Vertical Datum (NGVD) with 42,200 acre-feet of storage. The flood control storage pool (elevation 712.0 feet) provides an additional 419,000 acre-feet of storage. The cumulative damages prevented since the project has been in operation (1959 through September 1993) are estimated at $49.2 million.

The Red Rock Dam and the Lake Red Rock Project on the Des Moines River are chiefly in Marion County, but extend into Jasper, Warren and Polk Counties. The dam is approximately 60 miles downstream from the City of Des Moines.

The drainage area above the dam site is 12,323 square miles. A permanent lake of 265,500 acre feet storage area is formed behind the dam. With the flood control pool full (elevation 780.0 feet), the reservoir storage is 1,484,900 acre feet above the conservation pool of 742 feet NGVD. The net cumulative damage prevented since the project has been in operation (1969 through September 1993) is estimated at $390.4 million. Flood protection is provided to 36,000 acres of agricultural lands in the Des Moines River basin and to the Cities and Towns of Ottumwa, Eldon, Eddyville, Keosauqua and Farmington.

In 1958, Congress authorized construction of Saylorville Lake on the Des Moines River about 11 miles upstream from the City of Des Moines. The principal purpose of the Saylorville Project is to furnish needed additional storage to supplement the flood control capacity of the downstream Red Rock Dam and Lake Red Rock and to provide flood protection to the City of Des Moines. The permanent conservation pool forms a lake with storage of about 90,000 acre-feet and extends some 17 miles upstream from the dam.

The reservoir has a total capacity of 676,000 acre-feet at full flood control pool elevation 890 feet and covers about 16,700 acres. The conservation pool was raised from 833 to 836 feet in 1983 to provide a water supply for the City of Des Moines and the Iowa Southern Utilities near Ottumwa, Iowa. The Saylorville Project has been in operation since April 1977. Estimated damages prevented (from 1977 to 1993) are $156.3 million.

Along the Mississippi River, downstream from the mouth of the Des Moines River, levee districts and the cities of Quincy, Ill. and Canton, LaGrange, and Hannibal in Mo. also benefit from the combined operation of these three reservoirs.

Examples of other local flood control protection projects built by the Rock Island District include Waterloo, Evansdale, Des Moines, Clinton, Dubuque, Marengo, Marshalltown and Bettendorf, Iowa; Rockford, Fulton, East Moline, Rock Island, Milan, Ill., and Hannibal, Mo.

II. Synopsis of the Flood

The Great Flood of 1993 affected a large portion of the midwestern United States, crossing the boundaries of several Corps of Engineers districts, including: St. Paul (CENCS), Rock Island (CENCR), Omaha (CEMRO), Kansas City (CEMRK), and St. Louis (CELMS). Each of these districts experienced some degree of flooding during the spring and summer of 1993. In no single district, however, was the geographic extent of flooding as large as Rock Island District. Virtually every major stream exceeded flood stage at least once in the six months from March through August, and numerous historic river stages, flows and rainfall events were recorded.

A. Antecedent Conditions

There are a number of factors that can create the conditions necessary for a major flood. These include: high base streamflows, heavy snow cover, heavy rainfall and saturated soil conditions throughout a watershed. All of these were present throughout the Rock Island District as the Winter of 1992-93 gave way to spring.

1. High Base Streamflows

Streamflows throughout the Rock Island District were unusually high during the winter of 1992-93 and on into the spring. Lock and Dam 11 on the Mississippi River lies near the upstream boundary of the Rock Island District. River flows at this site were between 30,000 and 40,000 cfs during the months of January and February, as shown in Plate 3, compared to average flows of 25,000 cfs for the same time of year. Lock and Dam 22, at the District's downstream boundary on the Mississippi River, recorded river flows greater than 60,000 cfs for most of same time period (Plate 4), compared to normal flows of 35,000 cfs.

The Rock and Illinois Rivers, two major tributaries to the Mississippi River from the Illinois side, experienced similar unseasonably high flows throughout the winter months.

2 . Heavy Snow Cover

Although not record breaking, the snow cover on the Upper Mississippi River basin at the beginning of the Spring of 1993 was relatively heavy. Table 1 outlines the approximate range of the water content of this snow cover for the five states which comprise the Upper Mississippi River basin. This table illustrates how much water was waiting to be released, much of it directly into runoff, when the spring warming began.

Table 1
Water Content of Snow Cover/Frost Line Depth
Upper Mississippi River Basin (Spring 1993)

State	Approximate Water Content of Snow Cover	Approximate Depth of Frost Line
Minnesota	1.5 - 5.1 inches	0 - 36 inches
Iowa	0.5 - 4.1 inches	6 - 12 inches
Wisconsin	1.0 - 3.6 inches	25 - 35 inches
Illinois	0.5 - 2.5 inches	12 - 24 inches
Missouri	0.5 - 2.5 inches	N/A

Table 1 also shows the range of depths of frost penetration in the region. Due to the near normal winter temperatures, these depths are not significantly greater than usual. Thus, while early spring rains did encounter a frozen basin in some areas, the depth of the frost line was not, in general, a major factor in the 1993 Flood.

3. Saturated Soil Conditions

As the ground began to thaw, the saturation of the soil became an increasingly important factor in the potential for runoff from precipitation and snow melt. Soil moisture in the Upper Mississippi River basin was exceedingly high in the Spring of 1993 as shown in Table 2. These high values meant that a large percentage of new precipitation had nowhere to go but directly into runoff.

Table 2
Soil Moisture Conditions
Upper Mississippi River Basin

State	Soil Moisture as a Percent of Capacity
Minnesota	85 %
Iowa	85 %
Wisconsin	75 %
Illinois	80 %

4. Heavy Rainfall and Temperature

The final two factors that created the potential for major flooding within the Rock Island District were heavy rainfall and abnormal temperatures. The precipitation increases actually began as early as the Fall and Winter of 1992. The November 1992 precipitation was higher than average in all of the midwest. Statewide precipitation in Iowa, Minnesota and Wisconsin was the greatest of any November since 1895. Illinois and Missouri were the second wettest. The period of January through August broke many precipitation records. The isohyetal map of the percent of normal of the total precipitation amount for that period is shown on Plate 5.

Precipitation in January was generally above average in the eastern and southeastern sector of the region. February regional temperature varied from 2 degrees F. to 6 degrees F. below average.

Precipitation for April was frequent and substantial. The monthly totals ranged from approximately 2 to 6 inches. Southwestern Wisconsin, Illinois and Missouri recorded 6 inches or more. The regional temperatures for April were again generally below average. They ranged from 3 to 4 degrees F. below average for the Rock Island District.

Rainfall for the month of May varied from 4 inches in Missouri, Iowa, Minnesota and southern Illinois to more than 6 inches in the western half of Iowa and extreme Missouri.

Precipitation for the month of June was extremely variable. Table 3 shows the monthly totals and how they compare to the period of record. The isohyetal map of the precipitation percent of average for the month of June is shown on Plate 6.

Table 3
Precipitation for June

State	June 1993 (inches)	Long-Term Mean (inches)	Long-Term Maximum (inches)	Category (since 1895)
Iowa	8.30	4.43	10.24	3rd wettest
Wisconsin	6.89	4.06	7.75	5th wettest
Illinois	6.40	3.88	8.37	7th wettest
Minnesota	6.44	3.90	8.00	6th wettest

June temperatures varied from 2 degrees F. below average in Iowa and Illinois to 4 degrees F. below average in Minnesota and northwest Iowa.

A complex pattern of precipitation occurred during the month of July as a result of convective activity of air masses. The July total precipitation and temperature deviation for each state are summarized below on Table 4. The precipitation percent of average isohyetal map for the month of July is shown on Plate 7.

Table 4
Mean Monthly Precipitation and Temperature Deviations for July

State	July Precipitation (inches)	% Average	Temperature Deviation (degrees F.)
Illinois	6.70	170%	1.1
Iowa	10.48	260%	-1.8
Minnesota	7.08	200%	-3.0
Missouri	7.16	200%	1.2
Wisconsin	4.68	150%	-0.9

The August precipitation continued the same distribution pattern as during June and July. In Illinois and Missouri the precipitation varied from 4 to 6 inches with isolated spots of 8 to 10 inches and 6 to 10 inches in Iowa. In many east-central areas of Iowa, the range was between 10 to 13 inches. Statewide, the mean August rainfall was the wettest on record in Iowa (since 1895). The isohyetal map for the month of August is shown on Plate 8.

B. Storm Pattern

The weather pattern that predominated the mid-western states during the winter months was a split flow pattern that is typical of El Nino events. At the jet stream level, the westerly air flow became split by a high pressure ridge over the western United States. The subtropical jet stream forced itself well to the south of the ridge into southern California while the polar jet stream was pushed to the north of the ridge into northwestern Canada. Those two rapidly moving streams of

air swung around the eastern side of the high pressure ridge and converged over the Midwest. This produced ideal conditions for the creation of significant precipitation. Plate 9 shows the dominant weather pattern that was responsible for the abnormal conditions that occurred between June and August 1993.

The weather pattern that predominated in the summer months was the result of a large dome of stationary high pressure (commonly called the Bermuda High) in the upper atmosphere that remained over the southeastern United States. The high pressure area was responsible for droughts in the south and east and for a major heat wave experienced along the eastern seaboard in July. The circulation pattern pushed moisture from the Gulf up into the midwest. At the same time, a strong low pressure system was present in the upper atmosphere in the northern Rockies. This stationary system was responsible for the unseasonably cold weather that much of the mountain west experienced during the summer. Unfortunately, the Midwest was located at the boundary system between the two systems. The high pressure system brought the warm and humid air into the region while the low pressure system continued to spin off disturbances across the plains that generated the thunderstorms. The exact demarcation between the two weather systems changed continually which explains why the heavy rains also changed locations. This pattern was initially noticed in mid-June and did not break up until the onset of Hurricane Camille in mid-August.

C. Flood Sequence

The general discussion of the flood sequence that follows includes a chronology of events that began as early as March 1993. Some of the early spring flooding produced the high base flows that existed when the more serious record breaking flooding began in June and July. Details of the flooding in each watershed are discussed in the sections called Main Stem Hydrology/Hydraulics.

1. March

The Green and Rock Rivers watersheds received 2.75 inches of precipitation between March 23-24. Flooding on these two basins occurred when numerous sections of non-federal agricultural levees failed. The Rock River crested at a new record high in Joslin, Ill., March 26. One of the primary causes of the flooding was ice jams. Heavy precipitation that occurred March 31 in the Iowa River and Cedar River basins produced flooding in low lying areas. Other areas along the Iowa River began to rise rapidly.

2. April

a. Week 1

April 1 a federal levee on the Iowa River, under construction in Tama, Iowa, was intentionally breached to alleviate the interior drainage problem due to head built-up on the landside of the levee. The Waterloo, Cedar Falls and Cedar Rapids areas along the Cedar River, implemented active flood fighting efforts to reduce damages. The Cedar River crested April 5 at Cedar Rapids. Local precipitation in the upper Rock River watershed that occurred between April 1 and 3

caused the river to rise again. By April 4, the upper Rock River had crested. The Mississippi River began to reach or exceed flood stage by April 5 in a few areas. On April 7, the lower Rock River at Joslin crested without significant problems. The Cedar and Iowa Rivers showed little change. The Mississippi River at Hannibal, Mo., and the Quad-Cities continued to rise. The Saylorville Reservoir was at 70 percent capacity and three feet below the spillway.

b. Week 2

The lower Rock River, Cedar-Iowa River and Mississippi River at Hannibal remained above their flood stages but were falling. Saylorville and Coralville Dams lake levels were still rising slowly. Significant rainfall, with amounts varying from 1/2 inch to 1 1/2 inches, occurred on April 19 throughout the district watershed. As a result, the Mississippi River rose again throughout most of the Rock Island District. Flood fighting began in Davenport, Iowa.

c. Week 3

By April 21, Lock and Dams 16, 17, 18, 19, 20, 21, and 22 were closed due to high water. The Illinois River from La Salle, Ill., to Meredosia, Ill., also began to rise in response to the additional precipitation. The Saylorville Reservoir spillway was overtopped by .5 foot.

d. Week 4

The continued above flood-stage levels on the Mississippi River impacted the levees. Signs of distress such as seepage, boils and saturation of levee material were observed at several of the structures.

3. May

By May 25, most of the Mississippi River from Lock and Dam 10 to Burlington, Iowa, was below flood stage. Below Burlington, Iowa, to Hannibal, Mo., the river was from .25 foot to 1.25 feet above flood stage. The Illinois River from La Salle to Meredosia, Ill., was below flood stage except Beardstown, Ill., where it was .2 foot above flood stage.

4. June

a. Weeks 3 and 4

On June 18, there were 4 inches of precipitation over central Iowa, an area with already saturated soils. This resulted in temporary flooding of highways and roads. Two more inches of rain fell the next day. On June 25, additional localized rainfall in central Iowa contributed to the runoff at the three reservoirs. At Saylorville Lake, 5 feet of water flowed over the spillway. On June 27, several areas recorded up to 4 inches of rainfall. The Iowa River basin below Coralville Lake was one of the areas that received heavy precipitation. All of the reservoirs had more than 90 percent of their storage utilized, and all of the locks and dams on the Mississippi River, except Lock and Dam 15, were closed. Additional rainfall that occurred June 28 around Iowa City,

Iowa, and the Upper Mississippi basin below Dubuque, Iowa, continued to aggravate the situation. An additional 2 inches of rain fell during the night of June 29 and the three reservoirs rose higher. The Mississippi River continued to rise. Some residents in Davenport, Iowa, temporarily evacuated their homes due to their lack of adequate flood protection.

5. July

a. Week 1

Near Quincy, Ill., an additional 2 to 5 inches of precipitation fell on July 1. Flooding continued in the Quad-Cities area. Seepage through the levee systems in Oquawka, Ill.; Keithsburg, Ill., and Bay Island, Ill., was a problem. Flood waters continued to rise along a 300-mile stretch of the Mississippi River on July 2. Evacuation of homes occurred at Andalusia and Keithsburg, Ill. New records were established at Keithsburg, Ill., and Burlington, Iowa. Evacuation of homes at Muscatine, Iowa, occurred and the high water also created problems with the sanitary sewers. The Quad-Cities continued to experience flooding throughout certain areas. The Mississippi-Fox River Drainage District levee overtopped, and approximately 8,000 acres of farmland became inundated. Evacuation of residents in low lying areas occurred at Oquawka, Ill., as seepage through the levee accumulated. On July 6, the Mississippi River crested for a second time at Dubuque, Iowa.

The second crest continued downstream to the Quad-Cities, Keithsburg and Hannibal, and new record levels were established. The Governor of Illinois declared the following 12 counties disaster areas: Adams, Calhoun, Carroll, Hancock, Henderson, Henry, Jersey, Jo Davies, Mercer, Pike, Rock Island and Whiteside. Coralville Lake continued to rise, and the outflow was 17,000 cfs through the conduit and 4,000 cfs over the spillway. Reservoir storage reached 106.6 percent. Saylorville Lake discharge maintained 30,000 cfs, and the storage was at 97.5 percent. Lake Red Rock discharge maintained 65,000 cfs with the storage at 107.6 percent. Additional rainfall on the Des Moines River basin occurred July 7.

b. Week 2

A non-federal levee at Union Township, Mo., was overtopped, flooding approximately 5,000 acres of agricultural land. At Ottumwa, Iowa, a private levee broke, and some residents evacuated their homes. At Keithsburg, Ill., a non-federal levee overtopped, and the town became inundated. Another non-federal levee overtopped at Louisa, Iowa (Louisa Co. Levee Districts 8 and 11), and flooded 5,700 acres of farmland and some private residences. Some of the residents evacuated their homes. Another 1.5 inches of rainfall fell in the Des Moines River basin July 8. The Mississippi River was at crest stage from Camanche, Iowa, to the Quad-Cities. Coralville Lake continued to discharge 18,000 cfs with the reservoir storage at 106.3 percent. Saylorville Lake discharge decreased to 24,000 cfs, and the reservoir storage was at 94 percent. Lake Red Rock increased to 75,000 cfs, and the reservoir storage was at 106.3 percent. The Gregory Drainage District levee in Missouri, a federal levee, overtopped, breached and inundated 8,000 acres became inundated. At the Des Moines-Mississippi Drainage District in Iowa, the federal levee overtopped and the Town of Alexandria became inundated with 6 feet of water. The Governor of Iowa declared disasters in 45 counties.

On July 9, up to 8.5 inches of rain occurred on the Des Moines River basin at Jefferson, Iowa. In Des Moines, Iowa, on the Raccoon River, the non-federal levee overtopped inundating many homes and businesses. Marshalltown, Iowa, had up to 3 inches while 1 to 2 inches of rain fell over various parts of eastern Iowa and western Illinois. The Mississippi crested for a third time at Camanche, Iowa, and the Quad-Cities also crested again. The Hunt-Lima Lake Drainage District's federal levees overtopped inundating about 28,000 acres of agricultural land and the Town of Meyer, Ill.

On July 11, moderate to heavy rainfall fell in central Illinois. Flash flood conditions on the Raccoon River resulted in the overtopping of the City of Des Moines levees that protected the water treatment plant, a power substation and residential housing. The City of Des Moines lost its water supply for three weeks. The high water on the Des Moines River caused a federal levee T-wall, below the confluence of the Raccoon River, to fail, and an older industrial section of the town became inundated. Flash flooding along Deer Creek caused inundation of much of the Town of Tama, Iowa. A non-federal levee in Niota, Ill., overtopped, and homes and buildings inundated with flood water. A federal levee at Green Bay Drainage District, Iowa, overtopped, flooding about 13,500 acres of agricultural land, a fertilizer plant and a grain elevator.

On July 12, the Mississippi River crested from Camanche, Iowa, to Keokuk, Iowa. The work to restore the operation of the Des Moines water treatment plant continued; however, high river levels resulted in limited effectiveness of pumping. The Indian Grave Drainage District federal levee overtopped at the lower section and about 8,000 acres of agricultural land and 12 farms were inundated. Heavy rainfall occurred on July 13 in the City of Des Moines area. The Mississippi River continued to very slowly drop. The South River Drainage District federal levee overtopped at Willings Crossing, Mo., and approximately 10,000 acres flooded. The upper end of the Indian Graves federal levee overtopped, and 10,000 acres flooded.

c. Week 3

The Coralville Lake discharge on July 15 remained at 25,000 cfs and the reservoir storage was at 122.6 percent. At Saylorville Lake, the release rate was 40,000 cfs and the reservoir storage was at 106.8 percent. Lake Red Rock discharged 104,000 cfs and the reservoir storage was at 111.1 percent. The Fabius Drainage District federal levee experienced two problems. A slide in the clay portion of the levee system developed and a seepage area required continuous attention. The Fabius Drainage District federal levee overtopped, causing a barge/tow to be drawn into the breach and hit a fuel supply station. Approximately 14,300 acres inundated with flood water as were 400 homes and buildings. A private levee section in the City of Des Moines experienced some sloughing and some residents evacuated from their homes. The levee overtopping in the Fabius Drainage District caused the bridge from West Quincy, Mo., to Quincy, Ill., across the Mississippi River to be closed.

July 18, there was light to heavy precipitation across the Rock Island District. Portions of the Iowa-Cedar River basin received up to an additional 5 inches of rainfall. There was a major effort to restore access to the bridge across the Mississippi River at Keokuk. July 19, the Mississippi River remained above flood stage throughout the entire Rock Island District. Preparations were made to relocate electrical wiring to higher locations at the Iowa City water treatment plant in the event of flooding. Also, the University of Iowa water treatment plant set up

an emergency water intake using a 12-inch Crisafulli portable pump in the event they lost the main intake.

d. Week 4

On July 23, the Iowa Cedar River basin recorded up to 1.67 inches of rain. The City of Des Moines water plant became operational for use of non-potable water. On July 24, an additional 4 inches of rain fell on southern portions of the district. The Mississippi River began to climb again, and the Illinois Waterway also went above flood stage. Certain areas recorded up to 1.75 inches of rain. At the Sny Island Drainage District, the upper third of the levee system overtopped and 30,000 acres flooded including 150 to 200 homes.

On July 26, parts of the Mississippi River began to gradually drop at the upper end of the district while the lower end continued to rise. Stages on the Mississippi River remained above flood stage. By July 30, the levels on the Mississippi and Illinois Rivers continued to fall although they remained above flood stage. The outflows at the three reservoirs dropped as follows; Coralville, 22,000 cfs; Saylorville, 22,000 cfs and Lake Red Rock, 68,000 cfs. On July 31, significant precipitation occurred in eastern Iowa. Iowa City and areas south reported 2 to 3 inches of additional rain. The additional rain increased the inflows to Coralville Reservoir. The Mississippi River remained above flood stage below Lock and Dam 15.

6. August

August 2, the Mississippi River remained above flood stage below Lock and Dam 15; however, throughout the Rock Island District the levels continued to fall. By August 9, Lock and Dams 11-19 were opened to navigation subject to Coast Guard restrictions. August 10 up to 4 inches of rain fell near Iowa City. By August 11, the Mississippi River dropped below flood stage from Burlington, Iowa, upstream to the upper Rock Island District boundaries. Additional precipitation occurred throughout the Rock Island District with up to 5 inches falling in the Iowa River and Cedar River basins. Flash flooding occurred along the Iowa River near Marshalltown and Tama, Iowa, in the same area that experienced flooding previously. By the end of August, all of the rivers had crested; however, many remained above flood stage.

D. Areal Extent of Flooding

The Great Flood of 1993 was unique in its areal extent as well as its duration. It encompassed several months of relatively heavy rainfall that occurred at a time when the ambient conditions already posed a greater probability for flooding. Along the Mississippi River, many of the federal and non-federal levees either were overtopped or breached as a result of the record breaking stages. A total of 190,000 acres of land was inundated by floodwater.

Aerial photographs 1 through 4 are LANDSAT images that show the Mississippi River (in the vicinity of Quincy, Illinois, and Hannibal, Mo.) from about river mile 343 to river mile 301, before and during the flooding. (LANDSAT images were produced by ERDAS, Inc. of Atlanta, Ga., from Thematic Mapper Imagery provided by EOSAT Inc. of Lanham, Md.) Photos 1 and 2 were taken on May 27, 1989. Photos 3 and 4 show the extent of the inundation for the same reach of the river taken on July 25, 1993. Levee and drainage districts included in these

photographs in Illinois are: the Lima Lake Drainage District, the Indian Grave Drainage District, and the Sny Island Drainage District; and in Missouri are: the Union Township Drainage District, the Fabius River Drainage District, Marion County Drainage District, the South River Drainage District, and the Hannibal local flood protection project. The interruption of navigation traffic and the inundation of an industrial site south of Keokuk, Iowa is shown in Photo 5. The Canton, Mo. local flood protection project is in the foreground of Photo 6 with Lock and Dam No. 20 and Meyer, Ill. in the center of the photo.

III. Meteorology

A. Antecedent Conditions

General antecedent conditions including a discussion of the high base flows, soil moisture conditions, temperature trends, snow cover and regional precipitation trends for the period prior to the summer flooding, are included in Section II, Synopsis of the Flood. Below is a discussion of the precipitation for the basins that were impacted and how it deviates from the period of record.

The Upper Mississippi River basin within the Rock Island District set near records for rainfall during the spring and summer of 1993. Although records were not broken in the fall of 1992, November and December were well above average. Particularly in November, the rainfall totals were 2 to 3 times the average amount.

The Des Moines River basin showed similar trends in precipitation for the months of November and December of 1992. The months of January through April for the Des Moines River basin were generally above average for the monthly totals. By May, the totals were consistently 1.5 to 2 times the average, and June showed similar trends although even more extreme than May. The Skunk River basin had a very wet November, with all stations reporting 3 times the average monthly total. December through May for the Skunk River basin were generally average to 1.5 to 2 times that amount. Precipitation totals in June were higher than in May. The Iowa River and Cedar River basins had the greatest deviation from the average than the other basins for the month of November. Precipitation totals were at least twice the average with some stations reaching 3.5 times. December through May were as much as 1.5 to 2.0 times the average. June totals were consistently greater than those in May.

Missouri precipitation gages that are within or close to the District boundaries show the monthly totals for November all exceed 2.5 times the average and most either approach or exceed 3 times the average. For December through April, the totals ranged from less than average to close to 1.8 times the average amounts.

The Illinois precipitation records show that between February and July the monthly amounts were approximately 1.2 times the average amount.

The total precipitation from November 1992 through April 1993 for three NOAA/NWS stations in Iowa, one in Illinois and one in Missouri are shown on Plate 10. In addition to the total precipitation, Plate 10 also shows the average totals for the same period.