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Report to Congressional Requesters

August 1995

MIDWEST FLOOD

Information on the Performance, Effects, and Control of Levees

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GAO

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Resources, Community, and
Economic Development Division

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August 7, 1995

The Honorable Robert A. Borski
Ranking Minority Member
Subcommittee on Water Resources
and Environment
Committee on Transportation
and Infrastructure
House of Representatives

The Honorable William L. Clay
House of Representatives

This report responds to your request that we examine the performance, effects, and control of levees involved in the 1993 Midwest flood.

As agreed with your offices, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of this letter. At that time, we will send copies to the Secretaries of Defense, Agriculture, and the Interior; the Director, Office of Management and Budget; and other interested parties. We will make copies available to others on request.

Please contact me at (202) 512-7756 if you or your staff have any questions. Major contributors to this report are listed in appendix VII.

James Duffus III

James Duffus III
Director, Natural Resources
Management Issues

Executive Summary

Purpose

The intense rainfall that deluged the upper Mississippi River basin in the spring and summer of 1993 caused the largest flood ever measured at St. Louis. This unprecedented event in nine midwestern states generated the highest flood crests ever recorded at 95 measuring stations on the region's rivers. The catastrophic flooding caused 38 deaths, as well as extensive damage to property and agriculture; required the evacuation of tens of thousands of people; and created large-scale disruptions in transportation, business, and water and sewer services. The President declared 505 counties to be federal disaster areas, and estimates of the damage have reached as high as $16 billion.

The Ranking Minority Member of the Subcommittee on Water Resources and Environment, House Committee on Transportation and Infrastructure, and Representative William L. Clay asked GAO to examine the operation of levees, which are earthen or masonry structures, including floodwalls, that are typically built along rivers to keep floodwaters from overflowing adjacent floodplains. Specifically, GAO was asked to review the extent to which (1) the U.S. Army Corps of Engineers' (the Corps) flood control levees prevented flooding and reduced damage during the event; (2) the federal levees increased the height of the flooding and added to the damage; and (3) federal, state, and local governments exercise control over the design, construction, placement, and maintenance of nonfederal levees.

Background

The Corps has invested over $23 billion nationwide in flood control projects, such as reservoirs, levees, floodwalls, and channel improvements. Today, 251 Corps levees are found in the five Corps districts covering the upper Mississippi River basin, which includes the Missouri River basin; 193 of these levees are found in the area affected by the 1993 flood.

Nearly half of these 193 levees are located on major rivers—the Mississippi River between Rock Island and Cairo, Illinois, and the Missouri River between Omaha, Nebraska, and Kansas City, Missouri. Over one-third of the levees on major rivers protect urban areas, such as Omaha, Nebraska, and Kansas City and St. Louis, Missouri. The remaining Corps levees protect agricultural areas. Other Corps levees lie on tributary streams, and most of them protect small communities.

A levee's design capacity is based on the particular level of protection that is justified by an analysis of the risks, costs, and benefits of constructing the levee. Corps levees generally provide more protection than do nonfederal levees. A typical Corps levee in an urban area protects against a large flood that is relatively unlikely to occur in a given year, such as a flood with an annual probability of 1 percent—commonly called a 100-year flood. A typical nonfederal agricultural levee protects against a smaller flood that is more likely to occur in a given year, such as a flood with an annual probability of 20 percent—commonly called a 5-year flood.

Results in Brief

According to Corps records, 157 of the 193 Corps levees found in areas affected by the 1993 flood prevented rivers from flooding about 1 million acres and causing $7.4 billion in damage. Another 32 levees withstood floodwaters until the water rose above the levees and overtopped them. Four other levees were breached or otherwise allowed water into protected areas before the levees' design capacity was exceeded. The Corps estimated the damage caused by the overtoppings and breachings of these 36 levees at about $450 million.

Because a levee confines a flood to a portion of a floodplain, it pressures the floodwater to rise higher than it otherwise would. Whether a levee significantly increases the level of a flood varies by location. Many other natural and man-made factors, however, also affect the peak level of a flood, but their exact impact is difficult to identify. While Corps levees increase the levels of floodwaters that could cause damage elsewhere, Corps officials emphasized that the net effect of the Corps levees and reservoirs in the upper Mississippi River basin is to reduce flooding.

No federal program specifically regulates the design, placement, construction, or maintenance of nonfederal levees built by private individuals or by public entities such as levee districts. However, federal programs for regulating navigable waters and wetlands and for providing flood insurance and disaster and emergency assistance may exercise control over certain levees, depending on whether the levees are built in navigable waters or in wetlands, help qualify a community for flood insurance, or are damaged in a flood. Seventeen states have programs to regulate levees, including five of the nine states involved in the 1993 flood. Local programs to control levees have generally been created in response to the requirements of the federal National Flood Insurance Program and state regulatory programs that require localities to control land use or implement other floodplain management measures.

Principal Findings

Most Corps Levees Prevented Flooding and Reduced Damage

Of the 181 levees for which the Corps had information on design capacity and flood flows or levels, 145 performed up to their design capacity and prevented flooding, 32 met their design capacity until the floodwaters exceeded their height and overtopped them, and 4 allowed water to enter their protected areas before they were overtopped. The information showed that many levees withstood flood flows that were greater than the levees were designed to withstand. In addition, the levees were able to withstand saturation far longer than the 1 to 2 weeks contemplated in their design.

For example, the Keach levee in Greene County, Illinois, which was designed to protect against floods of up to 438.5 feet, withstood water that rose to 442.8 feet. The levee held because sandbagging efforts raised its height and prevented the flood from entering the protected areas.

The Corps has qualified the accuracy and completeness of its and the National Weather Service's (NWS) estimates of the damage prevented and incurred because of the broad scope of the flood damage and the rapid compilation of preliminary estimates. Because of the methodologies they use to estimate damage, the Corps and NWS report that their estimates of the damage prevented and incurred are probably understated.

Levees Increase Flood Levels but Are One of Many Factors Affecting the Extent of Flooding

Levees in the upper Mississippi River basin increased the height of water in the 1993 flood, according to three modeling simulations. The simulations indicated that agricultural levees on the Mississippi River added up to 2.7 feet to the flood peak at St. Louis. Corps officials told GAO, however, that the floodwater storage capacity of reservoirs compensates for the increases in flood levels caused by levees. Experts agree that natural and man-made factors also directly affect the height of the water levels and the amount of the damage that occur during a flood. Natural factors include the flood's duration, the seasonal level of vegetation, the deposition of sediment carried by the water, and the water's temperature. Man-made activities include urban development, agriculture, navigation, and other development in wetlands.

Studies have indicated that, cumulatively, natural and man-made changes within the basins have raised the levels of the Mississippi and Missouri rivers. In addition, precipitation in the upper Mississippi basin appears to be increasing over the long term. These trends concern experts because increases in the frequency and extent of flooding increase the damage it causes.

Federal, State, and Local Governments Exercise Some Control Over Nonfederal Levees

Nonfederal levees are regulated to some extent under two federal regulatory programs that require permits for constructing levees in wetlands (the Clean Water Act) or in navigable waters (the Rivers and Harbors Appropriation Act of 1899). Also, under the National Flood Insurance Program, the Federal Emergency Management Agency (FEMA) exempts communities from certain requirements of the flood insurance program if the communities can show that the levees protecting them are designed, constructed, located, and maintained according to specified criteria. Under the levee rehabilitation program, the Corps will make cost-shared repairs of nonfederal levees that are threatened or damaged by floods if the levees meet the program's qualifying standards and have been properly maintained.

Of the nine states involved in the 1993 flood, five—Iowa, Kansas, Minnesota, North Dakota, and Wisconsin—have programs to regulate levees. Iowa, for example, generally requires permits for constructing, operating, and maintaining levees in rural areas and in urban areas that exceed a minimum size. For each levee, Iowa specifies requirements for the level of protection, location, drainage, and other design factors.

Local governments generally exercise more control over local floodplains and levees than the states or the federal government because FEMA requires that communities adopt floodplain regulations to join its flood insurance program. Local ordinances can require building codes for development in floodplains, and zoning regulations can restrict land uses—including the construction, operation, and maintenance of levees—in floodplains.

Recommendations

GAO is not making any recommendations.

Agency Comments

GAO discussed the facts in its report with responsible officials of the five agencies primarily involved. These included the Chiefs of the Corps' Readiness, Hydraulics and Hydrology, Central Planning Management, and Policy Development branches; the Director of FEMA's Program

Implementation Division; the Deputy Chief for Programs of the Natural Resources Conservation Service; the Chief of the U.S. Geological Survey's Science and Applications Branch; and the Chief of NWS' Hydrological Service Branch. Generally, these officials agreed with the information provided but offered comments, corrections, and suggestions to improve the accuracy and clarity of the report. GAO made changes to the report where appropriate.

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Abbreviations

cfs	cubic feet per second
EDA	Economic Development Administration
FEMA	Federal Emergency Management Agency
GAO	General Accounting Office
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
USGS	U.S. Geological Survey

Introduction

The 1993 Midwest flood, termed "the Great Flood of 1993," was unprecedented in the United States in terms of the amount of precipitation, the recorded river levels, the duration and extent of the flood, the damage to crops and property, and the economic impact. The intense rainfall that deluged the upper Mississippi River basin in the spring and summer of 1993 caused the largest flow[1] ever measured at St. Louis. Affecting nine midwestern states, the rainfall generated record-high flood levels[2] at 95 measuring stations on the region's rivers. Because of the catastrophic flooding, 38 people died, millions of acres were inundated, property and agriculture sustained heavy damage, tens of thousands of people were evacuated from their homes, and transportation, business, and water and sewer services were disrupted. President Clinton declared 505 counties to be federal disaster areas, and estimates of the damage have ranged from $12 to $16 billion.

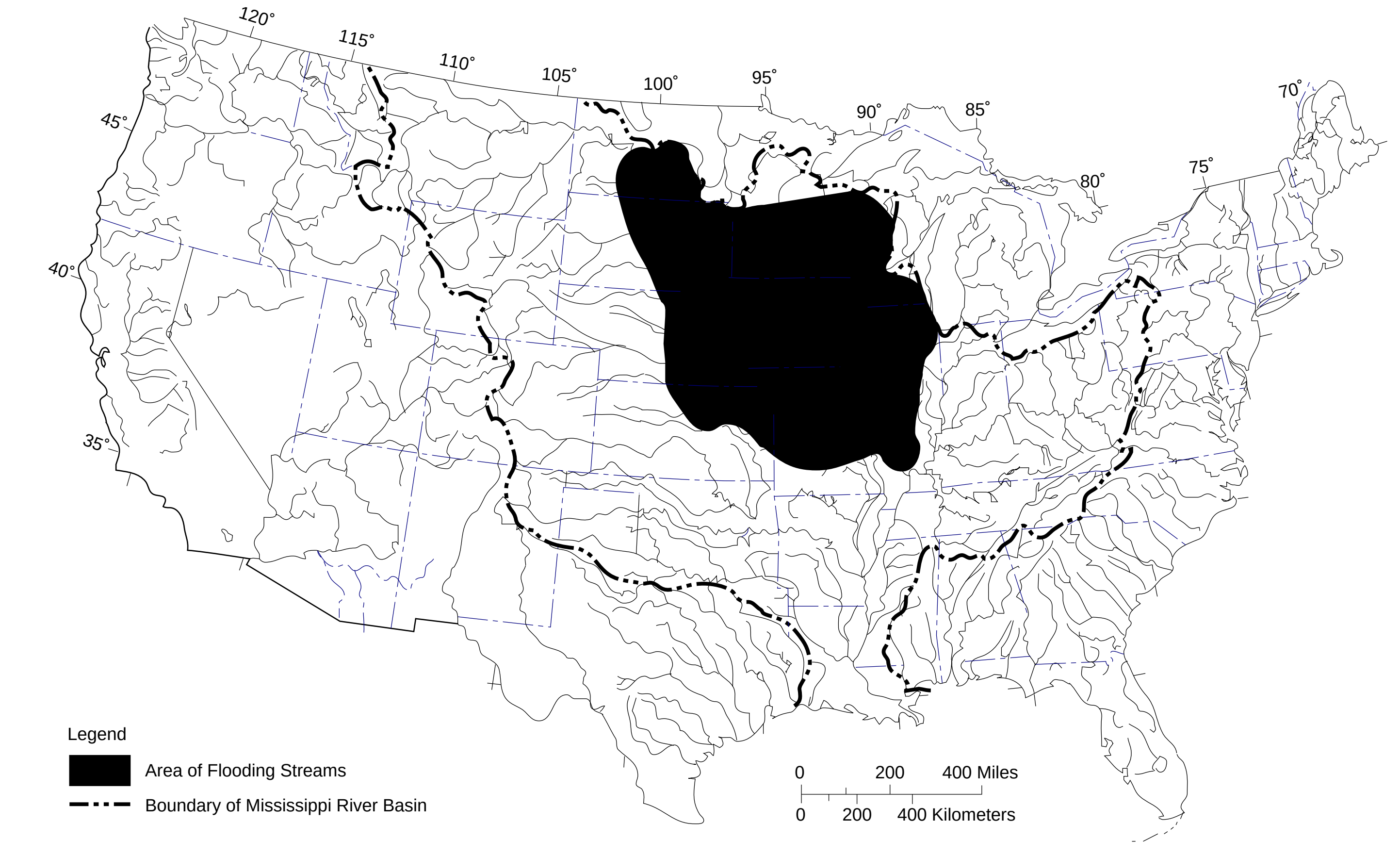
The Great Flood of 1993

The 1993 flood affected most of the upper Mississippi River basin. The basin drains all or part of 13 states and encompasses about 714,000 square miles, or 24 percent of the contiguous United States. The upper basin includes the Mississippi River from its source in Minnesota to its confluence with the Ohio River at Cairo, Illinois. Its principal tributary is the Missouri River, which joins the Mississippi at St. Louis, Missouri. Other major tributaries include the Minnesota, Wisconsin, Iowa, Des Moines, and Illinois rivers. Figure 1.1 shows the Mississippi River basin and the area of the 1993 flooding, and figure 1.2 compares two satellite images of the St. Louis, Missouri, area at the confluence of the Illinois, Mississippi and Missouri rivers during a severe drought and during the 1993 flood.

[1]Flow is also called discharge and refers to a given volume of water passing a measurement point in a stream within a specified period. Flow is commonly expressed in cubic feet per second (cfs).

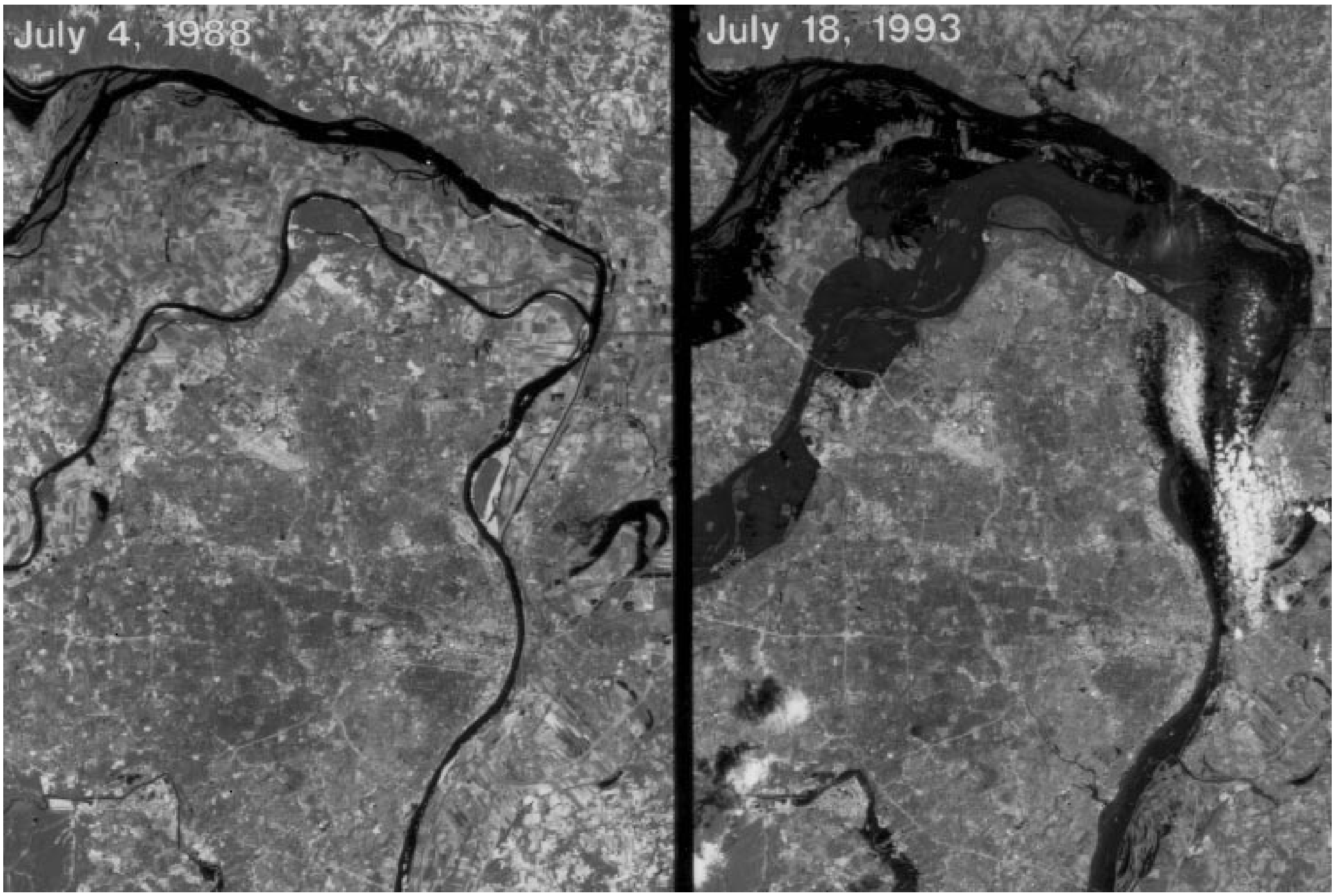
[2]In this report, we will use the terms "water level" or "flood level" instead of the term "flood stage" to refer to the height of the water's surface in a river above a predetermined point that is usually on or near the channel's bottom.

Figure 1.1: The Mississippi River Basin and the 1993 Flood Area



Source: Flood Discharges in the Upper Mississippi River Basin, 1993, U.S. Geological Survey (USGS) Circular 1120-A, Department of the Interior (Washington, D.C.: 1993), p. 1.

Figure 1.2: Landsat Images of the St. Louis, Missouri, Area, Including the Confluence of the Illinois, Mississippi, and Missouri Rivers During the 1988 Drought and the 1993 Flood



Source: Earth Observation Satellite Company, Lanham, Maryland.

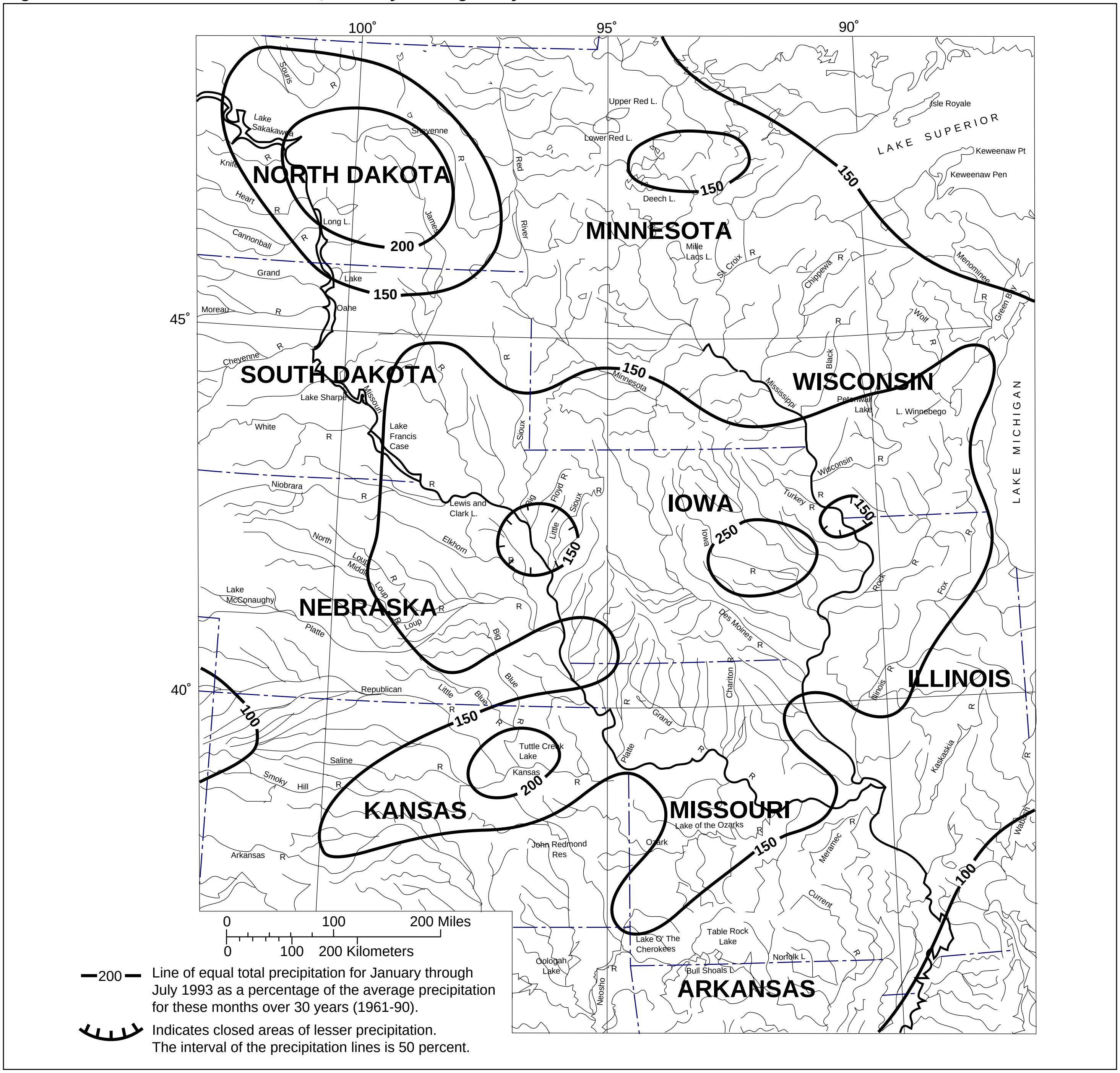
Saturated Soil, Heavy Rainfall Led to Flooding

The conditions that produced the flood began in the summer of 1992. According to the Department of Commerce's National Weather Service (NWS), July, September, and November 1992 were much wetter than normal in the upper Mississippi River basin. Winter precipitation was near normal, but a wet spring followed. The period from April to June 1993 was the wettest observed in the upper basin in the last 99 years. As a result, soils were saturated, and many streams were flowing well above normal levels when summer rains began.

A persistent atmospheric pattern during the summer of 1993 caused excessive rainfall across much of the upper Mississippi River basin. Major flooding resulted primarily from a series of heavy rainfalls from mid-June through late July. A change in the upper air's circulation pattern created drier conditions in late July and early August, but heavy rainstorms brought more flooding to parts of the upper basin in mid-August.

The rainfall over the upper Mississippi River basin from May to August 1993 is unmatched in the historical records of the central United States. Generally, rainfall from the Dakotas to Missouri and Illinois was well above normal. Figure 1.3 locates the heaviest concentrations of rainfall from January through July 1993 in the flood region.

Figure 1.3: Concentration of Rainfall, January Through July 1993

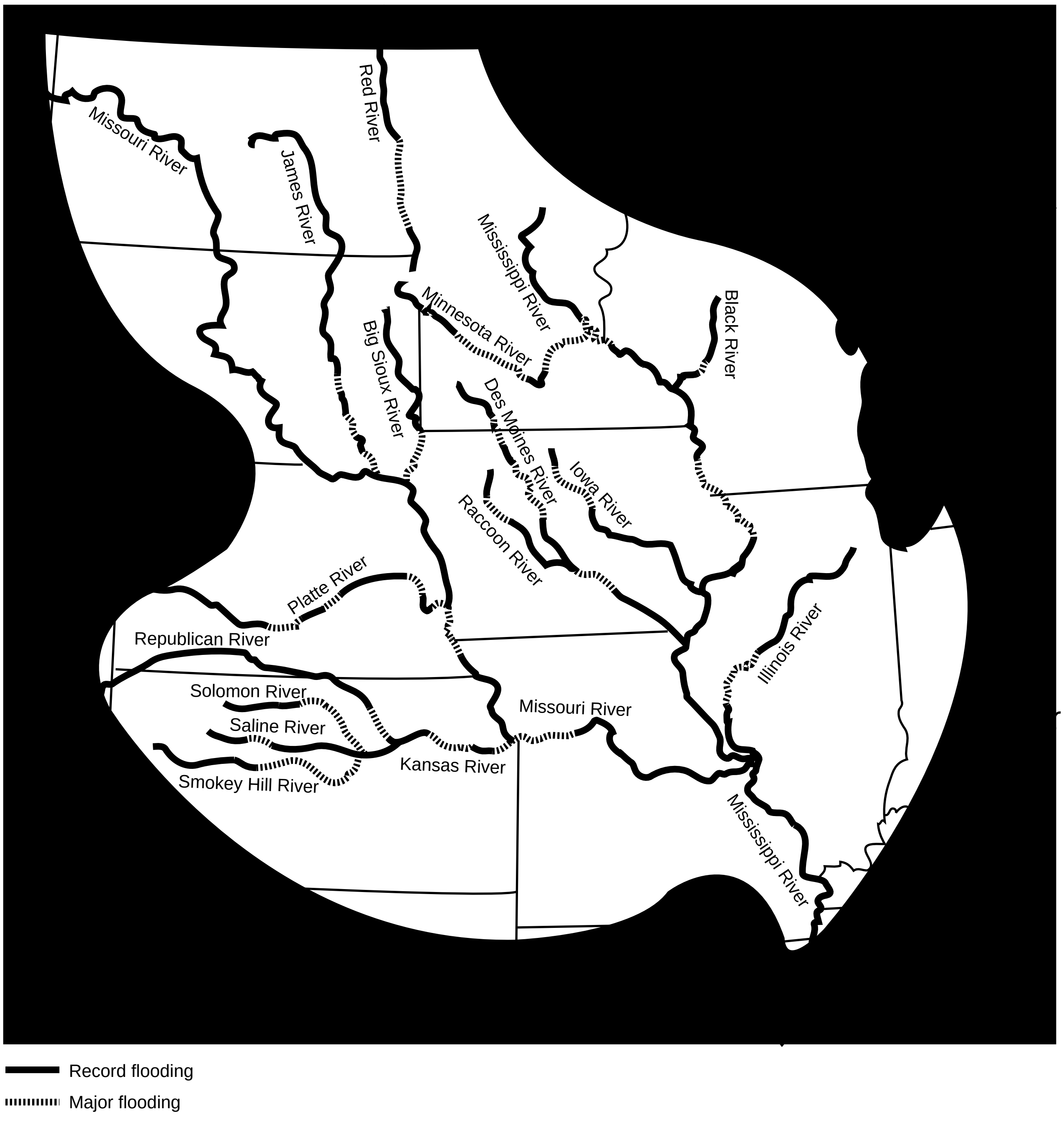


(Figure notes on next page)

Source: Precipitation in the Upper Mississippi River Basin, January through July 31, 1993, USGS Circular 1120-B, Department of the Interior (Washington, D.C.: 1993), p. 5. The figure is based on data from NWS.

Rivers rose above flood levels at about 500 measurement points in the nine-state region, NWS reported. Record flooding occurred at 95 measurement points in the Upper Midwest—44 on the upper Mississippi River system, 49 on the Missouri River system, and 2 on the Red River of the North system. Water flow rates along major parts of the upper Mississippi and lower Missouri rivers equalled or exceeded floods with an annual probability of 1 percent—commonly called a 100-year flood. Figure 1.4 shows where the heaviest flooding occurred.

Figure 1.4: Location of Record and Major Flooding Along Large Midwestern Rivers in 1993



(Figure notes on next page)

Source: Natural Disaster Survey Report: The Great Flood of 1993, NWS, National Oceanic and Atmospheric Administration, Department of Commerce (Washington, D.C.: 1994) p. 1-2.

Extreme flooding of major river systems like the Mississippi and Missouri rivers seldom occurs in the summer. During a typical midwestern summer, a few localized heavy rains are scattered throughout the region. In 1993, the rare combination of closely timed and record-level rainfall occurred on both the lower Missouri and upper Mississippi basins, causing a record flood at St. Louis.

NWS reported that the extended duration of the flood was also extremely rare. Typically, periods of above-average rainfall during a midwestern summer last from 2 to 5 weeks, sometimes persisting up to 8 weeks. In 1993, major flooding continued throughout the summer along the Missouri and Mississippi rivers. For example, as of September 1, 1993, Hannibal, Missouri, had experienced 153 consecutive days, or about 22 weeks, of water above flood level. Flooding continued through the middle of September in many regions along the Mississippi River.

Flooding Caused Widespread Damage

The administration established the Interagency Floodplain Management Review Committee to evaluate the performance of existing floodplain management programs in light of the 1993 flood. Their review of existing damage estimates for the flood found that these estimates ranged from $12 billion to $16 billion. The available estimates are from such federal agencies as NWS and the Federal Emergency Management Agency (FEMA), which develop estimates for specific program purposes, such as disaster response and assistance. The Committee estimated that $4 billion to $5 billion in damage was to crops in upland areas outside the floodplain, which were destroyed by the heavy precipitation there. The Committee attributed about $2.5 billion in agricultural damage directly to the flooding.

Other significant damage occurred to about 100,000 residences, more than 5,000 businesses, many bridges, hundreds of miles of roads and railroads, and 33 airports. The flood also closed the major rivers to navigation and affected about 200 municipal water systems, 388 wastewater facilities, and other public facilities, such as public buildings and parks.

FEMA reported that about 6.6 million acres in the floodplain were flooded in 1993, of which 63.4 percent were agricultural lands and 2.5 percent were urban areas. The remaining acres in the floodplain were normally covered by water, were wetlands, and/or were used for other purposes.

Federal Involvement in Flood Control

The primary federal agency involved in flood control is the U.S. Army Corps of Engineers (the Corps). The Department of Agriculture's Natural Resources Conservation Service (NRCS)[3] is indirectly involved in flood control when it addresses the effects of flooding in agricultural watersheds.[4]

U.S. Army Corps of Engineers

After a series of disastrous floods affected wide areas, the Congress enacted the Flood Control Act of 1936. This act established a nationwide policy that (1) flood control was in the interest of the general public and (2) the federal government would cooperate with the states and local entities to carry out flood control activities. The Corps' flood control programs are designed to reduce the susceptibility of property to flood damage and to relieve human and financial losses.

The Corps has invested over $23 billion in flood control projects nationwide. It has constructed more than 600 projects, including reservoirs and about 10,500 miles of levees and floodwalls. Flood control reservoirs often provide the capacity to store water for multiple uses, including municipal and industrial water supplies, navigation, irrigation, production of hydroelectric power, conservation of fish and wildlife, maintenance of water quality, and recreation. Levees and floodwalls are usually turned over to local sponsors for operations and maintenance.

The Corps is also authorized to perform emergency activities, such as fighting floods, repairing and restoring flood control works, and supplying emergency clean water to communities. It also performs emergency assistance work requested and funded by FEMA. Permanent repairs to levees and other flood control facilities are provided under a levee rehabilitation program. Five of the 37 Corps districts performing civil works activities were involved in the 1993 flood: St. Paul, Minnesota; Rock Island, Illinois; St. Louis and Kansas City, Missouri; and Omaha, Nebraska.

[3]Under the authority of the Federal Crop Insurance Reform and Department of Agriculture Reorganization Act of 1994 (P.L. 103-354, Oct. 13, 1994), the former Soil Conservation Service was abolished and NRCS was established.

[4]A watershed is a region or area contributing to the water supply of a particular stream, river, or body of water.

Of the 251 Corps levees located in these districts, 193 were in the flooded area.

The Corps operates 98 reservoirs in the upper Mississippi River basin to reduce flood damage. Of these, 22 were constructed by the Bureau of Reclamation. While not all of the reservoirs were in the flooded area, most had some impact on the flood because they stored water. For example, Corps headquarters officials said the reservoirs stored more than 20 million acre-feet[5] of floodwater on August 1, 1993, reducing flood levels throughout much of the flood area—for example, lowering the crest of the Mississippi River at St. Louis on that day by 5 feet. In addition to the reservoirs, the Corps has built or improved more than 2,200 miles of levees for the protection of communities and agriculture in the basin.

Corps' Floodplain Management Assessment

After the 1993 flood, the Congress funded a broad 18-month effort by the Corps to assess floodplain management in the upper Mississippi River and lower Missouri River basins. This effort, which was separate from the work of the interagency committee, describes the existing resources in the floodplain, identifies alternatives for the future use of the floodplain, and suggests policy changes and areas for further study. The assessment was conducted in collaboration with numerous federal, state, and local governments and interested parties. The Corps presented its findings and conclusions in a report published on June 30, 1995.[6]

Natural Resources Conservation Service

NRCS' programs are designed to protect and prevent flooding in small watersheds, repair or relocate agricultural levees that are damaged in flooding, and convert cropland to wetland reserves. The Small Watershed Program authorized by the Watershed Protection and Flood Prevention Act of 1954 (P.L. 83-566) provides for NRCS to install land conservation measures and flood damage reduction works nationally. NRCS traditionally works on smaller projects affecting watersheds of fewer than 400 square miles; the Corps addresses needs in larger watersheds. In addition, NRCS has authority under the Flood Control Act of 1944 (P.L. 78-534) for a flood prevention program for 11 watersheds.

In the nine midwestern states affected by the 1993 flood, NRCS has performed soil and water conservation work on 3 million acres, installed

[5]An acre-foot is a unit measure of volume equal to 1 acre covered to a depth of 1 foot. One acre-foot is equal to 326,700 gallons.

[6]Floodplain Management Assessment of the Upper Mississippi and Lower Missouri Rivers and Their Tributaries (St. Paul, Minn.: June 1995).

2,964 reservoirs, and worked on 818 miles of channel. NRCS estimated that its watershed projects prevented $400 million in damage from the 1993 flood.

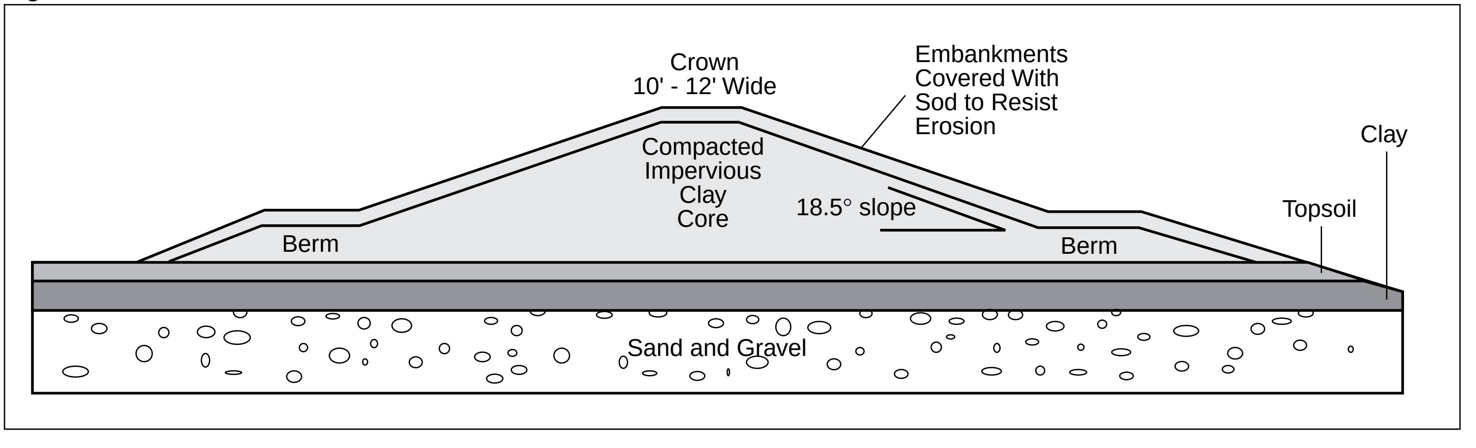
When a disaster strikes, NRCS implements the Emergency Watershed Protection Program under section 403 of the Agricultural Credit Act of 1978 (P.L. 95-334). This program provides assistance—including repairs to damaged levees—to reduce hazards to life and property.

Flood Control Levees in the Upper Mississippi River Basin

Levees are linear earthen embankments whose primary purpose is to prevent high water from reaching the floodplain. They normally extend from high ground along one side of a floodplain and around it to another area of high ground. Levees protect the area between the levee and the high ground.

For stability, an earthen levee is normally constructed so that its bottom width is several times its height; hence, a levee requires considerable land area. In urban areas where space is limited, the Corps builds masonry floodwalls. A long levee system may include a combination of several segments of earthen levees and floodwalls. Figure 1.5 represents a cross-sectional view of a typical earthen levee.

Figure 1.5: Cross-Sectional View of an Earthen Levee



Source: GAO's drawing based on a St. Louis Post-Dispatch graphic and data from the Corps.

Levees reduce but do not eliminate flooding in the floodplain because levees may be overtopped by floods larger than those for which they are designed. Generally, the Corps analyzes the risks, costs, and benefits of constructing a levee to various heights; determines, with the participation of a local cost-sharing sponsor, how much protection the levee should provide; and proposes a plan to the Congress. After reviewing the Corps' analyses, the Congress can authorize and fund the plan.

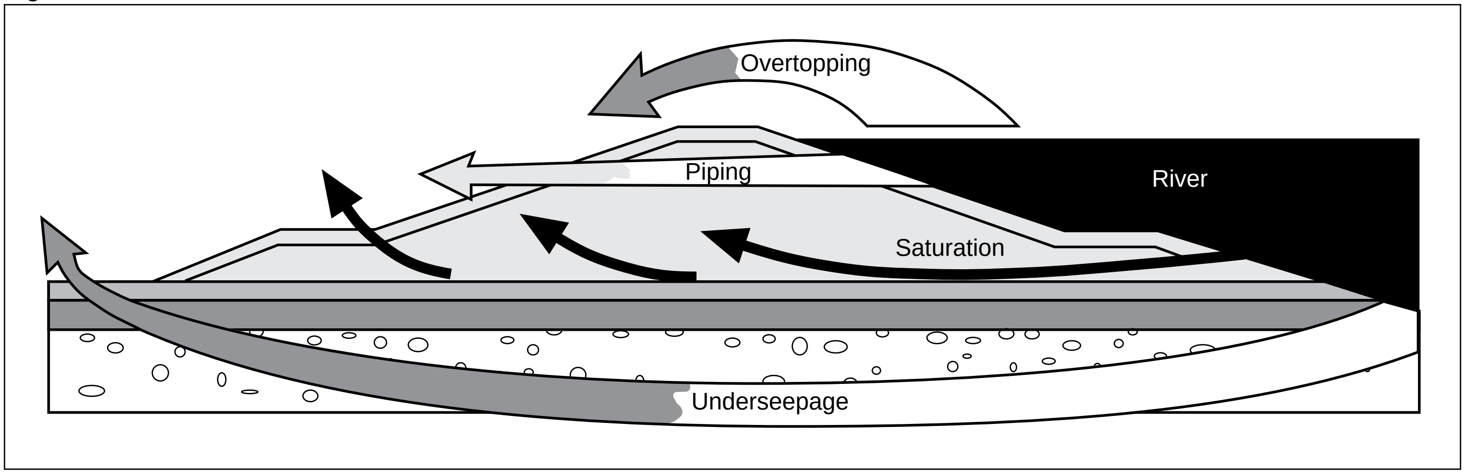
The height of a levee is based on the maximum flow (discharge) of floodwater, measured in cubic feet per second (cfs),[7] associated with flooding of a particular frequency, or average recurrence level, at the levee's location. For example, the Kaskaskia Island levee in the Mississippi River in Illinois, which is designed to withstand a flood with an average frequency (or recurrence interval) of 50 years, was built to withstand a water level of 45.7 feet[8] and a flow of 1,010,000 cfs. At other locations, floods of the same frequency will be associated with different heights and flows. For example, the Des Moines-Mississippi River levee in Missouri, which also protects against a flood with an average recurrence interval of 50 years, was built to withstand a water level of 24 feet and a flow of 371,000 cfs. Both levees provide the same degree, or level, of protection but have different performance criteria because the river's channel and flows differ greatly at these levees.

Engineers have accounted for uncertainties in the water level and for unknown factors—such as wave action, bridge openings, and the effects of urbanization—by adding 1 to 3 feet to the overall elevation of a levee's design; this addition is known as freeboard. A levee should withstand floods up to and including the flood for which it was designed. Floods larger than the design flood may overtop or breach the levee—that is, cut a hole through it. The ways that floods can damage levees—by overtopping, piping, saturation, and underseepage—are depicted in figure 1.6.

[7]A unit of measurement for a river's flow or discharge: 1 cfs is equal to the discharge of a stream at a rectangular cross section, 1 foot wide by 1 foot deep, flowing at an average velocity of 1 foot per second. One cfs is equivalent to 7.5 gallons.

[8]This number represents the number of feet above a site-specific river level, also known as the flood stage, at which damage may start to occur; it is usually at or above the top of the riverbank.

Figure 1.6: Potential Levee Failure Scenarios



Note: Overtopping refers to water flowing over the top of the levee. This action quickly erodes the landward slope, causing a breach in the levee. Internal erosion, called piping, occurs when water finds its way through animal burrows or channels formed by plant and tree roots to erode the levee internally. Through saturation, water permeates the levee's material, weakening the levee's ability to hold together. Underseepage occurs when the river pushes through a loose layer of sand beneath the levee and weakens the levee's foundation.

Source: GAO's drawing based on a St. Louis Post-Dispatch graphic and data from the Corps.

Hydrologists have several ways of describing the size of a flood at a specific location. They may refer to the water's level and flow, or they may refer to the average interval between occurrences of that particular water level and flow. They also refer to the annual probability that the same water level and flow may occur. Because floods occur randomly, the interval between extreme water levels of the same height are far from uniform—a large flood in one year does not preclude the occurrence of an even larger flood the next year. For example, a flood with an average recurrence interval of 100 years has a 1-percent chance of being equaled or exceeded every year. This means that a "100-year" flood may occur several times within a 100-year period, or it may not occur at all.

As communities and farms have grown on the floodplains of the upper Mississippi and Missouri rivers since the early to mid-1800s, levees have been constructed by various nonfederal entities, ranging from cities to individuals, to protect floodplains from seasonal flooding. Owners have wanted to protect the floodplain from flooding because it has often contained the most fertile land for farming. While no inventory of nonfederal levees exists, the Interagency Floodplain Management Review Committee estimated that such levees extend over 5,800 miles in the upper Mississippi River basin.

The Corps estimated that about 1,100 of the 1,358 nonfederal levees in the area covered by the five Corps districts involved in the 1993 flood failed to keep the flood out of the areas they were designed to protect or were otherwise damaged. Corps officials told us, however, that this estimate was approximate and incomplete.

Corps and nonfederal levees protect nearly all of the floodplain in the upper Mississippi River basin. Above Rock Island, Illinois, the Mississippi River floodplain is narrow and is filled largely with navigation pools. The remaining floodplain contains wildlife refuges, some farmland, and a few levees; scattered towns are protected by urban levees. Below Rock Island, the floodplain widens to as much as 6 miles, and because the extensive floodplain is used for crops, the river is almost continuously lined with Corps agricultural levees to Fort Madison, Iowa, and from Keokuk, Iowa, to Cairo, Illinois. In addition, many cities and towns, including St. Louis, are protected by levees and floodwalls in this section of the river.

Missouri River floodplains, used predominantly for agriculture, are protected to varying degrees by levees. Between Omaha and Kansas City, Missouri, the river is heavily lined with Corps agricultural levees. Between Kansas City and St. Louis, the Missouri River has four Corps levees, but the river is heavily lined with nonfederal levees.

Developed floodplains with larger urban areas—such as Omaha/Council Bluffs, Kansas City, and St. Louis—are largely protected by Corps urban levees. Near Kansas City and St. Louis, several residential, industrial, and commercial areas are built on floodplains behind levees.

Objectives, Scope and Methodology

The Ranking Minority Member of the Subcommittee on Water Resources and Environment, House Committee on Transportation and Infrastructure, and Representative William L. Clay of Missouri asked GAO to review the extent to which (1) the Corps' flood control levees prevented flooding and reduced damage during the event; (2) these federal levees increased the height of the flooding and added to the damage; and (3) federal, state, and local governments exercise control over the design, construction, placement, and maintenance of nonfederal levees.

To address these objectives, we obtained information from the Corps and other federal agencies, state agencies, and other public and private organizations. We also interviewed officials and obtained documents from these agencies and organizations, as well as from individuals. Appendix I provides further details on our scope and methodology.

We conducted our review between November 1993 and July 1995 in accordance with generally accepted government auditing standards. We discussed the facts in our report with responsible officials of the five agencies primarily involved: the Chiefs of the Readiness, Hydraulics and Hydrology, Central Planning Management, and Policy Development branches in the Corps' Civil Works Directorate; the Director of FEMA's Program Implementation Division; the Deputy Chief for Natural Resources Conservation Programs and the Acting Director of the Watershed Projects Division at NRCS headquarters; the Chief of the Science and Applications Branch and staff from the Office of Surface Water at USGS headquarters; and the Chief of NWS' Hydrological Service Branch. Generally, these officials agreed with the basic information provided but offered comments, corrections and suggestions to improve the accuracy and clarity of the report. We made changes to the report where appropriate.

Most Corps Levees Performed as Designed and Prevented Significant Damage

According to the Corps, 157 (81 percent) of the 193 Corps levees located in the area affected by the 1993 flood prevented rivers from severely flooding about 1 million acres. However, some of these acres were flooded by smaller streams behind the levees and by seepage under the levees. Nevertheless, the Corps estimated that the 157 levees prevented about $7.4 billion in damage during the flood.

Another 32 Corps levees withstood flood flows until the water exceeded their design capacity and overtopped the levees. Three other levees were breached without being overtopped by floodwaters, and an opening in an urban floodwall for railroad tracks was not closed in time to prevent flooding. The Corps estimated that flooding at the 36 levees caused about $450 million in damage.

To assess the levees' performance, we compared information on the levees' design values for either flows or water levels (design capacity) with the flows and water levels recorded during the 1993 event. Data were not available on either the levees' design capacity and/or the 1993 flows or water levels for 12 of the 193 levees. Data on the other 181 levees show that 177 withstood the flows and water levels at least as well as designed and 4 did not. The flood eventually overtopped some of the levees. Nevertheless, local flood-fighting efforts at some locations permitted levees to withstand flows and water levels that exceeded the levees' design capacity. Most levees also withstood saturation far longer than they were designed to do.

Levees' Performance Is Measured Against Design Criteria

Corps officials told us that generally three basic design criteria apply to each levee. Two of these are flood level, expressed in feet, and flow, expressed in cfs. The five Corps districts involved in the 1993 flood used data on either flood level or flow or on both criteria to judge the performance of levees. The third design criterion is the extent to which a levee can be saturated and still withstand its design flood.

The Corps designs levees to withstand saturation. However, according to Corps district officials, the time required to reach a levee's maximum saturation point varies by flood. A Corps manual (No. 1110-2-1913, Mar. 31, 1978) provides that levees are expected to be exposed to flood flows for only a few days or weeks per year. Embankments that will be exposed to flows for longer periods must meet more stringent criteria for earthen dams.

Water standing against a levee for an extended period may move through or under the levee, leading to problems such as sinkholes[9] or sandboils[10] on the landward side. The higher pressure of the floodwater will eventually overcome the materials within the levee and its foundation, and a breach may occur.

To determine whether a levee performed to its design capacity, we attempted to compare its design flow capacity with actual or estimated flows during the flood. If the levee's flow capacity was not available, we used the levee's flood level capacity. Corps district officials agreed that these measures were acceptable bases for assessing a levee's performance. As an additional criterion, we considered the length of time the levee withstood saturation from flooding.

We asked the Corps to give us the design capacity of, and the flow rates or water levels at, the 193 levees involved in the flood. District personnel told us that all or some of the data were not readily available for 12 levees. They said that Corps field staff or local officials advised them that the land behind the 12 levees was not flooded. Therefore, they said they can reasonably assume that these 12 levees performed within their design capacity. None of the 12 levees were designated as overtopped on Corps levee repair schedules. Appendix II lists the levees for which insufficient data were available for our comparison.

Most Corps Levees Performed to Their Design Capacity

Of the 181 levees for which comparative data were available, 177 clearly performed up to their design capacity and sometimes exceeded it during the 1993 flood. Many levees withstood flows that, in some cases, were greater than those for which the levees had been designed because flood-fighting efforts extended their performance by raising their height. In addition, many levees experienced saturation far longer than they were designed to do.

Of the 177 levees that clearly met performance criteria, 145 prevented the river from entering the protected floodplain. The flood eventually exceeded the design capacity of the remaining 32 levees and overtopped them. Only four levees allowed floodwater to enter the protected

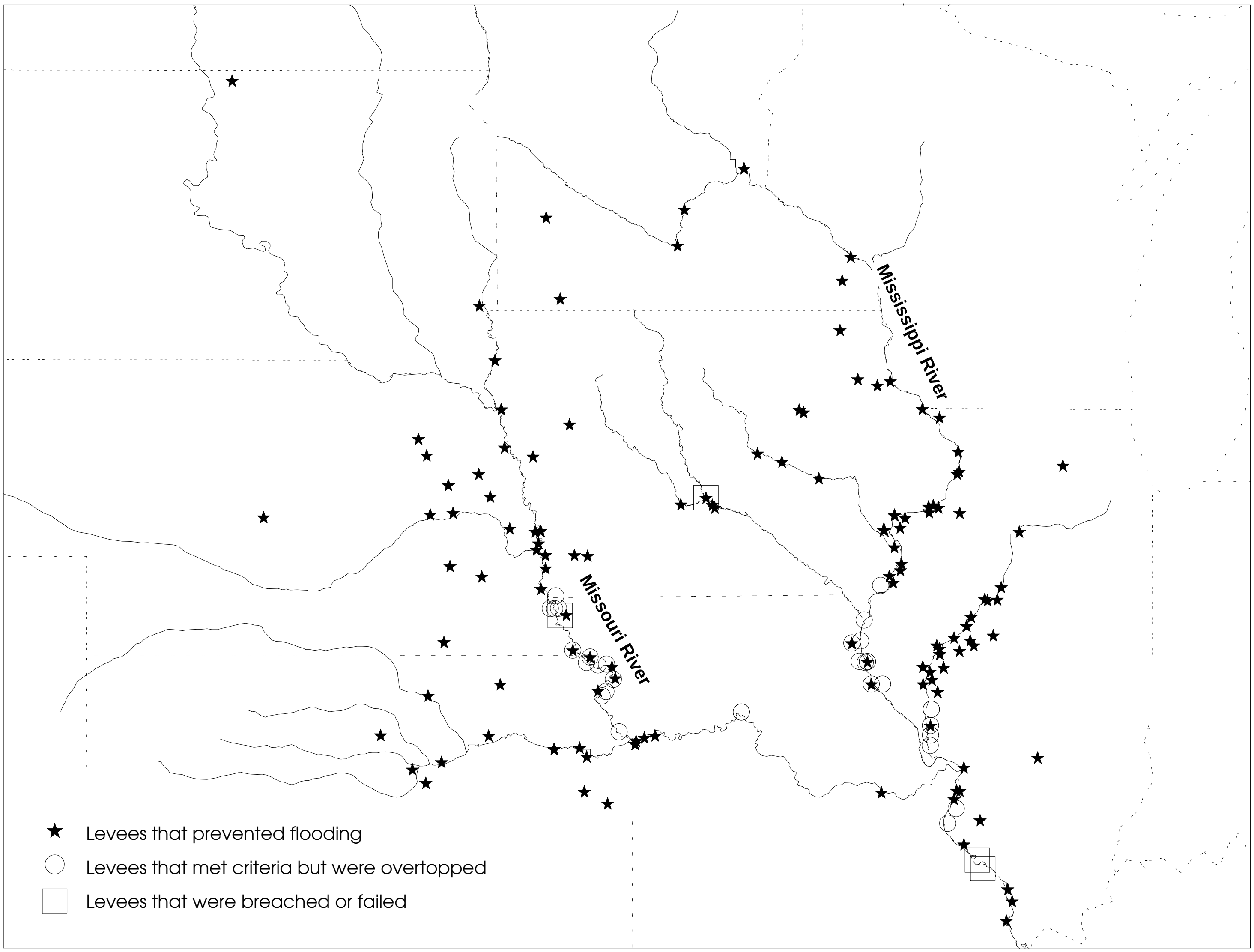
[9]Sinkholes occur when water pressure creates a void underground and progressively collapses the soil until the void reaches the surface and the surface collapses downward.

[10]Sandboils occur when underground water forces its way to the surface to create a bubbling, or boiling, fountain of water and sand.

floodplain before the levees were overtopped. Appendix III lists the 145 Corps levees in the flood area that the Corps said prevented flooding.

Figure 2.1 displays the location of the 193 levees in the flooded area and identifies the levees that met design criteria but were overtopped, as well as the levees that were breached or otherwise failed without first being overtopped.

Figure 2.1: Location and Performance of Corps Levees in the 1993 Midwest Flood



(Figure notes on next page)

Source: GAO's analysis of data from the Corps.

Flood-Fighting Efforts Extended the Performance of Some Levees

Corps officials said that, in some instances, flood-fighting at levees prevented water from entering protected areas when the water reached flow rates or elevations beyond the levees' design capacity. They said that workers prevented overtopping by piling sandbags and building other makeshift barriers on the top and landward sides of the levees. In these cases, a levee exceeded its design capacity in three ways. First, the added height permitted the levee to continue holding back the flood even when the water rose above the top of the levee. Second, the base of the levee withstood the additional water pressure created by extending the height. Third, because flood-fighting prevented or delayed overtopping, the levee withstood saturation far longer than anticipated.

Flood-fighting techniques effectively increased the design capacity of many levees. For other levees, such as those at St. Louis or North Kansas City, the success or failure of flood-fighting determined whether the levees were able to meet their original design capacity. Examples of flood-fighting efforts during the 1993 flood are described in appendix IV.

Floodwaters Exceeded the Design Capacity of Some Levees

According to the Corps, flooding caused 32 Corps levees to be overtopped. These levees were designed to protect against floods whose average recurrence intervals ranged from 20 to 500 years. Of the 32 levees, 26 were on the Mississippi and Missouri rivers where the flood was greatest. Five of the other six levees were located on the Illinois River, and one was located near the Missouri River. Table 2.1 lists, by Corps district and by river, the 32 levees that the flood overtopped, the design capacity of each levee, and the flood's estimated flow or water level at each levee.

Table 2.1: Comparison of Levee Design Capacity With Flood Flow or Level for 32 Levees That Were Overtopped

District/river/levee project	Design recurrence interval	Design flow (cfs)	Flood flow (cfs)	Design water level (feet)	Flood water level (feet)
Rock Island District					
Mississippi River					
Des Moines-Mississippi	50	371,000	446,000		
Fabius River	50	374,000	404,000		
Green Bay	50	376,000	422,000		
Gregory	50	371,000	393,000		
Hunt/Lima Lake	50	371,000	418,000		
Indian Grave - Upstream	50	349,000	419,000		
Indian Grave - Downstream	50	349,000	419,000		
Marion County	50	374,000	418,000		
Sny Island	50	349,000	400,000		
South River	50	349,000	524,000[a]		
St. Louis District					
Mississippi River					
Columbia	50	925,000	1,080,000	45.0	49.5
Harrisonville	50	980,000	1,080,000	45.0	49.5
Illinois River					
Eldred	20		74,200	438.0	440.8
Hartwell	20		79,300	440.5	440.9
Hillview	20		79,300	440.5	443.6
Nutwood	20		56,000	437.0	440.2
Spankey	20		76,200	437.5	440.8
Omaha District					
Missouri River					
MRLU[b] L-561	50	13,000	37,700		
MRLU L-575	50	35,000	38,000		
MRLU R-520[c]	200	310,000	307,000		
MRLU R-548	50	304,000	307,000		
MRLU R-562[c]	70	300,000	196,000		
Kansas City District					
Missouri River					
Chariton	50	476,000	487,000		
MRLU L-246	25	400,000	487,000		
MRLU L-400	100	348,000	503,000		
MRLU L-408[c]	100	270,000	335,000		

(continued)

District/river/levee project	Design recurrence interval	Design flow (cfs)	Flood flow (cfs)	Design water level (feet)	Flood water level (feet)
MRLU L-448-443[c]	100	325,000	335,000		
MRLU L-488[c]	100	322,000	335,000		
MRLU R-471-460[c]	100	325,000	335,000		
MRLU R-482[c]	100	325,000	335,000		
MRLU R-500[c]	100	309,000	307,000		
Tributary[d]					
Kimsey-Holly Creek	100	308,000	319,000		

Note: No Corps levees in the St. Paul District were overtopped.

[a]Peak event figure; flow for day of overtopping was not available.

[b]Missouri River Levee Unit. This system of levees was authorized by the Flood Control Acts of 1941 and 1944 as part of the Pick-Sloan plan for the Missouri River.

[c]The next section of this chapter explains why this levee was overtopped even though some or all of the data do not suggest that it was overtopped.

[d]Because USGS does not have a measurement gauge on Kimsey Creek, the figures appearing in the table are for the unbuilt portion of the levee along the Missouri River.

Source: GAO's analysis of data from the Corps and USGS.

Levees Were Overtopped for Various Reasons

We compared either the design flow capacity of the levee with the flood flow recorded at the gauge nearest the levee, or the design height of the levee with the flood level recorded at the gauge nearest the levee.

For 29 of the 32 levees, either the flood flow exceeded the design flow capacity of the levee or the flood level exceeded the design height of the levee. For example, the peak flood flow for the South River levee along the Mississippi River just south of Hannibal, Missouri, was 524,000 cfs, far above the levee's design flow capacity of 349,000 cfs.

The flood overtopped three levees, identified in table 2.1, even when the data indicated that the flood flow did not exceed the design flow capacity of the levees. Corps officials said that these cases may be generally explained by (1) a decline from the levee's design flow capacity, which they attribute to a change in the relationship between the flood level and the flow rate at the levee that resulted in higher flood levels for the same flow rate; (2) the distance between the levee and the gauge used to measure the flood flow, which resulted in an inaccurate flood flow estimate for the levee location; and (3) the location of the overtopping. For example, the main portion of Missouri River Levee Unit R-520 was not overtopped, just as the data indicate. However, the levee was overtopped at a point along a creek where the levee's design flow capacity was much lower.

The 32 levees whose design capacity was exceeded by the flood were concentrated in six general areas: above St. Louis, below St. Louis, the lower Illinois River, southeast Nebraska/northwest Missouri, north of Kansas City, and central Missouri. With one exception, the levees in these areas were built by the Corps to protect agricultural lands from floods. One levee was built to protect Elwood, Kansas, a community of about 1,000 residents, which lies across the river from St. Joseph, Missouri.

Four Corps Levees Were Breached or Failed

Three Corps levees, two on the Mississippi River and one on the Missouri River, were breached without first being overtopped by floodwaters. In addition, a railroad opening in a floodwall along the Raccoon River was not closed to prevent flooding in the city of Des Moines. Table 2.2 lists the design criteria and flood flows for these four levees.

Table 2.2: Comparison of Levee Design Capacity With Flood Flow or Level for Four Levees That Were Breached or Failed

District/river/levee project	Design recurrence interval	Design flow (cfs)	Flood flow (cfs)	Design water level (feet)	Flood water level (feet)
St. Louis District					
Mississippi River					
Bois Brule	50	1,010,000	905,000	45.70	46.01
Kaskaskia Island	50	1,010,000	898,000	45.70	47.38
Rock Island District					
Tributary					
Des Moines	100	100,000	116,000		
Omaha District					
Missouri River					
MRLU L-550	50	305,000	196,000		

Source: GAO's analysis of data from the Corps and USGS.

Corps officials said that they would not classify the breaches of the Bois Brule and Kaskaskia Island levees as performance failures for two reasons. First, these breaches occurred when the water reached the freeboard area of the levee, which is the safety zone above the levee's design height. They said that when water rises above a levee's design height, the levee cannot be expected to continue holding against a flood. Second, because the duration of the 1993 flood far exceeded the design standard for levees, some Corps officials believe that the breaches should not be characterized as performance failures.

According to Corps district staff, the breach in the third levee, Missouri River Levee Unit L-550, was caused by the use in the construction of the levee of a material that allowed underseepage. Corps staff told us that the fourth levee failed to prevent flooding because a railroad opening in the floodwall protecting the city of Des Moines was not closed in time. Each of these situations is described in appendix V.

Corps' Estimates of Flood Damage Are Imprecise

In its April 1994 report to the Congress on flood damage for fiscal year 1993, the Corps qualified the accuracy and completeness of estimates of the damage prevented and incurred because of the broad scope of the damage and the rapid compilation of preliminary estimates. Given their methodologies for estimating flood damage, the Corps and NWS said that their estimates of both the damage prevented and the damage incurred, presented in this report, are probably understated.

The Corps estimated that its levees prevented the flooding of about 1 million of about 1.4 million acres protected. The overtopping and breaching of levees caused about 400,000 acres to be flooded. However, in areas behind levees that held, some flooding still occurred because of heavy seepage through and under the levees and heavy flows from streams draining areas behind the levees. Corps officials said that they have not estimated the number of acres flooded from these sources.

According to the Corps, the levees prevented about $7.4 billion in flood damage during the 1993 flood. To calculate the damage prevented, the Corps uses damage curves that employ the principles of hydrology and economics to graphically depict the estimated costs of the damage that would occur if a Corps levee were not protecting the area. Economists compare curves depicting the estimated damage with and without a levee. The difference is the estimated value of the damage prevented by the project.

Corps staff said that the severity and duration of the 1993 flood in the St. Louis district were so great that the existing damage curves could not be used to estimate the damage accurately. As a result, Corps personnel extrapolated damage estimates for the 1993 flood from damage estimates for the large 1973 flood and used their professional judgment.

Corps staff pointed out that because the dollar values on the damage curves tend to be outdated, the estimates of flood damage derived from these curves are probably understated. They said that some of the dollar values they developed when they constructed the levee have not been updated to reflect the value of development that has since occurred behind the levee. They also mentioned that obtaining information about urban land values requires extensive fieldwork and research, which are labor-intensive, expensive, and time-consuming. Corps officials said that because their resources are limited, they give priority to updating information on the largest urban centers where the greatest threat of damage exists.

The four Corps districts where levees were overtopped and breached estimated that about $450 million in damage was incurred behind the levees. According to the Corps, it did not have sufficient funding to complete on-site field surveys to estimate the damage incurred from the 1993 flood and, as an alternative, used a variety of techniques to estimate the damage.

In the Rock Island District, for example, estimates were based on data from county-level sources that, according to Corps district officials, were rough estimates and were specific to only a few sites. The Omaha and St. Louis districts used computer programs and actual river elevations to compute the damage incurred, supplementing these sources with information from surveys of businesses, local and state government officials, and field personnel from the Department of Agriculture. The Kansas City District used water levels and damage curves to estimate the damage incurred.

NWS makes the overall estimates of flood damage suffered each year that the Corps reports to the Congress. For fiscal year 1993, NWS estimated that all floods caused more than $16 billion in damage. According to staff from NWS' Office of Hydrology, loss estimates can be considered only approximate because they are developed as an ancillary function to NWS' primary mission of forecasting weather and floods. They said the quality of resulting estimates is uneven because of insufficient resources, inconsistent methods and sources, incomplete data collection by field offices, and early reporting deadlines.

Conclusions

While data on the design flow capacity of the Corps levees and the actual flows during the 1993 flood are incomplete, the Corps levees in the area affected by the 1993 flood generally performed as designed. In fact, some levees withstood significantly greater flood flows and elevations than they were designed to withstand, especially when the duration of the flood is considered. Where the levees did not prevent water from entering protected areas, the Corps levees were overwhelmed by the size of the Great Flood of 1993.

Levees Increase Flood Levels, but Other Factors Also Affect Extent of Flooding

By confining floodwaters within a smaller portion of a floodplain than they would otherwise occupy, levees pressure the waters to rise higher and flow faster than they would do without restraint. Whether levees significantly increase flood levels varies by location. Computer simulations of the 1993 flood estimated that the nearby Corps levees added up to 2.7 feet to the flood crest at St. Louis and up to 7.3 feet to the flood crest at other locations.

Corps officials acknowledge that levees increase flood levels and induce some flooding. However, they emphasized that the net effect of levees, reservoirs, and navigation structures in the upper Mississippi River basin is to reduce flood levels and damage. There is no consensus among researchers, however, about the long-term effects of these structures on flood levels.

Many factors besides levees help determine the peak level of a flood. These include the amount of water entering a river from precipitation, the size and shape of the river's channel and floodplain, and other natural factors. Human activities, such as clearing the floodplain for cultivation, have also affected flood levels.

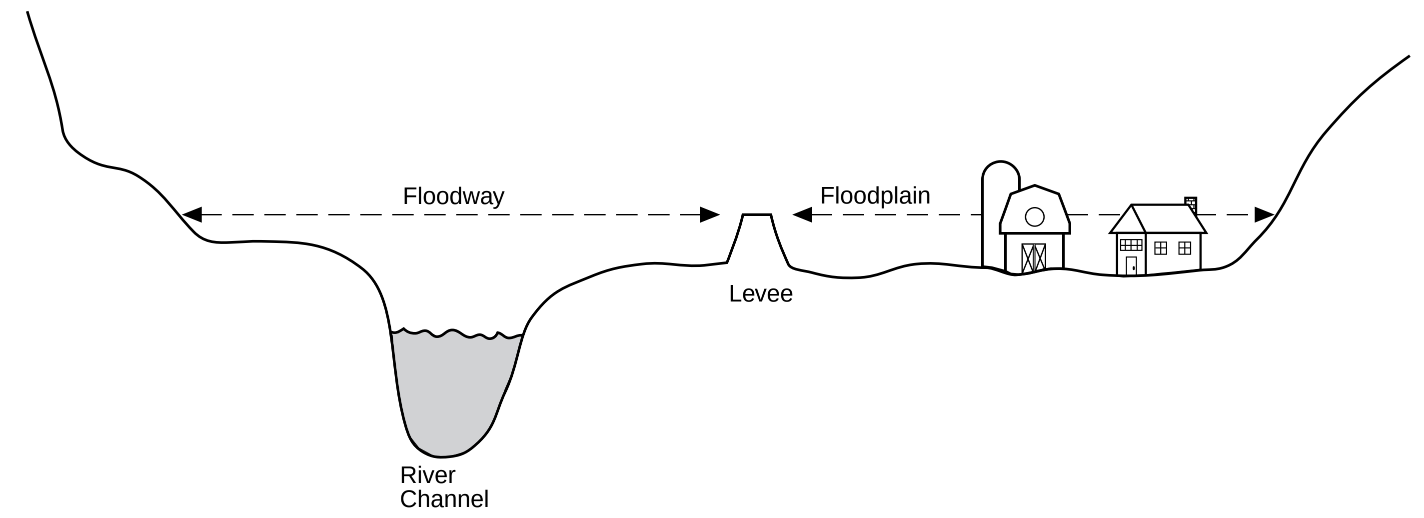
Studies show that cumulative changes within the basins have caused higher flood levels for Mississippi and Missouri river flows. In addition, available evidence suggests that precipitation in the upper Mississippi basin may be increasing. If these trends continue upward, rather than cycling downward, more frequent and more extensive flooding will occur and future damage from flooding may increase.

Experts Agree That Levees Contribute to Higher Flood Levels

Available studies and the experts we spoke with agreed that levees generally contribute to higher flood levels above and within the levied part of a river. They said that the construction of a levee in a floodplain forces the water into an artificial floodway,[11] causing the water to back up, just as the loss of a traffic lane on a busy highway causes heavy traffic to become congested. This restriction raises the level of the water both upstream of the levee and at the levee itself. It also forces the water to flow faster than it would if it were permitted to spread out across the whole floodplain. Figure 3.1 depicts a cross-sectional view of a floodplain and the floodway created by the construction of a levee.

[11]The floodway consists of the river channel and the adjacent floodplain areas that remain available to convey a flood after a levee or other structures are built.

Figure 3.1: Cross Section of a Typical Floodplain and Floodway



Impact of Levees on Flood Levels Varies

According to the results of a 1994 study conducted by a federal interagency team, a levee can increase flood levels from a few inches to several feet. Factors such as the size of the flood, the height of the levee, and the dimensions of the floodway compared with those of the natural floodplain account for much of the variation.

The U. S. Army Engineer Waterways Experiment Station, a Corps research facility, identified the impact of some of these factors in a 1991 study requested by FEMA.[12] Using a model developed by NWS, the Corps simulated a range of hypothetical floods and levees for 150 miles along the Missouri River from Jefferson City to Waverly, Missouri. This portion of the river is lined by mostly small private and other nonfederal agricultural levees that do not allow for the floodway recommended by FEMA.[13] These levees are built to varying heights and, as a result, do not provide a consistent level of protection. Overall, these levees prevent only small floods—those with average frequency intervals below 10 years—from entering the protected floodplain.

[12]Brad R. Hall, "Impact of Agricultural Levees on Flood Hazards," U. S. Army Engineer Waterways Experiment Station, Corps of Engineers, Technical Report HL-91-21 (Vicksburg: Oct. 1991).

[13]FEMA recommends that a floodway be that portion of the floodplain that, without encroachment from levees and other structures, would allow a 100-year flood to pass without increasing the water level by more than 1 foot.

The 1991 study found that the impact of levees on flood levels increases with the size of the flood until the flood is large enough to overtop the levees. It also estimated that raising the height of the existing levees to contain the 100-year flood would further increase flood levels by about 5 inches. Moving the existing levees back to FEMA's recommended floodway boundary would reduce peak flood levels for the 100-year flood by an average of about 1.2 to 1.5 feet. The study concluded that flood levels are more sensitive to the size of the available floodway than to the height of the levees.

Mississippi River Basin Levees Caused Some Increases in Flood Levels but Generally Prevented Damage in 1993

The results of three studies show that Corps levees and nonfederal levees contributed to the flood levels experienced during the 1993 flood. These studies used computer modeling to simulate flows and water levels in part of a river during the 1993 flood, with and without levees. Observed differences, therefore, can be attributed directly to the presence of levees. However, the accuracy of a model's results depends on the accuracy of the information describing the flood and the floodplain. It also depends on how well mathematical equations in the model represent actual hydrologic processes. These studies are the only modeling efforts on the 1993 flood to date and use models created by or accepted by the Corps. Because of the extremely complex nature of hydrologic computer models, we did not review the accuracy of the models or their results.

In 1993, the St. Louis Post-Dispatch commissioned an associate professor of civil engineering at the University of Illinois to simulate the 1993 flood. According to the researcher, the simulation included the Mississippi River beginning just north of St. Louis and extending 50 miles downstream to Prairie Du Rocher, Illinois. He used a Corps model that, for simplicity, assumes that floodwaters flow at a steady rate rather than at varying actual rates.[14] The simulation estimated that Corps agricultural levees added about 1.0 to 1.5 feet to the flood crest at St. Louis.[15]

The flood's crest passed St. Louis just as two large downstream agricultural levees were being overtopped and the land behind them flooded. The Post-Dispatch simulation indicates that if these levees had not been overtopped or if they had been overtopped at another time, they would have added from 1.4 to 1.8 feet to the crest. This would have

[14]The simulation used the Water Surface Profile Program, called HEC-2, which was developed by the Corps' Hydrologic Engineering Center, Davis, California. It is primarily used to compute profiles of water surface levels for complex rivers and streams.

[15]Robert L. Koenig, "The Flood That Wasn't," St. Louis Post-Dispatch (Dec. 26, 1993).

brought the crest to within a foot of the design capacity of the St. Louis floodwall.

After the 1993 flood, the administration established an interagency Scientific Assessment and Strategy Team to provide data and an analysis of the 1993 flood. At the request of the Interagency Floodplain Management Review Committee, the team simulated the flood. The simulation included the Mississippi River and major tributaries from near Hannibal, Missouri, to Cairo, Illinois, and the Missouri River from Hermann, Missouri, to the mouth at St. Louis, Missouri. This area contains Corps urban and agricultural levees and smaller private and other nonfederal levees. The team used a recently developed model capable of simulating the varying rates of flow that occur during a flood. The simulation estimated that Corps agricultural levees added a few inches to 7.3 feet to the flood crests at 14 locations. For St. Louis, it estimated that the levees added a maximum of about 1.5 feet to the flood crest.[16] These results were consistent with the results simulated for the Post-Dispatch.

The Corps, as part of its 1995 Floodplain Management Assessment,[17] also ran computer simulations of the 1993 flood. Its analysis, which included the lower Missouri River and the middle and upper Mississippi River basins, was performed on a systemwide basis using the model employed by the Scientific Assessment and Strategy Team. One simulation estimated that agricultural levees added up to 7.2 feet to the flood levels recorded at 11 locations in the Corps' St. Louis District, including about 2.7 feet at St. Louis. Similarly, it estimated that agricultural levees added from a few inches to 4.7 feet to the flood levels along the Missouri River with one exception: Agricultural levees reduced the 1993 flood levels at Hermann, Missouri, by about 1 foot.

No evidence is available to show the extent of the damage brought about by the addition to the flood's height attributable to the levees, but Corps officials acknowledge that damage was caused by the levees. The Corps also points out that its levees provided substantial benefits in 1993 by preventing flooding on about 1 million acres in the developed floodplain. The Corps estimates that its levees in the Kansas City, Omaha, Rock Island, St. Louis, and St. Paul districts prevented about $7.4 billion in flood

[16] Science for Floodplain Management into the 21st Century: Preliminary Report, Scientific Assessment and Strategy Team, Interagency Floodplain Management Review Committee (Washington, D.C.: June 1994), pp. 179-86.

[17] Floodplain Management Assessment of the Upper Mississippi River and Lower Missouri Rivers and Their Tributaries, U.S. Army Corps of Engineers, (St. Paul, Minnesota: June 1995)

damage. Although unprotected areas within reach of levee backflows are subject to greater flooding than would occur if no levees existed, Corps officials believe that the damage prevented by levees greatly outweighs that induced by levees. In addition, they said that the capacity of reservoirs to store floodwater compensates for the increases in flood levels caused by levees. For example, the Scientific Assessment and Strategy Team found that storing water in flood control reservoirs reduced the peak flood level at St. Louis by 5 feet in 1993. Thus, levees and reservoirs at St. Louis achieved a net reduction in flood levels.

Debate Continues Over Long-Term Effects of Navigation and Flood Control Structures on Flood Levels

Levees are one type of navigation or flood control structure that can affect flood levels. While the impact of levees on a particular event, such as the 1993 flood, has been estimated with sophisticated models, the long-term effects of such structures on flood levels in the Mississippi River basin is less certain. Over the years, researchers have used trend analysis to assert a relationship between long-term increases in flood levels and these structures. However, the value of this analysis is limited by a lack of accurate information about historic flood flow rates, as well as by the conflicting results these studies have yielded.

Historical Records of Floods Are Not Accurate

Much of the research is based on flow rates estimated for extreme floods at St. Louis. Some of the flow rates for extreme floods in the historical record are estimates based on observations of water levels recorded at the time of the floods. Other flow rates in the historic record are based on methods or equipment now shown to be inaccurate. In any case, measuring flow rates during extreme floods is very difficult and sometimes impossible. Not only can a flood destroy recording equipment, but it can also prevent access to the best measurement sites. As a result, 7 of the 10 highest flow rates recorded for St. Louis before 1993 are estimates rather than actual measurements.

A more accurate and now generally used device for measuring flow, the Price current meter, was not used exclusively at St. Louis until 1931.[18] Before that time, various methods of measuring flow rates were used. Some researchers question the accuracy of these methods for very high flows because of the findings of two studies conducted at the University of Missouri at Rolla.

[18]A Price current meter uses a set of rotating cups, which the river's current turns to indicate the flow's velocity.

The first study, conducted in 1976, found that estimates of very high flow rates are subject to large errors and that flows above the banks of the river could not be estimated satisfactorily.[19] The second study, conducted in 1979, tested the accuracy of measurement devices used at St. Louis before 1931.[20] Although the author concluded that most of the pre-1931 measurements were valid for use in analyses, he found that 57 percent of the test measurements taken for flows above the banks of the river using double floats[21] exceeded the measurements taken with a Price current meter by more than 10 percent. Double floats were used at St. Louis from October 1881 through December 1930. On the basis of his findings, the author recommended that historical estimates of high flow rates be used only for the relative ranking of floods.

In 1985-86, researchers at the Corps' Waterways Experiment Station found a further indication of errors in pre-1933 flow rate information. Using a physical model of the Mississippi River, the researchers found that they could reproduce the high water marks at St. Louis for the 1844 and 1903 floods using flow rates 33 percent and 23 percent lower than historic flow estimates published by USGS.

Researchers' Findings Vary

Three studies performed during the 1970s analyzed the trends in water levels for similar flows at specific locations and produced dissimilar results. In addition, two of the studies used pre-1939 historical data that are of questionable accuracy. Given the data and/or methodological problems associated with these studies, no conclusions can be drawn from them about the long-term impact of navigation structures (such as dikes) or flood control structures (such as levees) on flood levels. The following paragraphs outline the results of each study.

In a 1974 study, researchers at Colorado State University addressed the impact of constructing levees and channelizing the river for navigation on water levels and flow rates at St. Louis before and after 1900.[22] Their comparison found that water levels were higher for all flows above 300,000 cfs, but maximum annual water levels and average and maximum

[19]Paul Munger, et al., "Lower Mississippi Valley Division Potamology Study (T-1)," Institute of River Studies, University of Missouri (Rolla: 1976).

[20]Glendon T. Stevens, Jr., "SLD Potamology Study (S-3)," University of Missouri (Rolla: 1979).

[21]Double floats were fabricated by joining a surface float to a subsurface float with twine.

[22]Daryl B. Simons, Stanley A. Schumm, and Michael A. Stevens, "Geomorphology of the Middle Mississippi River," Engineering Research Center, Colorado State University (Fort Collins: July 1974).

annual flow rates remained unchanged. They also found that lower water levels existed after 1900 for all flows below 300,000 cfs. The researchers asserted that the construction of navigation dikes and levees between 1900 and 1940 caused both decreases and increases in the water level's relationship to the flow rates at St. Louis.

Another study, which was published in 1975 by an associate professor of geology at St. Louis University and was widely cited during the 1993 flood, compared the relationship between maximum annual water levels and flow rates at St. Louis in 1973 with the same relationship during a base period from 1861 through 1927. This study found that the 1973 flow rate of about 851,100 cfs produced a flood elevation about 7.9 feet higher than it did during the base period. The researcher attributed the rise in water level per flow rate to a combination of navigation works, levees, and riverbed sedimentation. He has since refined his results and attributes about 4 to 5 feet of the total increase to levees, about 2 to 3 feet to navigation works, and about 1 foot to riverbed sedimentation.[23]

The Corps has questioned the results of both studies because the studies used the suspect historical data. In addition, a USGS headquarters hydrologist who specializes in the statistical analysis of hydrologic information told us that modeling is better than trend analysis[24] for identifying the effects of navigation dikes and levees. The USGS hydrologist said that trend analysis can never prove what caused the changes identified. Thus, changes in water levels and flow rates that occur after the construction of navigation dikes and levees may suggest but do not prove that these structures are the source of the changes.

In 1975-76, researchers from the University of Missouri at Rolla attempted to study the effects of levees on flood levels.[25] Unlike the authors of the 1974 and 1975 studies, they used only post-1930 data to avoid questions about the accuracy of historical data. As a result, they concluded that the Mississippi River had not experienced enough floods of sufficient size from 1930 through 1976 to evaluate the effect of levees on floods.

Their study also examined the effect of navigation dikes on water levels in the middle Mississippi River. They found that changes in water level per

[23]Charles B. Belt, Jr., "The 1973 Flood and Man's Constriction of the Mississippi River," Science, Vol. 189, No. 4204 (1975), p. 681.

[24]Trend analysis arranges data along a time line and then measures changes or movement in the data.

[25]Jerome A. Westphal, Paul R. Munger, and Clifford D. Muir, "Mississippi River Dikes and Stage-Discharge Relations," Rivers '76, Vol. II, p. 138.

flow rate between 1934 and 1974 at three major gauging stations were dissimilar. The University of Missouri researchers concluded that changes in water level per flow rate at the study gauges showed no association with dike construction. The study stated that although the constriction of the channel caused by building an individual dike must have at least a temporary effect on the relationship between the water level and the flow rate, the dissimilar findings at the three gauging stations suggest that the effect may be restricted to the area immediately around the dike. Therefore, they said data on water levels and flow rates cannot be extrapolated from a single point of record to an entire reach of the river.

Other Factors Affect River Flood Levels

Although floods result from heavy rainfall during a short time or above-normal rainfall over a long time—sometimes in combination with snowmelt—this precipitation interacts with the atmosphere, land topography, vegetation, soils, channel geometry, and human activities to determine the amount of runoff. The chief determinants of a flood's peak level at a particular location in a river are the amount of water reaching the river as runoff, the size and shape of the river channel, and the size of the floodway. Assessing the impact of a single factor, such as levees, on water level is very difficult because hydrologic models can only approximate the complex processes that move and store water.

Variations in flood levels under like conditions are not uncommon. According to the Corps, records of the relationship between high flows and water levels at St. Louis show about a 5-foot variation in water levels for like flows. For example, two floods passed St. Louis within a month in the spring of 1983 with similar flows but with crests whose height differed by 2.7 feet. According to the Corps, no accurate accounting for this variation exists.

Over time, some of the factors that help determine a flood's peak level also shift the range of water levels produced by like flows. Several studies have addressed the factors, both natural and man-made, that affect flood levels.

Many Natural Factors Affect Flood Levels

Natural variables that help determine a flood's peak level include (1) the flood's duration and whether it is rising or receding, (2) the seasonal level of vegetation in the floodway, (3) the way the flood carries sediment, and (4) the water's temperature. Long-term changes in the river's channel from erosion, past floods, and earthquakes, as well as the growth of vegetation in the floodplain, particularly in the floodway, also affect peak flood levels.

A 1994 study on the relationship between flow rate and flood level simulated hypothetical floods of 4.5 days, 9 days, and 13.5 days with the same peak flow rate through a channel approximating the Mississippi River at St. Louis.[26] The study found that the speed with which a flood reaches its peak flow and the duration of that peak flow help determine the flood's peak water level. For instance, in 1993, flow rates of 1,030,000 cfs at St. Louis on 2 consecutive days increased the water level by half a foot on the second day.

According to the Scientific Assessment and Strategy Team's study, the vegetation in the floodway affects flood levels because it obstructs and slows the flow of water, causing the water to rise. Consequently, the water level in an area covered with shrubs and trees would be higher than in an area covered with grass. Similarly, the same flood can be higher during the summer than during the late fall, winter, or early spring because of the summer foliage.

Researchers have found that swiftly moving floodwater can cause intense erosion and sedimentation. The transport and deposition of sediment during a flood can increase or decrease water levels at various locations. In addition, changes in water temperature affect the amount and shape of sediment in the river. Cold water carries more sediment and enlarges the size of the sediment particles, increasing the friction that, over time, can scour the channel and increase its flood-carrying capacity, reducing all water levels.

Human Activities Affect Flood Levels

Floodplains reduce flood levels by providing space for the temporary storage of floodwaters until natural drainage can carry them away. They also reduce flood velocities. In addition to flood control, human activities in the last 175 years in agriculture, navigation, and urban development have altered the floodplains in the upper Mississippi River basin. These activities have altered water flow rates, the width and depth of the river channel, the size of the floodway, the pattern of erosion and sedimentation, the level of vegetation, and the speed with which precipitation flows into streams.

Changes for Agriculture

Early development in the upper Mississippi River valley was closely tied to the rivers. By the late 1800s, settlers had cleared millions of acres in the floodplain for cultivation. Vegetation in the unaltered floodplain,

[26]J.A. Westphal, University of Missouri at Rolla; C.N. Strauser, U.S. Army Corps of Engineers; and D.B. Thompson, Texas Tech University, "Single-Valued Rating Curves," unpublished manuscript (Rolla: 1994).

especially in wetlands, created resistance to flow. Researchers have shown with modeling that removing resistance reduces flood levels and increases flow velocities and erosion. They speculate that clearing the floodplain for agriculture had the same effects.

Between 1780 and 1980, an estimated 57 percent of the original wetlands in the nine midwestern states affected by the 1993 flood were converted to other uses, mainly agriculture. Wetlands temporarily store and hold some floodwater for later drainage. According to the 1994 report from the Interagency Floodplain Management Review Committee, the loss of wetlands contributes to higher flood levels for smaller, more frequent floods, like 25-year or smaller floods.[27]

Agricultural land management practices affect the processes of erosion, sedimentation, and runoff. For example, the Illinois Natural History Survey found that planting crops in rows and plowing with moldboards (which lift and turn the soil) increased the rate at which Illinois lakes were filling with sediment. Although researchers have observed the influence of agricultural land management practices on small watersheds, the influence of these practices on major rivers is still largely speculative.

Changes for Navigation

Travel to and commerce with early settlements along the rivers created a demand for improved navigation on the rivers. The Congress first approved a plan for improving the Mississippi River's channel in 1881. However, most channel improvements for navigation on the Mississippi and Missouri rivers were made between 1927 and 1944. The improvements generally narrowed the natural channels and shortened the rivers.

The Corps has constructed about 3,100 wing dikes to create and maintain navigation channels on the Mississippi and Missouri rivers. Wing dikes are embankments built in the river perpendicular to the shoreline to increase channel depths by reducing channel widths and increasing flow rates. The dikes help keep sediment from accumulating in the main channel and trap it along the shoreline. The previously cited 1974 Colorado State University study found that, between 1888 and 1968, wing dikes decreased the average width of the middle Mississippi River by 2,100 feet, or by about 40 percent. The report also stated that degradation of the riverbed has occurred along the middle Mississippi River whenever the channel has been narrowed.[28]

[27]Sharing the Challenge: Floodplain Management into the 21st Century, Interagency Floodplain Management Review Committee (Washington, D.C.: June 30, 1994).

[28]Simons, Schumm, and Stevens, "Geomorphology of the Middle Mississippi River".

The Corps also stabilizes and dredges hundreds of miles of river bank and channel, respectively, to maintain open water navigation on the Missouri and Mississippi rivers. Stabilizing the banks reduces shoreline erosion, and dredging deepens the channel. In addition, the Corps has built and operated a system of locks and dams on the upper Mississippi River since the 1930s. This system converted the upper river into a series of pools to maintain channel depths at low and normal flows. A 1988 study of the long-term effects of the oldest lock and dam on the upper Mississippi River found that initially the river's width and volume had increased behind the dam. However, the long-term impact has been to trap sediment. As a result the river has steadily lost both width and volume and returned to near pre-dam water levels and flow.[29]

Changes Due to Urban Development

Studies have shown that the growth of urban areas increases the speed of water running off the land into streams. Rain that falls on paved, tiled, or other impervious surfaces and runs into storm drainage systems is delivered to streams more quickly than it could run off porous surfaces. Hence, urban runoff produces higher, sharper flood peaks on small rivers and streams than rural runoff. However, as the water from each small stream joins the water in larger streams, the effects of urbanization on flood levels are diluted. One expert told us that researchers have not been able to measure the impact of urban development on the flooding of the Mississippi or Missouri rivers because the effects of urbanization are too small to isolate.

The Upper Mississippi River Basin May Have to Contend With Increasing Flood Damage

Recent analyses show that water levels for high flows may be increasing for some locations in the upper Mississippi River basin. A continuing Corps study of Missouri River water levels shows that flow rates that once nearly filled the channel have been producing higher flood levels since the late 1920s. Similarly, a 1994 study of flow rates on the Mississippi and Missouri rivers found that flood levels for like flow rates have increased over time. Evidence also suggests that precipitation in the upper Mississippi basin may be increasing. These trends concern the Corps because they increase the frequency and extent of flooding, thereby increasing the damage from flooding.

Water Levels at High Flow Rates Are Increasing

According to the Corps' Missouri River Division, seven of nine gauges on the Missouri River have slowly and consistently produced higher water

[29]J.W. Grubaugh and R.V. Anderson, "Long-Term Effects of Navigation Dams on a Segment of the Upper Mississippi River," Research and Management, Vol. 4 (1989), p. 97.

levels for the same high flow rates since about 1927. The rising trends are most noticeable at Nebraska City and Omaha, Nebraska, and at St. Joseph, Missouri. Table 3.1 shows the approximate increases in water levels for selected high flow rates.

Table 3.1: Approximate Increases in Missouri River Water Levels at High Flow Rates

Location of gauge	Period of analysis (years)	Flow rate (cfs)	Increase in water level (feet)
Bismarck	53	40,000	2
Omaha	62	100,000	6
Nebraska City	63	100,000	7
St. Joseph	66	100,000	6
Waverly	59	200,000	4
Boonville	64	200,000	3
Hermann	52	400,000	4

Source: GAO's presentation of data from the Corps.

Statistical studies performed in 1994 at the Environmental Management Technical Center at Onalaska, Wisconsin, also examined water levels and flow rates for the period of record at six gauges: St. Louis, Chester, and Thebes on the Mississippi River; and St. Joseph, Waverly, and Hermann on the Missouri River.

The studies found that water levels for like flood-level flow rates have been increasing at all six gauges at an average of about 1.2 inches annually. Over the periods of record, which range from 51 years at Chester to 132 years at St. Louis, increases in water levels at the six gauges ranged from about 3 to 9 feet.[30] Table 3.2 shows the approximate increase at each gauge.

[30]Joseph H. Wlosinski, "Discharges and Water Levels During Floods on the Upper Mississippi and Lower Missouri Rivers," unpublished manuscript, Environmental Management Technical Center (Onalaska, Wis.: Nov. 1994).

Table 3.2: Approximate Increases in Water Levels at High Flow Rates for Six Gauges on the Mississippi and Missouri Rivers

Location of gauge	Period of record (years)	Flow rate (cfs)	Increase in water level (feet)
St. Joseph	62	140,000	7.5
Waverly	62	220,000	5.5
Hermann	62	385,000	4.0
St. Louis	132	780,000	9.0
Chester	51	780,000	5.0
Thebes	59	780,000	3.0

Source: GAO's presentation of data from the National Biological Service (Onalaska, Wis.).

The studies also found that, except at Thebes, the trend for maximum annual water levels is increasing. The studies found no changes in trends for flow rates.

The Climate of the Upper Mississippi River Basin May Be Changing

According to the 1994 Natural Disaster Survey Report issued by NWS, the duration and size of the 1993 Midwest flood and the wet conditions leading up to it suggest a significant variation in climate. An air circulation feature, called El Niño/Southern Oscillation, driven by abnormal sea surface temperatures occurred in both 1992 and 1993. Preliminary NWS modeling using the temperatures associated with the El Niño episode produced large-scale atmospheric results resembling the abnormal precipitation and temperature pattern experienced in 1993. However, NWS stated that it requires more in-depth and thorough analyses to understand the role played by El Niño in the extreme precipitation.

According to a 1993 report on the Midwest flood by the Illinois State Water Survey, increases in the volume of water flowing down the Mississippi River are most closely related to the overall climate and precipitation. The report states that climate and resulting precipitation exert such a strong impact on streamflow that it masks changes from other sources, such as physical changes to the basin.[31]

The Illinois State Water Survey reports that, for most locations along the Mississippi River, average streamflows for the 28-year period since 1965 have been the highest on record. On the basis of an 11-year moving average, the Survey calculated that average flow rates at Clinton and Keokuk, Iowa, and St. Louis, Missouri, have increased by about 25 to

[31]Nani G. Bhowmik, et al., "The 1993 Flood on the Mississippi River in Illinois," Illinois State Water Survey, Misc. Pub. 151 (Champaign, Ill.: 1994)

33 percent over the long-term average since the mid-1960s. An 11-year moving average is used to describe the trend because it smooths out natural fluctuations in the data. Also, average streamflows at Keokuk and St. Louis between 1965 and 1992 are about 17 and 13 percent, respectively, above the long-term average streamflows based on over 100 years of record. Average streamflows for the same period for the tributaries between Clinton and Keokuk, Iowa, for the Des Moines River, and for the Illinois River are even further above their long-term average streamflows. According to officials of the Survey, these deviations are significant because, historically, average streamflow has remained remarkably consistent with long-term average streamflow.

USGS headquarters officials cautioned that because weather is cyclical and variable, any trends in climate are difficult to distinguish from normal weather cycles of higher precipitation and drought.

Rising Water Levels Are Causing Concern

For the 10-year period from 1983 through 1992, NWS estimates that damage to the United States from flooding totaled about $20.5 billion, or an average of about $2.1 billion annually, unadjusted for inflation. With the inclusion of data for 1993, the total estimated flood damage became $36.9 billion, or about $3.4 billion annually over the 11-year period.

According to the Corps, upward trends in water levels are of concern, whether they are caused by increased streamflow or by higher water levels for the same flow rates, because they increase the frequency of flooding and the area subjected to flooding. For instance, between 1928 and 1959, flows of 100,000 cfs at St. Joseph, Missouri, never exceeded water levels of 17 feet, the official level at which flooding begins. Since 1959, flows of 100,000 cfs have exceeded flood level 16 times. If changes in the climate of the upper Mississippi River basin increase precipitation in the future and if water levels for like flow rates continue to rise, then the damage from flooding will rise unless the ability of flooding to cause damage is mitigated.

The Interagency Floodplain Management Review Committee Addresses Levees

The administration's Interagency Floodplain Management Review Committee was formed to identify the major causes and consequences of the 1993 Midwest flood, evaluate the performance of existing floodplain management programs, and recommend changes that make the programs more effective. Among the Committee's findings and recommendations are many related to flood control activities, particularly levees. See appendix VI for a summary.

Conclusions

That levees increase flood levels is subject to little disagreement. Whether this increase is significant varies from location to location, but whether unprotected lands are more likely to be flooded than protected lands depends on the increase in flood levels after the construction of a levee. Proponents of levees point out that the impact of a levee should not be isolated because the net effect of all flood control projects has been to reduce flood levels and prevent billions of dollars in flood damage.

Levees are only one of many natural and man-made factors that help determine the peak level of a flood. Cumulative changes within the upper Mississippi River basin have caused higher water levels for similar flows. These trends could mean that the damage from flooding may increase in the future because higher water levels are associated with more frequent and more extensive flooding.

Federal, State, and Local Governments Exercise Some Control Over Nonfederal Levees

No federal program regulates the design, placement, construction, or maintenance of nonfederal levees.[32] However, the federal government can exercise some control over nonfederal levees through programs that regulate navigable waters and wetlands and that provide flood insurance and disaster and emergency assistance.

Overall, 17 of the 50 states have specific programs for regulating levees. Five of the nine states involved in the 1993 flood have regulatory programs that, to varying degrees, affect nonfederal levees. Most often, states are responsible for the overall coordination of floodplain management activities within the state and across state lines. In some cases, states may regulate local land use when localities are unable or unwilling to take the actions needed to reduce the risk of flooding.

Local governments usually exercise control over nonfederal levees in response to requirements of the National Flood Insurance Program[33] and state regulatory programs. However, in states without a regulatory program, local land use regulations generally affect the placement and construction of levees.

Some Federal Control of Nonfederal Levees Exists Under Federal Programs

Nonfederal levees are regulated to some extent under two federal programs that require permits to construct or modify levees affecting navigable waters and wetlands.[34] In addition, the programs of three federal agencies that provide flood insurance and emergency and disaster assistance to repair flood-damaged levees affect nonfederal levees.

Under the National Flood Insurance Program, FEMA exempts communities from certain requirements of the flood insurance program if they can show that the levees protecting them are designed, constructed, located, and maintained according to specified criteria.

[32]Nonfederal levees are those that are not built, maintained, or operated by the federal government. Some nonfederal levees may qualify for repairs under federal programs if they have been damaged by flooding.

[33]The National Flood Insurance Program, administered by FEMA, is a major component of the federal government's effort to provide flood-related disaster assistance. The National Flood Insurance Act of 1968, as amended (P.L. 90-448), established the program to identify flood-prone areas, make insurance available to property owners in communities that join the program, and encourage floodplain management efforts to mitigate flood hazards.

[34]The regulatory programs are administered by the Corps under section 10 of the Rivers and Harbors Appropriation Act of 1899 (33 U.S.C. 403) and section 404 of the Clean Water Act (33 U.S.C. 1344).

As part of its mission to provide disaster assistance, the Corps is authorized to repair levees through its levee rehabilitation program.[35] The Department of Agriculture's Natural Resources Conservation Service (NRCS) provides funds and technical assistance for the emergency repair of nonfederal levees that are damaged during a flood.

In all of these programs, the federal government exercises some direct or indirect control over the nonfederal levees' design, placement, construction, or maintenance. However, all of these elements are not always affected by each program. Table 4.1 lists the federal programs affecting levees, and table 4.2 shows whether these programs affect a nonfederal levee's design, placement, construction, or maintenance.

Table 4.1: Federal Programs and Types of Levees Affected

Federal program	Types of levees affected
Section 10, Rivers and Harbors Appropriation Act of 1899	All proposed levees that may obstruct or alter navigable U.S. waters.
Section 404, Clean Water Act	All proposed levees in U.S. waters, including wetlands.
FEMA's National Flood Insurance Program	Levees certified as providing protection from a 100-year flood.
Corps' Levee Rehabilitation Program	Damaged nonfederal levees that have met the Corps' standards for the program and have drainage areas that exceed 400 square miles.
NRCS' Emergency Watershed Protection Program	Damaged levees designed to protect agricultural drainage areas of less than 400 square miles or critical infrastructure in agricultural areas.

[35]This Corps program is authorized under section 5 of the Flood Control Act of 1941, as amended (P.L. 84-99).

Table 4.2: Federal Programs and Levee Elements Affected

	Element			
Program	**Design**	**Placement**	**Construction**	**Maintenance**
Section 10, Rivers and Harbors Appropriation Act of 1899	Yes	Yes	Yes	No
Section 404, Clean Water Act	Yes	Yes	Yes	No
FEMA's National Flood Insurance Program	Yes	Yes	Yes	Yes
Corps' Levee Rehabilitation Program	No[a]	No	No[a]	Yes
NRCS' Emergency Watershed Protection Program	No	No	No	Yes

[a]Design and construction are involved if the levee must be modified to meet conditions of the rehabilitation program.

Legislation Requires Permits for Certain Levees

Section 10 of the Rivers and Harbors Appropriation Act of 1899 prohibits the obstruction or alteration of navigable U.S. waters without a permit from the Corps. Section 404 of the Clean Water Act requires a permit from the Corps when wetlands are to be altered. Under both of these authorities, the Corps may control the design, placement, and construction of a nonfederal levee when the levee affects areas regulated by these programs. However, the owner, sponsor, or builder is responsible for informing the Corps of the intent to construct a levee and for obtaining a permit. The Corps' data do not indicate how many of the 15,000 permits requested for activities in wetlands or navigable waters in fiscal year 1994 were for constructing or modifying levees.

For the 1993 flood, the Corps issued a nationwide permit for the construction of temporary levees and emergency repairs to levees. This permit encompassed U.S. waters—including rivers, streams, lakes, and wetland areas—in the counties that had been declared flood disaster areas. The permit was specific and identified conditions where it applied. For example, the permit required any levee that was reconstructed or repaired to be maintained after the flood. Since some levees were being constructed in new locations, the Corps could also require that the former location of the levee be restored to its previous condition. The permit also required that any temporary levees built must minimize damage to U.S. waters and that measures must be taken to maintain near-normal downstream flows. Furthermore, all levees were to be designed and constructed so as to prevent the channel from being constricted or redirected and erosion from occurring upstream or downstream.

Corps' Regulatory Authority May Extend to Additional Nonfederal Levees

Section 10 prohibits the obstruction of the navigable capacity of waters of the United States without a permit from the Corps. To clarify the extent of the Corps' authority to regulate levees under this section, we asked the Corps to provide its interpretation of this authority. Specifically, we asked whether the Corps has the authority to regulate upland[36] nonfederal levees. Currently, these levees are not regulated by the Corps.

In a November 1994 response, the Chief Counsel of the Corps indicated that the Corps might be able to assert jurisdiction over upland nonfederal levees on the basis of section 10. While this provision prohibits the obstruction of the navigable capacity of waters of the United States, it also prohibits the alteration or modification of the course, location, condition, or capacity of "any navigable water of the United States unless recommended by the Chief of Engineers and authorized by the Secretary of War" before work begins.

From his review of court cases dealing with section 10, the Chief Counsel opined that a prerequisite to the Corps' exercising jurisdiction would be circumstances demonstrating an alteration or modification of the course, location, condition, or capacity of navigable U.S. waters. However, he noted that a court might require that jurisdiction be founded on a negative effect and that, arguably, nonfederal levees have an essentially beneficial effect on navigable capacity.

The Chief Counsel concluded that if the Corps exercised jurisdiction over upland federal levees under section 10 without clear authority and direction from the Congress, this action would likely be overturned upon appeal to the federal courts.

The National Flood Insurance Program Imposes Requirements for Levees

FEMA administers a levee certification program under the auspices of the National Flood Insurance Program. To be certified and to enable communities to enact less stringent building codes, levees must meet FEMA regulations specifying design, placement, construction, and maintenance standards. In all cases, the levee must, at a minimum, protect against a 100-year flood and, in most cases, have at least 3 feet of height (or freeboard) above the 100-year level of protection.

[36]Upland refers to areas on land above the mean high tide line for tidal waters or the ordinary high water mark of other navigable waters that do not include U.S. waters such as wetlands.

When FEMA maps a community, it designates the 100-year floodplain and floodway. When a community joins the insurance program, it must require that all buildings constructed or substantially improved be protected to the base flood elevation.[37] This is usually accomplished by elevating the structure above the base flood elevation or, in some instances, by floodproofing. While increasing construction costs, these requirements make buildings more resistant to flood damage. FEMA officials said that experience confirms that elevated buildings are less susceptible to flood damage and, therefore, cost less to repair when a flood occurs. When FEMA certifies a levee as protecting against a 100-year flood, it exempts new construction and substantial improvements from the requirement to build above the base flood elevation. The effect of this exemption is to increase the costs of repairing buildings that are more susceptible to flood damage because they are not elevated.

Corps' Program Repairs Flood-Damaged Levees

The Corps will repair, on a cost-shared basis, nonfederal levees that are damaged by floods if the levees meet the qualifying standards of the program and are in good standing with the program at the time of flooding. In order to be accepted into the Corps' rehabilitation program for damaged nonfederal flood control levees, a sponsor's levee must meet or be improved to meet the Corps' minimum design standards before flood damage occurs. The owner may need to modify the levee in order for the levee to be admitted to the program. Once in the program, the levee must be maintained in accordance with the Corps' criteria.

For levees that have qualified, the Corps provides 80 percent of the repair costs and the levee's sponsor pays the rest. To qualify, the levee must (1) be publicly sponsored to ensure that the 20-percent share can be paid, (2) be a primary levee providing a 10-year level of protection for urban areas and a 5-year level of protection for agricultural areas, (3) be properly maintained and regularly inspected, and (4) provide benefits that equal or exceed the cost of the levee's repair. The rehabilitation program includes levees maintained by local sponsors, such as levee districts, individual municipalities, or Indian tribes.

The Corps received 546 requests for assistance under the levee rehabilitation program after the 1993 flood. Of these requests, as many as 345 either were declared ineligible for assistance because the levees did not meet the basic requirements identified above or had been repaired

[37]The base flood elevation is the height that a 100-year flood would reach. A 100-year flood is the flood that has a 1-percent probability of being equaled or exceeded in any given year.

under other disaster assistance programs, such as NRCS' program. As of October 1994, the Corps estimated that the costs of repairing the 201 levees that met its established criteria would be $250 million.

Also, during 1993, the Corps worked with the Department of Commerce's Economic Development Administration (EDA) to identify and repair levees that were deemed to affect the economic development of the community where the levee was located. The Corps assisted EDA in assessing the levees that had not qualified for the Corps' program in advance primarily because they lacked public sponsorship. Because one of EDA's missions is to provide economic assistance to areas experiencing sudden and severe economic distress, the agency provided funding on a cost-shared basis to repair levees that protect critical public infrastructure.

Working with the Corps, EDA reviewed all applications and funded those that identified local sponsors to share costs and maintain the levees. EDA has funded the repair of 13 levees at a cost of about $4.2 million.

NRCS' Program Affects Some Nonfederal Levees

NRCS' Emergency Watershed Protection Program, authorized by the Agricultural Credit Act of 1978 (P.L. 95-334), funds repairs to levees. To be eligible for these funds, the levee project must protect property threatened by a watershed emergency and the owner must either have exhausted, or lack, the funds needed to remedy the problem. To be eligible for assistance after the 1993 Midwest flood, potential applicants were also required by NRCS to show that the levee restoration project protected property or life, that benefits exceeded the costs of repair, and that regular maintenance would be performed. Since the program supports the repair of nonfederal levees to their preflood condition, it does not control the original design, placement, or construction of nonfederal levees. However, because regular maintenance is required for future assistance, the program does set maintenance standards.

NRCS also received funding in a 1994 supplemental appropriation[38] to make repairs to levees otherwise ineligible for assistance on condition that a sponsor share the cost and that the levee qualify for the Corps' levee rehabilitation program. The levee also had to be environmentally sound and provide a 5-year level of protection.

While NRCS' Emergency Watershed Protection Program provides for a smaller proportion of the funding for repairs than the Corps' levee

[38]Emergency Supplemental Appropriations Act of 1994 (P.L. 103-211).

rehabilitation program (75 percent versus 80 percent), NRCS would provide 100 percent of the funding in the case of extreme need or hardship on the part of the levee sponsor. As of February 1, 1995, NRCS had approved repairs for 375 levees at a cost of $10.2 million under the Emergency Watershed Protection Program. NRCS had also determined that 16 levees were eligible for repairs, costing a total of $650,000, under the supplemental appropriation for fiscal year 1994. NRCS officials reported the agency is evaluating repairs for 26 more levees under the supplemental appropriation. Some of these repairs were for levees whose drainage area exceeded NRCS' threshold of 400 square miles and would, therefore, normally have fallen under the Corps' levee rehabilitation program. However, NRCS was given the responsibility for repairing these levees under the supplemental appropriation.

Some States Regulate Nonfederal Levees

In 1992, the Association of State Floodplain Managers issued a report[39] documenting the scope of floodplain management programs in the states and found that 17 states regulate levees as part of their floodplain management programs. Of the nine states involved in the 1993 flood, five states (Iowa, Kansas, Minnesota, North Dakota, and Wisconsin) have programs to regulate levees. These programs have standards regulating the design, construction, placement, and maintenance of levees. We judgmentally selected Iowa as an example of a state that regulates its levees.

Iowa Has a Regulatory Program for Levees

Iowa's program for regulating levees addresses the design, placement, construction, and maintenance of nonfederal levees. The program, which is described in Iowa's statute on floodplain management, is administered by the state's Environmental Protection Division within the Department of Natural Resources and has been in existence since at least 1967.

In general, Iowa requires permits to construct, operate, and maintain levees in rural areas where the watershed drainage area exceeds 10 square miles and in urban areas where the watershed drainage area exceeds 2 square miles. Specific requirements must be met to comply with the statute's criteria for level of protection, placement, interior drainage, freeboard, or design. For example, Iowa requires agricultural levees, at a minimum, to protect against a 10- to 25-year flood and urban levees to protect against a 100-year flood. Urban levees must provide at least 3 feet

[39] Floodplain Management 1992: State and Local Programs, Association of State Floodplain Managers, Inc. (Madison, Wis.: 1992). The data in this report are from 1991 and were being updated at the time of our review.

of freeboard above the design flood profile. Furthermore, any agricultural levee whose protection level is increased must comply with the state's equal and opposite conveyance rule: An increase in the levee on one side of a river's floodplain cannot cause a disproportionate increase in the flooding of the river's opposite floodplain.

Iowa officials told us that only one FEMA regulation more strictly controls levees. Under this rule, development within FEMA's identified 100-year floodway cannot increase the area designated as the 100-year floodway. The effect of this rule is that agricultural levees may be placed farther away from the river than the equal and opposite conveyance rule may initially require.

Some States Have Not Yet Established Regulatory Programs for Nonfederal Levees

Of the nine states involved in the 1993 flood, four (Illinois, Missouri, Nebraska, and South Dakota) have yet to develop specific regulatory programs for levees. All of these states have a floodplain management program that may (1) provide technical expertise to localities and individuals on complying with FEMA's or other federal agencies' requirements, (2) regulate local land use when localities are unable or unwilling to take needed actions to reduce the risk of flooding, or (3) coordinate local and regional floodplain management programs. We judgmentally selected Missouri as an example of a state that does not regulate levees.

Missouri does not currently regulate its levees but has identified areas of its floodplain management program that need to be improved. A task force established by Missouri's governor to review and evaluate the state's floodplain management program recommended the development of a levee oversight program to help decrease the risk to life and property from flooding.

The task force recommended in a July 1994 report that Missouri (1) adopt a permit program for constructing and modifying levees; (2) identify all existing levees for the purpose of developing design criteria and policy guidelines; (3) determine the need for setbacks, relocations, and construction standards; and (4) enact legislation that would make it easier for levee districts to form and obtain public sponsorship for participation in the Corps' levee rehabilitation program. As of June 1995, the Missouri General Assembly had not yet enacted these recommendations into law.

Local Governments Often Exercise Control Over Nonfederal Levees Through Floodplain Regulations

Local governments generally exercise more control over local floodplains and levees than do the states or the federal government. This is often because FEMA requires the adoption of community floodplain regulations as a condition for joining its flood insurance program. The 1992 report by the Association of State Floodplain Managers noted that every state has granted its localities enough authority to meet the regulatory requirements of FEMA's flood insurance program. As a result, localities may enact ordinances that allow them to (1) require certain building codes for development in the floodplain, (2) issue zoning regulations describing the types of land uses permitted in the floodplain, or (3) require that development incorporate improvements to alleviate potential flood hazards.

Two exceptions to this local authority exist, however: First, most localities cannot regulate federal or state property or development by other localities, and, second, some states have exempted from local control certain activities that are important to the state's economy (i.e., transportation, agriculture, mining). Under these exceptions, a local government could be prevented from exercising control over a nonfederal levee if, for example, the state determined that such control would negatively affect the economy of the river's transportation industry.

In a state that regulates levees, the locality is generally required to enforce and comply with the state's standards for the design, placement, construction, and maintenance of levees. For example, in Iowa, local regulations must meet state requirements. In Minnesota, the state government may directly regulate levees and enforce compliance if the local government does not.

In states that do not regulate levees, such as Missouri, local governments are bound by the standards of FEMA's flood insurance program if the community participates in the program. According to the city engineer in St. Louis, the city complies with FEMA's standards for floodplain management but has not established local levee regulations.

Interagency Committee Calls for Better State Regulation of Nonfederal Levees

As part of its review of floodplain management in the aftermath of the 1993 flood, the Interagency Floodplain Management Review Committee reported that few states control the design, placement, construction, and maintenance of nonfederal levees. As explained in detail in appendix VI, the Committee found that the states' involvement in many floodplain management activities—including issuing permits for levees, flood-fighting, and repairing levees—was highly variable and in need of enhancement. The Committee recommended that the states assume responsibility for regulating the location, alignment, design, construction, upgrading, maintenance, and repair of levees and flood-fighting at levees.

Conclusions

While no comprehensive federal program regulates the design, placement, construction, or maintenance of nonfederal levees, control over nonfederal levees is exercised through various federal programs for regulating navigable waters and wetlands and for providing flood insurance and disaster and emergency assistance. Not all aspects of levees are regulated in every program, and not all nonfederal levees are affected.

Five of the nine states involved in the 1993 flood have regulatory programs that, to varying degrees, affect the design, placement, construction, or maintenance of nonfederal levees. Most often, states are responsible for the overall coordination of floodplain management activities within the state and across state lines, and local governments exercise direct control over levees through land-use regulations. Local governments often impose regulations to comply with the requirements of the National Flood Insurance Program and state regulatory programs.

Scope and Methodology

We conducted our work at the Corps' headquarters in Washington, D.C., and district offices in Rock Island, Illinois; St. Louis and Kansas City, Missouri; and Omaha, Nebraska. We also performed work at USGS' headquarters in Reston, Virginia, and field offices in Independence and Rolla, Missouri and Urbana, Illinois; NWS' headquarters in Silver Spring, Maryland, and field office in Pleasant Hill, Missouri; FEMA's headquarters; NRCS' headquarters and field office in Champaign, Illinois; and the Interagency Floodplain Management Review Committee in Washington, D.C. We visited various groups, such as the Association of State Floodplain Managers in Richmond, Virginia, and the National Wildlife Federation in Washington, D.C., and state government offices, such as the Missouri Department of Natural Resources and the Illinois State Water Survey. At these locations and others, we interviewed federal officials, state government representatives, university researchers, and others knowledgeable about the 1993 flood. We also contacted a variety of local and state government officials, associations, businesses, and individuals in the flooded area.

To determine to what extent federal levees prevented flooding and related flood damage, we collected data from the Corps and USGS on the design capacity of the levees and the flows and water levels of the 1993 flood to analyze how well the levees were able to withstand the flood. The numbers for the actual flood flows and levels, which we compared with the levees' design capacity, are based on our analysis of the best and/or nearest gauge data available from USGS or the Corps. We compared the number of acres protected by each federal levee with the number of acres flooded when the levees were overtopped or breached to estimate the extent to which federal levees prevented flooding. We collected and analyzed Corps data on the damage incurred after levees failed, as well as on the damage prevented by federal levees that withstood the flood. We interviewed Corps officials about instances when the flood exceeded the levees' design capacity and discussed the reasons why some levees were overtopped or breached.

To determine whether levees contributed to the record flood heights and increased flood damage, we solicited the opinions of 26 experts representing the Corps, NWS, USGS, FEMA, the State of Illinois, and the Universities of Illinois and Missouri at Rolla. We also spoke with other individuals concerned with the effects of levees on flooding. In addition, we reviewed books and studies containing information relevant to the effect of levees on flooding.

To describe federal, state, and local control over the design, construction, placement, and maintenance of nonfederal levees, we gathered information from sources at each level of government. To obtain information on federal control over nonfederal levees, we interviewed officials from the Corps, FEMA, NRCS, and EDA on the federal programs that may control the design, placement, construction, and maintenance of nonfederal levees. We interviewed Corps officials about the applicability of section 10 of the Rivers and Harbors Appropriation Act of 1899 and section 404 of the Clean Water Act to the levees and requested a legal opinion from the Corps on the applicability of these sections to nonfederal levees. From the Corps, FEMA, NRCS, and EDA, we collected information on the repair of nonfederal levees. We analyzed a FEMA data base that identified the levees certified by FEMA in the area affected by the flood.

To learn what state controls exist over nonfederal levees, we interviewed representatives of the Association of State Floodplain Managers, floodplain managers for the states of Iowa and Missouri, and the Interagency Floodplain Management Review Committee and reviewed information on the states' regulation of levees. We also reviewed information on the programs that regulate levees in the five states involved in the flood that have programs.

To obtain information on local controls over nonfederal levees, we interviewed state officials in Iowa and Missouri; local officials in St. Louis and Chesterfield, Missouri; and the Chairman of the Association of State Floodplain Managers. We also interviewed officials of FEMA and reviewed documents on the role of the National Flood Insurance Program in establishing controls over nonfederal levees.

List of 12 Corps Levees for Which Data Were Not Sufficient to Compare Levee Design Capacity With Flood Flow

District/levee project	River or stream
Rock Island District	
Worthington	Illinois
Lost Creek	Illinois
Valley	Illinois
Galena	Galena
Volga	Volga
Omaha District	
Broken Bow	Mud Creek
Hawarden	Dry Creek
Macy	Blackbird Creek
Kansas City District	
MRLU R-351, Sec. 2	Little Blue
Abilene	Mud Creek
Gypsum	Gypsum
Stonehouse Creek	Stonehouse Creek

Source: GAO's presentation of data from the Corps.

Comparison of Levee Design Capacity With Flood Flow for 145 Levees That Prevented Flooding

District/river/levee project	Design flow (cfs)	Flood flow (cfs)	Design water level (feet)	Flood water level (feet)
Rock Island District				
Mississippi River				
Bay Island	308,000	400,000		557.0
Bettendorf	385,000	260,000		557.0
Burlington NB	435,000	400,000		536.5
Canton	400,000	446,000		499.0
Clinton	385,000	239,000		585.7
Drury	308,000	340,000		556.3
Dubuque	362,000	239,000		609.3
East Moline	385,000	260,000		572.5
Fulton	385,000	239,000		585.7
Hannibal	444,000	524,000		481.2
Henderson, No. 1	314,000	400,000		536.5
Henderson, No. 2	314,000	400,000	535.0	536.5
Iowa River-Flint Creek	370,000	400,000		547.4
Lock and Dam 17	308,000	400,000		557.0
Lock and Dam 18	314,000	400,000	539.0	541.5
Lock and Dam 20	345,000	446,000	496.5	499.0
Meredosia		239,000	588.0	585.7
Milan	385,000	260,000		557.0
Muscatine (Mad Creek)	364,000	340,000		557.0
Muscatine Island	364,000	340,000		557.0
Rock Island	385,000	260,000		565.0
Sabula		239,000	599.0	585.7
South Quincy	441,000	524,000		489.0
Illinois River				
Banner Special	82,000	56,600	455.6	449.5
Beardstown	135,000	84,900[a]	454.0	446.6
Big Lake	78,000	56,600	451.0	447.0
Coal Creek	135,000	56,600	454.7	446.6
Crane Creek	100,000	56,600	450.0	446.6
East Liverpool	82,000	56,600	455.0	448.0
East Peoria	92,000	56,600	462.4	451.0
Lacey Langellier	110,000	70,800[a]	456.0	447.7
Liverpool	82,000	56,600	455.0	448.0
Hennepin	136,000	62,000	462.4	456.0

(continued)

District/river/levee project	Design flow (cfs)	Flood flow (cfs)	Design water level (feet)	Flood water level (feet)
Pekin and LaMarsh	76,000	56,600	458.0	450.0
Seahorn	87,000	70,800[a]	452.0	447.4
Spring Lake	77,000	56,600	455.0	449.5
South Beardstown	135,000	84,900[b]	453.8	446.6
Tributary				
Avon		116,000	785.5	796.8
Carlisle		116,000	785.5	796.8
Dekalb	2,000	1,310	845.0	841.0
Elkport			669.0	659.7[b]
Evansdale	126,300	68,100		844.7
Farmers		29,300	468.0	472.1
Herget		29,300	479.0	477.1
Marengo	52,000	39,000	746.0	740.8
Marshalltown	44,000	19,200	877.0	873.8
Mason and Menard		29,300	489.0	472.1
Oakford		29,300	482.0	472.1
Penny Slough		46,500	587.0	582.4
Southeast Des Moines		116,000	786.0	796.8
Tama	40,500	19,200		873.8
Van Meter	1,900	1,900[c]		867.5
Waterloo	126,300	68,100	864.5	844.7
St. Louis District				
Mississippi River				
Big Five	1,025,000	996,000	50.0	47.9
Degognia/Grand Tower	1,010,000	1,000,000	45.7	49.7
MetroEast	1,250,000	1,080,000	52.0	49.6
N. Main/Main Streets	1,200,000	996,000	49.2	47.9
Prairie du Pont	1,250,000	1,080,000	52.0	49.6
Prairie du Rocher	980,000	1,080,000	45.7	49.6
St. Louis	1,250,000	1,080,000	52.0	49.6
Wood River	1,250,000	1,080,000	52.0	49.6
Illinois River				
Big Swan			441.5	443.6
Keach			438.5	442.8
Little Creek			443.3	445.0
Mauvaise Terre			444.5	444.0

(continued)

District/river/levee project	Design flow (cfs)	Flood flow (cfs)	Design water level (feet)	Flood water level (feet)
McGee Creek			452.0	445.0
Meredosia Lake			445.5	445.0
Scott County			444.0	444.0
Willow Creek			442.5	445.0
Valley City			444.0	444.0
Tributary				
Coon Run			449.0	444.0
Dively			483.3	477.4
New Athens			422.1	402.0
New Pankey's Pond			448.5	445.0
Omaha District				
Missouri River				
Council Bluffs	250,000	115,000		30.3
MRLU L-536	306,000	307,000		25.4
MRLU L-594	295,000	196,000		27.2
MRLU L-601	295,000	115,000		30.3
MRLU L-611-614	250,000	115,000		30.3
MRLU L-624	250,000	115,000		30.3
MRLU L-627	250,000	115,000		30.3
MRLU R-573	295,000	196,000		27.2
MRLU R-613	250,000	115,000		30.3
MRLU R-616	250,000	115,000		30.3
Omaha	250,000	115,000		30.3
Tributary				
Big Sioux	98,000	66,700		23.1
Clarkson	23,500	6,270		14.3
Emerson	16,300	18,600		
Floyd River	71,500	9,680		22.3
Herreid	9,000	1,480		
Hooper	47,750	29,900		14.2
Ida Grove	33,500	7,130		9.7
Lincoln	34,400	28,400		26.5
Little Papillion Creek	20,000	1,520		
Little Sioux River	35,000	26,300		24.0
Loup River	150,000	27,500		11.0
Mandan	66,000	11,800		15.5

(continued)

District/river/levee project	Design flow (cfs)	Flood flow (cfs)	Design water level (feet)	Flood water level (feet)
Norfolk	59,000	14,000		10.2
Pierce	24,000	1,570		13.6
Red Oak	93,000	21,600		22.0
Schuyler	68,000	123,000		11.0
Sioux Falls	7,300	18,000		23.8
Waterloo	100,000	42,100		17.3
West Point	130,000	29,900		14.2
Kansas City District				
Missouri River				
Birmingham Unit	540,000	541,000	48.9	48.9
East Bottoms Unit	540,000	541,000	48.9	48.9
Fairfax-Jersey Creek	540,000	541,000	48.9	48.9
Missouri/Kansas CID	540,000	541,000	48.9	48.9
MRLU L-455	325,000	335,000	32.7	32.1
MRLU L-476	325,000	335,000	32.7	32.1
MRLU L-497	319,000	307,000	25.7	25.4
MRLU R-351, Section 1	436,000	371,000[a]	46.2	48.9
MRLU R-440	329,000	335,000		32.1
MRLU R-512/513	309,000	307,000	25.2	25.4
New Haven	529,000	750,000		37.0
North Kansas City	540,000	541,000	46.2	48.9
Tributary				
Argentine Unit	390,000	170,000		26.9
Armourdale Unit	390,000	170,000		26.9
Auburndale	364,000	170,000		34.9
Barnard	39,000	21,300		26.5
Blue River	35,000	17,900		33.9
Clyde/Elk Creek	36,000	31,100		
Fairbury	72,000	24,100		21.2
Frankfort	43,000	18,700		19.8
Lawrence Unit	295,000	190,000		24.7
Little Blue River	18,000	6,600		18.0
Manhattan	220,000	199,000		27.3
Oakland	364,000	170,000		34.9
Osawatomie	130,000	17,100		33.9
Ottawa	80,000	17,100		33.9

(continued)

District/river/levee project	Design flow (cfs)	Flood flow (cfs)	Design water level (feet)	Flood water level (feet)
Salina	50,000	13,100		
Seward	31,000	25,700		28.8
North Topeka	364,000	170,000		34.9
Soldier Creek	314,000	170,000		34.9
South Topeka WW	314,000	170,000		34.9
South Topeka	364,000	170,000		34.9
St. Paul District				
Mississippi River				
Guttenberg	350,000	238,700		
St. Paul	210,000	104,000		
South St. Paul	168,000	105,000		
Winona	290,000	168,900		
Tributary				
Dry Run, Decorah	25,000	4,620		
Henderson	113,000	86,000		
Mankato	150,000	75,600		
Marshall	6,500	6,380		
Rushford	45,000	8,500		

Note: For some levees in this table, the numbers for the flood flow and/or level were higher than for the flow/design level. According to the Corps, this may be explained by flood-fighting efforts that enhanced the levees' performance. Also, data from the nearest gauge may not reflect the actual flood flow or level at a levee because of the distance separating the levee and the gauge.

[a]Estimated by GAO.

[b]The 1993 value was not available but was below the value for a prior flood indicated here.

[c]No gauge data were available. However, Corps staff reported flow was 1,900 cfs or below.

Source: GAO's presentation of data from the Corps and USGS.

Flood-Fighting Efforts That Extended Some Levees' Performance

Examples of the flood-fighting efforts that occurred during the 1993 flood follow.

The Keach Levee, Greene County, Illinois

Located along the Illinois River, the Keach levee protects an agricultural area from 25-year floods. Although the Illinois River drainage basin received large amounts of rainfall, flooding on the Illinois River was caused primarily by backwater from the Mississippi River. At the Keach levee, the local sponsor installed flashboarding and sandbags to raise the levee's height.[40] The flashboarding gave way, and water came over the top of the levee for 2 to 3 hours. According to Corps district personnel, National Guard personnel locked arms and stood across the top of the levee to prevent sandbags from washing away. Meanwhile, workers deposited additional sandbags on the levee to stop the flow of water over it.

The North Kansas City Levee, Missouri

According to the Corps, flood-fighting activities at the North Kansas City levee prevented flooding of the Kansas City downtown airport. This levee, which lies along the left bank of the Missouri River, is part of a system of levees and floodwalls that protects against a 500-year flood. During the flood, the levee developed sinkholes on its landward side. A stability berm made of gravel was constructed on the landward side of the levee, and temporary pumps returned water to the river. Although water reached the levee's freeboard, it did not overtop the levee. Corps officials said that without these flood-fighting efforts, the levee would have been breached and the airport would have been inundated. They estimate that more than $820 million in damage would have resulted.

The St. Louis Floodwall

Early in the morning of July 23, 1993, a geyser of water appeared on the landward side of the St. Louis floodwall. Approximately 100 tons of rock were placed behind the wall, closing off the sinkhole and slowing the flow of water. Piping and underseepage continued, so the Corps constructed a ring levee around the hole and placed rock on the river side of the floodwall. These methods did not reduce the underseepage, and the sinkhole reappeared at its original location. Rock was immediately placed in the hole to reduce the underseepage. The Corps then repaired the hole beneath the wall's foundation, thereby preventing the collapse of the St. Louis floodwall. The floodwall protects 7 miles of riverfront in an

[40]Flashboarding is a board fence covered with plastic and reinforced with sandbags to give the levee extra height.

industrial area with an appraised property value of $300 million. Figure IV.1 depicts a section of the St. Louis floodwall.

Figure IV.1: a Section of the St. Louis Floodwall Along the Mississippi River

Source: The Corps.

Four Corps Levees That Were Breached or Failed

The following describes (1) three Corps levees, two on the Mississippi River and one on the Missouri River, that were breached without first being overtopped by floodwaters and (2) a Corps floodwall along the Raccoon River in which an opening for a railroad was not closed to prevent flooding.

Kaskaskia Island, Illinois

According to Corps district staff, the Kaskaskia Island levee was breached by excessive underseepage and internal erosion caused by saturation. The levee encircles Kaskaskia Island, which lies about 70 river miles south of St. Louis in the Mississippi River. This agricultural levee protects 9,400 acres and the villages of Kaskaskia and Pujol, which together have about 200 residents, from floods with average recurrence intervals of up to 50 years.

Water rose above the design height of the levee but was still in the freeboard area 1 to 2 feet below the top of the levee. Water pressure from the Mississippi River produced a large sandboil next to the levee. Attempts to contain the sandboil were overwhelmed by the great volumes of water and sand erupting from it. A 600-foot-long breach opened in the levee and water inundated the protected area. Figures V.1 and V.2 show the Kaskaskia Island levee before and after it was breached.

Figure V.1: Kaskaskia Island, Illinois, Levee Before the 1993 Breach

Figure V.2: Kaskaskia Island, Illinois, Levee After the 1993 Breach

Source: The Corps for both photos.

Bois Brule, Perry County, Missouri

The Bois Brule levee in Perry County, Missouri, an agricultural levee protecting 26,000 acres and about 200 residents, was also breached by excessive underseepage and internal erosion. Bois Brule is immediately downstream from Kaskaskia Island. The levee protects against floods with an average recurrence interval of up to 50 years. Water rose above the design height of the levee but was still in the 2-foot freeboard area when it began seeping through the foundation of the levee. Eventually, a 1,500-foot section of the levee collapsed, and the protected area was flooded.

Missouri River Levee Unit L-550, Atchison County, Missouri

Floodwater first overtopped Levee Unit L-550 on the Missouri River on July 23, 1993. The next morning a 330-foot section of the levee was breached about 1/2 mile upstream of where the overtopping occurred. The water at this location was still about 4 feet below the top of the levee when the levee was breached. As in the other cases, water seeping under the levee caused the breach, Corps officials reported. However, the use of sand for previous levee repairs contributed to the seepage problem.

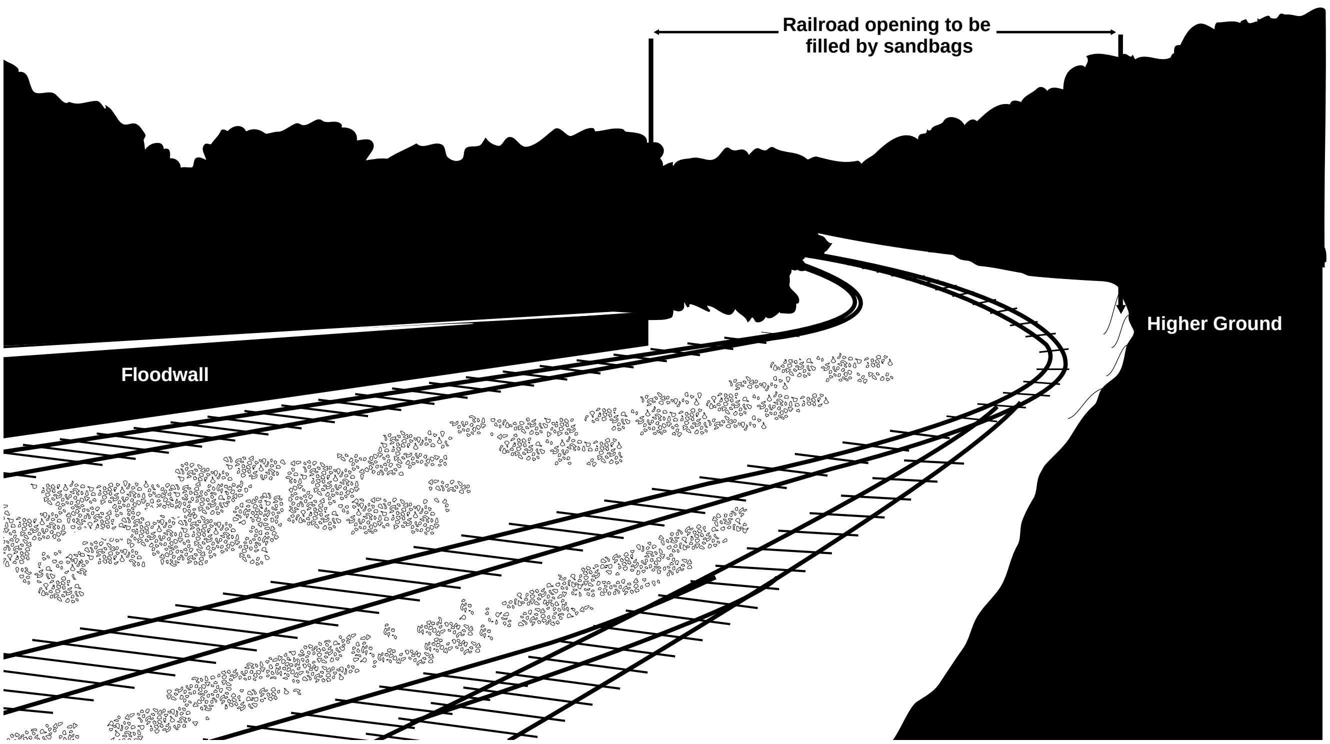
The Corps repaired a breach in the levee in 1952 with sand dredged from the river. In 1984, it again repaired the levee with sand dredged from the river side of the levee. The Corps used the river sand because, although it was not the best material for repairing levees, it was available at little cost to the government. Corps officials said the levee had failed in the same location in 1993 because the sand used in the previous repair became too saturated to withstand the water. This time, the Corps used commercial sand that is more impervious to water to repair the levee.

City of Des Moines, Iowa

According to the Corps, the flood control plan for the City of Des Moines, Iowa, Local Flood Protection Project along the Raccoon River calls for city workers to build a sandbag closure across a 100-foot opening for a railroad right-of-way that passes through the floodwall. (See fig. V.3.) Previous floods had never made the closure necessary. The Corps reported that city workers did not build the closure before the river rose to record levels on July 11, 1993; flowed through the opening in the floodwall; and flooded 58 blocks of downtown Des Moines occupied by offices, retail businesses, residences, and industry.

According to the NWS, the forecast of a record flood crest for the Raccoon River in the area of the railroad opening was given to the city two days before an even higher crest occurred. The Corps estimates that the flooding caused about $117 million in damage. The Corps installed a gate at the railroad track opening after the 1993 flood to permit the more efficient closure of the levee.

Figure V.3: Railroad Opening at the City of Des Moines, Iowa, Local Flood Protection Project Along the Raccoon River



Findings and Recommendations of the Interagency Floodplain Management Review Committee

The administration's Interagency Floodplain Management Review Committee was formed to identify the major causes and consequences of the 1993 Midwest flood, evaluate the performance of existing floodplain management programs, and recommend changes to make the programs more effective. As stated in its final report, issued in June 1994, the Committee found that projects for reducing flood damage and programs for managing floodplains, where implemented, essentially worked as designed.[41] Flood control reservoirs and levees prevented billions of dollars in damage. Nevertheless, the flood overtopped many smaller, locally constructed levees and caused considerable damage. According to the Committee, the 1993 flood would have covered much of the floodplains of the lower Missouri and upper Mississippi rivers whether or not the levees had been there.

The Committee found that the loss of wetlands and vegetation and the modification of the landscape in the upper basin over the last century and a half significantly increased runoff. Although efforts to conserve land and restore wetlands can reduce flood levels in smaller, more frequent floods, such activities would probably not have had a significant impact on the 1993 flood.

In the area affected by the 1993 flood, flood control structures were not completed as part of a plan for an overall system. Rather, they were developed for specific purposes by private landowners, levee and drainage districts, and the federal government. The Committee found that the result is a mixture of federal and nonfederal structures that provide differing levels of flood protection for similar land uses.

Because the levees in the area affected by the 1993 flood were built without benefit of an overall plan, the Committee found that levees cause problems in some areas by raising flood levels and backing up flows onto lowlands. It found that many nonfederal levees were located and designed in a manner that contributes to erosion and deposition in the floodplain and are built without regard for their impact on the river and neighboring communities. During large floods, such as the 1993 flood, levees have minor effects on overall flood levels but may significantly increase local levels, the Committee said. It also found that the height and location of levees are key factors in determining these local effects, as well as in indicating whether levees will be prone to failure. The Committee concluded that, in certain locations, levees should not be constructed and

[41]Sharing the Challenge: Floodplain Management into the 21st Century, Interagency Floodplain Management Review Committee (Washington, D.C.: June 30, 1994), pp. 50-51.

greater setbacks from the rivers would allow the rivers to behave more naturally during flooding. The Committee also concluded that locks and dams and other navigation structures did not raise flood heights in 1993. The Committee estimated that nonfederal levees extend up to 5,800 miles along rivers in the upper Mississippi basin.

The Committee found that floods like the one in 1993 are natural events that will continue to occur at random intervals. Flood recurrence intervals are difficult to predict, especially given the nation's short history of hydrologic recordkeeping and limited knowledge of long-term weather patterns, the Committee noted. Activities in the floodplain, even when protected by levees, remain at risk.

On the basis of these conclusions and others, the Committee outlined the following findings and recommendations on levees for the administration.

- To reduce the nation's vulnerability to flood damage in the floodplain, full and equal consideration should be given to all options for reducing damage, including building levees, evacuating high-risk areas, improving flood warning systems, floodproofing structures remaining in the floodplain, and creating additional capacity for storing floodwaters.
- To provide for efficiency in operations and consistency in standards, assign principal responsibility for building and repairing levees under federal programs to the Corps.
- To ensure the integrity of levees and the environmental and hydraulic efficiencies of the floodplain, increase the role of states and tribes in ensuring the proper siting, construction, and maintenance of nonfederal levees. Specifically, the Committee recommended that states assume responsibility for regulating the location, alignment, design, construction, upgrading, maintenance, and repair of levees and for flood-fighting.

To integrate the management of hydrologic, hydraulic, and ecological systems in the upper Mississippi River basin, the Committee also recommended a number of actions to improve the coordination of federal and state efforts, including (1) the establishment of river basin commissions and (2) the assignment of responsibility to an expanded Mississippi River Commission under the Corps for managing efforts to reduce flood damage, ecosystems, and navigation in the basin.

The Committee also recommended that the Corps' current floodplain management assessment of the upper Mississippi River basin be redirected to develop a plan for reducing flood damage in the basin that would include both structural and nonstructural measures. They recommended placing the assessment under the expanded Mississippi River Commission within the Corps, which would determine how best to integrate existing facilities in the upper basin into an efficiently functioning system for reducing flood damage.

Major Contributors to This Report

Resources, Community and Economic Development Division, Washington, D.C.

John H. Anderson, Jr.
Leo E. Ganster
John P. Scott

Kansas City Regional Office

Julie A. Cahalan
Patricia M. Crown
Frederick T. Lyles, Jr.
Darryl S. Meador
Denice M. Millett

Office of the General Counsel

Stanley G. Feinstein

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