CHAPTER 6

Hydrology

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Discussion of hydrology in this report is concerned mainly with the distribution, amounts, and effects of surface waters within the floodplain of the Upper Mississippi River System (UMRS). Floodplain hydrology, however, is affected by the entire Upper Mississippi River watershed as described in Chapter 5.

The Missouri River, which drains the Great Plains region, is the largest tributary of the Upper Mississippi River, draining 74 percent of the basin and supplying 40 percent of the long-term discharge below St. Louis, Missouri. The Illinois River, largest of the other major tributaries within the five UMRS states, supplies 12 percent of the long-term discharge. Of the remaining tributaries, the Wisconsin and Iowa Rivers each supply 5 percent, and the Des Moines, Minnesota, St. Croix, and Chippewa Rivers, and the Mississippi River at Minneapolis, Minnesota, each supply 2 to 4 percent. Although the natural watershed does not include the Great Lakes, a human-made canal now links Lake Michigan and Chicago, Illinois, to the Illinois Waterway (see Chapter 14).

Factors that shaped the floodplain are its geologic and glacial history, physiographic setting (see Chapter 4), and the river's ability to erode and deposit sediments (after Kellerhals and Church 1989). Since European settlement, humans have become a major factor in influencing the hydrology of these rivers.

Although no single theory about the hydrologic system and ecosystem processes is universally accepted, scientists generally agree these systems are connected. The River Continuum Concept (Vannote et al. 1980; Minshall et al. 1985) linked energy sources and consumption to stream order. The Flood Pulse Concept (Junk et al. 1989), as applied to large floodplain rivers, includes the view that organisms adapt mechanisms to use resources of the land area wetted and dried during the annual flood and low-flow cycle. In a review of the literature, Johnson et al. (1996) reported that altering upland and wetland ecosystems often results in modified flow regimes.

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Present Status

The UMRS floodplain encompasses approximately 2.7 million acres (1.1 million ha), although only about 19 percent of it is normally covered with water (Laustrup and Lowenberg 1994). The rest of the area may or may not be covered with water depending on discharge rates and the effectiveness of levees. The potential difference in water coverage is shown in satellite imagery of an area near the confluence of the Illinois, Mississippi, and Missouri Rivers (Figure 6-1, following page). The top image was taken during the 1989 drought and the bottom one during the 1993 flood.

The hydrology of the UMRS has been altered significantly by humans. Hundreds of thousands of square miles of historical

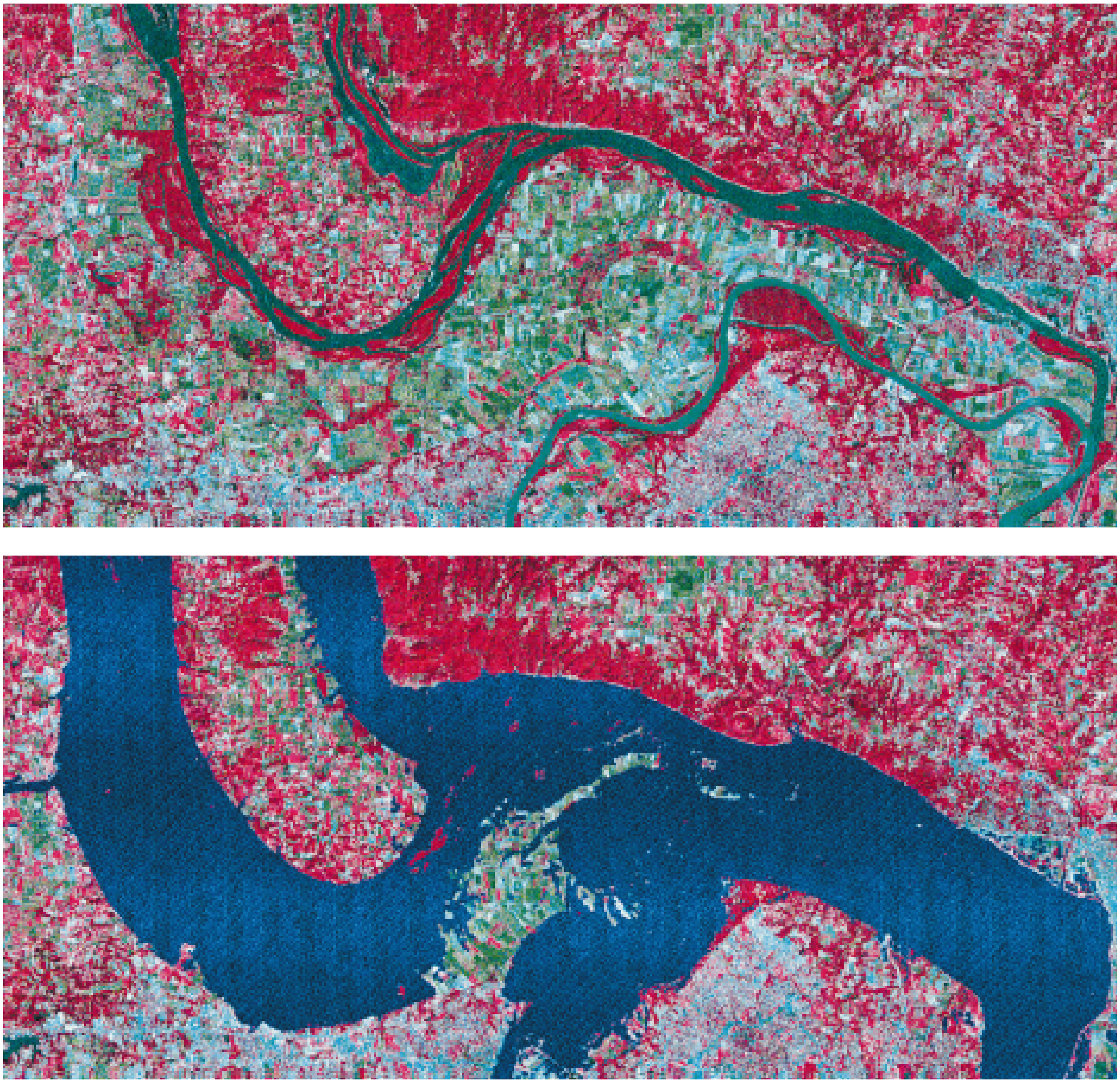

Figure 6-1. **These satellite images of the confluence of the Illinois, Mississippi, and Missouri Rivers illustrate the extent of the flood zone. The top image was taken during low flows in 1989, the bottom image during extreme flooding in 1993 (Source: USGS Environmental Management Technical Center, Onalaska, Wisconsin, and IFMC 1994).**

wetlands, prairies, and forests have been converted to agricultural and urban areas, changes that increased the velocity and erosiveness of waters flowing through the watershed. The U.S. Army Corps of Engineers constructed 76 reservoirs in the basin that provide a combined flood storage volume of 40 million-acre feet (49 billion m^3; IFMRC 1994). These reservoirs are used primarily to store excess water during floods and release it at other times. In addition, more than 3,000 other reservoirs have been constructed by other agencies and individuals. The flood storage volume of 40 million-acre feet (49 billion m^3) would take over 3 months to flow past St. Louis at average discharges. Wetland drainage in the Mississippi and Missouri

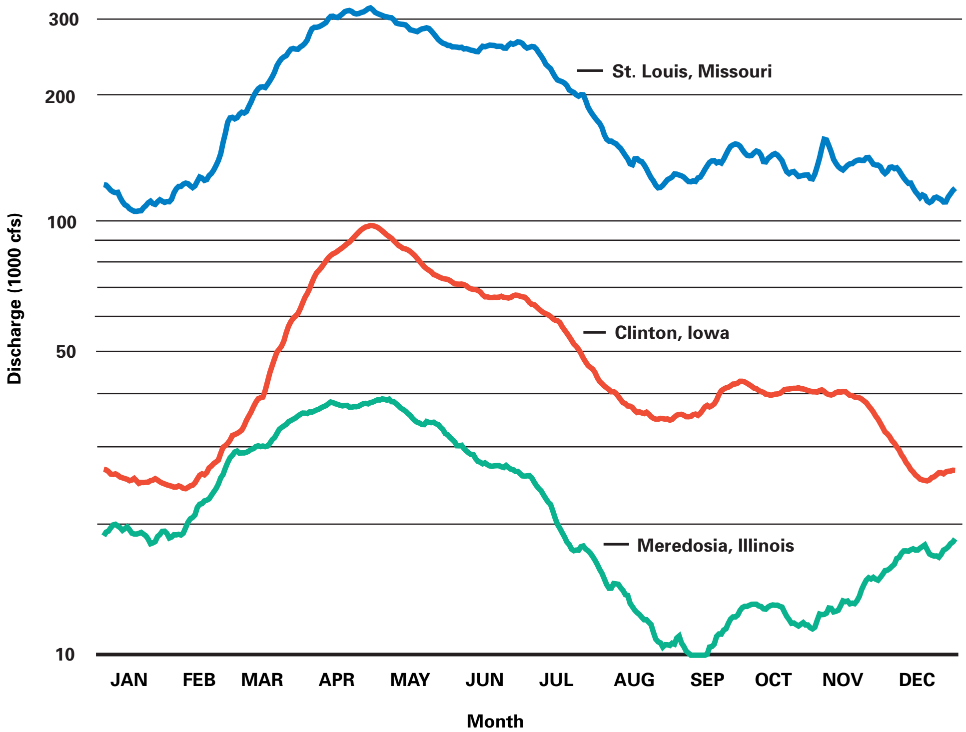

Figure 6-2. The daily mean discharge in cubic feet per second (cfs) at St. Louis, Missouri, Clinton, Iowa, and Meredosia, Illinois (Illinois River) illustrates seasonal patterns in flow. The logarithmic scale on the left axis helps distinguish trends among wide-ranging data, i.e., the large difference between the Illinois River and the Mississippi River below the confluence of the Missouri and Mississippi Rivers.

River watersheds over time has affected 26 million acres (10.5 million ha; Hey and Philippi 1995). An estimated 34 to 85 percent of wetlands have been lost in Wisconsin and Minnesota and 85 to 95 percent in Iowa, Illinois, and Missouri (Dahl 1990). Highways, railroads, cities, and other structures also affect UMRS hydrology though they were not constructed for that purpose.

On the main stem of the Mississippi and Illinois Rivers 34 dams have been constructed, mostly as an aid to navigation. Thousands of wing dams also were constructed to help maintain a minimum 9-foot (2.7 m) deep navigation channel. An estimated 8,000 miles (12,900 km) of levees have been constructed for flood protection. As stated, the waters of Lake Michigan were not historically connected to the Mississippi River watershed. When the Chicago Sanitary and Ship Canal opened in 1900, water was diverted to the Illinois River at the rate of up to 10,000 cubic feet per second (cfs) (283 cubic meters per second [cms]), raising the river's average water surface elevation by 1.5–4 feet (0.5–1.2m; Talkington 1991). A U.S. Supreme Court decision limited discharge levels to 6,500 cfs (184 cms) in 1930, 5,000 cfs (142 cms) by 1936, and finally a maximum of 1,500 cfs (42.5 cms) by 1939 because of concerns over lowered water levels in Lake Michigan.

The long-term average hydrologic pattern on the UMRS is dominated by high discharge in the spring and low discharge in the fall and winter (Figure 6-2). The Mississippi River at St. Louis, which drains 97 percent of the UMRS watershed, shows the highest mean discharges in April and May and the lowest discharges in December and January. The Mississippi River at Clinton, Iowa, has the lowest discharges in midwinter, with autumn discharges somewhat higher than those in late summer. The Illinois River at Meredosia, which drains most of the Illinois River watershed, most often experiences low discharges in September, followed by

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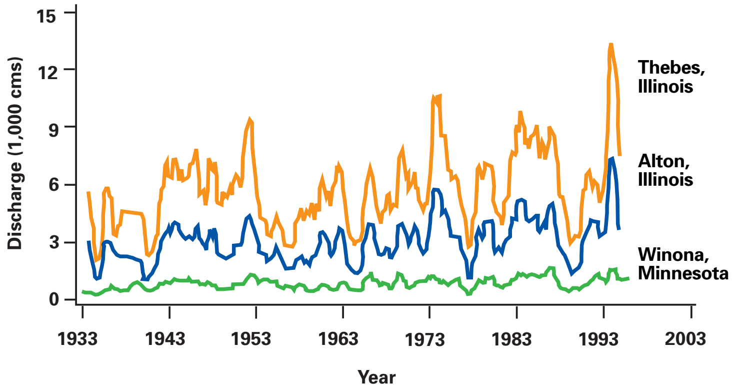

Figure 6-3. The 12-month moving average discharge in cubic feet per second (cfs) at Winona, Minnesota; Alton, Illinois; and Thebes, Illinois; shows approximate 11-year cycles, an apparent long-term increase in flow over the period, and an increase in the frequency and amplitude of multiyear fluctuations in recent decades (Source: USGS Environmental Management Technical Center Onalaska, Wisconsin).

increased discharges through the fall and winter. The 12-month moving average discharge (Figure 6-3) shows approximate 11-year cycles, an apparent long-term increase in flow over the period and an increase in the frequency and amplitude of multiyear fluctuations in recent decades (also reported by Knox 1984). The 12-month average is used to smooth annual variation when investigating longer-term trends. Droughts in the 1920s and 1930s contributed to development of the navigation system and also exacerbated water-quality problems such as algae blooms, increased un-ionized ammonia concentrations, and vegetation decline (John Sullivan, Wisconsin Department of Natural Resources, La Crosse, Wisconsin, personal communication).

Change From the Past

The reduced extent of land intermittently flooded (the flood zone) each year is one of the most significant changes caused by human influence on the UMRS. Chief among the activities that affect the river system's hydrology was construction of dams and levees. Dams permanently flooded areas that previously had drained and exposed bottom soils during a considerable portion of the annual discharge cycle. Levees effectively eliminated a large portion of the floodplain from normal high waters.

A Long Term Resource Monitoring Program (LTRMP) study looked at changes in the flood zone at both pool and floodplain reach scale (see Chapter 2 for a discussion of scales). Pool 8 represents the Upper Impounded Reach (Pools 2–13) and Pool 25 the Lower Impounded Reach (Pools 14–26). Three 2-mile (3.2-km) long sections of geographic information system (GIS) coverages within Pools 8 and 25 (upper, middle, and lower portions of the pools) were selected for analysis along with one section within the Unimpounded Reach. In the study we calculated the difference between the long-term average high- and low-water surface elevation for each of the seven locations and used that calculation to determine the areal extent of the flood zone as it is and as it would be if dams and levees were not present (Figure 6-4). Decrease in the areal extent of the flood zone in Pool 8 is attributable to the presence of a navigation dam that inundates much of the flood zone upriver from the dam. In Pool 25, the change is attributable to the combined presence of levees and a navigation dam. In the Open River, the change is attributable to the presence of levees. These changes affect animal migrations, nutrient exchange, and geomorphological processes.

Daily water-surface elevation and discharge data are available, dating back over 130 years from St. Louis, Missouri, and over 60 years from Chester and Thebes, Illinois. Analyses of data from these three stations show two clear trends. At the same low discharge of 60,000 cfs (1,700 cms), water-surface elevations decreased while at the same high discharge of 780,000 cfs (22,090 cms), water-surface elevations have increased (Figure 6-5). Thus, at low discharge habitats previously aquatic now are dried, and at high discharges greater land areas may now be inundated during floods if levee systems fail.

Expanding this line of investigation, analyses of maximum water levels for several 10-year periods at five stations from St. Paul, Minnesota, to near Cape Girardeau, Missouri, show that flood heights have increased over time (see Figure 6-3). The linear trend at St. Paul is not significant, but it is at each of the other four stations.

The number of days water elevations are above flood stage also is increasing. At St. Louis, water-surface elevations were above flood stage for 217 days from 1880 to 1917; 312 days from 1918 to 1955; and 485 days from 1956 to 1993. Without the influence of the Missouri River, the change is even more significant. In Pool 24, the number of days above flood stage for the same three periods was 295, 470, and 1,166 respectively.

Discussion

The daily mean discharge shown in Figure 6-2 was computed from data collected over a span of more than 50 years. The annual variability in discharges for all stations is notable about these means. As an example, daily discharge is presented for the wettest (1993), driest (1934), and long-term average years of record for Clinton, Iowa (Figure 6-6, following page). The pattern for these years and rate of change is quite different than the overall means.

The areal extent of the present flood zone for each of the seven locations studied is significantly less than what would occur if dams and levees were not present (Figure 6-4). Between 52 to 90 percent of the floodplain historically was affected by the flood zone in the study locations. Currently the flood zone affects 0.1 to 50 percent of the floodplain. In addition changes in the direction of water surface elevations upriver of many dams may be the opposite of what occurs naturally. As discharge increases water levels now may drop. Water surface profiles at high discharge closely approximate unregulated flow/stage relations.

Changes in the relation between water surface elevations and discharges

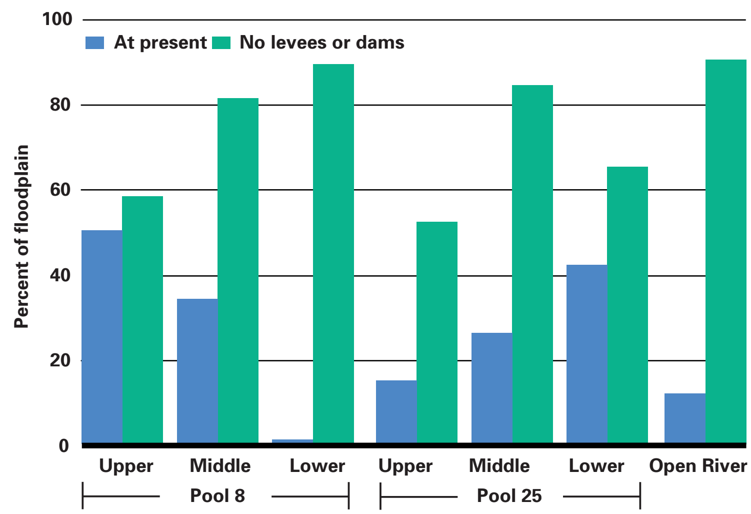

Figure 6-4. The percent of floodplain normally wet or dry during a given year is shown as it is at present and as it would be if there were no levees or dams. Pool 8 experiences the greatest impact from dam effects; Pool 25 is affected at the upstream end by levees and at the downstream end by the dam; the Open River is affected only by levees.

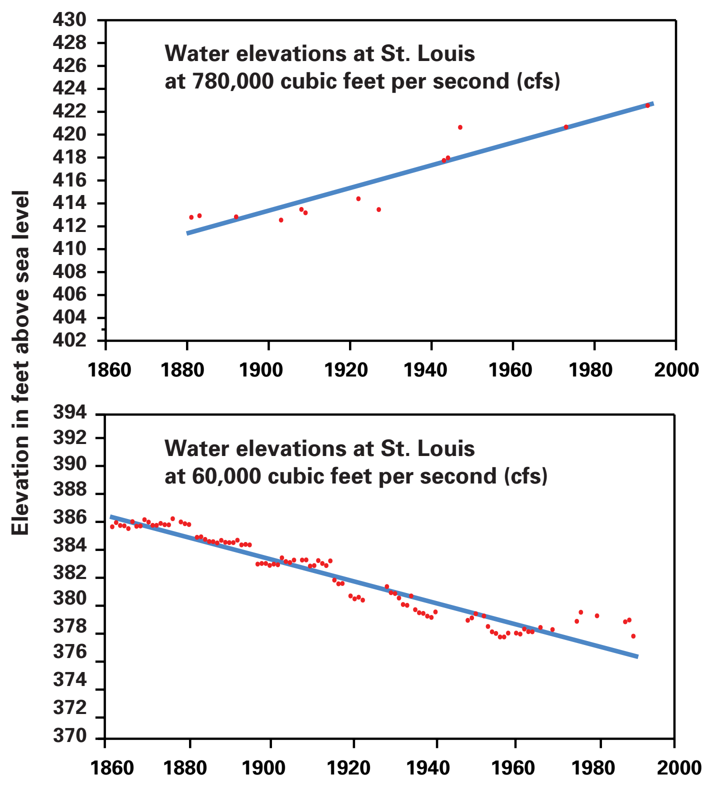

Figure 6-5. Changes in the relation between water surface elevations and discharge during floods at 780,000 cubic feet per second (cfs) (22,090 cubic meters per second [cms]) and 60,000 cfs (1,700 cms) in the Unimpounded Reach at St. Louis, Missouri. Levees and wing dams have been implicated in these changes.

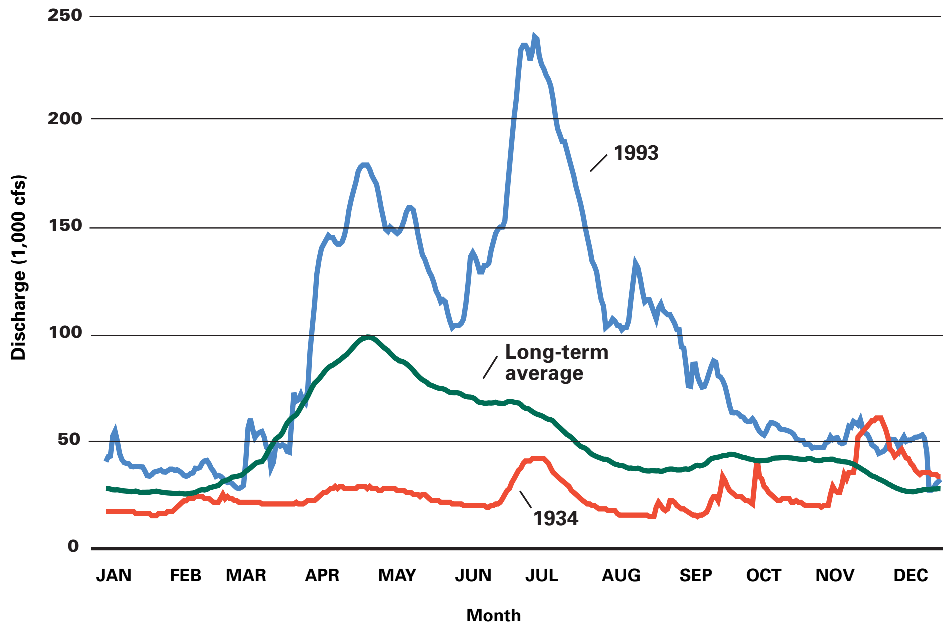

Figure 6-6. Daily mean discharge in cubic feet per second (cfs) on the Mississippi River at Clinton, Iowa, is useful to analyze seasonal patterns, but the divergence from the mean during a year with high discharge (1993) and one with low discharge (1934) shows the wide range of flows beyond the long-term average that can be experienced on the Upper Mississippi River System.

Present-day floods on the Mississippi River at St. Louis tend to be 9 feet (3 m) higher than historic floods at 780,000 cfs.

(Figure 6-5) result from a number of factors. Methods in measuring discharge have changed; thus river hydrologists question the accuracy of discharge measurements during flood periods at St. Louis before 1933. Dikes that project out from the river banks have narrowed and scoured the channel. During high flows, levees restrict use of the entire floodplain. Bridges and other structures tend to slow the flow of waters. In addition changes in the watershed, such as the increase in urban areas and the conversion from forests to agricultural areas have affected the speed at which water reaches these main stem stations on the Mississippi River.

Present-day floods on the Mississippi River at St. Louis tend to be 9 feet (3 m) higher than historic floods at 780,000 cfs. A plot of the 10 greatest floods at St. Louis (as measured by water-surface elevations) shows they were all recorded after 1942 (Figure 6-7). In the last 60 years, a major flood (water-surface elevations reaching at least 418 feet [127 m] above sea level or 12 feet [3.7 m] above flood stage) has occurred at St. Louis about once every 6 years on average.

Information Needs

Water-surface elevation and discharge data have been collected continuously at a few locations on the UMRS for up to 130 years. Collection of these two important variables should continue at these long-term sites to allow for trend detection. In addition, depth, width, and velocity measurements taken at these sites, available only in hard-copy format, could be converted to electronic databases and historic data could be calibrated.

Elevation data are available only for the floodplain at 5-foot (1.5 m) intervals but dams can be used to manipulate water levels in smaller increments. To manage more effectively, better resolution data are needed for land-surface elevations. Better information also is needed on system response to changes in water-surface elevations. Such data will help in determining the best management alternatives for both structural and nonstructural changes. Two-dimensional hydrodynamic models also are needed on a pool-wide basis to allow prediction of erosion, sedimentation, and water velocities at the local habitat scale.

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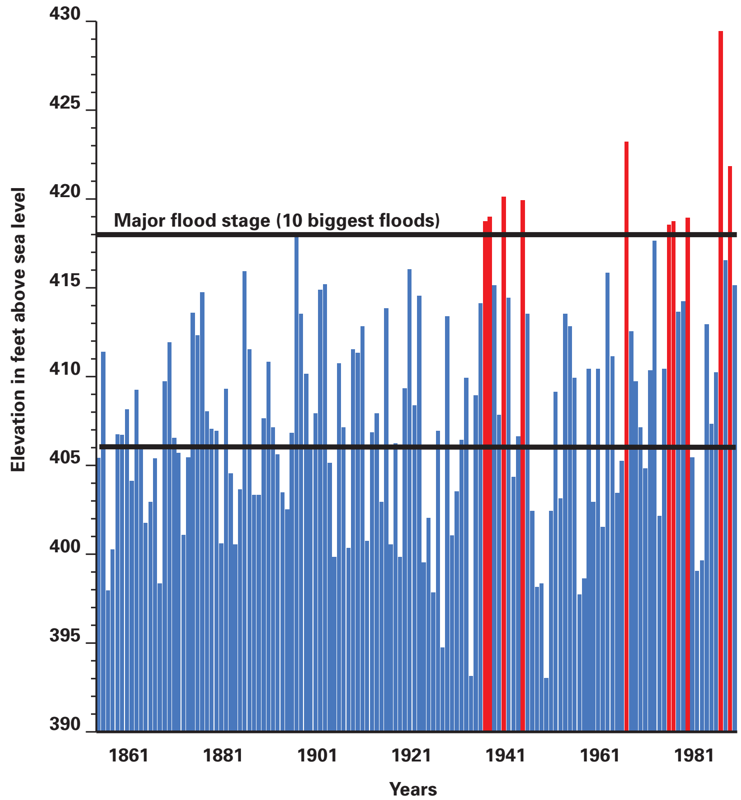

Figure 6-7. The 10 highest floods at St. Louis, Missouri, ranked by water-surface elevation, have occurred in the last 60 years. Rainfall has shown an increasing trend through the period, but some of the cause for higher flood stages has been placed on development within the floodplain.

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