Presented at U.S.-Italy Research Workshop
Water Resources Research and Documentation Center (WARREDOC)
University of Foreigners at La Colombella, Perugia, Italy
November 13-17, 1995

THE GREAT USA FLOOD OF 1993

Lee W. Larson
Office of Hydrology
NOAA, National Weather Service
Silver Spring, Maryland, USA 20910

1. INTRODUCTION

From May through September of 1993, major and/or record flooding occurred across North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, and Illinois. Fifty flood deaths occurred, and damages approached $15 billion. Hundreds of levees failed along the Mississippi and Missouri Rivers.

The magnitude and severity of this flood event was simply over-whelming, and it ranks as one of the greatest natural disasters ever to hit the United States. Approximately 600 river forecast points in the Midwestern United States were above flood stage at the same time. Nearly 150 major rivers and tributaries were affected. It was certainly the largest and most significant flood event ever to occur in the United States (Fig. 1).

Tens of thousands of people were evacuated, some never to return to their homes. At least 10,000 homes were totally destroyed, hundreds of towns were impacted with at least 75 towns totally and completely under flood waters. At least 15 million acres of farmland were inundated, some of which may not be useable for years to come.

Transportation was severely impacted. Barge traffic on the Missouri and Mississippi Rivers was stopped for nearly 2 months. Bridges were out or not accessible on the Mississippi River from Davenport, Iowa, downstream to St. Louis, Missouri. On the Missouri River, bridges were out from Kansas City downstream to St. Charles, Missouri. Interstate highways 35, 70, and 29 were closed. Ten commercial airports were flooded. All railroad traffic in the Midwest was halted. Numerous sewage treatment and water treatment plants were impacted (Larson, 1993).

2. BACKGROUND

2.1 FORECASTING MODELS

The soil moisture model in primary use was the Antecedent Precipitation Index (API) model. API models have been used in most National Weather Service (NWS) River Forecast Centers (RFC) to produce flood crest forecasts since the 1940s (Fig.2). Hydrologists at NWS RFCs developed API procedures based on historical storm events. A given API value at the beginning of a rain event is typically related to the week of the year, the storm duration, and the amount of actual rainfall from the event. The API model used during The Great Flood of 1993 computes a daily index of soil moisture, considers additional rainfall, and computes any possible runoff.

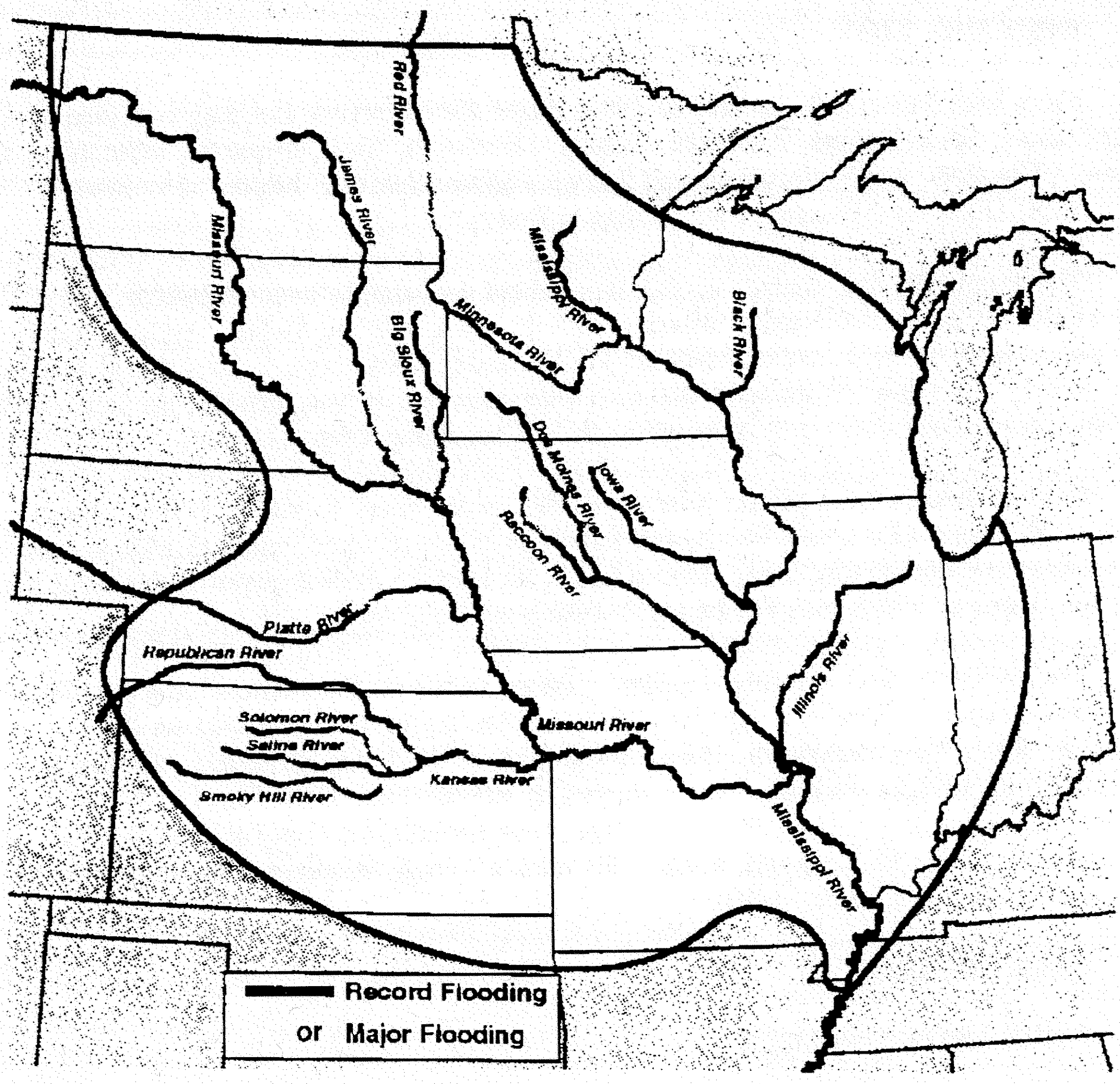


Figure 1 Area Impacted by the 1993 Midwest Flood

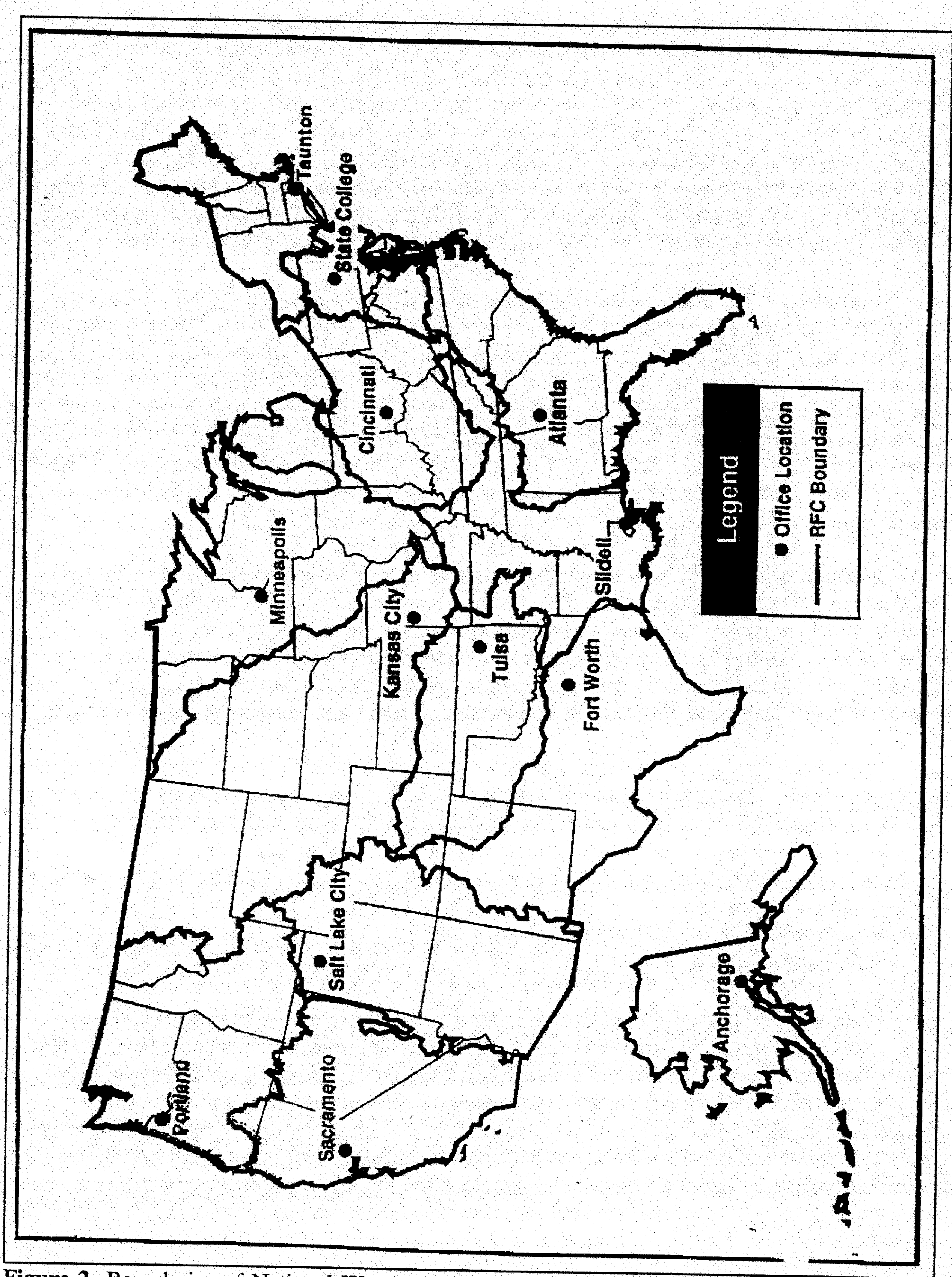


Figure 2 Boundaries of National Weather Service RFC's

Various components are involved in the preparation of flood forecasts. Precipitation and temperature data are input into a snow model. This model determines whether the precipitation is rain or snow based on temperature input. The output from the snow model plus rain becomes input for the soil moisture model. Because of its empirical nature and physical limitations, the API model has a relatively short memory. The assumption is that during periods of no precipitation, soil moisture decreases logarithmically. Another limitation is that baseflow is not addressed directly. However, the model's ease of operation lends itself to quick operational adjustments. This feature allows hydrologists to make timely decisions in balancing the observed physical response with model computed results.

Runoff from the soil moisture model becomes input for the flow model. The "unit hydrograph" technique is employed here. The unit hydrograph is an empirical normalization that represents 1 inch of runoff from rain falling uniformly over a specific basin for a given time step. Constant physical characteristics across the basin and similar hydrograph shapes from storms with uniform rainfall patterns are assumed. A unit hydrograph, to be used in conjunction with an event API model, is best derived from a single rainfall event when all surface runoff occurs in a given time period, e.g., 6 hours. Operationally, the runoff time step is 6 hours. This time step lends itself to data availability, i.e., 6-hourly synoptic precipitation reports.

A storm hydrograph is determined by combining 6-hour incremental runoff values. While model computations are based on volumes of water, most river observations are only available as river stages. In addition, river stages are far easier for the public to comprehend. Therefore, a conversion between discharge and stage is necessary. This relation varies for each location and is affected by many factors. The rating curve is a relation between stage and discharge at a particular location and must be routinely updated.

The above procedure produces a hydrograph for a headwater basin. In a continuous simulation model, all upstream flows at a given point, whether they are floodwaves or not, must be continuously routed to a downstream point. It is essential that this routed or predicted flow be accurate for the forecasting of flows at locations downriver. RFC's use a variety of routing techniques including dynamic routing and Tatum and Muskingum methods (Braatz, 1991).

2.2 PRECIPITATION

During June through August 1993, rainfall totals surpassed 12 inches across the eastern Dakotas, southern Minnesota, eastern Nebraska, Wisconsin, Kansas, Iowa, Missouri, Illinois, and Indiana. More than 24 inches of rain fell on central and northeastern Kansas, northern and central Missouri, most of Iowa, southern Minnesota, and southeastern Nebraska, with up to 38.4 inches in east-central Iowa. These amounts were approximately 200-350 percent of normal from the northern plains southeastward into the central United States. From April 1 through August 31, precipitation amounts approached 48 inches in east-central Iowa, easily surpassing the area's normal annual precipitation of 30-36 inches.

From a seasonal standpoint, much above-average rainfall fell over the entire Upper Midwest from May through August 1993. The May through August 1993 rainfall amount is unmatched in the historical records of the central United States. In July, there were broad areas in North Dakota, Kansas, and Nebraska, as well as a smaller pocket in Iowa, that experienced more than four times normal precipitation. The June through July precipitation amounts are remarkable not only in magnitude but also in their broad regional extent. Record moisture existed over an area of 260,000 square miles. Seasonal rainfall records were shattered in all nine midwestern states.

April saw the start of the prolonged period of very wet weather. The period from April through June was the wettest observed in the upper Mississippi basin in the last 99 years. The moisture conditions across the north central United States on May 1, 1993, can best be described as "saturated." The extremely wet, cool spring of 1993, coupled with normal to above-normal precipitation in the summer, fall, and winter of 1992-93, caused significant spring flooding in the upper Mississippi River basin. Soil moisture conditions, from the surface to a depth of 6 feet, across most of the nine-state region were at "field capacity" by the end of May.

A critical factor affecting the record flooding was the near continuous nature of the rainfall. Many locations in the nine-state area experienced rain on 20 days or more in July, compared to an average of 8-9 days with rain. There was measurable rain in parts of the upper Mississippi basin on every day between late June and late July. The persistent, rain-producing weather pattern in the Upper Midwest, often typical in the spring but not summer, sustained the almost daily development of rainfall during much of the summer.

The semi-stationary nature of the convectively unstable frontal conditions across the Upper Midwest from June through early August not only caused the near continuous occurrence of daily rains but also frequently created extensive areas of moderate to heavy rains. Frequently, a day in June or July 1993 would have rain areas that were 100-200 miles wide and 400-600 miles long (typically about 75,000 square miles) across parts of the nine-state area. Most of these rain areas included zones with 1-2 inches of rain over 5,000-15,000 square miles. A few such large-sized areas of convective rainfall normally occur in most midwestern summers, but their high frequency in 1993 with quite large dimensions capable of affecting both the Missouri and Mississippi River basins was exceptional.

The Great Flood of 1993 had been set by June 1 with saturated soils and streams filled to capacity across the Upper Midwest. Runoff from the ensuing persistent heavy rains of June, July, and August had no place to go other than into the streams and river channels. Record summer rainfalls with amounts achieving 75- to 300-year frequencies thus produced record flooding on the two major rivers, equalling or exceeding flood recurrence intervals of 100 years along major portions of the upper Mississippi and lower Missouri Rivers (Fig.3) (Stallings, 1994).

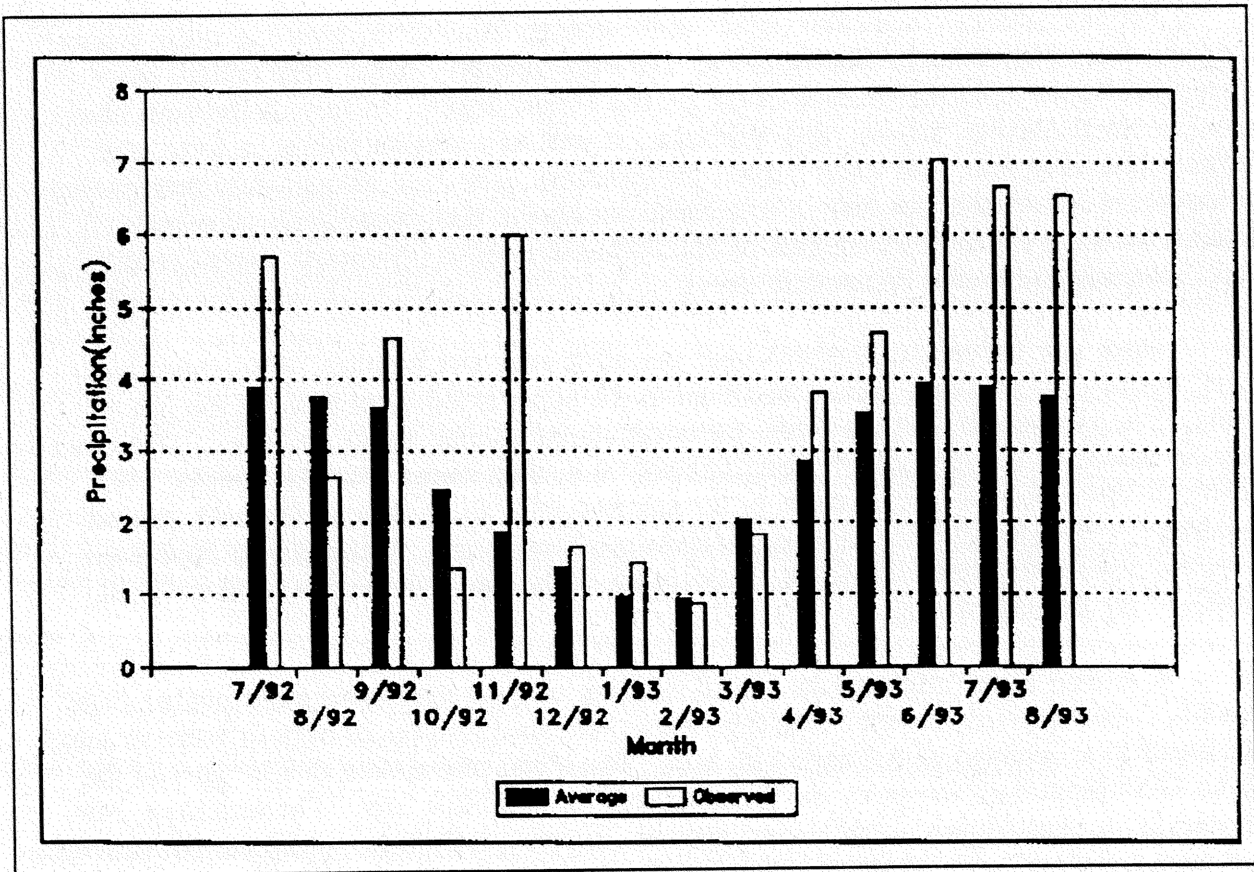


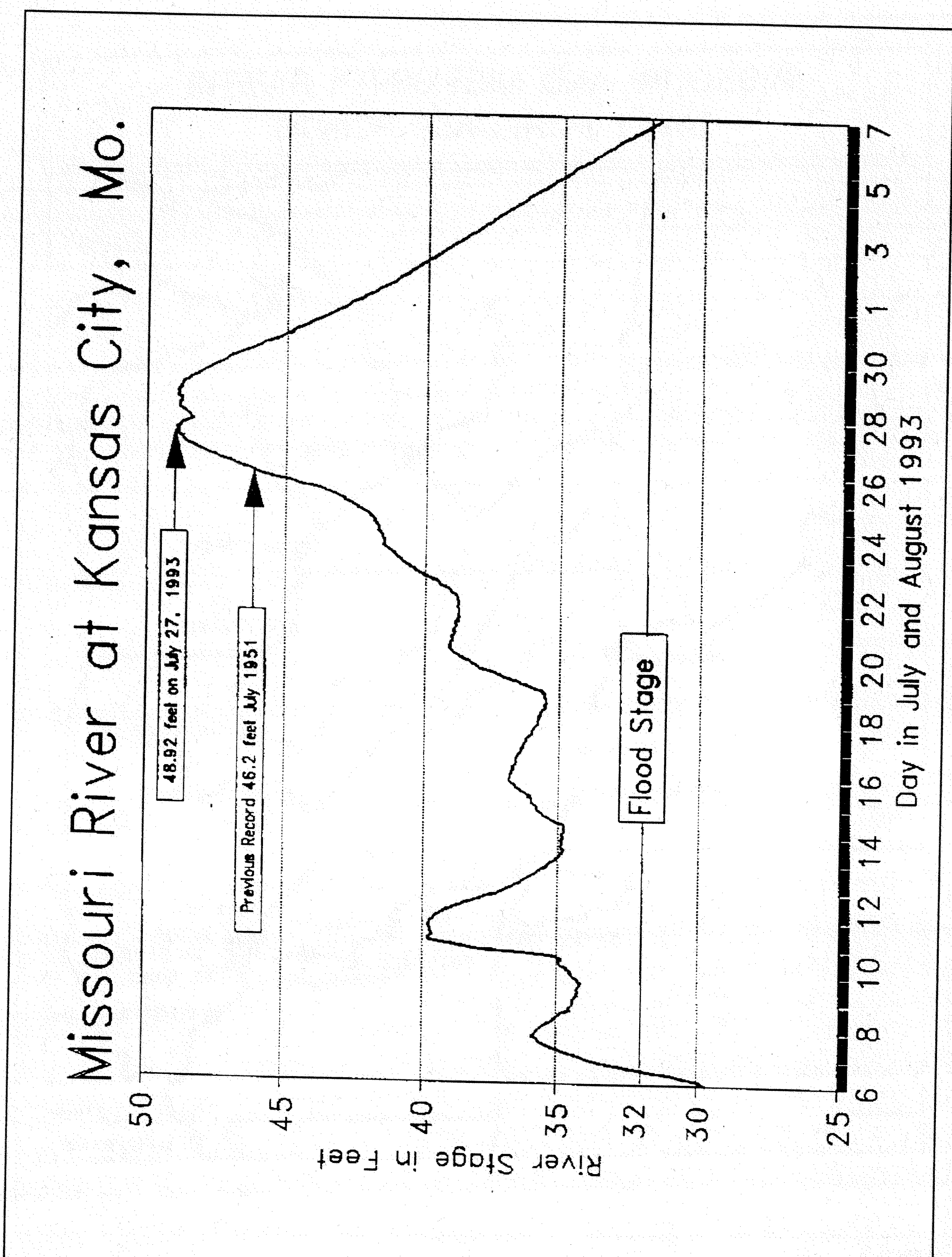
Figure 3 Comparison of average and observed monthly precipitation totals for the upper Mississippi River basin.

3. FLOOD EVENT

Significant rainfall in June and July in the Upper Midwest, combined with wet soil conditions, was the cause of severe flooding in the Upper Mississippi River basin. In mid-June, 8 inches of precipitation fell across the Upper Midwest. This resulted in flooding on rivers in Minnesota and Wisconsin and eventually pushed the Mississippi River to a crest at St. Louis on July 12th of about 43 feet, equalling the previous stage of record (Figs. 4 and 5).

In early July, Iowa was hit with numerous record rainfalls. Storm totals of up to 8 inches were again common. Record flooding occurred on the Skunk, Iowa, and Des Moines Rivers. The city of Des Moines, Iowa was particularly hard hit by flooding on July 9th. The flow from these rivers combined with already near-record flows on the Mississippi River to push the stage at St. Louis up to a new record high stage of 47 feet on July 20th.

In mid to late July, heavy rains began further west in North Dakota, Nebraska, Kansas, and Missouri. Record flooding began on rivers in Missouri, Nebraska, Kansas, North Dakota, and South Dakota. The Missouri River crested at 48.9 feet at Kansas City on July 27th breaking the previous record crest, set in 1951, by 2.7 feet (Fig. 6). This crest

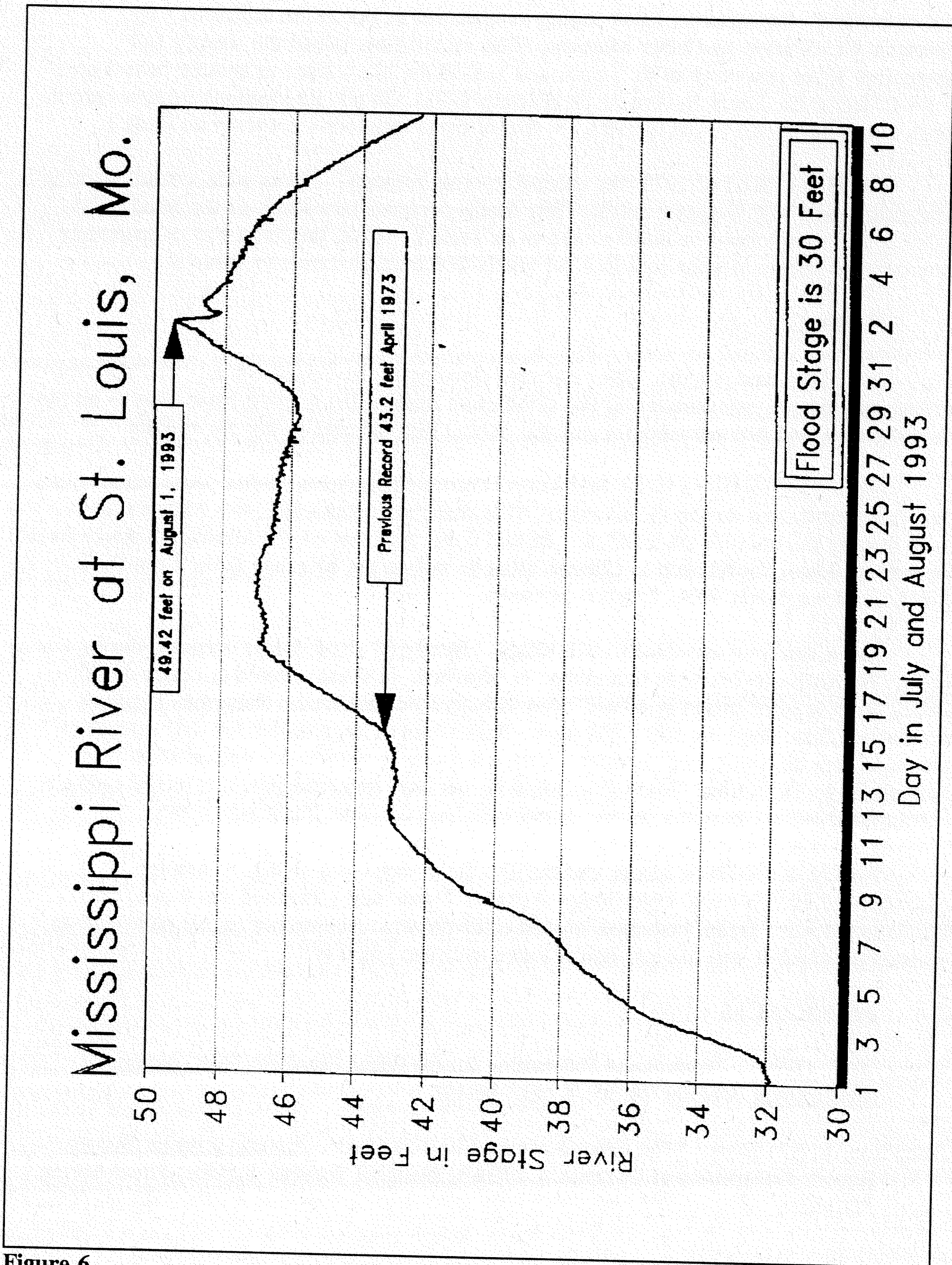


Missouri River at Kansas City, Mo.
48.92 feet on July 27, 1993
Previous Record 46.2 feet July 1951
Flood Stage
River Stage in Feet
50
45
40
35
32
30
25
6
8
10
12
14
16
18
20
22
24
26
28
30
1
3
5
7
Day in July and August 1993

Figure 4


MISSOURI AND MISSISSIPPI RIVERS
DAILY FORECAST POINTS
ST. PAUL
LA CROSSE
GUTTENBURG
SIOUX CITY
QUAD CITIES
OMAHA
NEBRASKA CITY
BURLINGTON
RULO
HANNIBAL
ST. JOESPH
WAVERLY
GLASGOW
GRAFTON
HERMANN
ALTON
KANSAS CITY
ST. CHARLES
BOONEVILLE
ST. LOUIS
JEFFERSON CITY
CHESTER
11/22/93 JLB

Figure 5



Mississippi River at St. Louis, Mo.
49.42 feet on August 1, 1993
Previous Record 43.2 feet April 1973
Flood Stage is 30 Feet
River Stage in Feet
50
48
46
44
42
40
38
36
34
32
30
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 2 4 6 8 10
Day in July and August 1993

Figure 6

pushed on down the Missouri River setting new records at Boonville, Jefferson City, Hermann, St. Charles, and other locations. This record flow joined the already full Mississippi River just north of St. Louis, and pushed the Mississippi to another record crest of 49.47 feet at St. Louis on August 1st (Parrett, 1993). In all, 92 locations set new record crests during the Great Flood of 1993. A few of those locations are shown in Table 1.

The Great Flood of 1993 was unusual in other respects. It was wide spread covering nine states and 400,000 square miles. Fifty deaths occurred as a result of the flood. Over 1,000 levees were topped or failed as shown in Table 2. Also, the flood was of extremely long duration lasting at some locations for nearly 200 days as shown in Table 3.

4. SUMMARY

June, July, and August, 1993, saw epic flooding in the United States. The severity, wide-spread nature, and duration of this flood event made it the greatest flood ever to hit the United States, and it is probably the greatest natural disaster ever to hit this country.

Nearly 100 locations in the Midwest set record flood crests. Some locations set more than one record crest during the summer. Nine states were impacted, with Missouri and Iowa bearing the brunt of the flooding. Record crests were set on the Mississippi River from Davenport, Iowa, downstream to Chester, Illinois, and on the Missouri River from Rulo, Nebraska, downstream to St. Charles, Missouri.

Flood damages amounted to $15 billion. Nearly 50 flood deaths occurred during this event. Numerous levees were overtopped or breached. It is estimated that nearly 1,100 levees, most local or privately owned, were damaged or destroyed. Numerous locations were above flood stage for 150 - 200 days. Rainfall totals approached 300-400 percent of normal during the spring and summer. Iowa set statewide records for precipitation from 1 month up to 48 months. Some river locations not only exceeded previous record crests, but stayed above the previous record crest for 30 days or more (Josephson, 1994).

Finally, it should be recognized that this flood event was so big, it simply overwhelmed everyone and everything. As Mark Twain said a hundred years ago, the Mississippi River "cannot be tamed, curbed or confined.....you cannot bar its path with an obstruction which it will not tear down, dance over and laugh at."

5. REFERENCES

Braatz, D.T. (1994). "Hydrologic Forecasting for the Great Flood of 1993", Water International, Volume 19, No.4, pp. 190-198.

Josephson, D.H. (1994). "The Great Midwest Flood of 1993". Natural Disaster Survey Report, Department of Commerce, NOAA, National Weather Service, Silver Spring, Maryland.

Larson, L.W. (1993). "The Great Midwest Flood of 1993", Natural Disaster Survey Report, National Weather Service, Kansas City, Missouri.

Parrett, Charles, Melcher, N.B. and James, R.W. (1993). "Flood Discharges in the Upper Mississippi River Basin:" in Floods in the Upper Mississippi River Basin, US Geological Survey Circular 1120-A.

Stallings, E.A. (1994). "Hydrometeorlogical Analysis of the Great Flood of 1993", Department of Commerce, NOAA, National Weather Service, Silver Spring, Maryland.

6. SUGGESTED RESEARCH TOPICS

6.1 The duration and magnitude of The Great Flood of 1993 might suggest that this was a significant climate variation. Research should be conducted on the complex interaction of atmospheric, oceanic, and land factors which may have contributed to this situation.

6.2 Dynamic routing procedures should be further investigated and implemented as appropriate, especially at confluences of major rivers.

6.3 Modeling of levee failures should be investigated, especially when subjected to long term flooding.

6.4 Investigations should continue on the development and use of Quantitative Precipitation Forecasts (QPF) in hydrologic forecasting.

6.5 Rating curve extension procedures should be refined.

6.6 Hydrologic data gathering techniques should be reviewed and improved.

6.7 Advanced conceptual hydrologic modeling techniques, such as soil moisture accounting, need to be further investigated, refined, and implemented.

6.8 Probabilistic forecasting needs to be pursued to place confidence levels on river forecasts.

6.9 Radar precipitation estimation techniques need to be refined, implemented, and utilized in river forecasting.

Table I Locations with new record stages in the Mississippi River Basin

LOCATION	FLOOD STAGE (ft.)	OLD RECORD Stage (ft.)	OLD RECORD Date	NEW RECORD Stage (ft.)	NEW RECORD Date
Mississippi R					
Quad Cities L/D15	15	22.5	650428	22.6	930709
Muscatine IA	16	24.8	650429	25.6	930709
Keithsburg IL	13	20.4	650427	24.2	930709
Burlington, IA	15	21.5	730425	25.1	930710
Keokuk L/D16 IA	16	23.4	730424	27.2	930710
Gregory Landing MO	15	24.6	730424	26.4	930707
Quincy Il	17	28.9	730423	32.2	930713
Hannibal Mo	16	28.6	730425	31.8	930716
Louisiana MO	15	27.0	730424	28.4	930728
Clarksville MO L/D24	25	36.4	730424	37.7	930729
Winfield MO L/D25	26	36.8	730427	39.6	930801
Grafton IL	18	33.1	730428	38.2	930801
Melvin Price IL	21	36.7	730428	42.7	930801
St Louis MO	30	43.2	730428	49.6	930801
Chester IL	27	43.3	730430	49.7	930807
Missouri R					
Plattsmouth NE	26	34.7	840614	35.7	930725
Brownville NE	32	41.2	840615	44.3	930724
St. Joseph MO	17	26.8	520422	32.7	930726
Kansas City MO	32	46.2	510714	48.9	930728
Napoleon MO	17	26.8	510715	27.8	930727
Lexington MO	22	33.3	510715	33.4	930708
Waverly MO	20	29.2	840623	31.2	930728
Miami MO	18	29.0	510716	32.4	930729
Glasgow MO	25	36.7	510718	39.6	930729
Boonville MO	21	32.8	510717	37.1	930729
Jefferson City MO	23	34.2	510718	38.6	930730
Gasconade MO	22	38.7	861005	39.6	930731
Hermann MO	21	35.8	561005	36.3	930731
St. Charles MO	25	37.5	861007	39.5	930801

Table II Levee Failures During the Midwest Flood of 1993

CORPS OF ENGINEERS DISTRICT	NUMBER OF FAILED OR OVERTOPPED LEVEES	
	Federal	Non-Federal
St. Paul	1 of 32	2 of 93
Rock Island	12 of 73	19 of 185
St. Louis	12 of 42	39 of 47
Kansas City	6 of 48	810 of 810
Omaha	9 of 31	173 of 210
Totals	40 of 226	1043 of 1345

Table III Duration of Flooding, 1993

	FS	DATES, NUMBER OF DAYS	TOTAL # DAYS
MISSOURI RIVER			
JEFFERSON CITY	23	7/2--8/19,49 9/22-10/4,13	62
HERMANN	21	7/2--8/25,55 9/14-10/5,22	77
ST. CHARLES	25	7/3--8/30,95 9/3--10/7,35	94
MISSISSIPPI RIVER			
QUINCY	17	4/2--5/26,55 6/9---9/13, 97	152
HANNIBAL	16	4/1-----------------9/21,174	174
LOUISIANA	15	4/2----------------10/4 ,186	186
D24 CLARKSVILLE	25	4/2----------------10/5 ,187	187
D25 WINFIELD	26	4/3--6/2 ,61 6/7--10/6 ,122	183
GRAFTON	18	3/26-6/2 ,69 6/7--10/10,126	195
MELVIN PRICE TW	21	4/3--5/28,56 6/8--10/8 ,123	179
ST. LOUIS	30	4/11-5/24,44 6/27--9/13,79 9/15-10/7,23	146
CHESTER	27	4/3--5/31,59 6/8--10/12,127	186
CAPE GIRARDEAU	32	4/3--5/28,56 6/10-10/12,125	181
THEBES	33	4/4--5/26,53 6/29-10/11,105	158