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.

B. Description of Storms

The severe flooding that occurred in the Upper Mississippi River basin was the culmination of the wet spring and a series of storms in March, June and July. Flooding was influenced by not only the wet antecedent conditions and large rainfall totals, but also by the distribution of the daily rainfall in July. The storm of July 4-5 was a significant event that produced a large amount of rainfall over southern Iowa. The conditions that existed in the mid-west which were responsible for this storm are described below in detail.

A high pressure system was positioned over the southeastern United States while an area of warm moist air flowed into the midwestern states as a result of the circulation around the southeastern high and the low pressure system in southern Canada. This pattern was typical for most of June and July, as previously discussed. However, to aggravate the situation, a stationary front extended from northern Missouri across southeastern Iowa to southern Wisconsin, and a series of cold fronts rotated cyclonically around the low into western Iowa. The dense air behind each cold front collided into the warm air over Iowa, southern Minnesota and southern Wisconsin. Aiding the production of rain was a strong area in the middle atmosphere that caused an additional upward motion. This produced additional lift to enhance the creation of thunderstorms. This area began over Kansas and Nebraska to the west of the cold front in western Iowa and proceeded over Iowa from the southwest. The jet stream that passed over Iowa from the southwest to northeast also aided the production of rain and created what is called the chimney effect in which strong winds in the upper atmosphere blow across the region of thunderstorm development. The effect of the winds was to evacuate air from the top of the thunderstorms, which created an updraft. More warm moist air was then drawn up into the thunderstorms and produced an exceptional amount of rain. As the storm moved northeastward at about 10 to 20 miles per hour, new thunderstorms formed to the southwest of the original thunderstorms and passed over the same areas, adding to the large rainfall totals.

This storm produced a total of four to eight inches of rain across a 250-mile long path from Taylor County in southwest Iowa, northeastward through Oskaloosa, Marengo, Cedar Rapids and Dubuque.

Strong thunderstorms moved into central Iowa before sunrise on July 8 and rapidly traversed eastward across Iowa and into Illinois. A second set of thunderstorms developed over west central Iowa later that afternoon and slowly moved along the same path as the morning storms. By the time these storms weakened on July 9, a wide area of 3 to 9 inches of rain fell in an uninterrupted 275-mile long band from the Nebraska border at Onawam eastward through Denison, Ames, Marshalltown, Waterloo, Independence and Guttenburg.

C. Rainfall Data

Rainfall totals for the month of May are shown on Plate 11. The isohyetal map shows that the heaviest rainfall in the district occurred in Iowa with a monthly total of 8 inches. Central Iowa recorded up to 6 inches in many places and western Illinois had a total of 4 inches.

Precipitation totals were significantly higher for the month of June (Plate 12). The western Illinois/eastern Iowa area recorded a total of 13 inches. Other parts of Iowa had from 7 to 11 inches for the monthly total. Southern Wisconsin and southern Minnesota had between 7 to 13 inches of precipitation. Northern Missouri had a total of about 7 inches.

For the month of July (Plate 13), of the areas within the Rock Island District, Iowa had the highest totals. Eastern and central Iowa recorded up to 14 inches. The western part of the state had from 6 to 14 inches. Southern Minnesota and southern Wisconsin had from 6 to 10 inches and northern Missouri recorded between 6 and 14 inches of rain.

The rainfall totals for August are shown on Plate 14. In Iowa, the totals ranged from 4 to 14 inches, with the heaviest occurring in the northeastern part of the state. In Illinois, the totals ranged from 4 to 6 inches. Wisconsin's totals were about 4 inches. Minnesota recorded between 4 and 8 inches, and Missouri had from 4 to 8 inches.

IV. Mississippi River Basin

A. Main Stem Basin Description

The Mississippi River drains an area of 79,200 square miles at its upstream end of the Rock Island District at Guttenburg, Iowa, and has a total drainage area of 137,500 square miles at Lock and Dam 22, Saverton, Mo., the downstream limit of the District. Plate 1 shows the District's drainage area. Table 5 summarizes the drainage areas of the major tributaries and adjacent inflows contributing to each pool within the District. The slope of the Mississippi River between St. Anthony Falls at Minneapolis, Minn., downstream to its confluence with the Missouri River averages approximately 6 inches per mile except at the Rock Island-LeClaire Rapids in Pools 14-15 and the Des Moines Rapids in Pool 10, where the low water slope prior to construction of the pools was approximately 1.5 feet per mile. Topography near the pools is generally characterized by high bluffs and rolling hills.

The climate is variable at this junction where various air masses cross the continent. The weather is subject to change from cold, dry Arctic air masses in the winter to hot, dry air masses from the desert southwest in the summer. In addition, the area may be affected by mild Pacific Ocean air that has lost considerable moisture crossing the mountains, by cool Canadian air or by warm moist air from the Gulf of Mexico. The seasons also vary from year to year. The spring and fall seasons are more noted for the rapid changes from one type of air mass to another, and it is normally during these seasons, when most of the precipitation occurs. The summer of 1993 was an exception to this norm.

Major historical floods have resulted from a combination of snow melt and heavy general rains over the upper Mississippi River basin. The mean annual runoff of the Mississippi River at Lock and Dam 20 is 7.0 inches. This is equivalent to 49,279,000 acre-feet from 134,300 square miles of drainage area. The infiltration rate over the watershed is approximately 0.1 inch/hour. The mean annual runoff fluctuates from year to year.

B. Main Stem Hydrology/Hydraulics

1. Description of Flooding

The flooding on the Mississippi River was the most devastating in terms of property loss, disrupted businesses and personal trauma (Photo 7) of any flood in the history of the United States. Millions of acres of farmland were under water for weeks during the growing season. Damaged highways and roads disrupted overland transportation throughout the flooded region.