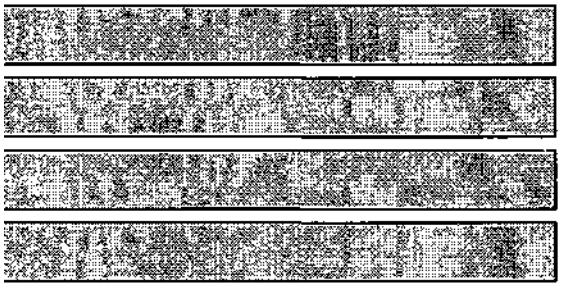
Miscellaneous Publication 163

1993 Mississippi River Record Stages and Levee Failures along the Illinois Border

by Sally McConkey, Kingsley Allan, and Barbara Pollock
Office of Surface Water Resources: Systems, Information, & GIS

December 1994



Illinois State Water Survey
Hydrology Division
Champaign, Illinois

A Division of the Illinois Department of Energy and Natural Resources

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2204 Griffith Drive
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INTRODUCTION

River stages recorded at gaging stations along the Illinois border illustrate some of the unusual features of the 1993 Mississippi River flood: new record river levels, the length of the river that was simultaneously impacted by flooding, the timing of the most severe flooding, the duration of river levels over flood stage, and the ultimate failure of levee systems. Graphical and tabular comparisons of stage data recorded during previous major flood events and the 1993 flood dramatically illustrate the uniqueness of the 1993 flood.

A review of Mississippi River flood levels predicted for events with various return intervals demonstrates that the 1993 flood far exceeded the anticipated 100-year event. River stage records show more than a single flood wave. Stations below the confluence of the Iowa River, from Keithsburg, IL, downstream to Thebes, MO, show a minor flood wave occurring in early March. Stations from Dubuque, IA, downstream to Thebes show the river level rising in April, the prelude to significant flooding in April and May. This was followed by the most significant and record-setting flood wave, which peaked in late July and early August.

River levels well above flood stage persisted for a substantially longer period of time than during previous significant flood events, and this contributed to the ultimate failure of levee systems. The failure of levees and subsequent flooding of the levee districts created temporary drops in river stages that were quickly recovered once the available storage behind the failed levees had filled. Flood waters were contained behind failed levees, not conveyed downstream. The response of river stage to levee failures is recorded in the records of stations located downstream of the flooded levee districts.

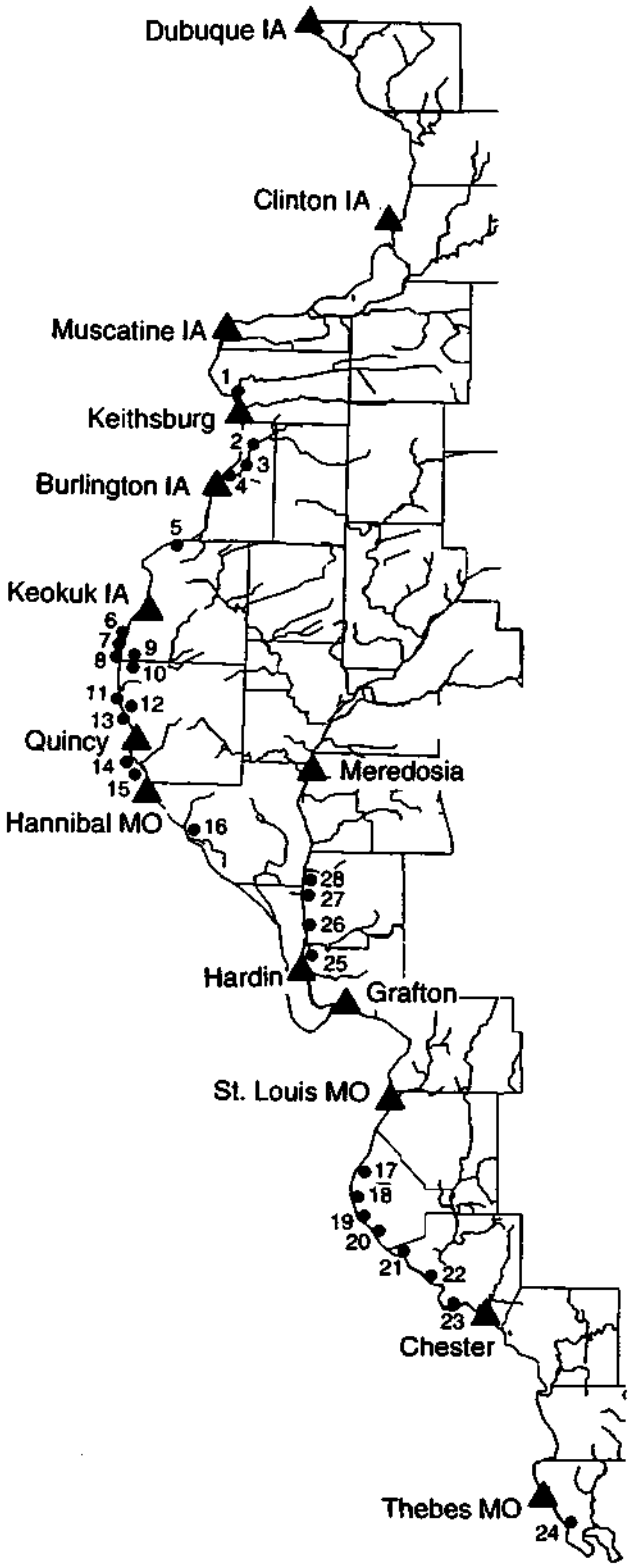
River stage and discharge observations of the Mississippi River date back over 100 years at some stations, such as St. Louis, MO, and Chester, IL. This report discusses the stage records from Mississippi River gaging stations along the Illinois border. The stations were selected to be geographically representative of the Mississippi River along this border. Figure 1 shows the locations of these recording stations. Color illustrations dramatically contrast the 1993 flood with other events and demonstrate its unique features. The data and illustrations in this report provide additional information related to the topics covered in Illinois State Water Survey (ISWS) Miscellaneous Publication 151, *The 1993 Flood on the Mississippi River in Illinois.*

RECORD PEAK STAGES AND HISTORICAL COMPARISONS

One distinctive aspect of the 1993 Mississippi River flood is the length of the river that was severely impacted, as evidenced by the setting of new peak stage records. While previous floods set records on segments of the river, in 1993 new records were established along a greater length of the river than in any previous record-setting flood event. Table 1 provides a list of 12 Mississippi River stations and four Illinois River stations, their river mile, previous peak stage and date, and the 1993 peak stage.

Peak Stage Records

Before the 1993 flood, the 1965 and 1973 floods had the record peak stages at stations along the Illinois border. The flood of 1965 held the peak stage record at stations between Dubuque and Keithsburg. Below Keithsburg, the 1973 flood had established the highest recorded stage downstream to Cape Girardeau, MO. The 1983 and 1979 flood events were also significant in terms of peak stages and the length of the river experiencing high stages. The 1993 flood established new record peaks from Muscatine, IA, downstream to Thebes. Two major tributaries, the Missouri and Illinois Rivers, join the Mississippi River just above St. Louis. Historically, major flood events on the Mississippi River above and below St. Louis do not necessarily coincide. The 1965 event, which held the peak stage records at stations above St. Louis, does not rank in the ten highest peak stages set at stations below St. Louis. The 1973 flood event is more



Failed levees	No.
Keithsburg	1
Henderson No. 3	2
Henderson No. 1	3
Henderson No. 2	4
Niota	5
Des Moines & Miss.	6
Miss. & Fox	7
Gregory	8
Hunt	9
Lima Lake	10
Union Twp.	11
Indian Grave (N & S)	12
Fabius	13
Marion Co.	14
So. River	15
Sny Island	16
Columbia	17
Harrisonville & Ivy	18
Moredock&Ivy	19
Fort Chartres & Ivy	20
Stringtown	21
Prairie du Rocher & Modoc	22
Kaskaskia Island	23
Len Small	24
Nut wood	25
Eldred	26
Hartwell	27
Hillview	28

Figure 1. Mississippi River stage recording stations and locations of failed levees

Table 1. Mississippi and Illinois River Stations and Peak Stage Records

Gaging station	*River mile (feet)*	*Gage datum (feet)*	*Flood stage feet)*	*1993 Peak stage (feet)*	*(date)*	*Feet over flood stage*	*Historical peak stage (feet)*	*(date)*	*Difference from record (feet)*
Mississippi River									
Dubuque, IA[2]	579.9	585.47	17.0	23.84	7/1	6.8	26.81	4/26/65	-3.0
Clinton, IA[3]	511.8	562.68	16.0	22.98	7/8	7.0	24.65	4/28/65	-1.7
Muscatine, IA[2]	455.2	530.74	16.0	25.61	7/9	9.6	24.81	4/29/65	0.8
Keithsburg, IL[2]	427.7	523.19	13.0	24.15	7/9	11.2	20.46	4/28/65	3.7
Burlington, IA[2]	403.1	511.45	15.0	24.98	7/10	10.0	22.0	4/73	3.0
Keokuk, IA[3]	364.2	477.41	16.0	27.58	7/10	11.6	23.35	4/24/73	4.2
Quincy,IL[2]	328.9	458.59	17.0	32.13	7/13	15.1	28.9	4/73	3.2
Hannibal, MO[2]	309.7	449.43	16.0	31.80	7/16	15.8	28.23	4/25/73	3.6
Grafton, IL[3]	218.6	403.79	18.0	38.17	8/1	20.0	33.20	4/28/73	5.0
St. Louis, MO[3]	180.0	379.94	30.0	49.58	8/1	19.5	43.23	4/28/73	6.3
Chester, IL[3]	109.9	341.05	26.9	49.74	8/7	22.7	43.32	4/30/73	6.4
Thebes, MO[3]	43.7	300.00	33.0	45.51	8/7	12.5	45.14	7/4/44	0.4
Illinois River									
Henry[3]	196.0	425.88	19.0	26.75	4/22	7.8	32.67	3/22/79	-5.9
Kingston Mines[3]	144.4	428.00	20.0	21.41	4/23	1.4	26.02	5/25/43	-4.6
Meredosia[3][4]	71.3	418.00	14.0	26.96	7/28	13.0	28.61	5/26/43	-1.7
Hardin[3]	21.5	400.00	25.0	42.4	8/3	17.4	38.2	4/29/73	4.2

Notes:

[1]River mile from mouth.

[2] Stage data for Mississippi River obtained from U.S. Army Corps of Engineers, Rock Island and St. Louis Districts.

[3] 1993 data from USGS *Water Resources Data Illinois Water Year 1993*.

[4]Water discharge records prior to October 1989, combined with records for Illinois River at Valley City.

comparable to the 1993 event in that it ranks in the top ten highest peak stage events from Dubuque to Thebes.

The new peak stage records from Muscatine to Thebes were set between July 9 and August 7, 1993. Figures 2, 3, and 4 depict the river stage along the Illinois border in terms of feet over flood stage for July 1, July 9, and August 1, respectively. These illustrations show the length of the river that was simultaneously impacted. Flood stage is typically established as the level where the river goes out of its banks; however, where levees have been constructed, flood stage may be defined in terms of the levee height. Flood stages defined in *River Stages in Illinois: Flood and Damage Data* (Illinois Department of Transportation (IDOT), Division of Water Resources, 1991) were used for this report. The illustrations in figures 2 through 4 were developed using Geographic Information System (GIS) technology. The flood stages recorded at the selected gaging stations were interpolated between stations. Development of the illustrations is discussed in the section *GIS Analysis and Applications*.

Comparison of Daily River Levels during Major Floods

Mississippi River stages have been recorded since the mid-1800s at gages from Dubuque to Chester. Typically, the most severe flooding, coinciding with the peak stage reached during flood events, occurs in the spring (most frequently in April and May), although it is not unusual for the river to rise above flood stage in the late summer or autumn. The 1993 flood departed from past major floods in that the peak stages were recorded between July 1 and August 7. The stages recorded for the periods 1964-1965, 1972-1973, and 1992-1993 are shown in figure 5 for Keithsburg, St. Louis, and Chester. These station records show that the river stages recorded in 1972 and 1992 are comparable and higher than those observed in 1964.

River stages recorded at Keithsburg (figure 5 a) show that while the peak stage recorded in 1965 exceeded that in 1973, it was a high peak of short duration. Stages recorded in 1972-1973 and 1992-1993 are similar until early June of the second year, (1973 and 1993, respectively). The flooding in April 1993 was significant in its own right, of similar magnitude to the 1973 flood. In May 1973, the river levels were declining,

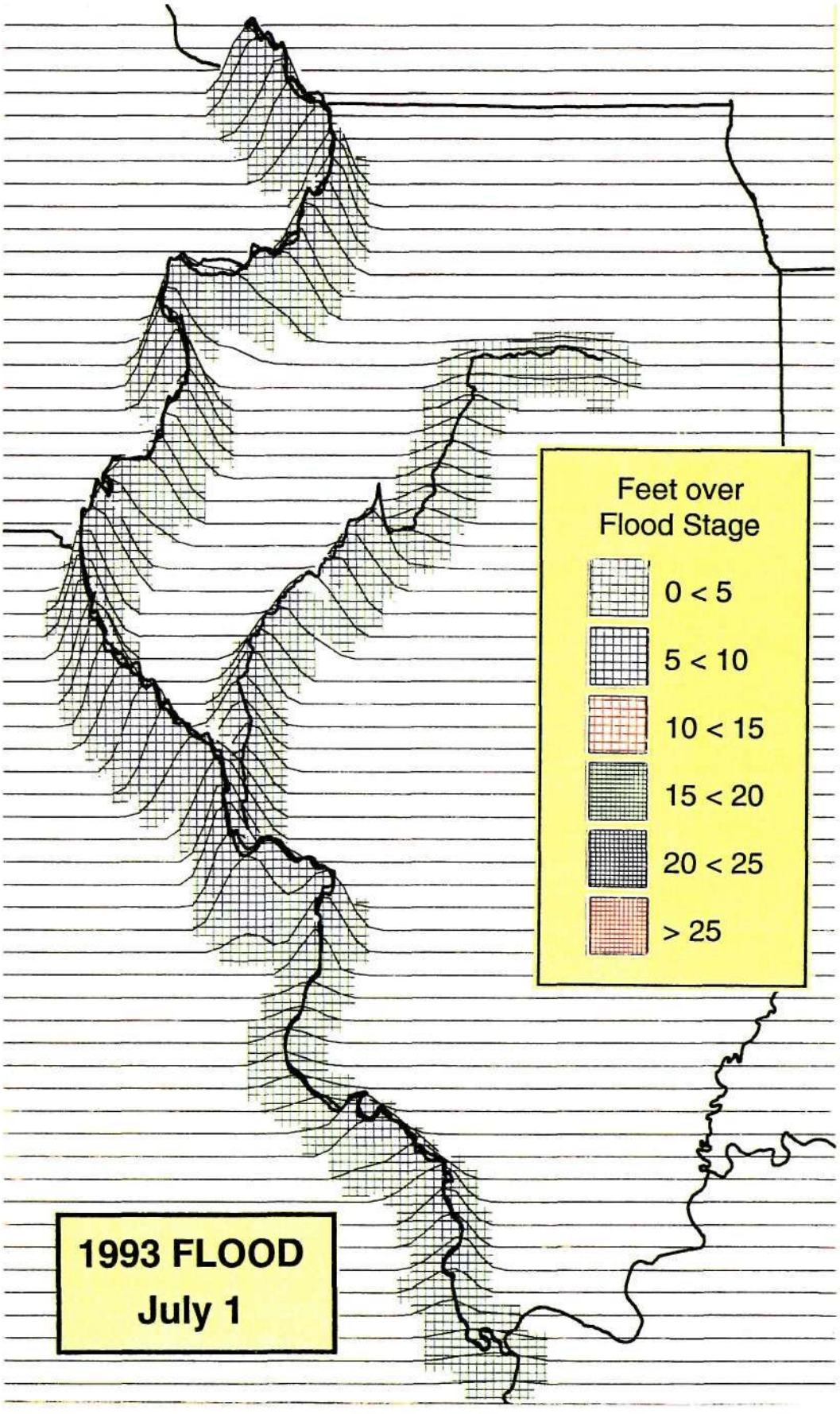


Figure 2. Mississippi River stage in feet over flood stage on July 1, 1993

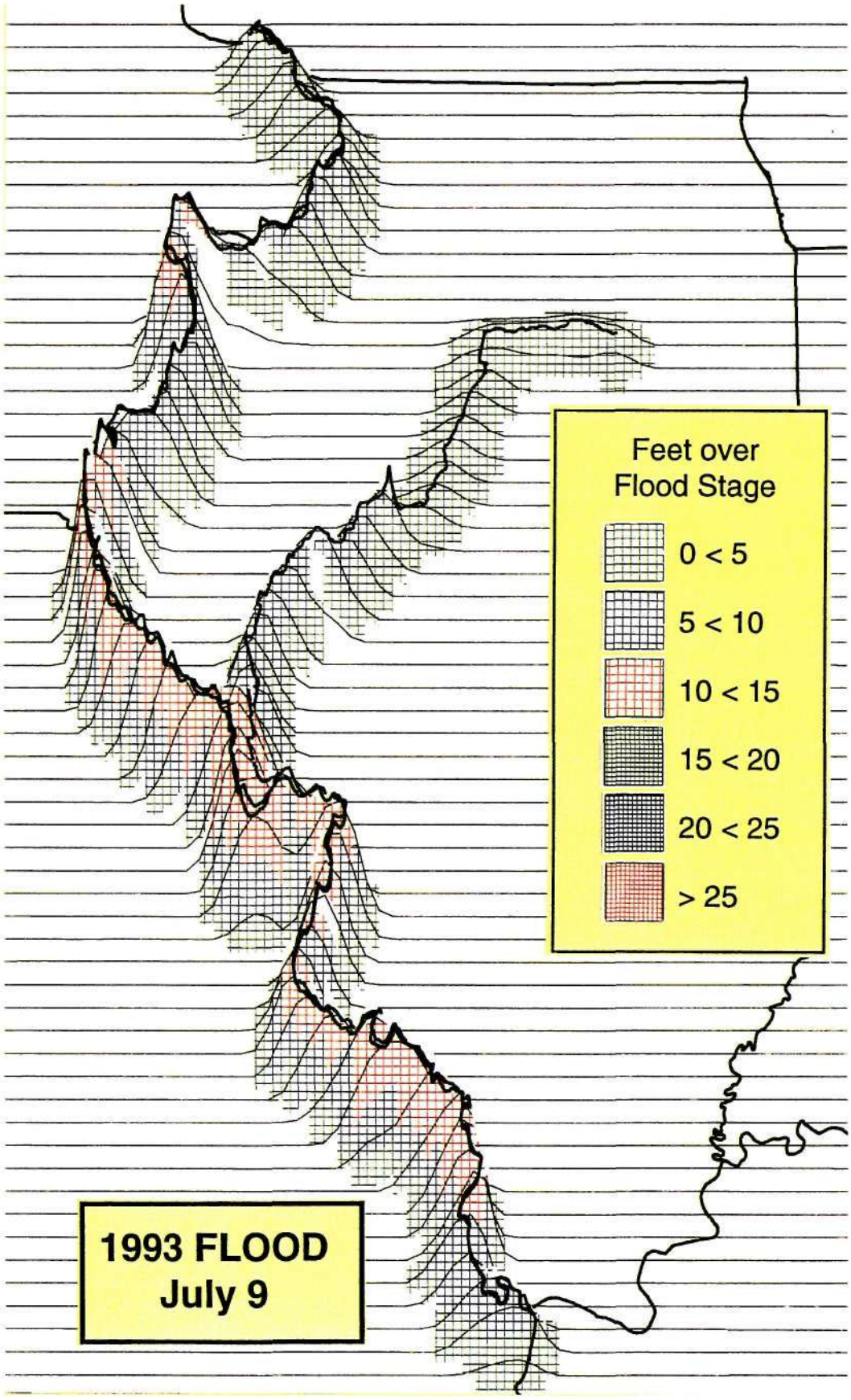


Figure 3. Mississippi River stage in feet over flood stage on July 9, 1993

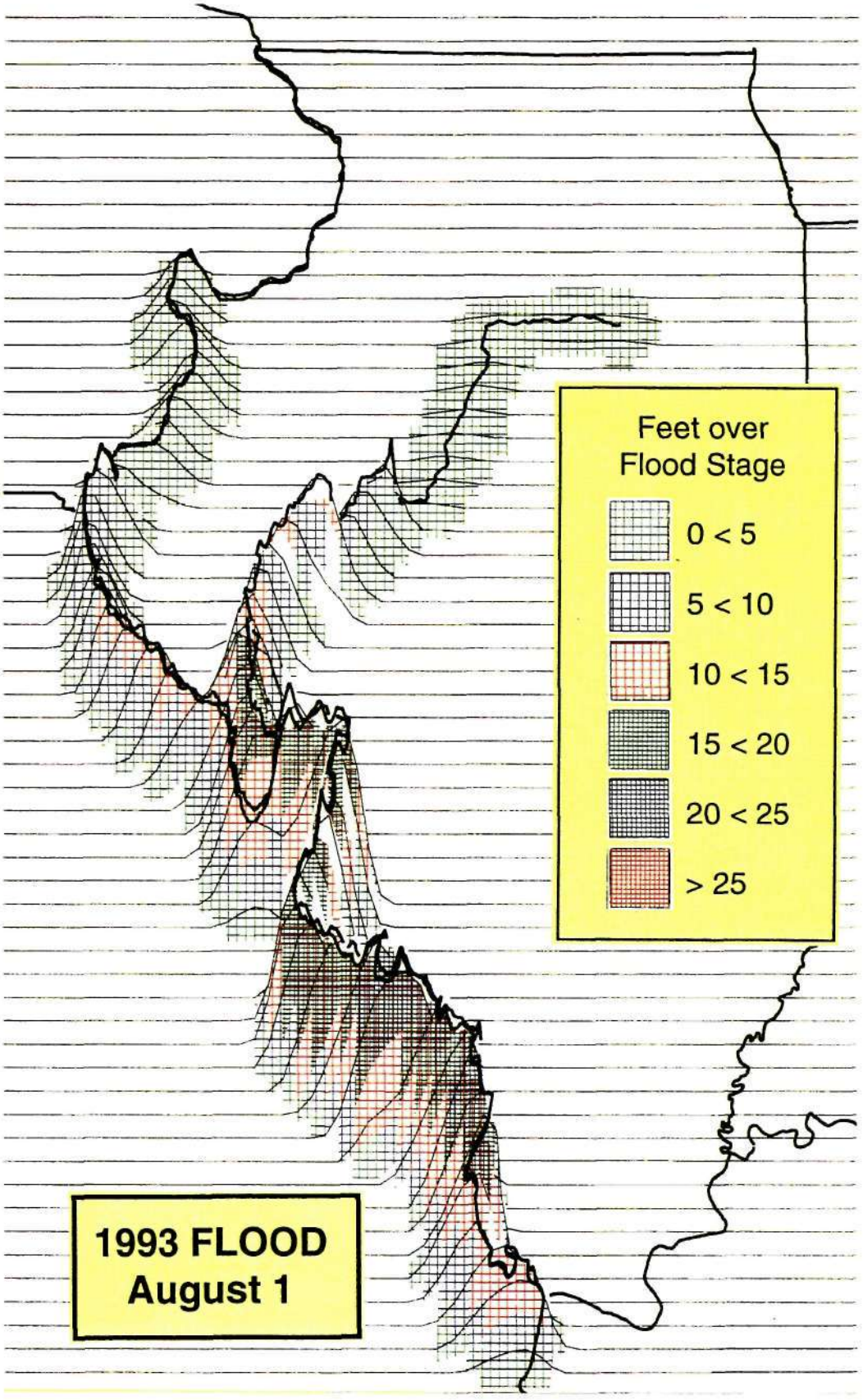


Figure 4. Mississippi River stage in feet over flood stage on August 1,1993

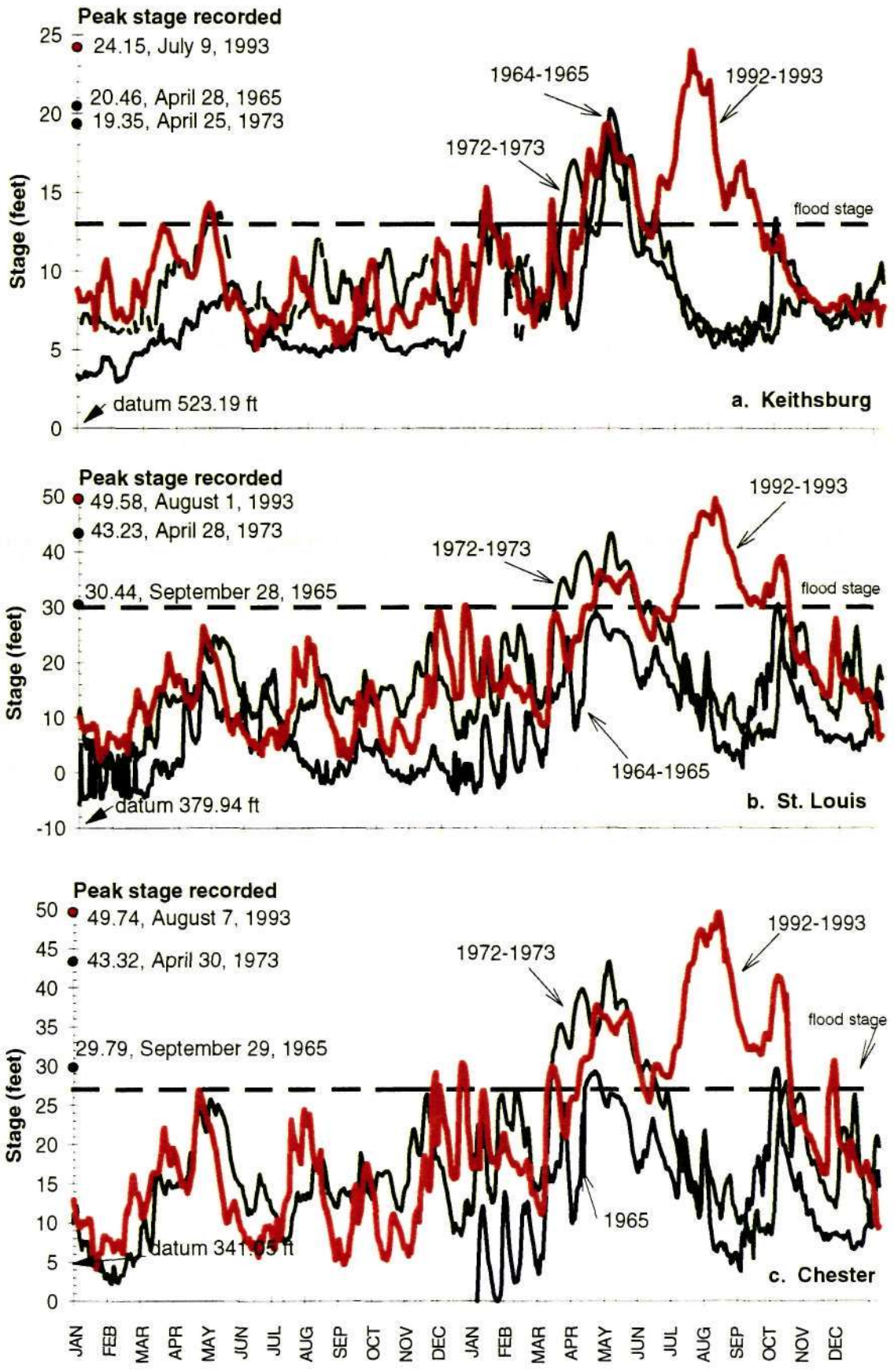


Figure 5. Comparison of Mississippi River stages recorded during record-setting floods

dropping and staying below flood stage by early June. In contrast, the 1993 flood had not yet reached its zenith. The temporary drop in river levels in May was followed by the worst flooding in July.

The plot of river stages recorded at St. Louis (figure 5b) shows that during 1965, the peak stage was only 0.44 feet over flood stage. On average, river levels in 1992 were higher than in 1972, but flooding in April 1973 exceeded the 1993 spring flooding in terms of stage and duration. It was the flooding in July-August 1993 that far exceeded the 1973 record-holding event both in terms of stage and number of days over flood stage.

Plots of river stage at Chester (figure 5c) tend to resemble those recorded at St. Louis; the tributary rivers between these two locations have considerably smaller drainage areas than the Missouri and Illinois Rivers. River stage only briefly exceeded flood stage in 1965. The spring flooding in 1993 was significant, although it did not exceed the stage or days over flood stage experienced in 1973. Again, it was the flood wave in late July, early August that set the new record.

DURATION OF RIVER LEVELS EXCEEDING FLOOD STAGE

The unprecedented peak river levels at stations along the Illinois border between July 1 and August 8, 1993, followed high river levels that exceeded flood stage for the greater part of four months. River levels above flood stage persisted well into fall as illustrated by the plots in figure 5.

The long duration of the flooding is another aspect of the 1993 flood that had not been experienced in this century. Station records show that river levels from Keithsburg to Thebes first spiked above flood stage in March. The river briefly dropped below flood stage only to rise again a few weeks later in April. From the first week of April until mid-September, the river remained almost continuously above flood stage between Keithsburg and Quincy, IL, and into October at stations further downstream. Table 2 shows the number of days that the Mississippi River exceeded flood stage at different stations for the 1993, 1973, and 1965 flood events. The 1993 values in the table were developed on the basis of stages recorded at 6 A.M. for stations above St. Louis, and from stages recorded at 8 A.M. at stations from St. Louis downstream. (Analysis of hourly stage data could

Table 2. Mississippi River Flood, Duration of River Stages Exceeding Flood Stage

Gaging station	*River mile*[1]	*Date first rose above flood stage in 1993*[2]	*Date dropped and stayed below flood stage*[2]	*Total days in period*	*Days> flood stage*	*Percent time over flood stage*	1965 *days> flood stage*	1973 *days> flood stage*	*Gage datum*[3]	*Flood stage (feet)*
Mississippi River										
Dubuque	579.9	4/16	7/27	102	52	51	29[6]	14[6]	585.47	17
Camamche	511.8	4/7	7/31	116	82	71			562.68	16
Muscatine	455.2	4/5	8/4	121	103	85			530.74	16
Keithsburg	427.7	4/3	9/11	162	148	91	38[6]	67[6]	523.19	13
Burlington	403.1	4/3	9/11	162	147	91			511.45	15
Quincy	328.9	4/2	9/18	171	155	91			458.59	17
Hannibal	309.7	3/25	10/1	200	184	92	44[6]	95[6]	449.3	16
Grafton	218.6	3/6	10/11	220	202	92			403.79	18
St. Louis	180.0	4/8	10/8	184	146	79	2	77[6]	379.94	30
Chester[4]	109.9	3/7	10/13	220	195	89	17	97[6]	341.05	26.9
Cape Girardeau[5]	52.1	3/7	10/13	221	193	87			304.65	32
Thebes	43.7	3/8	10/12	219	167	76			300.00	33

Notes:

[1] River mile from mouth.

[2] Data sources: Mississippi River stations: Dubuque to Hannibal, 6 A.M. reading, U.S. Army Corp of Engineers, Rock Island District; Grafton to Thebes, 8 A.M. reading, U.S. Army Corps of Engineers, St. Louis District.

[3] Relative to National Geodetic Verticle Datum, 1929.

[4] Above flood stage 4 days in November.

[5] Above flood stage 6 days in November.

[6] Ranks in top 10 highest flood stages.

show slight differences of a day or so.) Even though the 1993 flood did not set a new peak stage record at Dubuque, the river did exceed flood stage for 52 days during 1993 compared to 29 days in 1965. Along the river reach between Keithsburg and Quincy, river levels were, on average, above flood stage 150 of 165 days from the first week of April to mid-September 1993. The record at Keithsburg shows that the river exceeded flood stage 38 days in 1965 and 67 days in 1973. Downstream of Quincy to Thebes, river levels exceeded flood stage more than 180 days out of approximately 220 days, from March through October 1993. At Hannibal, the river stage exceeded flood stage for 44 days in 1965, 95 days in 1973, and 184 days in 1993. Similar statistics can be observed in the record of stages at Chester, where the river exceeded flood stage 97 days in 1973 and 195 days in 1993.

COMPARISON TO PREDICTED FLOOD STAGES

For any flood event, the return interval-such as 100-year or 50-year-is the reciprocal of the probability of the event's occurrence in any given year. For example, a 100-year flood has a one percent chance of occurrence in any given year. Common practice in flood prediction is to statistically analyze the discharge records at gaging stations and predict the discharge that corresponds to selected probabilities of occurrence. A hydraulic analysis of the river using these predicted discharges yields estimates of the expected river levels for the given discharge. The elevations simulated for a 100-year event are used to delineate the floodplain boundaries used in administering the National Flood Insurance Program, Illinois floodplain management and regulation, and local floodplain management ordinances. River stages estimated in this manner are used to evaluate the maximum flood events that levee systems are expected to withstand before being overtopped.

The 1979 report *Upper Mississippi River Water Surface Profiles River Mile 0.0 to River Mile 847.5,* prepared by the U.S. Army Corps of Engineers (USACOE), Rock Island, St. Paul, and St. Louis Districts, is cited in the Flood Insurance Study for **every** Illinois county bordering the Mississippi River as the source of 100-year flood elevations. Floodplain maps prepared for each county by the Federal Emergency Management

Agency (FEMA) show the areas expected to be inundated during a 100-year event. A comparison of the river stages recorded during 1993 and those simulated for events with various return intervals provides insight to expectations and the level of preparedness for the 1993 event.

In 1993, river levels predicted for a 10-year flood event were exceeded at stations from Dubuque to Thebes, while levels predicted for a 100-year event were exceeded along the reach of the river from Keithsburg to Chester. In July 1993, the river exceeded levels predicted for a 100-year event for 13 days at Keithsburg, 30 days at Hannibal, and 6 days at St. Louis. Station records show that the predicted 500-year flood level was exceeded for 2 days at Quincy and 12 days at Hannibal that July.

Figures 6 through 10 illustrate the extent and severity of the flooding from April through September 1993. These figures were developed by tabulating the number of days that the elevation predicted for various flood events was exceeded at each gage. In the right-hand portion of each figure is a color-coded legend of the different-frequency events determined from profiles of the Mississippi River developed by the USACOE (1979). The legend on the left side of each figure shows the number of days that levels exceeded the threshold stage during the month. The width of each color shown along the river corresponds to the number of days that the threshold level was equaled or exceeded.

Flooding was widespread in April (figure 6), with stages exceeding the 10-year flood (ten percent chance of exceedence) from Muscatine to St. Louis. During May and June, the river level dropped below flood stage from Dubuque to Comanche and below St. Louis; however, the predicted 50-year flood stage (two percent chance of exceedence) was briefly exceeded in the Burlington Area (figure 7). Along the Illinois border, the Mississippi River was above flood stage for the entire month of July (figure 8). The predicted 100-year event (one percent chance of exceedence) was exceeded from Keithsburg to St. Louis, and during July 1993 the river rose above elevations predicted for a 500-year event (0.2 percent chance of exceedence) in the Quincy-Hannibal area. Northern Illinois saw some relief from flooding in August (figure 9), but the river below Hannibal was still well above flood stage. The river below Hannibal continued to be above flood stage throughout September 1993 (figure 10), while below St. Louis, river levels over flood stage did not abate until October.

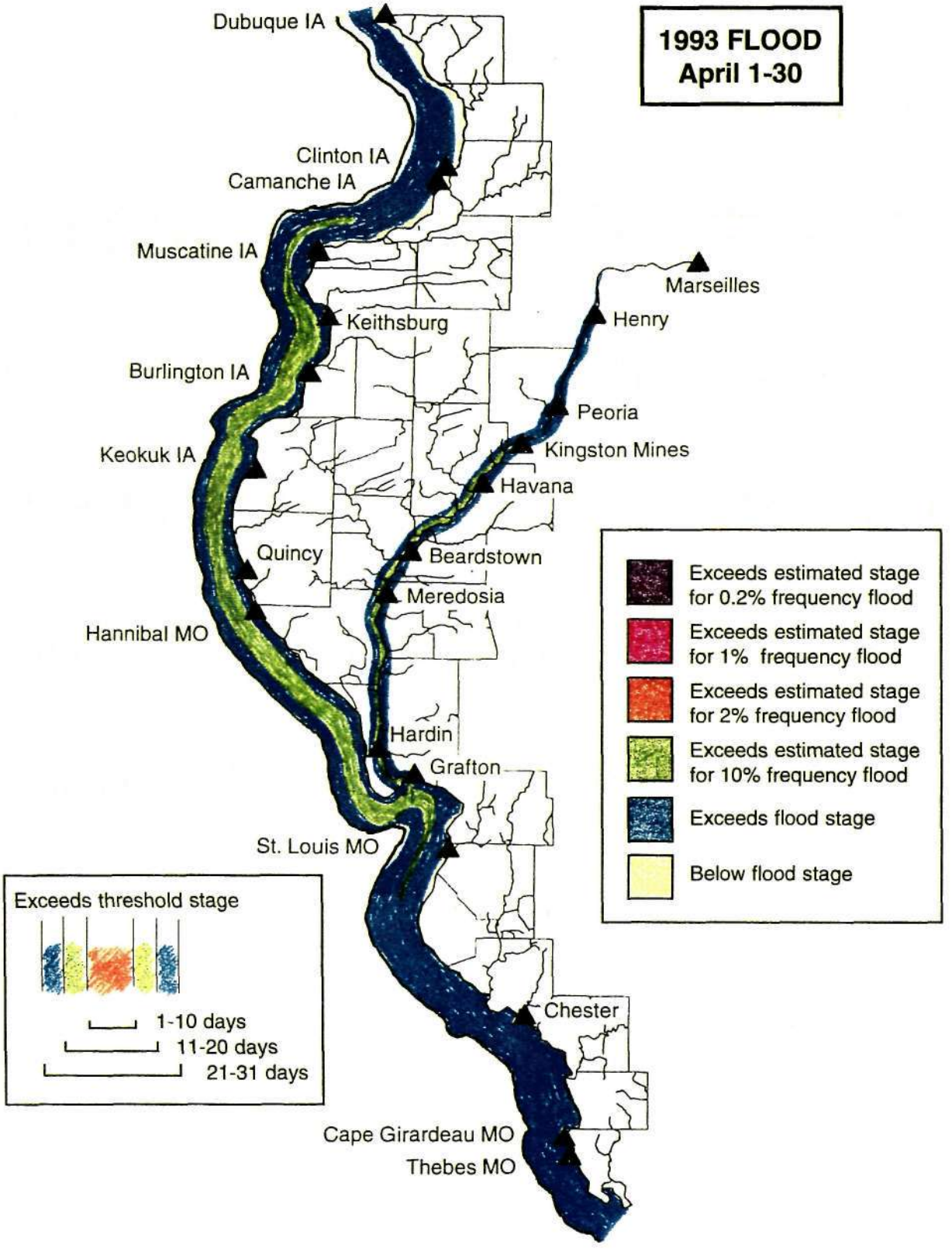


Figure 6. 1993 Mississippi River flood, days exceeding threshold elevations, April 1-30

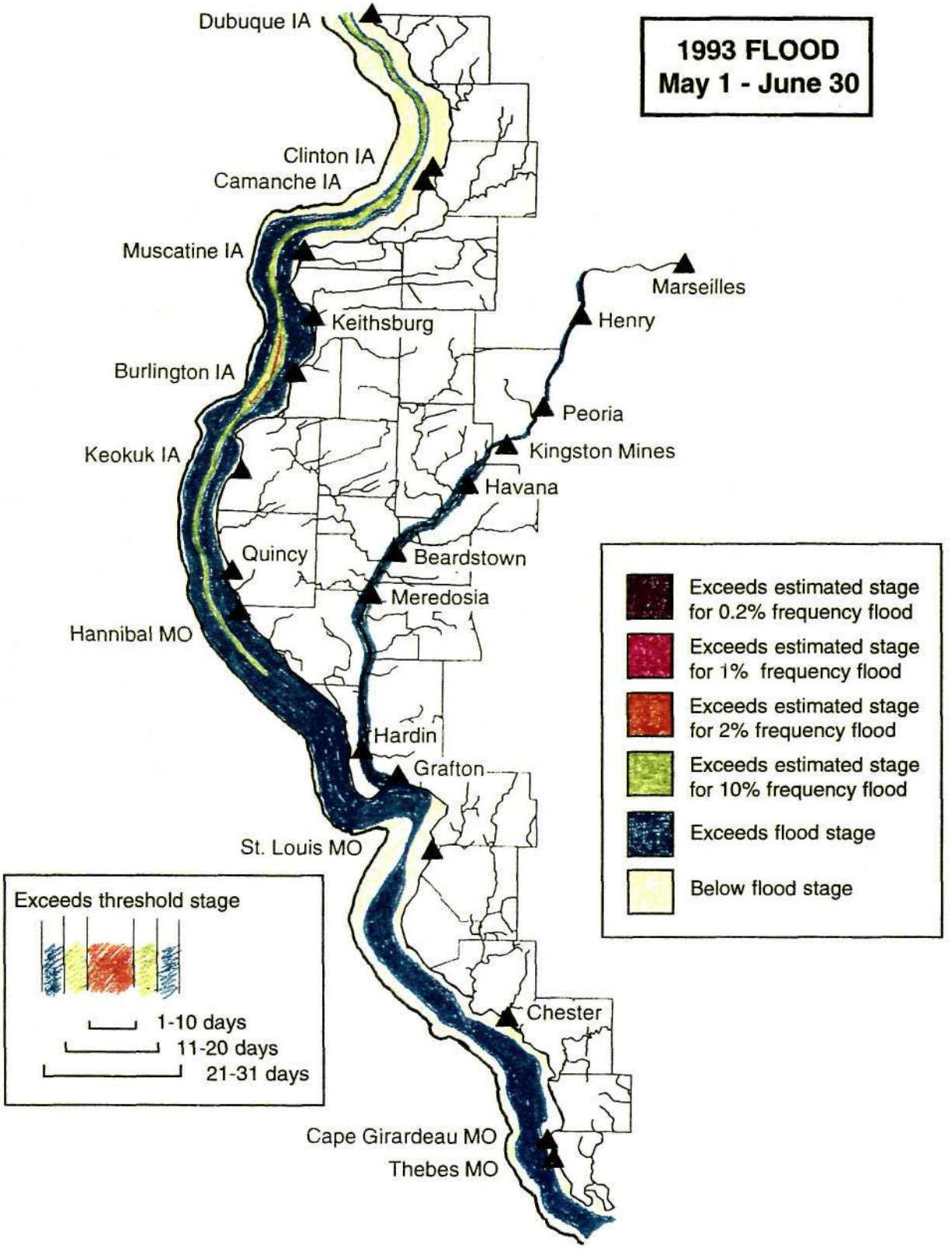


Figure 7. 1993 Mississippi River flood, days exceeding threshold elevations, May 1-June 30

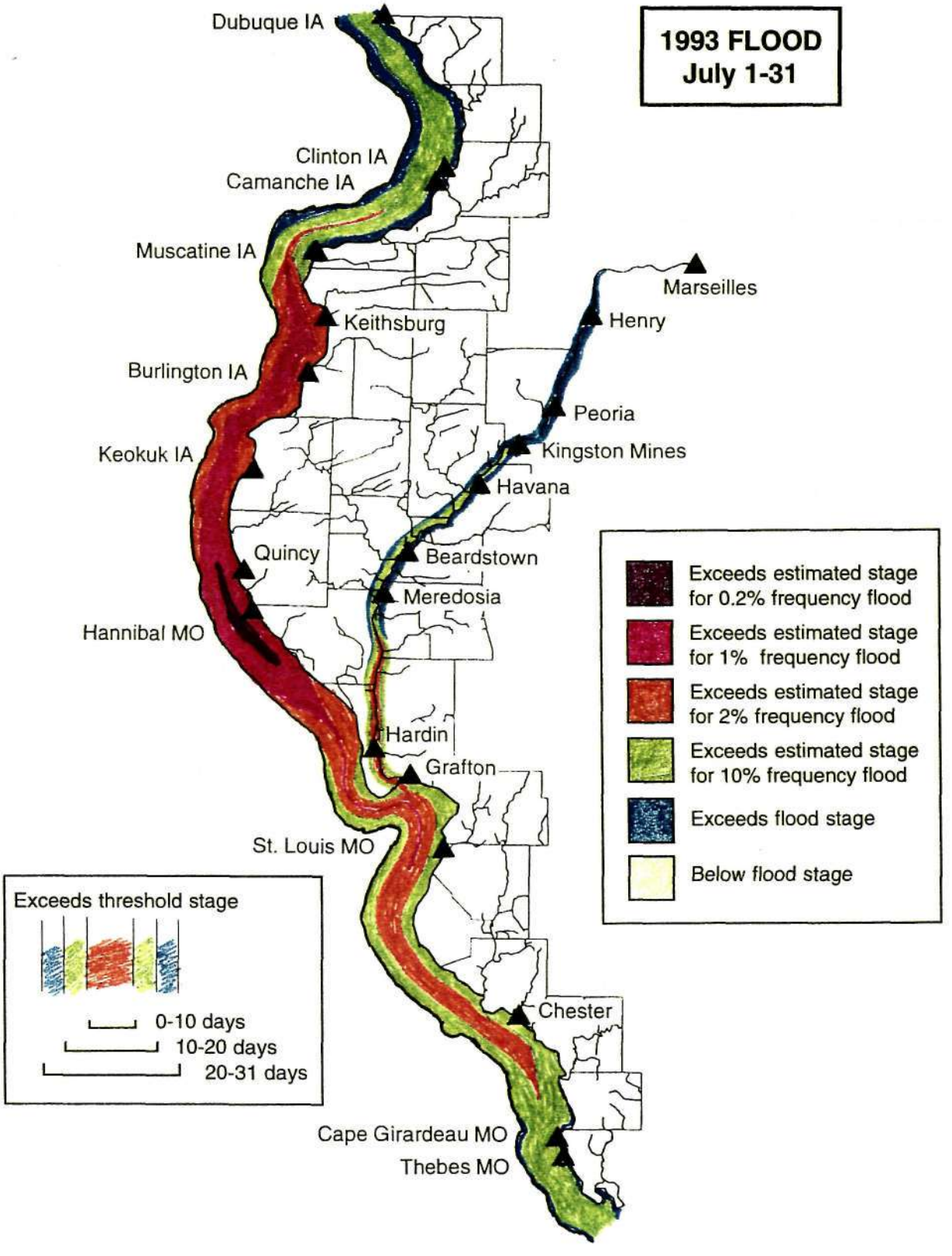


Figure 8. 1993 Mississippi River flood, days exceeding threshold elevations, July 1-31

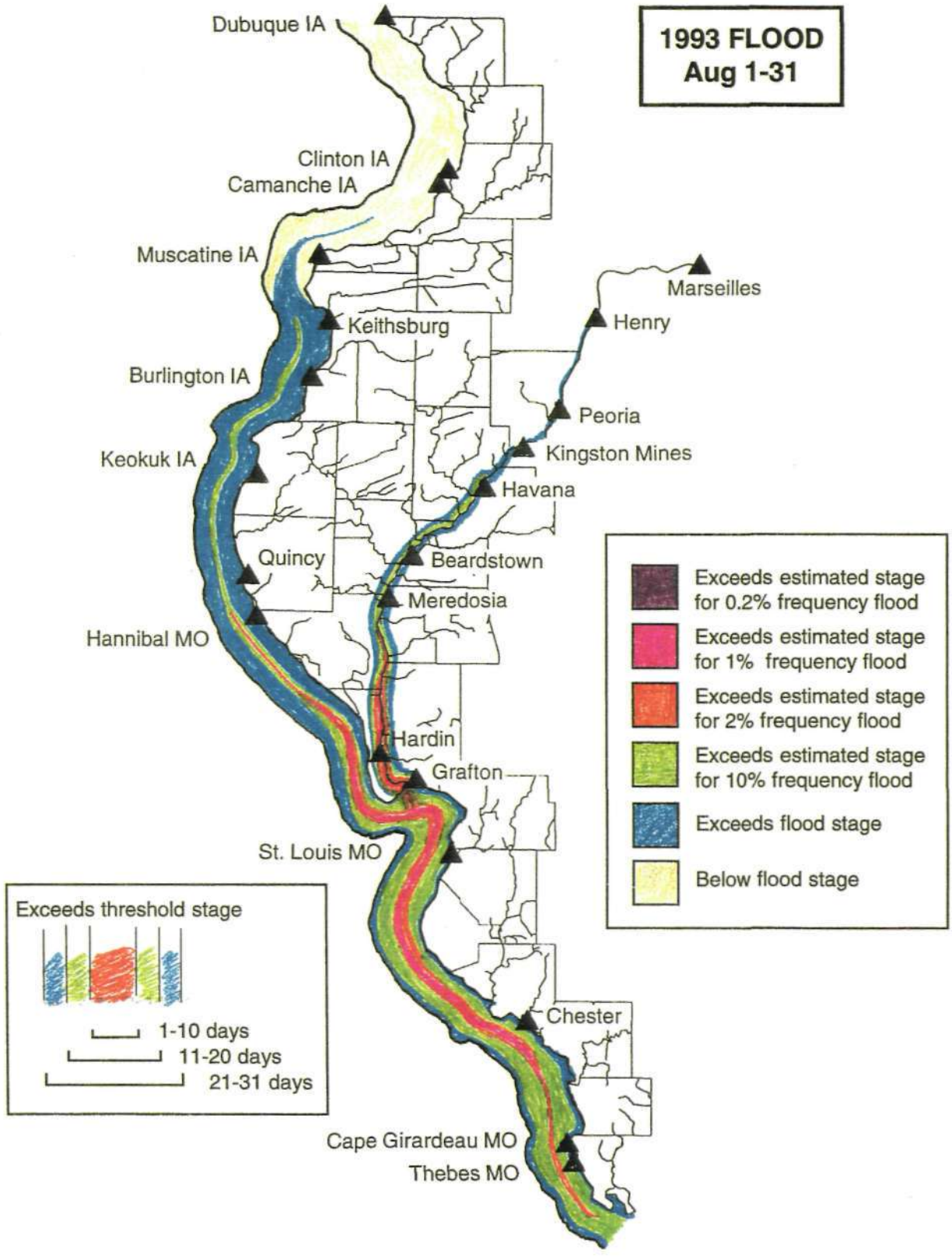


Figure 9. 1993 Mississippi River flood, days exceeding threshold elevations, August 1-31

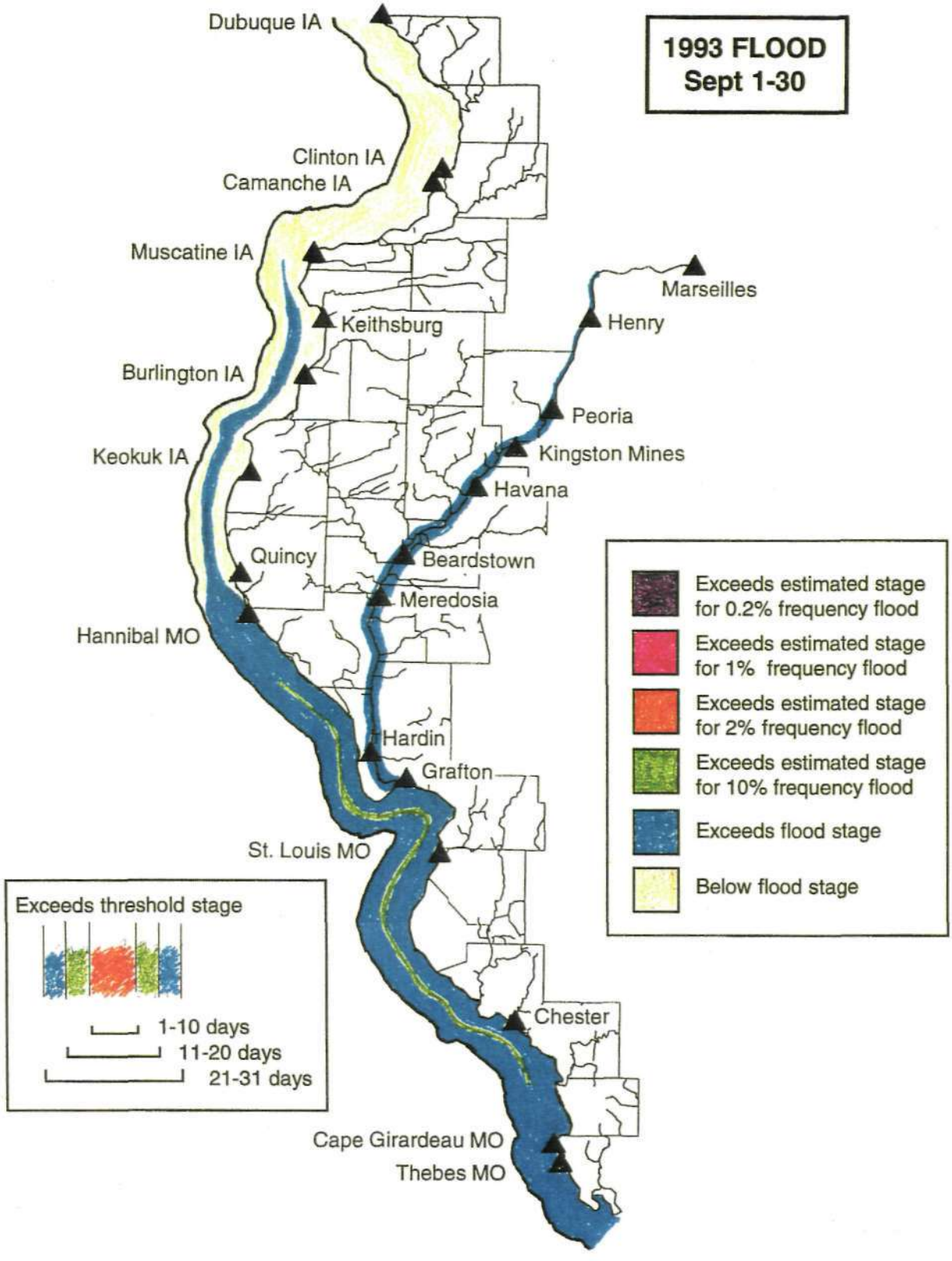


Figure 10. 1993 Mississippi River flood, days exceeding threshold elevations, September 1-30

LEVEE FAILURES

The duration and magnitude of the flood contributed to the ultimate failure of multiple levees along the Mississippi and its tributaries. Numerous levees failed during July and August 1993 in both Illinois and Missouri. The immediate impact of levee failures is recorded in sudden drops in river stage, but river levels quickly rose again after the levee districts were flooded.

The river stage recorded at the Quincy and Hannibal stations exceeded the estimated flood stage for a 500-year event (0.2 percent chance of exceedence), and for the entire month of July they were higher than the estimated elevation of the 100-year event (one percent chance of exceedence). It was in this area that successive levee failures occurred in July. The first levee break there occurred on July 7, with the failure of the Pope Creek levee near Keithsburg in Illinois and levees in the Union Township Levee District in Missouri. These failures were the first in four consecutive days of levee failures, as levees were breached from July 8 through 10. More levees failed on July 12, 13, 16, and 25. Figure 1 shows levee locations, and figure 11 shows the river stages recorded at 6-hour intervals at the Keithsburg, Quincy, and Hannibal stations. These graphs document the river response to the levee failures. The gage at Keithsburg is located above the levee failures. The stages recorded at this station serve as a baseline showing the gradual changes in river levels unaffected by levee failures.

Table 3 provides information on the Illinois and Missouri levees that failed in July 1993 along the reach between Keithsburg and Hannibal. The number of acres flooded is shown, as well as the response of the river level recorded at the Quincy and Hannibal gages. On July 7, more than 6,000 acres were flooded when the Keithsburg and Union Township levees failed. At Quincy the stage dropped more than 0.5 feet in 6 hours, but 12 hours later it had risen more than 1 foot. On July 8, another 30,000 acres were flooded upstream of Quincy. The station stage again dropped about 0.5 feet, rebounding more than 1 foot in 24 hours. Between July 9 and 10, nearly 49,000 more acres were flooded. The river stage dropped more than 2 feet at Quincy in 30 hours, but in another 30 hours rose more than 2.6 feet from the minimum level reached. By July 13, the stage had risen to a new high, but dropped almost 2 feet in 12 hours when another 20,000 acres flooded.

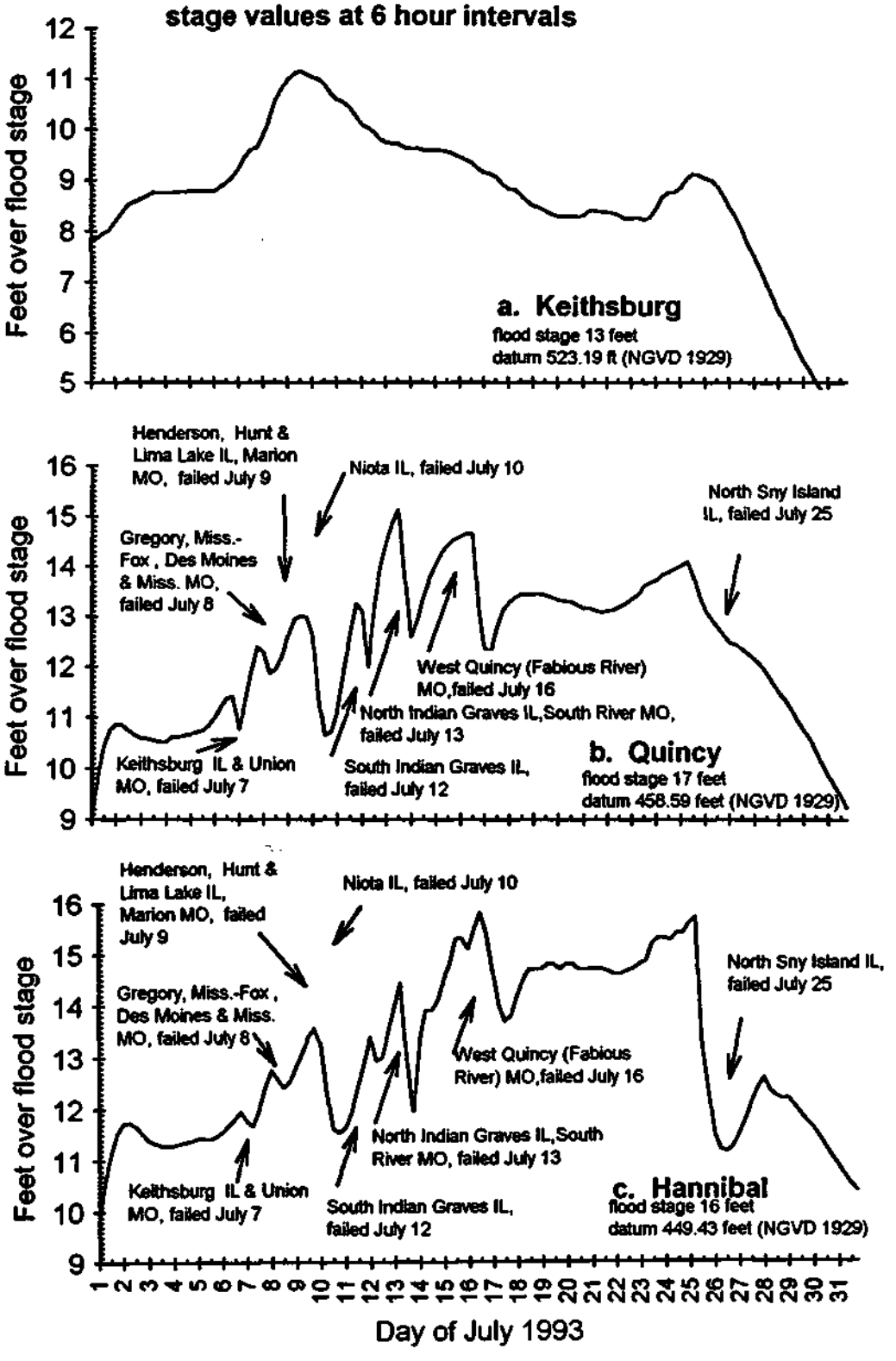


Figure 11. Effect of levee failures on Mississippi River stage, July 1-31, 1993

Table 3. Mississippi River Stage Response at Quincy and Hannibal after 1993 Levee Failures

				Quincy				*Hannibal*			
Date	*Failed Levees, district name*		*Acres flooded*	*Day*	*Time*	*Stage (feet)*	*Difference (feet)*	*Day*	*Time*	*Stage (feet)*	*Difference (feet)*
7/7	Keithsburg, IL		1,260	6	24:00	28.41		6	24:00	27.95	
	Union Township, MO		5,037	7	6:00	27.78	-0.63	7	6:00	27.77	-0.18
		Sum	**6,297**	7	12:00	28.29	0.51	7	12:00	27.68	-0.09
				7	18:00	28.89	1.11	7	18:00	28.00	0.23
				7	24:00	29.39	1.10	7	24:00	28.42	0.74
7/8	Gregory, MO		8,093	7	24:00	29.39		7	24:00	28.42	
	Mississippi-Fox, MO		11,500	8	6:00	29.29	-0.10	8	6:00	28.75	0.33
	DeMoines & Mississippi, MO		10,989	8	12:00	28.87	-0.42	8	12:00	28.56	-0.19
		Sum	**30,582**	8	18:00	28.96	0.09	8	18:00	28.41	-0.15
				8	24:00	29.22	0.26	8	24:00	28.53	0.12
				9	24:00	29.98	0.76	9	24:00	29.57	1.04
7/9	Henderson, IL		15,000	9	24:00	29.98		9	24:00	29.57	
	Hunt and Lima Lake, IL		28,469	10	6:00	29.65	-0.33	10	6:00	29.26	-0.31
	Marion, MO		3,995	10	12:00	28.36	-1.29	10	12:00	28.32	-0.94
7/10	Niota, IL		1,000	10	18:00	27.66	-0.70	10	18:00	27.61	-0.71
		Sum	**48,464**	10	24:00	27.72	0.06	10	24:00	27.53	-0.08
				11	24:00	30.26	2.54	11	24:00	28.92	1.39
7/12	South Indian Graves, IL		**8,000**	12	6:00	30.11		12	6:00	29.40	
				12	12:00	29.00	-1.11	12	12:00	28.94	-0.46
7/13	North Indian Graves, IL		10,000	13	12:00	31.86		13	12:00	30.44	
	South River, MO		10,300	13	24:00	30.71	-1.15	13	24:00	27.90	-2.54
		Sum	**20,300**	14	12:00	29.94	-0.77	14	12:00	29.90	2.00
				14	24:00	30.77	0.83	14	24:00	30.10	0.20
7/16	West Quincy (Fabious),MO		**14,264**	16	12:00	31.65		16	12:00	31.50	
				16	24:00	30.20	-1.45	16	24:00	31.40	-0.10
				17	12:00	29.28	-0.92	17	12:00	30.00	-1.40
				17	24:00	30.13	0.85	17	24:00	29.80	-0.20
				18	12:00	30.39	0.26	18	12:00	30.50	0.70
7/25	North Sny Island, IL		**44,000**	25	12:00	31.09		25	12:00	31.70	
				26	12:00	29.94	-1.15	26	12:00	27.20	-4.5
				27	12:00	29.44	-0.5	27	12:00	27.80	0.6
				28	12:00	29.02	-0.42	28	12:00	28.35	0.55
				29	12:00	28.36	-0.66	29	12:00	28.07	-0.28

Total Acres 171,907

At Hannibal, approximately 18 miles downstream of Quincy, a similar pattern of drops and rebounds in river stage was recorded. On July 9, when the Henderson, Hunt, and Lima Lake levees failed in Illinois and the Marion levee failed in Missouri, the stage dropped 2 feet in 24 hours, but rose 1.4 feet within the next 24 hours. The major difference between the stages recorded at Quincy and Hannibal occurred on July 25, when the Sny Island levee located downstream of Quincy and upstream of Hannibal failed, flooding 44,000 acres. Plots of the Keithsburg and Quincy stages (figure 11a and b) show that the river stages were dropping at the end of July. However, on July 25, the stage at Hannibal dropped 4.5 feet in 24 hours, rebounding more than 1 foot within the next 48 hours (figure 5c).

The failure of levees created a temporary decline in river levels, but once the available storage was occupied, river levels returned to near previous levels. Later visual inspections of the flooded levee districts revealed blue water and quiescent conditions behind the failed levees, as compared to the churning silt-brown water that marked flowing water in the main channel.

The Mississippi River levees protecting the St. Louis metropolitan area, Rockford-Moline area, and Quincy were designed to withstand a 500-year flood event. These levees did not fail, although some displacement of a section of the St. Louis levee did occur. Unlike levees protecting metropolitan areas, some agricultural levees were expected to fail during a significant flood event. The USACOE report (1979) notes that predicted river flood stages below St. Louis are approximate: "Agricultural levees (miles 48-167) were designed to protect against the 50-year event. Profiles for events exceeding the 50-year flood would be uncertain depending on the number and severity of levee breaches throughout the system."

The anticipated extent of flooding during a 100-year event is documented in Flood Insurance Rate Maps (FIRMs) and Flood Hazard Boundary Maps (FHBMs) prepared by the FEMA. The maps prepared for each Illinois county bordering the Mississippi River show agricultural levee districts along the Mississippi within the 100-year floodplain. As noted earlier, FEMA maps reflect the river elevations predicted in the USACOE 1979 report.

Table 4 lists the Illinois counties bordering the Mississippi and lower Illinois Rivers and indicates whether or not they participate in the National Flood Insurance Program. Participation in the program is optional. The table also indicates whether the FEMA floodplain maps show the failure of levees during a 100-year event and notes the levee districts that were flooded during 1993.

Bluffs bordering the Mississippi River along the boundaries of some counties, such as JoDavies and Jersey, make levees unnecessary. Counties such as Rock Island, St. Clair, and Monroe have large urban development along the river that is protected by levee systems. Only those levees bordering the Mississippi River and the lower Illinois River, not their tributaries, were considered in this report. A comparison of the predicted performance of levee systems and actual levee failures suggests that the Mississippi River was expected to inundate a large land area during an event with a one percent chance of occurrence in any given year (i.e., a 100-year event).

GIS ANALYSIS AND APPLICATIONS

Overview

GIS is a combination of specialty computer equipment, software, and processing techniques. While its purposes are many, it is generally used to store and process geographic locations of the various features one would find on a map, such as roads, rivers, and political boundaries. After map features are stored in a computer, they can be updated as needed or combined with other map features to produce paper maps of various scales. Information available at different scales can be integrated.

A truly powerful aspect of GIS is the ability to associate descriptive data with location information for a map feature. For example, descriptive attributes such as river mile, discharge, or stage can be linked to the river feature at specified locations (points). Attributes such as name or length can be linked to a segment of the river. Such information can be rapidly recalled from the GIS database and manipulated, analyzed, and printed out as a report. The attribute information, such as the discharge value at a gaging station location, can also be displayed on a map, and attributes may be represented symbolically; for instance, by varying line thickness on the basis of stream order.

Table 4. Illinois Counties Impacted by the 1993 Flooding on the Mississippi and Illinois Rivers

County	*Participates in NFIP[1]*	*Current floodplain map[2]*	*Map date*	*FEMA map status of levee districts (100-year floodplain)*	*1993 Levee failures, district names*
Mississippi River levees					
Jo Daviess	yes	FIRM	1/18/84	No levees shown on maps	
Carroll	yes	FIRM	12/15/83	Inundated during 100-year event	
Whiteside	yes	FIRM	2/19/86	Inundated during 100-year event	
Rock Island	yes	FIRM	2/4/87	Protected urban areas not flooded	
Mercer	yes	FIRM	1/3/86	Inundated during 100-year event	Keithsburg (Pope Creek)
Henderson	yes	FIRM	3/4/86	Inundated during 100-year event	Henderson 1 Henderson 2 Henderson 3
Hancock	yes	FIRM	4/30/86	Inundated, where levees are shown	Niota Hunt
Adams	yes	FIRM	11/15/85	Inundated during 100-year event	Lima Lake Indian Graves
Pike	yes	FIRM	1/3/86	Inundated during 100-year event	Sny Island
Calhoun	yes	FIRM	2/1/84	Inundated during 100-year event	
Jersey	yes	FIRM	2/1/84	No Mississippi River levees indicated on maps	See Illinois River levees
Madison	yes	FIRM	4/15/82	Protected urban areas not flooded	
St. Clair	yes	FIRM	8/5/85	Protected urban areas not flooded	
Monroe	yes	FIRM	4/5/88	Inundated during 100-year event	Columbia Harrisonville & Ivy Moredock & Ivy Fort Chartres & Ivy
Randolph	yes	FIRM	6/3/86	Inundated during 100-year event	Stringtown Prairie du Rocher & Modoc Kaskaskia Island
Jackson	yes	FHBM	6/3/79	Inundated during 100-year event	
Union	yes	FIRM	2/19/86	Inundated during 100-year event	
Alexander	no	FHBM	11/19/87	Inundated during 100-year event	Len Small
Illinois River levees					
Jersey	yes	FIRM	2/1/84	Inundated during 100-year event	Nutwood
Greene	yes	FIRM	8/5/85	Inundated during 100-year event	Eldred Hartwell Hillview

Notes:

[1]NFIP = National Flood Insurance Program. Participation status current as of January 1994.

[2] Current 100-year floodplain map prepared by FEMA. FIRM = Flood Insurance Rate Map, FHBM = Flood Hazard Boundary Map

ISWS researchers have actively used GIS technology to explore hydrology-related issues for almost two decades. Given that the technology is relatively new, the ISWS is considered something of an expert in the field. In the course of performing various projects, the ISWS and other agencies, such as the Illinois State Geological Survey (ISGS), Illinois Natural History Survey, and Hazardous Waste Research and Information Center, have built a massive collection of GIS data sets. Much of the ISWS research has been funded by the Lands Unsuitable for Mining Project (LUMP). This wealth of pre-existing GIS data for Illinois allows for increasing possibilities of advanced analyses.

Three-dimensional Mapping of Flood Peaks

One way of seeing the progression of the 1993 flood along the Mississippi and Illinois Rivers is to translate numerical data into maps. Stages recorded at gaging stations were converted to feet over flood stage and then transferred into a three-dimensional surface model representing the Mississippi and Illinois Rivers as "mountain ranges" whose height and steepness correspond to the feet over flood stage along the rivers. Three specific dates near the peak of the flooding were selected for map production. The intensity of the passing flood wave is illustrated in figures 2, 3, and 4, which depict the state of Illinois boundary as a thick black line, and the location of the Illinois and Mississippi Rivers within and along the state as thick blue lines. Thin black lines are applied to facilitate viewing of the three-dimensional surface, and the cross hatching corresponds to the level above flood stage. The cross-hatching colors cycle through green, red, and blue; loose hatching is used for the three lower levels and denser cross hatching for the higher levels. The cross hatching, river course, and state boundary have all been draped over the three-dimensional surface to give it a "mountainous" appearance. Steeper areas represent higher river levels compared to flood stage. Viewing the figures in succession shows a "ripple" of these high flood stages moving southward along the rivers on July 1, July 9, and August 1 (figures 2, 3, and 4, respectively).

Map Composition

The first step in creating the three-dimensional plots (figures 2, 3, and 4) was to collect the necessary map components including the state boundary, the Mississippi and Illinois Rivers, and the locations of the gaging stations. Each of these components is a resident database in the GIS. The next step was to assign to the map features the value of the attributes to be mapped, in this case feet over flood stage measured on each date at 15 gaging stations: 11 along the Mississippi River-Dubuque, Commanche, Keithsburg, Burlington, Quincy, Hannibal, Grafton, St. Louis, Chester, Cape Girardeau, and Thebes- and four along the Illinois River-Henry, Havana, Beardstown, and Hardin. The third step was to transfer the values from these stations to a GIS data layer of the rivers. The values were assigned to stream segments both upstream and downstream of each station to an approximate middle point between it and the next gaging station. The gage values for each date were added to the same river's data layer and stored as separate fields titled with the respective date.

The location and feet-over-flood-stage value of the river segment were made into a three-dimensional model, with the feet over flood stage simulating an elevation at the location of the rivers. All locations at least ten miles from the rivers were assigned zero as an elevation. The ten-mile zone was determined using the GIS buffering utility. The three-dimensional model used is referred to as a Triangulated Irregular Network (TIN), because it uses a triangulation method to interpolate elevation values between locations of known elevation. Elevation values within the ten-mile zone surrounding the river were interpolated, and the result is manifested visually as inclines of varying degrees sloping away from the rivers, which define the ridge. The elevation values were multiplied by ten in order to further exaggerate the differences between the river location and areas away from the river.

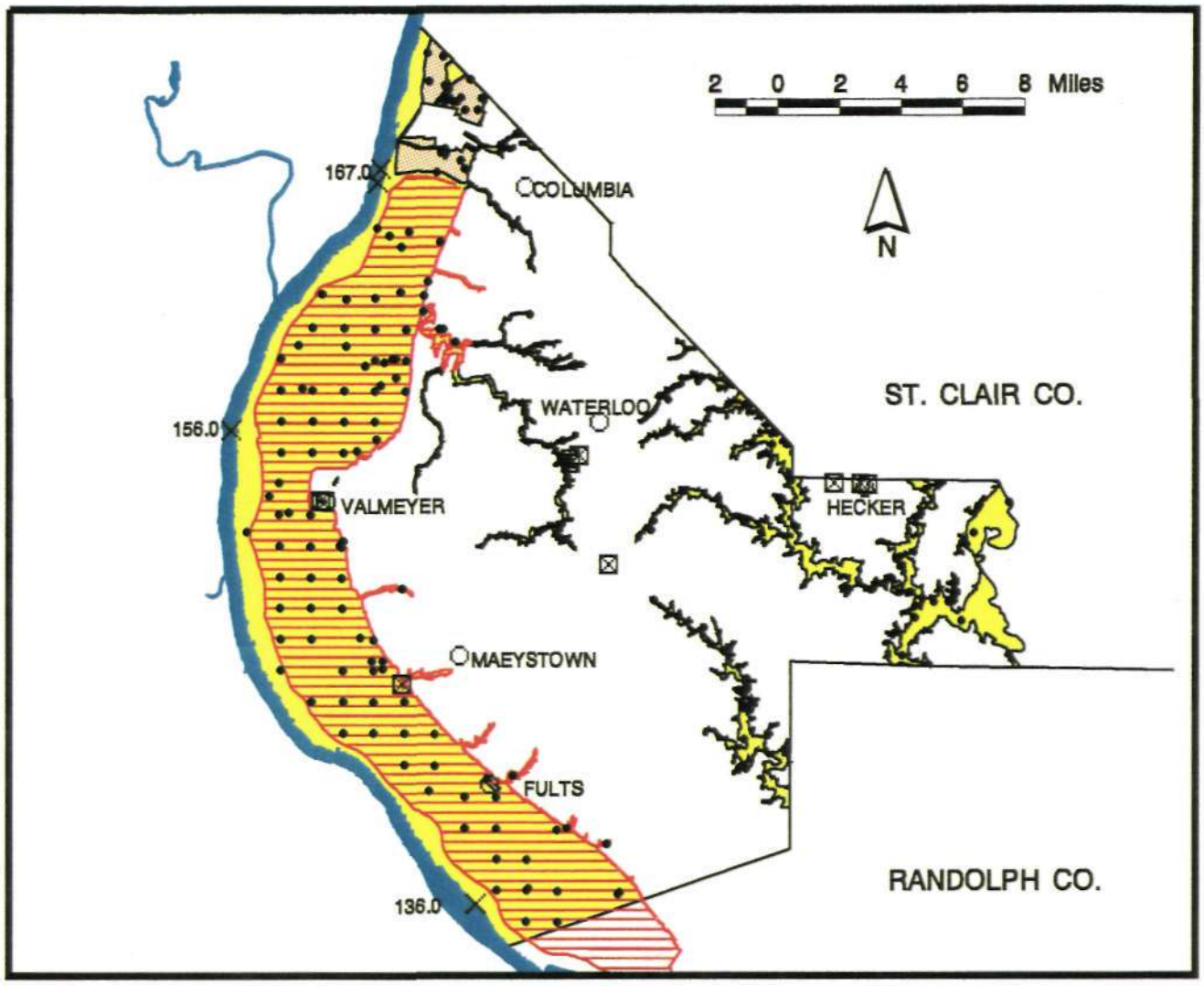
Color cross hatching was added to delineate selected ranges of river levels over flood stage. The legend accompanying figures 2, 3, and 4 lists the ranges of values associated with each color-coded hatched area. Preparing such symbology requires the generation of contour lines from the TIN. A GIS utility automatically interpolated the location of contour lines at 5-foot intervals. The areas between the contours were

assigned the appropriate color symbol, which, if not displayed three-dimensionally, would have the appearance of colored concentric circles of varying width surrounding the river, similar to the circles in figures 7, 8, 9, and 10. These shaded areas were draped over the thin black lines of the "mountain ridge." The 5-foot contour lines used to create the shaded areas were not included in the figure for aesthetic reasons. The result is a series of striking figures that allow a unique view of gaging station data often displayed merely as graphs or lists of numbers.

Geographical Identification of Areas Impacted by Flooding

Thousands of acres of land along hundreds of miles of shoreline were impacted by the flooding in 1993. In the aftermath of the flood, one task was to evaluate the effect of the flood on privately owned wells. Through a joint effort with the ISGS, customized maps were prepared of each Illinois county bordering the Mississippi River. The project was performed for and partially funded by the Illinois Department of Public Health. Through the capabilities of GIS technology and the massive historical databases developed by the ISWS and ISGS, 41 detailed flood-impact maps were created in eight weeks.

The project directive was to identify private wells within the Mississippi River floodplain so that water samples could be collected for analyses. The critical initial step was to quickly identify the well locations so that the sampling program could commence. GIS technology made it possible to integrate physically based databases into a map format that could be used by field investigators. The mapping process could not have been accomplished without the extensive databases of well locations developed by the Water and Geological Surveys, the Illinois 100-year floodplain database digitized by the ISWS from National Flood Insurance Program Maps (FIRMs and FHBMs), and the approximate inundated areas digitized from various sources by the ISGS. The private well and floodplain maps developed for Monroe County are shown in figure 12. GIS data management capabilities were employed to tabulate the number of water wells in flooded districts, floodplains, and total number of wells in the figure.



LEGEND

- Public Water Wells
- Private Water Wells
- Towns
- River Mileage
- Flooded Levee 1993
- Mississippi River
- County Boundaries

Flood Zone

- 500 Year
- 100 Year

Of 2031 recorded private wells in Monroe County, 358 occur within a 100 or 500 year floodzone, and 245 occur within a flooded levee district in 1993.

Figure 12. Monroe County flooded water wells

SUMMARY

River stages are a significant measure of the magnitude of the 1993 flood. A comparison of the stages recorded during the flood and stages predicted for floods with various return intervals demonstrates that the 1993 flood far exceeded the levels expected of a 100-year event. Review of the floodplain maps published for the National Flood Insurance Program shows that many levee districts and communities were expected to be inundated during an event with a one percent chance of occurrence in any given year (i.e., a 100-year flood). Discharge will determine the ranking of flood events. However, the extent to which a flood impacts communities, industries, farming, transportation, and individuals depends on the elevations to which the river rises.

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