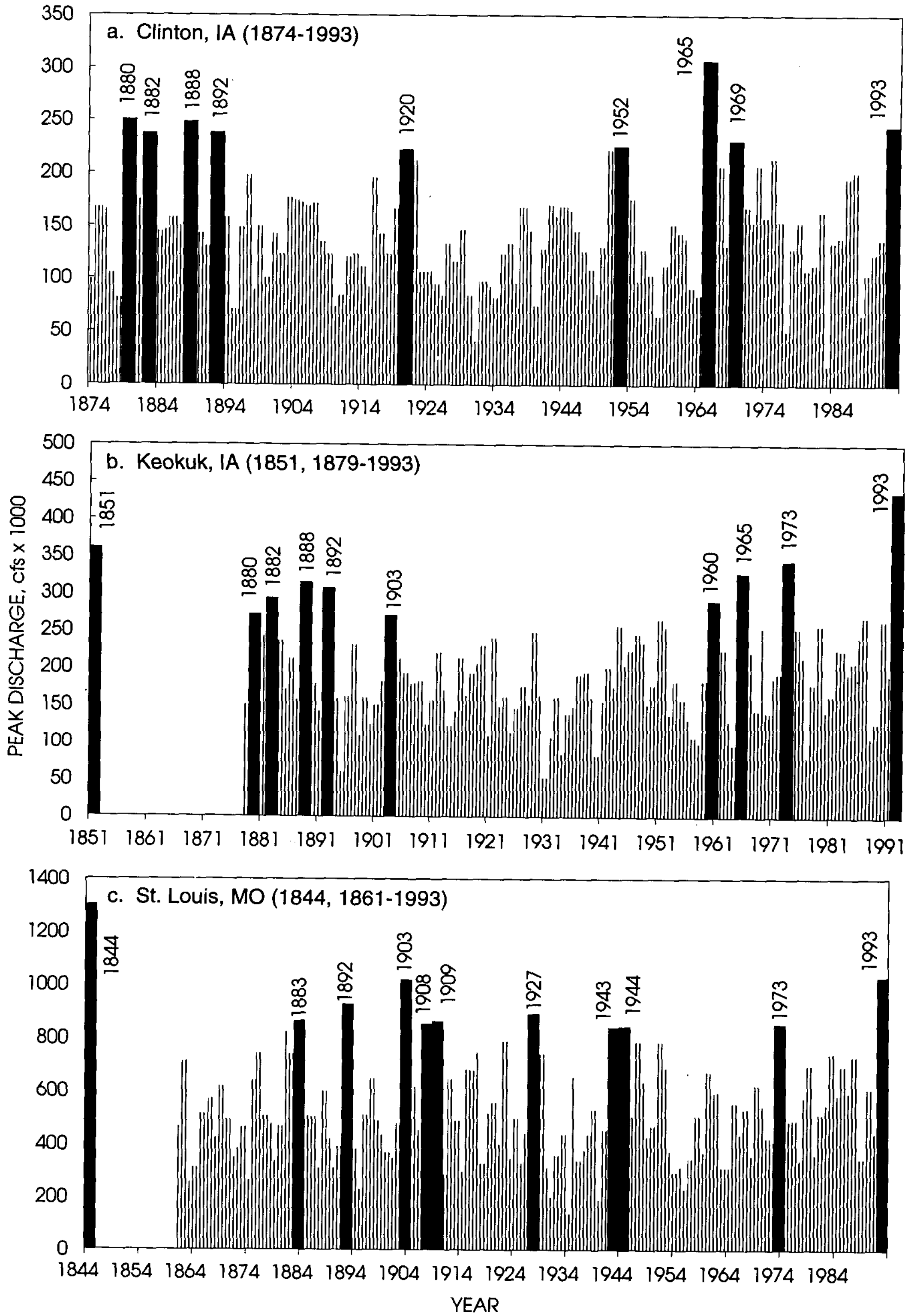

Figure 6. Annual peak discharges at Clinton, IA (a), Keokuk, IA (b), and St. Louis, MO (c) (major flood events highlighted in black)

However, when the expected and observed high flow records for St. Louis are compared, a definite trend is observed. The expected high flows are noticeably higher than the observed values since about the late 1950s, indicating a decreasing trend. Decreases in peak discharges over that time, relative to the average discharge, are also indicated (figure 7). The gage record for the Missouri River at Hermann, located above the confluence with the Mississippi River, also displays similar decreasing trends. These decreases in flooding, most noticeable during higher flow conditions, are likely to be directly attributed to the flood control provided by numerous reservoirs in the Missouri River watershed. The average annual decrease in flood peaks at Hermann and St. Louis is estimated to be as much as 40,000 and 60,000 cubic feet per second (cfs), respectively. In each case, these numbers represent roughly a 10 percent reduction in the average peak discharge. The analysis used in this study does not provide a method to estimate the impact on individual major floods.

Another major factor that could affect the perception of flooding trends is the change in streamgaging techniques and equipment over the last century. The most significant change is the introduction of the Price meter, which came into common use around 1930. But had this change or any others biased the records, these changes should have been detected during trend analysis. Both the average flow and peak discharge records maintain a strong correlation with watershed precipitation, and none of the observed changes in flow conditions occur around 1930. This suggests that the gaging records are reasonably consistent.

Flood Stage

Peak stage records were examined for two locations on the Mississippi River, and figure 8 shows the annual series of peak stage for the Clinton and St. Louis gages. Figure 9 shows the relationship between peak discharge and peak stage for each year of record. In both cases, peak stages have increased relative to discharge, a change especially evident for the St. Louis gage. It appears that the most substantial change in the discharge-stage relationship occurred around 1930, and the relationship has been relatively stable since then.

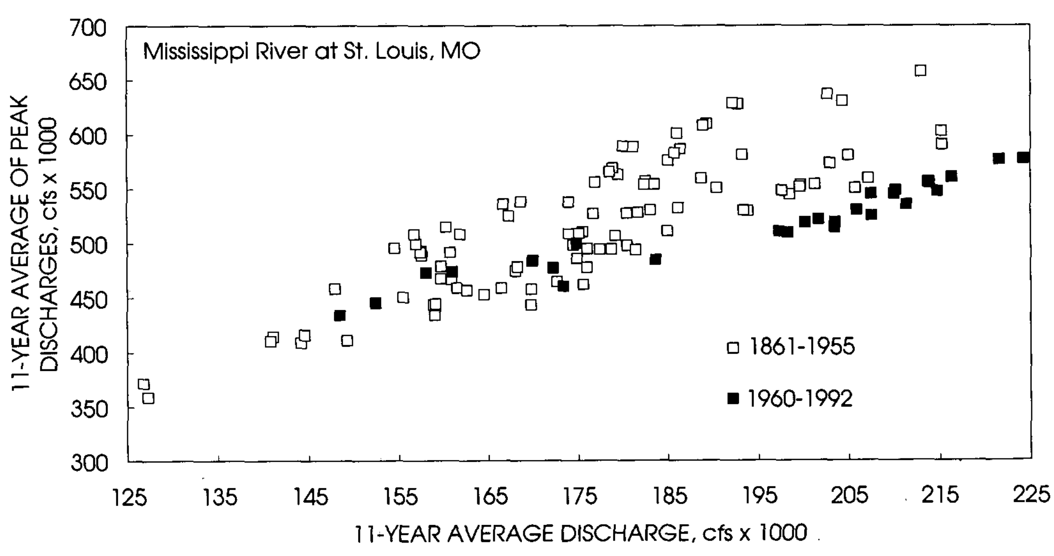

Figure 7. Relationship between 11-year moving average peak discharge and average discharge, Mississippi River at St. Louis, MO

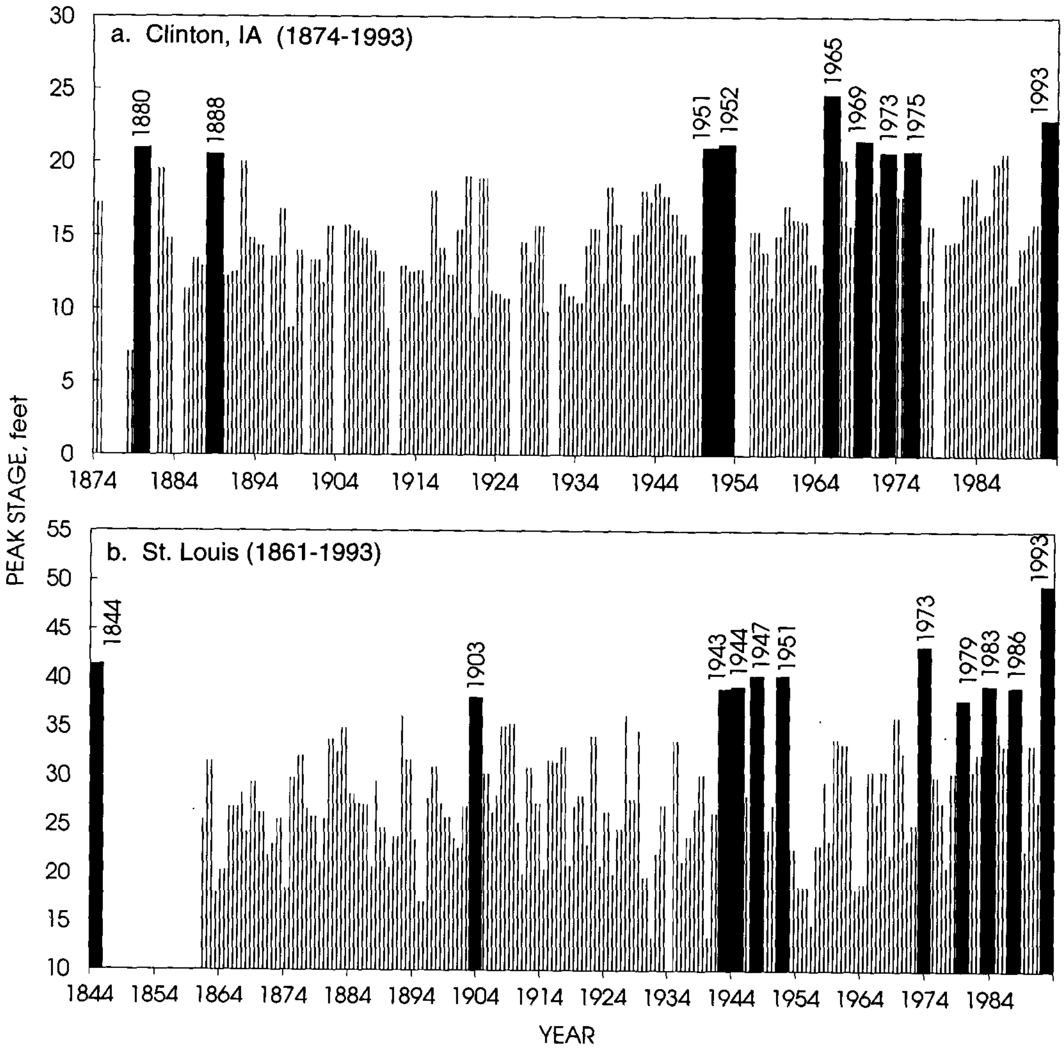

Figure 8. Annual peak stages at Clinton, IA (a) and St. Louis, MO (b)
(major flood events highlighted in black)

The change in the discharge-stage relationship is most likely related to the constriction in river flow as a result of levees, although it is conceivable that navigation works, such as wing dams, could also have an impact. The magnitude of the impact of levees on flood stage has long been debated in the engineering community. Detailed unsteady flow routing models are currently being developed to more accurately examine these impacts. The impact of levees and other modifications on flood conveyance capabilities is expected to have great variability from one location to another. Thus, the change in the discharge-stage relationship at any location may be considerably different than the change shown for either Clinton or St. Louis. Nevertheless, some change may be expected wherever the conveyance of the river during high flows has been modified.

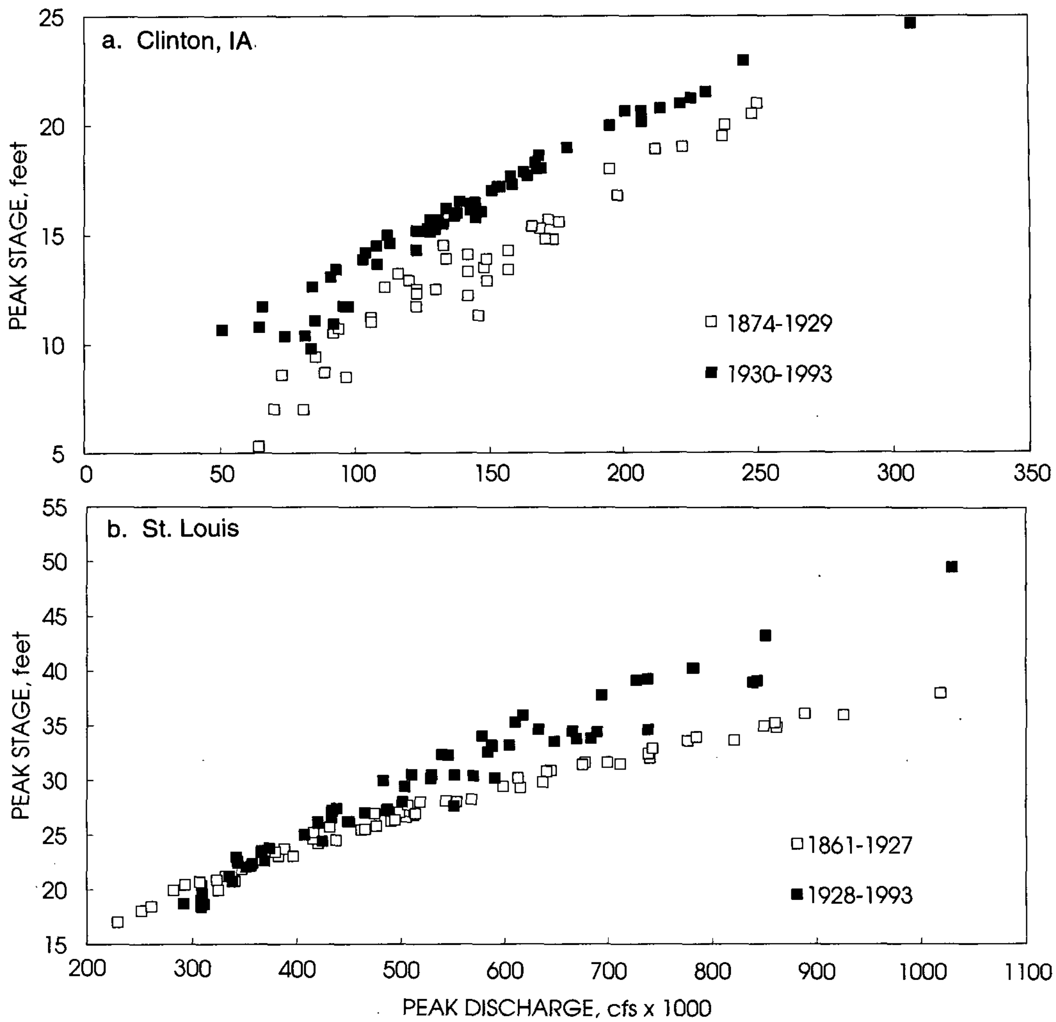

Figure 9. Relationship of peak stages to peak discharges at Clinton, IA (a), and St. Louis, MO (b)

Concluding Remarks

The magnitude of the trends in the discharge records is arguably less than might be expected, given the widespread physical modifications to the UMRB. Observed changes in streamflow are regional, and most of these changes are directly associated with climate variability. Furthermore, it is expected that the climate influences and streamflow will continue to fluctuate in the future largely as they have over the historical record. Much of the watershed has experienced above-average precipitation since 1965, which has also significantly changed the average streamflow. Underlying the changes resulting from precipitation variability are additional subtle trends in average streamflow. Major tributaries in Wisconsin and Iowa have experienced a reduction and an increase, respectively, in flows relative to those expected given the concurrent trend in precipitation. The change in Wisconsin is assumed to be related to reforestation, while the source of change in Iowa is still unclear.

Changes in peak discharges and high flows were also detected. Tributaries in Minnesota and Illinois have experienced increases in peak discharge and high flows proportional to the increase in average flows, while tributaries in Iowa have not. Most areas in Wisconsin have experienced a reduction in high flows, but minimal change occurred in peak discharges.

Although hydrologic modifications affecting average flows and flooding were detected for individual major tributaries, there was relatively little impact on the flows in the Mississippi River. These results suggest that watershed scale has a significant influence on the impacts of human-induced modification. Individual watershed changes must be widespread to modify large river flows, and this modification may often be attenuated by the substantial storage associated with large watersheds. Two specific impacts were noted, however: 1) the average flow in the Mississippi River at Clinton, IA, has been reduced by 6 percent, possibly as the result of reforestation in Wisconsin; and 2) flood control reservoirs in the Missouri River watershed appear to have produced a 10 percent reduction in the average flood peak and flood volume for the Mississippi River at St. Louis. In addition, the increases in average flow to Iowa watersheds since 1945 should be further investigated to identify possible causes.

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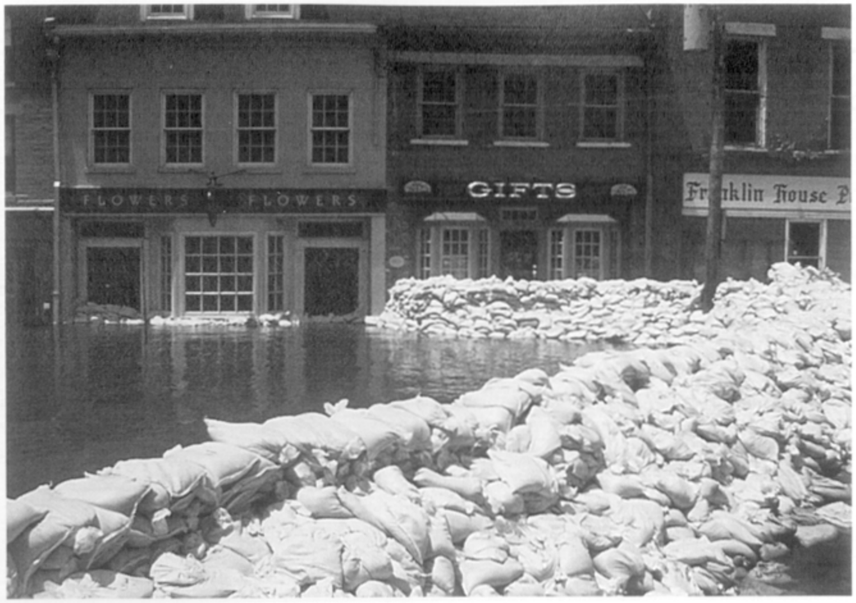
APPENDIX: PICTORIAL REVIEW OF THE FLOOD

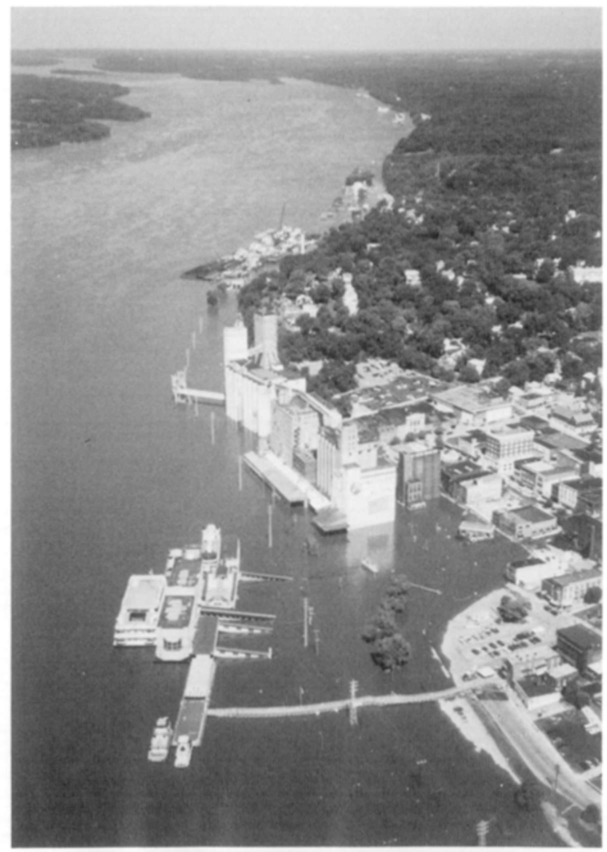
All photographs were taken by Illinois State Water Survey staff unless noted otherwise.



Sandbagging in downtown Alton

Water treatment plant at Alton

Gambling boat at Alton



Gambling boat at
Alton (loooking north)

Lock and Dam 26

Confluence of Mississippi and Missouri Rivers

St. Louis

Flooding by seepage south of St. Louis (looking north)

Kaskaskia Island (top); Mississippi River (middle); seepage (bottom)

Kaskaskia Island - bridge at Chester (looking southwest)

Kaskaskia Island - old channel (looking west)

Kaskaskia Island - old channel (looking south)

Supply of sandbags at a levee repair site on the Indian Graves Levee District north of Quincy

Sandbags on a levee

Sandbags protecting a road to a levee repair site

Sandbagging operation

Levee repair

Levee repair at Sny Island Levee District

Sand boil

Sandbagging to control a sand boil site

Flooding in Quincy Bay area

Flooding in North Quincy Bay area


Levee repair done by prisoners


Flooding in Quincy Bay area

Columbia Levee breach *(photo courtesy of U.S. Army Corps of Engineers)*

Kaskaskia Island Levee breach *(photo courtesy of U.S. Army Corps of Engineers)*

Nutwood Levee breach *(photo courtesy of U.S. Army Corps of Engineers)*

Len Small Levee breach causing severe damages *(photo courtesy of U.S. Army Corps of Engineers)*

Levee breach at Miller City, Mississippi River

Flooding of private home (note lower area in previous photo)

Same home at ground level

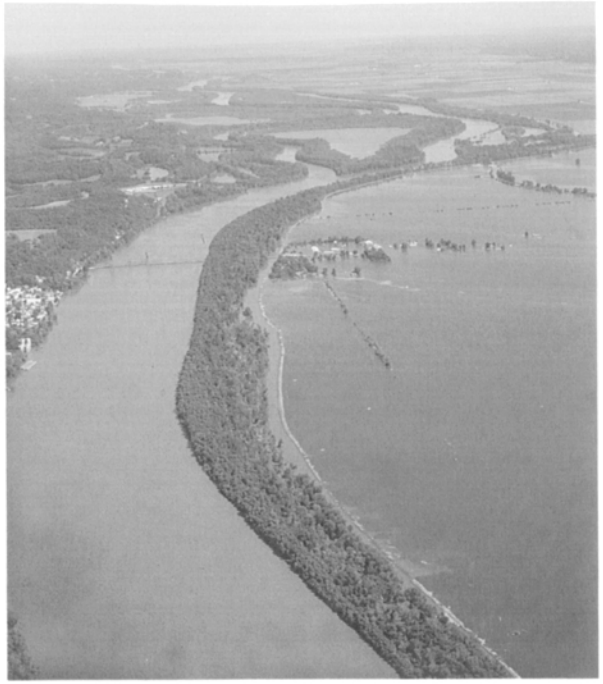
Same home and farm storage

Levee breach at Miller City - church

Levee breach at Miller City

Levee breach at Miller City

Levee breach at Miller City



East Hardin on
the Illinois River
(looking north)

East Hardin (Nutwood Levee District)

Hardin and East Hardin (looking north)

East Hardin
(looking south)

Lower Illinois River near Hardin

Flow over a levee on Lower Illinois River near Hardin

Lower Illinois River north of Hardin

Lower Illinois River north of Hardin

Illinois River

Flooding along Route 96 at Kampsville

Flooding at junction of Routes 96 and 100 at Kampsville

Flooding at Kampsville

Confluence of Mississippi and Illinois Rivers

Confluence of Mississippi and Illinois Rivers at Grafton

Illinois Route 100 under water at Grafton

Mississippi River south of Grafton

Alton highway bridges (new and old) U.S. Route 67

St. Charles county airport (ground level)

St. Charles, Missouri, area

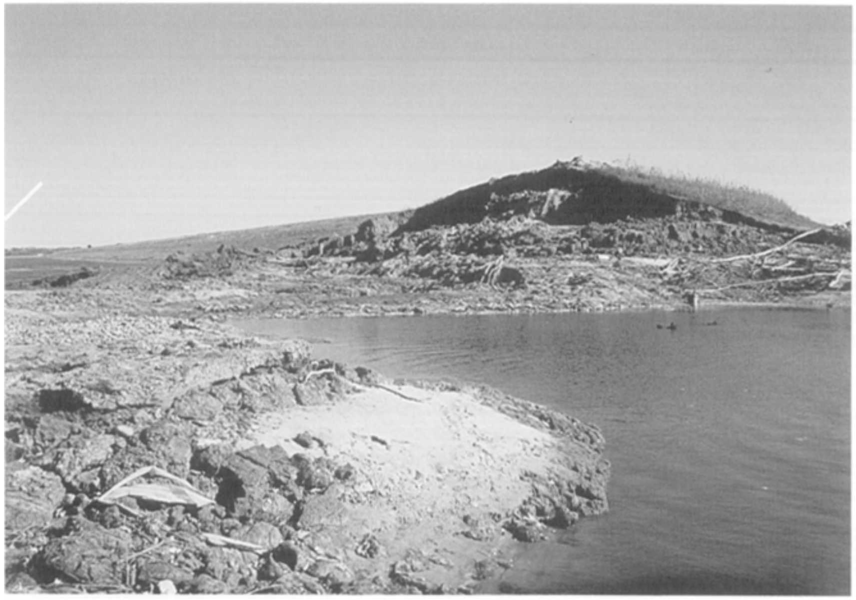
St. Charles county airport

Ground-water flooding, Route 97 looking south near Havana

Ground-water flooding near Havana showing 12" PVC dewatering pipes

Ground-water flooding near the city of Bath showing dewatering pipe

Ground-water flooding, Sand Lake on Route 97 near Havana



Levee breach along the Mississippi River north of Quincy

Forces of flood flow north of Quincy. Note barrel in tree.

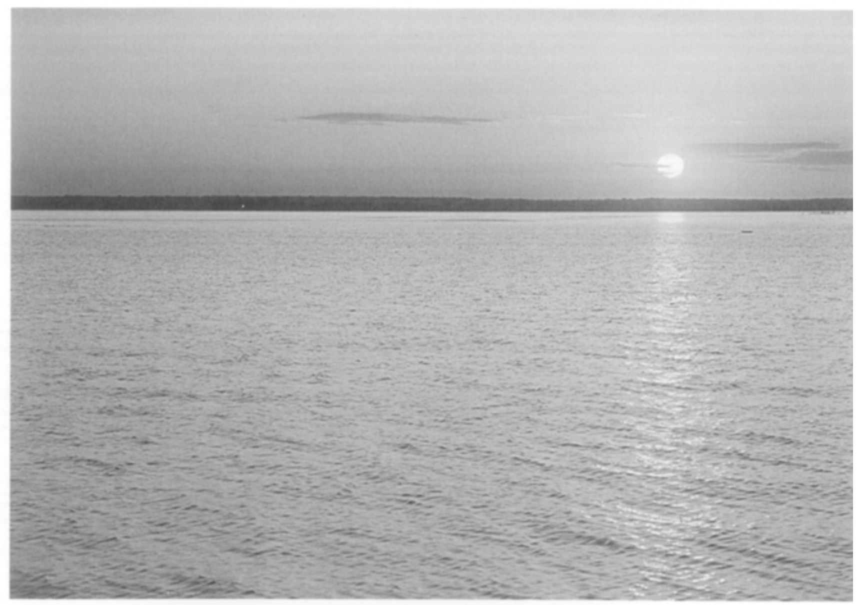
Sedimentation within a levee district

Sand deposit behind a failed levee district north of Quincy

Levee repair by the Illinois National Guard

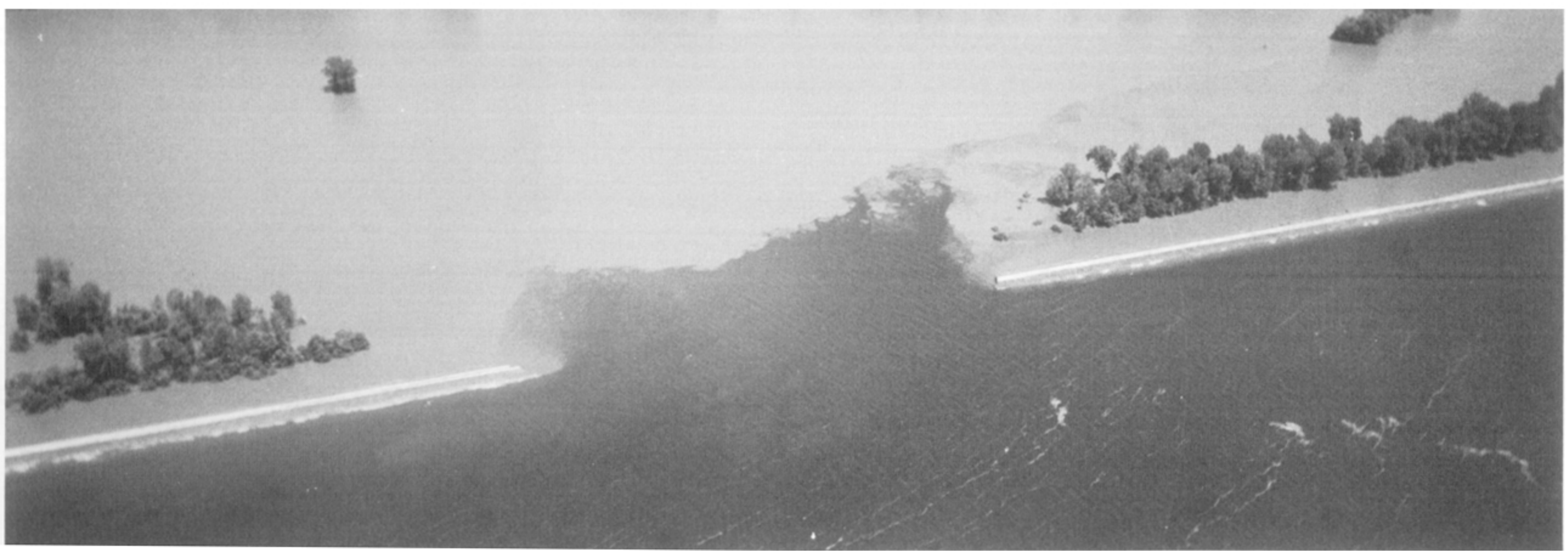
Failed levee (left) and intact levee (right) on the Illinois River

Horseshoe Lake



Sunset on the Illinois River behind a failed levee

Kaskaskia Island looking north. Circled area shows broken levee.



Broken levee at Kaskaskia Island