The Great Flood of 1993

Geologic Perspectives on the Flooding along the Mississippi River and Its Tributaries in Illinois

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Special Report 2

ILLINOIS STATE GEOLOGICAL SURVEY
Morris W. Leighton, Chief

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Cover photo *Flooding across the entire 6-mile-wide floodplain of the Mississippi River valley north of Quincy in Adams County, Illinois. View is toward the north across the Indian Grave and the Hunt and Lima Lake Drainage and Levee Districts. (July 21, 1993. Photo by J.M. Dexter, ISGS.)*

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Contents

1 Illinois counties declared disaster areas at the federal and state level (39) and at the state level (5) as a result of the heavy precipitation and flooding during the summer of 1993. (Computer-generated map from the Illinois Geographic Information System; data from Illinois Emergency Management Agency.)

THE 1993 FLOODING ALONG THE MISSISSIPPI RIVER AND ITS TRIBUTARIES: GEOLOGIC PERSPECTIVES

Damage caused by flooding in the Mississippi River valley and along its tributaries in Illinois during the summer of 1993 was the worst in the state's history. "The Great Flood of 1993," as it was aptly named, rose in places to nearly 23 feet above flood stage, advancing into areas never before flooded in historical time. Towns and croplands were damaged extensively—some towns will be relocated rather than rebuilt. In Illinois, 39 counties were declared federal and state disaster areas, and another five counties were declared state disaster areas (fig. 1). The total damage in Illinois is likely to exceed $1.3 billion, making this the most costly natural disaster in the state's history (figs. 2– 5). The total damage throughout the nine states of the upper Mississippi and Missouri Rivers is likely to exceed $10 billion, making this the worst flood disaster in U.S. history.

Geologic history and processes were critical to this flood event. Topography, which is the elevation and shape of the landscape, controlled the extent and impact of the flood waters in Illinois. In addition, erosion, sedimentation, and other geological processes responsible for the evolution and characteristics of the floodplains influenced the severity and extent of flooding. The nature of floodplain sediments determined how much moisture the soil could hold before it reached saturation, and as a result, controlled the integrity of levees built from and on these sedimentary materials. Sand-filled ancient river channels, left by rivers flowing hundreds to thousands of years ago, underlie some levees and contributed to the weakening and breaching of these defense structures. The flood modified the geologic features of some areas, not only through erosion and deposition, but also through high water tables and ground instability.

2 *Monroe County: Flood water rushing through the town of Valmeyer lifted this house off its foundation and carried it until it collided with a tree (October 12, 1993).*

3 Adams County: High water came up to the windows of this house on stilts along the Mississippi River near Quincy. Oily film of silt and clay covers the lower half. Although the house stayed high and dry during other floods, it was not safe from the flooding in 1993, which exceeded the design height for flood protection (August 25, 1993).

4 Randolph County: Asphalt pavement slabs next to the riverfront road at Chester were lifted and transported by flood water. Robert Bauer, ISGS engineering geologist, stands where the blacktop slabs were eroded (October 13, 1993).

5 Jersey County: Aerial view (below) shows how much of Grafton was flooded at about the time of the highest flood crest (August 6, 1993). Water-saturated plasterboard and insulation removed from flood-damaged houses such as this Grafton home (left) cannot be reused. The debris from buildings affected by flood water will be a new burden on landfills. (September 3, 1993)

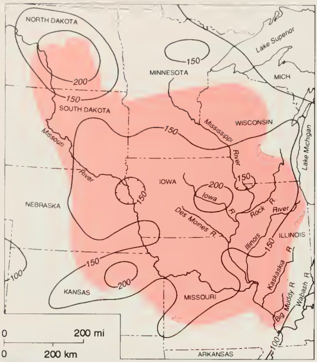
This report is not intended to be a detailed scientific report on the 1993 flooding. Other studies will focus on various scientific and engineering aspects of this catastrophic event. Instead, this report draws on historical data, research expertise, and the extensive databases of the Illinois State Geological Survey (ISGS) to illustrate in a general way how "The Great Flood of 1993" demonstrated the importance of geologic principles:

Geologic controls – how geology affected the extent and severity of the flooding,

Geologic impacts – how the landscape was altered because of the flood,

Geologic resources – how materials such as sand, gravel, and crushed stone were used in fighting and recovering from the flood,

Geologic information – how topographic maps and computerized databases of map information contributed to flood emergency management, recovery, and documentation.



area of flooding streams

line of equal total precipitation for January 1 through July 31,1993, as a percentage of the 30-year average for January 1 through July 31, 1961–1990.

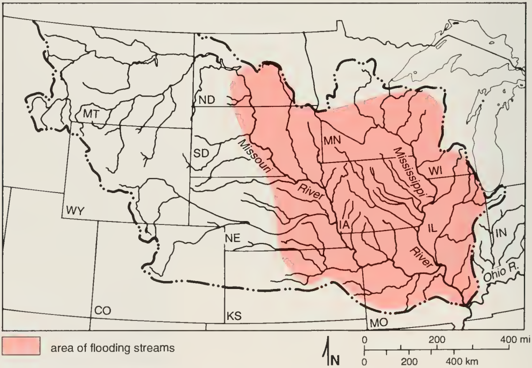
6 Distribution of total precipitation in the area of Midwest flooding, January 1 through July 31, 1993 (modified from Wahl et al. 1993). Red indicates the area of flooding streams.

OVERVIEW OF THE 1993 FLOOD

WEATHER

Above-normal precipitation and saturated soil conditions that led to the flood of 1993 actually began to develop in the fall of 1992 (Bhowmik 1994). On March 3, 1993, a National Weather Service report that appeared in the *Minneapolis Star-Tribune* first alerted the public to possible flooding in the upper Midwest (Dvorchak 1993). The forecast was for moderate flooding, which could be worsened by heavy rain.

Heavy rains came during the spring and continued through the summer. A high-pressure air mass (Bermuda high) stalled over the southeastern United States, and the clockwise circulation of the system brought warm, moist air from the Gulf of Mexico into the upper Midwest. A persistent jet stream pattern allowed cool Canadian air to converge with this moist air over the upper Midwest. As a result, thunderstorms formed along this convergence for most of the summer. In northwestern Illinois, rainfall was 150% of the 30-year average for January through July (fig. 6). North of Quincy in Adams County, rainfall between the spring and early fall of 1993 was the highest recorded this century. During 1993, several locations in Illinois had the most rainfall of any year since record-keeping began in the late 1800s. Although precipitation was extremely heavy, the excessive rainfall within the Mississippi and Missouri Rivers drainage basins in states to the north and west of Illinois was the primary cause of flooding along the Mississippi and Missouri Rivers (fig. 7).



area of flooding streams

boundary of Mississippi and Missouri Rivers drainage basin above confluence with the Ohio River

7 Drainage basin of the Mississippi and Missouri Rivers above the confluence with the Ohio River. Red indicates the area of flooding streams, June 1 through August 31, 1993 (modified from Parrett et al. 1993). The drainage basin is so extensive that river flow from as far west as Montana and Wyoming contributes to the river flow along the west border of Illinois south of the confluence of the Missouri and Mississippi Rivers.

RECORD FLOOD CONDITIONS

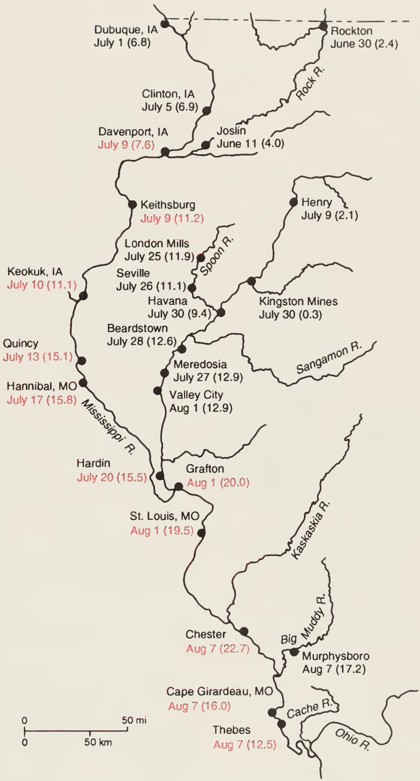
The flooding in 1993 had four characteristics that made this an unusual and unprecedented event:

- rivers remained above flood stage for months rather than days or weeks;
- flooding is common in the spring, but this event lasted through the summer;
- multiple flood crests occurred at most locations;
- flood crests set new highs for the historical flood record.

Records of previous high water levels were broken along the Illinois segment of the Mississippi River from Moline southward to Thebes, a river distance of approximately 440 miles. Figure 8 shows the maximum flood levels in feet above flood stage (when water begins to cover land outside the usual channel boundaries) and the dates the levels were reached along the Mississippi and its tributaries in Illinois. Flooding along the Mississippi River exceeded 10 feet above flood stage, as recorded at gauging stations from Keithsburg in southern Mercer County southward to Thebes in Alexander County. Previous high water records were shattered by more than 4 feet at both Grafton and Chester, Illinois, and by more than 6 feet at St. Louis, Missouri. At the height of the flood, river flow passing St. Louis was about 1 billion cubic feet per second—more than six times the normal discharge (volume).

Backwater flooding occurred in many tributary streams feeding into the Mississippi. Water levels in the Mississippi were so high that water from the tributaries had nowhere to go. The tributaries, dammed up by the Mississippi flood water, overflowed their banks and flooded their valleys. In some places, stream flow actually reversed and rivers temporarily flowed upstream.

As a result of the high rainfall in northern Illinois, many rivers in that part of the state reached flood stage independently of the Mississippi. Flooding even occurred in northeastern Illinois, including the Chicago metropolitan area, because of heavy precipitation and saturated soils (fig. 1).



8 *Dates of flood crests at selected gauging stations and maximum heights (feet) of flood water above flood stage. Numbers in red are new record flood heights.*

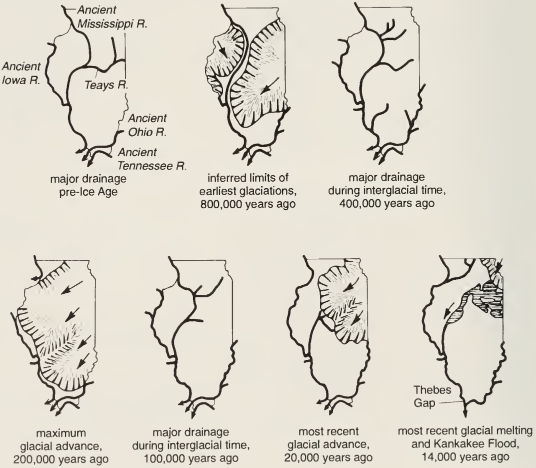
GEOLOGIC CONTROLS ON THE 1993 FLOODING

The extent and impact of flooding varied across the state. Much of the variation was controlled by geologic factors, which can be divided into three main categories.

Geologic history and landscape evolution Landscape evolution is a long-term process. Geologic events during the past hundreds to millions of years, especially changes brought about by the advance and melting back of glaciers during the past 2 million years, have determined the drainage pattern of the region and shaped the river valleys and floodplains that we see today.

Topography The general configuration of land surface, including its relief (differences in elevation from place to place) and the position of its natural and cultural features, was critical in controlling the extent and depth of flood waters as well as the direction and speed of flow. Where sediments were eroded and deposited also depended on the topography.

Floodplain sediments and their distribution The type of sediment, sand, silt or clay, is as important as the distribution of these sediments in controlling the flow and infiltration flow of water under or through levees, the movement of groundwater beneath the floodplain surface, and the susceptibility of different areas to erosion.



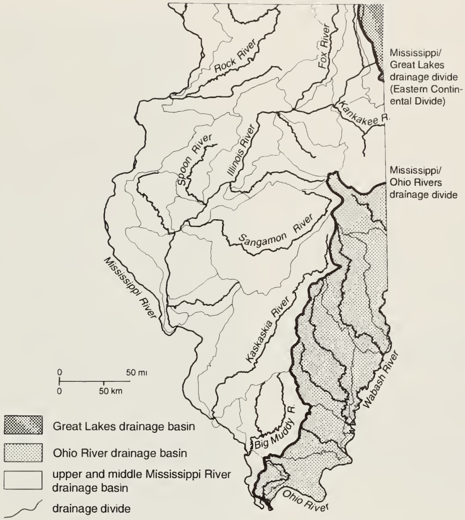
9 Evolution of Illinois drainage patterns as a result of multiple continental glaciations during the advance and melting back of glaciers across Illinois (modified from Willman and Frye 1970).

GEOLOGIC HISTORY AND LANDSCAPE EVOLUTION

Evolution of Drainage Patterns

Rivers from the north, east, and west meet in the low-lying region of Illinois and flow southward to the sea. This general pattern of drainage was established in the Ice Age (Pleistocene Epoch) about 1 to 2 million years ago. A series of continental glaciations diverted courses of the ancient rivers that converged in the region that is now Illinois. During the Ice Age, some valleys were repeatedly flushed out and filled with sand and gravel outwash that glacial meltwater carried away from the ice. The immense quantities of meltwater also eroded new channels across the region. Figure 9 illustrates the successive changes made to Illinois' major drainageways by the advance and retreat of these glaciers. Three of the changes in drainage patterns were dramatic:

- a major diversion of the Ancient Mississippi River, which altered its previous course along what is now the lower part of the Illinois River valley to its present position;
- a major diversion of the Ancient Mississippi River in southern Illinois, as it breached a course across uplands to occupy Thebes Gap;
- a major course change of the Ancient Ohio River from a channel through the Ancient Ohio River valley to its present channel along the southern margin of the state.



10 Major rivers and drainage divides in Illinois. Highlighted are the two major drainage divides that define the North American drainage areas of the Great Lakes, upper Mississippi River, and Ohio River.

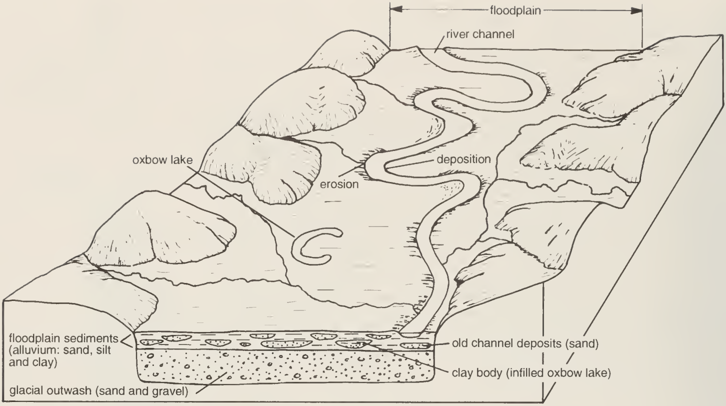
Of these three, advance of the glacial ice caused the first major alteration in regional drainage. A great glacial meltwater flood (the Kankakee Flood) probably caused the other two major changes in the channels of these ancient rivers.

During the Ice Age, geologic processes were shaping the valleys and floodplains of the Mississippi and Illinois Rivers and their tributaries as they exist today. Sediments carried by the glacial meltwater now partly fill these valleys and influence the present configuration and relief of the floodplains. Along the rivers, the width of the floodplain varies depending on where valley erosion has been constricted by bedrock.

GEOLOGIC CONTROLS

Landscape Evolution
Topography
Floodplain Sediments

In Illinois, runoff from rainfall and snowmelt collects in the three major drainage basins of the Great Lakes, Ohio River, and upper and middle Mississippi River (fig. 10). In northeastern Illinois, streams empty directly into Lake Michigan, part of the Great Lakes drainage basin. Most of northern, central, and western Illinois lies within the drainage basin of the upper and middle Mississippi River. In Illinois, streams contribute to the Mississippi River either directly or indirectly by way of intermediate streams. The largest tributary to the Mississippi in Illinois is the Illinois River, which has an extensive drainage basin encompassing most of the western and central part of the state. Although a few streams



11 Major features of a well-developed floodplain in Illinois (adapted from Tarbuck and Lutgens 1976).

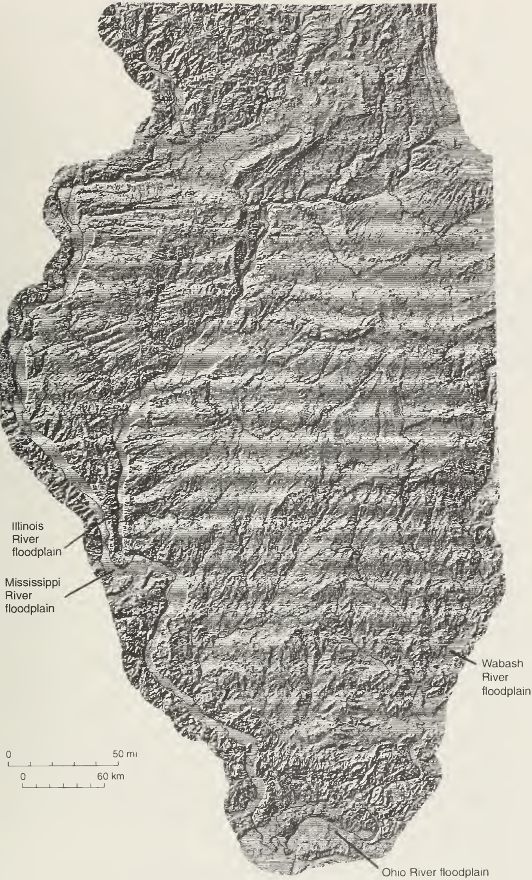
in southeastern Illinois flow into the Wabash and Ohio Rivers, this flow joins the Mississippi River at Cairo.

Floodplains

Rivers form floodplains, and floodplains are as much a part of the river system as the river channel. The relatively flat land that typically borders river channels is called a floodplain because it can be covered by water when the river overflows its banks (fig. 11). The course of the river across the floodplain develops the characteristic S-curves known as meanders. By eroding sediments along the outside bends and depositing them along the inside bends of meanders, the river reshapes its course so that its meanders continually migrate downstream and across the floodplain. Through time, the floodplain is widened by the river erosion against the valley margins.

Some floodplains are quite broad, as they are along the Mississippi and lower Illinois Rivers. The great width is due to the erosion of their valleys by the torrential flow of glacial meltwater down these rivers during the Ice Age. The floodplains of the Mississippi, Illinois, Ohio, and Wabash Rivers, the four major rivers in Illinois, are prominent features on the state's landscape (fig. 12).

Floodplains may appear flat and nearly featureless at first glance, but they have a subtle and complex topography. Former channel positions, remnants of the river's continual migration, are often marked by low-lying areas commonly occupied by streams or wetlands. The bars or bank deposits along the old channels often form higher areas. Fan-shaped areas of higher land (alluvial fans) form where streams from surrounding uplands deposit clay, silt, sand, or gravel (alluvium) onto the floodplain. During the 1993 flooding along the Illinois River, the higher ground of these alluvial fans at the edge of the floodplain often escaped inundation. These high-and-dry areas were used to store farm machinery, vehicles, and mobile fuel tanks threatened by rising flood water.



12 Shaded relief map of Illinois and parts of adjacent states. Nearly flat floodplains of the major rivers stand out in contrast to the variable relief of the uplands. (Computer-generated map from the Illinois Geographic Information System. Mapping derived from U.S. Geological Survey Digital Elevation Model data at 1:250,000 scale.)

Sediments vary considerably across the surface and in the subsurface of the floodplain. In general, floodplain sediments consist of coarse, sandy materials deposited in former channels, and fine silt and clay materials (overbank deposits) deposited in sluggish water outside the channels in former floods.

Floodplain Drainage and Levee Districts

Floodplains are usually excellent agricultural lands because they contain nutrient-rich sediments deposited by many floods. Soil moisture is commonly abundant because the river is so close and the water table shallow. There has been a long history of protecting these agricultural assets on many Illinois floodplains through private and government projects that drain excess waters from the floodplains and build levees.

Floodplains of the Mississippi and Illinois Rivers are divided into drainage and levee districts; each is managed by a local governing body. In Illinois, at least 41 drainage and levee districts and other flood-protection systems are located along the Mississippi River floodplain; at least 54 are along the Illinois River floodplain south of Peoria and floodplains of tributaries to the Illinois River. (There are more districts and flood-protection systems for the Illinois River and its tributaries because these districts are smaller than those along the Mississippi floodplain.) Geologic factors controlled the location of levees and the overall shape of the districts. Typically, the districts are semi-enclosed by a levee (shaped like a "C") that begins and ends against the highland on the floodplain margin and has its longest segment parallel to the river. Major streams that drain the uplands and flow across the floodplain to the Mississippi or Illinois Rivers commonly form the upvalley and downvalley margins of each district. Water that enters a district from smaller upland streams or directly from precipitation must be pumped out or allowed to drain through gates or culverts that run beneath the levee.

Figures 13 to 16 show the extent of floodplains along the Illinois segment of the Mississippi River and the Illinois River south of Peoria. These maps also show how widespread the flooding was (its maximum areal extent) in 1993. Also shown are locations and names of drainage and levee districts and other flood-protection systems, and the drainage and levee districts flooded in 1993. A subsequent section on sediment types and distribution discusses how levees are constructed and how they can fail.

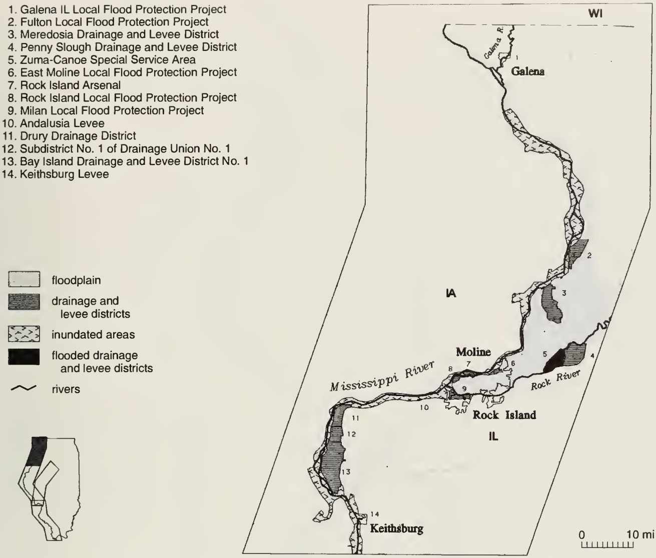
TOPOGRAPHY

Topography is an important geologic control on where flooding will occur and what path the flood waters will take.

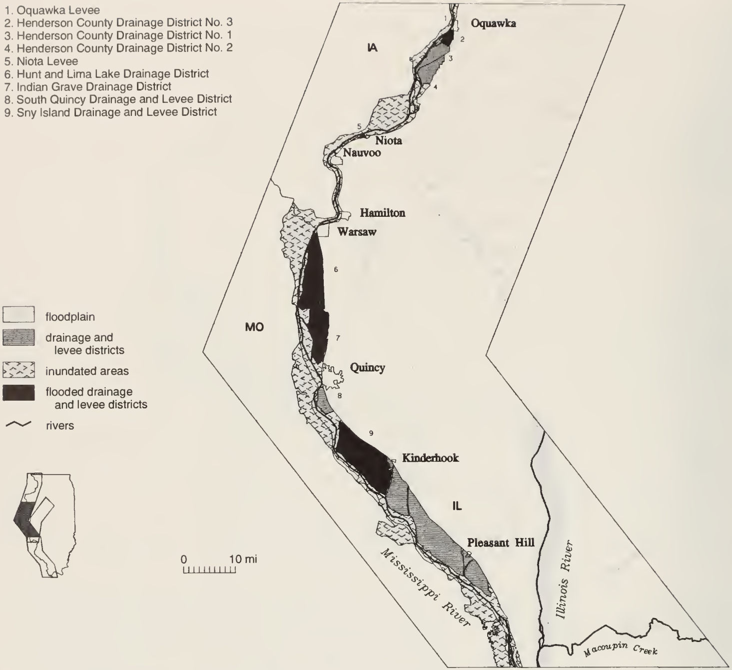
Overview of Topographic Controls

In any particular area along the flood margin, the surface elevation of flood water was uniform and defined a curving line of uniform elevation on the land surface (like the contours on a topographic map; fig. 17). As flood water receded, the high water line was well marked by the upper limit of dead vegetation, something like the ring left in a bathtub after the water drains out. Figure 17 shows the high water mark on a hillslope along the margin of the Illinois River valley. The extremely high water levels in this area caused flooding above the limits of the floodplain and up onto a bluff slope. The valleys and floodplains of tributary streams draining the uplands were low areas where flooding could extend even farther from the main river channel. The high water line in figure 17 goes around the hillslope and into the distant valley.

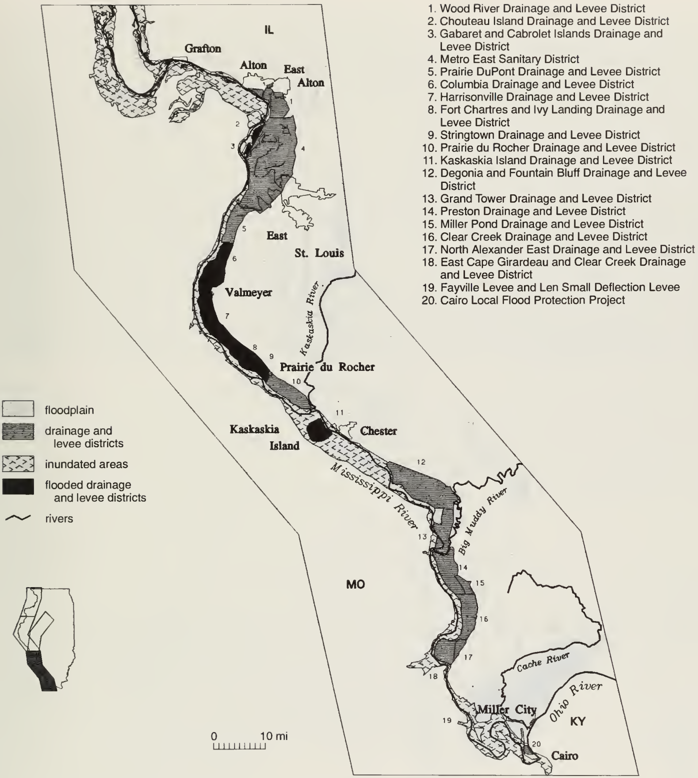
The importance of topography in the 1993 flood can be best explained through four examples, each presenting different aspects of the interplay between the elevation and shape of the landscape, and their influence on the extent of flooding and the flow path of flood waters.



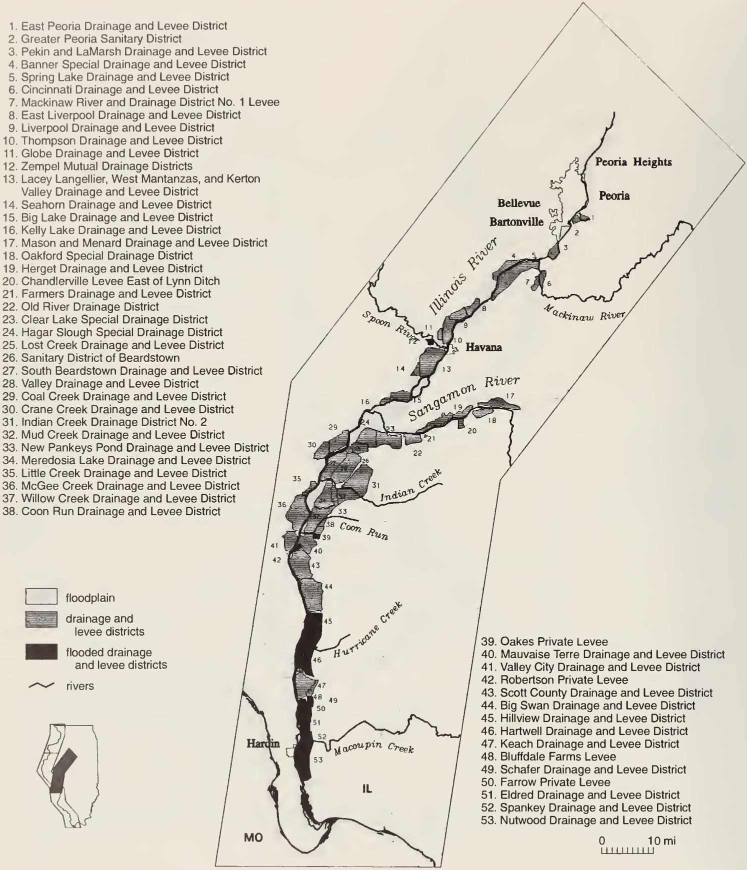
13 Floodplain and flood protection of the Illinois segment of the Mississippi River from the Illinois–Wisconsin state line southward to about 7 miles south of Keithsburg. (Figures 13–16: Computer-generated maps from the Illinois Geographic Information System [GIS]. Floodplain limits provided by the Illinois State Water Survey at scales 1:12,000 and 1:24,000. Flood inundation data, limited to Mississippi River valley, provided by the U.S. Geological Survey and the ISGS at 1:100,000 scale. Levee location data provided by the U.S. Army Corps of Engineers and the ISGS at 1:24,000 scale. Data on flooded levee districts from Illinois Department of Transportation Division of Water Resources and the U.S. Army Corps of Engineers.)



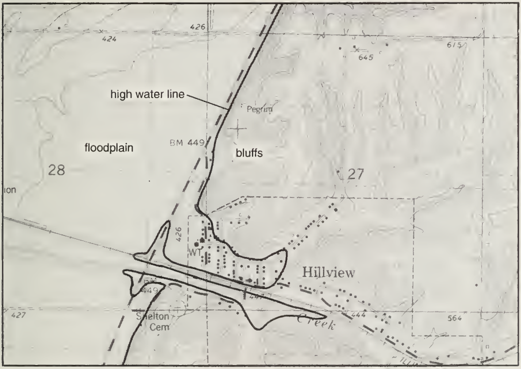
14 Floodplain and flood protection of the Illinois segment of the Mississippi River from about 4 miles north of Oquawka southward to about 25 miles south of Pleasant Hill.



15 Floodplain and flood protection of the Illinois segment of the Mississippi River from about 30 miles upstream from Grafton southward to Cairo.



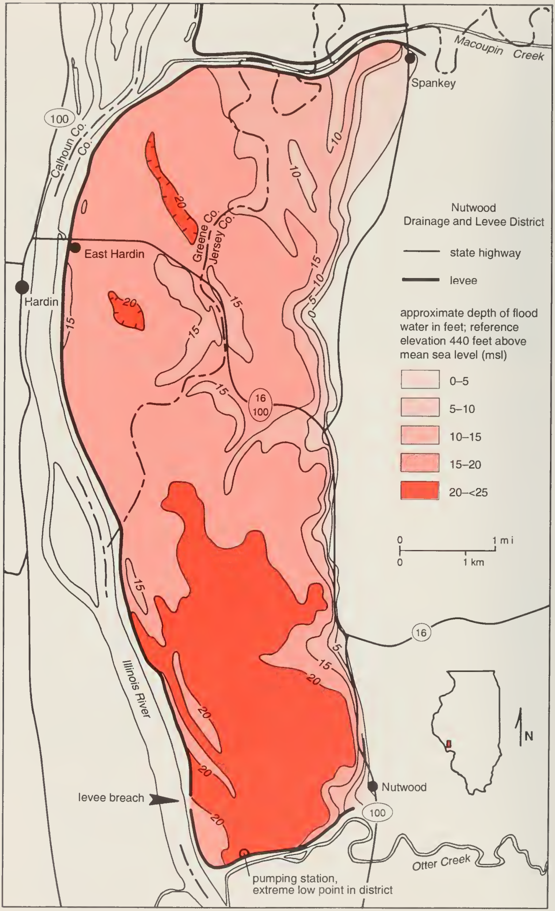
16 Floodplain and flood protection of the Illinois River south of Peoria and the lower Sangamon River. (No inundation data for the Illinois River).



17 *Greene County: Dead vegetation (above) commonly marks high water line, as in this view of the Illinois river valley within the Hillview Drainage and Levee District. The town of Hillview is in the distance. Note the abundance of corn plant debris caught in the barbed-wire fence (August 25, 1993). Topographic map of Hillview and vicinity (left) shows configuration of the high water line. Spacing between contours relates to land slope. The widely spaced contours represent the relatively flat land of the floodplain. Closely spaced contours are the steep slopes of uplands and bluffs. Base map, Pearl East Quadrangle, USGS 7.5-minute topographic map, 1980.*

Flooding in the Illinois River Valley

Of all the valleys tributary to the Mississippi River in Illinois, the southern part of the Illinois River valley suffered the most. Flood crests at Hardin, about 20 miles upstream from the confluence with the Mississippi, were as much as 4 feet above the previous record. Although the Illinois River drainage basin received high amounts of precipitation, flooding along the river valley was caused primarily by backwater from the Mississippi. Flood crests on the Mississippi formed a water dam at the mouth of the Illinois. Water was prevented from flowing out of the Illinois River valley, and for a time, Mississippi flood water backed into the Illinois River and caused it to flow temporarily upstream. In turn, high water on the



18 Contour map of approximate water depths at flood crest within the Nutwood Drainage and Levee District.

Illinois River caused backwater flooding in several of its tributary valleys, particularly the Spoon and Sangamon River valleys (figs. 8 and 16).

The low slope of the southern part of the Illinois River valley makes this area particularly prone to backwater flooding. The low slope results from deposition of large volumes of slackwater sediment from the Illinois and Mississippi Rivers. The average slope along the 30-mile segment of the river from Kampsville southward to its confluence with the Mississippi is about 0.1 foot per mile. In contrast, the average slope along the 120-mile segment of the Mississippi River from Quincy downstream to the Missouri River confluence is 0.6 feet per mile (Simons et al. 1975). A consequence of the low slope is that levees along the lower Illinois River need to be high enough to accommodate anticipated Mississippi River flood levels.

Four drainage and levee districts along the Illinois River floodplain (Nutwood, Eldred, Hartwell, and Hillview) were inundated in 1993 (fig. 16). Because the slope of the lower valley was so low, flood conditions lasted longer here than they did in many areas along the Mississippi River. The low slope of the floodplain also meant that water drained slowly from the inundated drainage and levee districts. In several cases, water had to be pumped out.

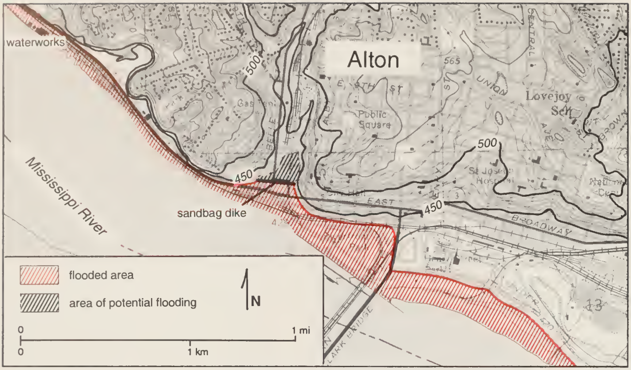
The southernmost Nutwood Drainage and Levee District was the first to flood along the Illinois River. On July 18, the Nutwood levee was overtopped and breached in its southwestern segment (fig. 18). Because of the break, 10,300 acres of the district flooded to depths of more than 20 feet.

The contour map of flood depths in the Nutwood Drainage and Levee District (fig. 18) was made by comparing elevation data along the high water line with contours of land elevations shown on topographic maps. Several examples of the effects of topography on the depth of flooding are illustrated by this map. First, the flood water was deepest in the downvalley or southern end of the Nutwood district. Second, maximum flood depths generally occurred closest to the river or in topographic lows, which were typically swales occupied by streams or drainage ditches. Third, fan-shaped, topographically high areas (alluvial fans) next to the bluffs were not flooded or only minimally inundated. Several alluvial fans occur along the east side of the Nutwood district; the town of Nutwood is located on one of them. Finally, the topography and slope of the floodplain also controlled the pattern of flood recession from the district. As the water receded, the areas adjacent to the bluffs, the highest elevations on the floodplain, were the first to emerge. The upvalley (northern) part of the district emerged before the downvalley (southern) part. Similar effects of topographic control can also be observed in other inundated districts along both the Illinois and the Mississippi River floodplains.

Topography and the Flood Threat at Alton

Most of the city of Alton was built on land higher than the floodplain of the Mississippi River, so nearly all of the city was high enough to be safe from the 1993 flood. The primary flood problem was defense of the city's water treatment plant, which stood next to the river. Downtown in the commercial district, the main threat was to the area occupying a stream valley cut into the uplands (fig. 19). Flood defense at Alton involved constructing a sandbag dike up to 9 feet high and approximately 700 feet long across the mouth of this stream valley (fig. 20).

The flooding at Alton illustrates a potential problem with tributary valleys that cut down through the bluffs adjacent to the Mississippi River valley. The lower stretches of the valleys are vulnerable to inundation when the Mississippi overruns its banks. If flooded, these valleys can become quiet-water areas where an abundance of sediment may be deposited. The village of Elsah, about 10 miles up the river from Alton, sits in such a tributary valley. The entire village is on the



19 Topographic map of Alton. Flooding threatened the commercial district located in a stream valley (highlighted by dark contours at 450 and 500 feet). Base map, Alton Quadrangle, USGS 7.5-minute topographic map, 1974.

National Register of Historic Places, and a major sandbagging effort was necessary to minimize inundation of the valley and damage to the historical buildings.

Flood Threat at Prairie du Rocher

One of the most striking examples of the importance of topography in determining flood impact occurred along the Mississippi River in southern Illinois near Valmeyer in Monroe County and Prairie du Rocher in Randolph County. During the flood of 1993, the media highlighted the calamities of levee breaks and the inundation of floodplains. So there was considerable confusion when the U.S. Army Corps of Engineers and levee district representatives intentionally broke a levee along the Mississippi River near Prairie du Rocher. Why this action was taken is best explained by referring to differences in elevation and slope along a 26-mile stretch of the river valley.

From just north of Valmeyer southward to Prairie du Rocher, the Mississippi River flows on the west side of its valley. On the east side, the floodplain is protected by levees of five districts (Columbia, Harrisonville, Fort Chartres and Ivy Landing, Stringtown, and Prairie du Rocher; figs. 16 and 21). The Harrisonville, Fort Chartres and Ivy Landing, and Stringtown districts actually form a single floodplain cell that is divided into three districts by two, low-lying flank levees. In flooding as extreme as that occurring in 1993, these flank levees were nothing more than "speed bumps" for the advancing water. For simplicity, this report refers to the entire floodplain cell as the Valmeyer cell. Figure 21 shows the geographic setting of the events that took place in the Valmeyer cell.

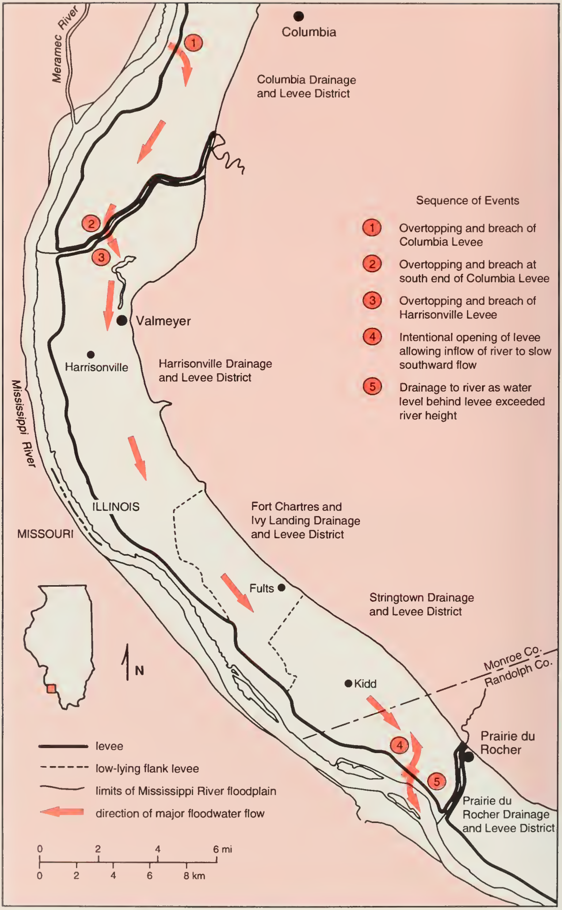
First, on August 1, a breach occurred along the river side of the Columbia levee. As water surged into the floodplain, it flowed primarily southward down the slope of the plain and reached the levee along the southern margin of the Columbia district. Second, the southern part of the Columbia levee was overtopped and breached. Pouring through three closely spaced breaks in the Columbia levee, flood water entered the Fountain Creek drainage channel, which was already backed up due to Mississippi River flood water. Third, the Harrisonville levee on the south side of Fountain Creek was overtopped and breached in one location, opposite the three breaches in the Columbia levee.

The breaching of the Harrisonville levee let the flood into the northern end of the Valmeyer cell. Because of the southward slope of the floodplain and the topographically low area of a former river bed, the flood water was channeled toward Valmeyer. The town was hit with a wall of water, destroying many buildings and moving some small houses off their foundations (fig. 2). South of Valmeyer, the flood water continued to advance across the broad floodplain. The two flank levees temporarily slowed the flood water's advance, but they were soon submerged as the water rose higher than the levees.

When a levee breaks, the enclosed floodplain cell acts as a lake basin. Water rises in the basin until it reaches the level of the water at the point of entry, or inflow. The Valmeyer cell breached at its upvalley (northern) end, the highest elevation of the levees confining the cell. The break was in the worst possible place because the flood water would rise at the downvalley (southern) end to reach the elevation of the upvalley breach. If this happened, the levee at the south end of the Valmeyer cell would be overtopped.

On the river side of the Valmeyer cell, the surface elevation of the flood water decreased toward the south because of the gradient of the river. This meant that the levee protecting Prairie du Rocher was high enough to protect the town from the projected flood crest on the river along this levee district. Inside the Valmeyer cell, however, flood water could be expected to rise, overtopping the entire length of the southern part of its levee. Once this levee was overtopped, the water would rise in the flooded drainage channel of Prairie du Rocher Creek and overtop the adjacent northern part of the Prairie du Rocher levee. The entire Prairie du Rocher Drainage and Levee District, including the towns of Prairie du Rocher and Modoc, would have been inundated. The decision to take action to prevent this from happening was made by the U.S. Army Corps of Engineers and the Division of Water Resources of the Illinois Department of Transportation.

20 Madison County: Looking west along the sandbag dike used to prevent inundation of the valley in the west part of downtown Alton. Water from backed-up sewers and underground steam pipes along Piasa Street was pumped to the river (July 24, 1993).



21 Floodplain and levees in the Valmeyer–Prairie du Rocher area—setting for a sequence of events leading to the flood threat and defense of Prairie du Rocher.

On August 2, the day after the Columbia levee was breached, the U.S. Army Corps of Engineers made the first of three breaks in the levee at the southern end of the Valmeyer cell. The ultimate goal was to provide a drain for the water impounded within the cell to flow back into the Mississippi River before it overtopped the southern levee. The initial goal was to intentionally flood the southern part of the cell before the southward-surging flood water could submerge the area. This advance flooding would "cushion" the potentially destructive direct impact of water against the levee at the southern end of the cell. As the water level rose in the Valmeyer cell, it eventually became deep enough to flow through the emergency breaks back to the Mississippi River. Some flood water did overtop the levee in a few places along the southern end of the Valmeyer cell until the initial breaches (made by excavating and dynamiting) were widened to accommodate the volume of water flowing through the cell.

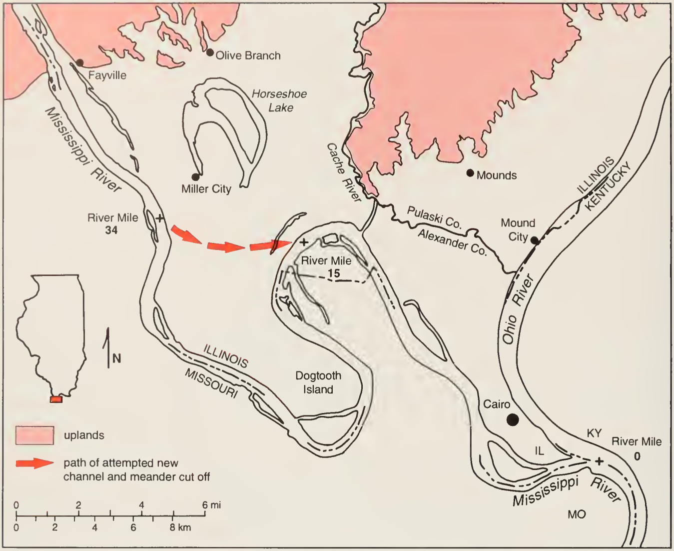
Of all the actions related to flood defense and mitigation in Illinois, no other action more clearly demonstrated the relationship of flood elevations, flood processes, and river and floodplain gradients as did the decision to intentionally open this levee. If action had not been taken, Prairie du Rocher and about 13,000 acres of farmland in the Prairie du Rocher Drainage and Levee District would have been flooded. The inundation of the Valmeyer cell demonstrates an important geologic fact: Although the slope of the valley may be imperceptible in any locality, the decline in elevation along several miles of the river valley is an important factor when considering flood dynamics. This case study also demonstrates that levee districts flood as if they were lake basins; the water levels out at a uniform elevation equal to the inflow elevation. In contrast, flood water outside levee-protected areas has a sloped surface that, corresponding to the gradient of the river, decreases in elevation down the river valley.

The Beginning of a Meander Cutoff Near Miller City

When meandering rivers flood, the water may cut a new channel in the floodplain at a place where the river can shorten the distance it must travel, and as a result, increase its slope. The process requires a sufficient volume of flood water and sufficient time. The cutoff is most likely to occur where the outside bend of one meander loop is close to the outside bend of the next loop downstream. The cutoff meander may still contain a small part of the river flow, or it may be completely closed off by sediment deposition at its two ends, forming an oxbow lake (fig. 11).

How meander cutoffs can develop was dramatically demonstrated during the 1993 flood. The Mississippi River nearly cut a new channel in southern Illinois near Miller City (fig. 22). In this area, the Mississippi River floodplain covers a wide area and merges with Ohio River floodplain (figs. 12 and 22). Many features on the floodplain near Miller City indicate that changes in channel positions and meander cutoffs have been frequent in the past. The floodplain includes Horseshoe Lake, an oxbow lake that formed by flooding since the end of the last glaciation.

The meander cutoff began to form on July 15, when a breach occurred in the Len Small deflection levee (an appendage of the Fayville levee) about 1.5 miles southwest of Miller City. The breach was at about river mile 34, which is 34 miles upstream from the confluence of the Mississippi and Ohio Rivers. The area south of Miller City was flooded, and because of the gradient, much of the water flowed southeastward for about 6 miles from the breach of the Len Small levee to rejoin the main river channel at about river mile 15 (fig. 22). It seemed that approximately 19 miles of river channel was about to be cut off and replaced by a new channel only 6 miles long. The Mississippi River would be shortened by 13 miles. The distance for river traffic would also be shortened, but the slope along the new channel was likely to be too steep for safe passage of tugs and barges. A new lock and dam might even have been needed for this river segment.



22 Between river miles 34 and 15 near Miller City, the Mississippi River nearly shifted its channel and cut off a meander.

The potential change in the channel before and after the peak flood conditions was monitored by the U.S. Geological Survey, the U.S. Army Corps of Engineers, and the Illinois Department of Transportation, Division of Water Resources (Bhowmik 1994). At the flood peak in this area on August 7, approximately 25% of the flood discharge from the Mississippi River was flowing across the floodplain along this potential channel (Jacobson et al. 1993). An irregular channel, up to about 60 feet deep and extending 1 to 2 miles downstream from the levee break, was eroded into the floodplain. The channel development stopped along a road running at right angles to the channel. The compacted roadbed, the paved road surface, and trees along the road apparently formed a barrier to further channel erosion. In this case, a manmade feature intercepted the natural processes developing the meander cutoff. In other cases, the process may be retarded by erosion-resistant sediment, such as a clay deposit, in the floodplain.

The first stage of a meander cutoff near Miller City is a prime example of the type of channel change that commonly occurred during floods along the river before structures such as dikes and levees were built to maintain the channel position. Such channel changes are part of the natural geomorphic processes of floodplain evolution as the river continually seeks the most efficient route, or path of least resistance, to the sea.

Possibly the most striking example in Illinois of a meander cutoff during historical time occurred at Kaskaskia Island. When pioneers established the original settlement of Kaskaskia between the Mississippi River, which flowed in a wide arc in a channel (now called "Old River") around what is now the north, west, and south sides of the island, and the old channel of the Kaskaskia River on the east side of the island (see inset map, fig. 31). During a flood of the Mississippi in 1881, the meander was cut off when the river assumed the old channel of the Kaskaskia River on the east side of the island. Because the boundary between Illinois and Missouri was established before the channel shift, Kaskaskia Island, now west of the Mississippi River, remains a part of Illinois, accessible by land only from Missouri.

FLOODPLAIN SEDIMENTS AND THEIR DISTRIBUTION

River meandering, sediment erosion and deposition, and other geologic processes that form floodplains also control what type of sediments can be found on a floodplain and how they are distributed. Sand is common in channel deposits; silt and clay are common in overbank deposits between old channels and in backwater swamp deposits. Clay also is common in the upper part of infill in old channels that became oxbow lakes. Another important geologic control is the areal distribution of these sediments—in other words, how and where they are distributed across the floodplain controls how susceptible different areas of the floodplain are to erosion. Whether the type of sediment is porous sand or relatively impermeable clay also determines whether water can infiltrate below and into levees. Once this happens, levees are weakened and more likely to fail.

Overview of Levee Construction and Failure

Levees are linear, earthen mounds of two general types, depending on what they protect. Agricultural levees protect farmlands; urban levees are higher and broader structures that protect cities. Levees along the floodplains in Illinois are primarily agricultural. One of the state's broadest floodplain areas, the Wood River–Granite City–East St. Louis area known as the American Bottoms (fig. 15), is protected by an urban levee.

Levees are typically constructed of sediments dredged from the river channels or excavated from the floodplains. Properly compacted clay is ideal for levee construction because it resists erosion and forms a relatively impermeable barrier to the infiltration of flood water. In contrast, sand allows infiltration, which can weaken the levee and lead to structural failure. Sand is also easily eroded from the levee.

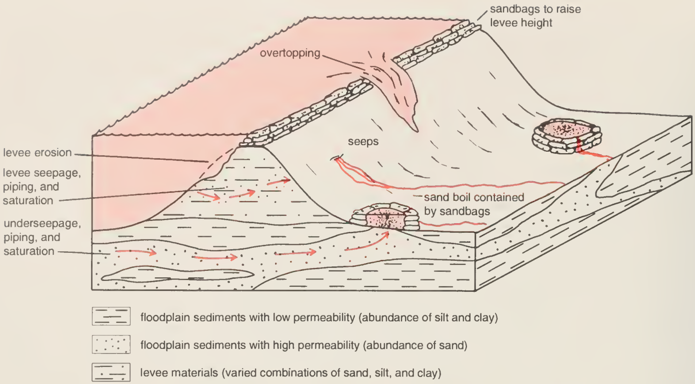
The characteristics of sediments relate to three causes of levee failure (fig. 23).

Surface erosion The surface of the levee is eroded by flood water lapping against it or by precipitation, as during a heavy rainfall, when drops of water pelt the surface and dislodge particles of sediment.

Levee seepage The levee is internally weakened as it becomes saturated by water seeping through permeable layers within the levee, or by the process called piping, which is water carrying sediment through animal burrows or along the openings made by plant roots, particularly tree roots.

Underseepage The ground under the levee is weakened as water moves through porous sand layers beneath the levee and pipes sediment away. Because of the loss of support, the levee may subside or collapse. (Levee seepage and underseepage cause seeps and boils, as described in the next section.)

A levee can also be weakened by overtopping, which simply means that water floods over the levee. Overtopping is not a type of levee failure, but a case of flood height exceeding the design height of the levee. Once overtopping begins, the flow of flood water usually breaches the levee.



23 Overtopping, seeps, and piping move water over, through, or under a levee during a flood (after U.S. Army Corps of Engineers, 1978).

Figure 23 illustrates how water moves through, under, and over a levee as it holds back flood water. During the 1993 flood, most levees that were breached in Illinois were overtopped rather than weakened by structural failure. In several cases, seepage and underseepage probably contributed to localized weakening and subsidence of levees, which made them more vulnerable to overtopping and breaching.

Levee Seeps and Sand Boils

Flood water on the river side of levees applies pressure to the levees, which are constructed to hold back water for a short time. Because of the unusually long duration of high water in the flood of 1993, water infiltrated permeable layers within and beneath the levees. The result was seeps piping sand out of the levee on exposed levee slopes. Along much of the Sny Island levee bordering the Mississippi River south of Quincy, seeps were a widespread problem, causing the levee to fail on July 25 (fig. 24).

Sand boils were common on the floodplain adjacent to many levees. They formed where lenses of sand under or within a levee provided a pathway for water to pipe sediment. Unless piping (erosion) of sediment under or within the levee was halted, the flowing water would quickly sap the levee structure and cause a catastrophic failure. Sand boils were counteracted by building a dike of sandbags around the boil (fig. 25) and allowing water to rise within the ring. The rate of flowing water slowed within the ring dike, and the sandbags minimized the loss of sediment by trapping it in place and equalizing water pressure. Allowing the water to flow over the sandbag dike prevented water pressure from building up elsewhere in the levee. Sand boils can develop, then cease activity as changes occur in the flow pathways within the levee. Fine grained materials (silt or clay) transported within the levee may block the flow path and shut off one sand boil while opening a channel for another (fig. 26).

Levee Underseepage, Piping, and Subsidence

Where a large amount of permeable, uncompacted sediment such as sand underlies a levee, the material may become unstable and mobile as it becomes saturated. If saturation occurs, the levee loses support and may sag, forming a low spot in the crest. If underseepage removes sediment beneath the levee, the undermining may bring about a sudden and catastrophic collapse. In either case, flood water can then pour over the subsided or collapsed segment of the levee and quickly erode a deep and wide breach.

A catastrophic collapse of the levee that protected Kaskaskia Island resulted in flooding of the island and the historic town of Kaskaskia. A large sand boil had developed next to the levee. Attempts to contain the boil were overwhelmed by the great volumes of water and sediment erupting from the boil. Just before the levee collapse, according to observers, the boil was like a geyser. The levee collapsed on July 22, and within 1 day, the island was inundated by more than 10 feet of water. The most discouraging aspect of the collapse is that the levee was high enough so that even maximum flood levels would not have overtopped it.

The porous materials that allowed the catastrophic underseepage and piping to develop beneath the breach at the Kaskaskia levee may have been deposited in an ancient channel of the Mississippi River. Data on the subsurface features in the area should be examined to verify the existence of such a channel because no surficial features on the floodplain suggest the presence of a former channel.

Surficial features of one or more ancient channels are associated with four levee breaches that occurred just north of Valmeyer (fig. 27). The breaks occurred along the Fountain Creek drainage channel. The locations of ancient channels were determined by interpreting landscape features shown on topographic maps and soil patterns shown on soil-survey maps (SCS, USDA 1987). The positions of some of these ancient channels, such as a former meander on the east side of the floodplain now occupied by Moredock Lake, are well defined on the present landscape. The old channels mark the different positions of the river as it migrated across the floodplain. Younger channels cut across older channels, which makes it possible to work out a relative chronology of the channel positions from oldest to youngest.

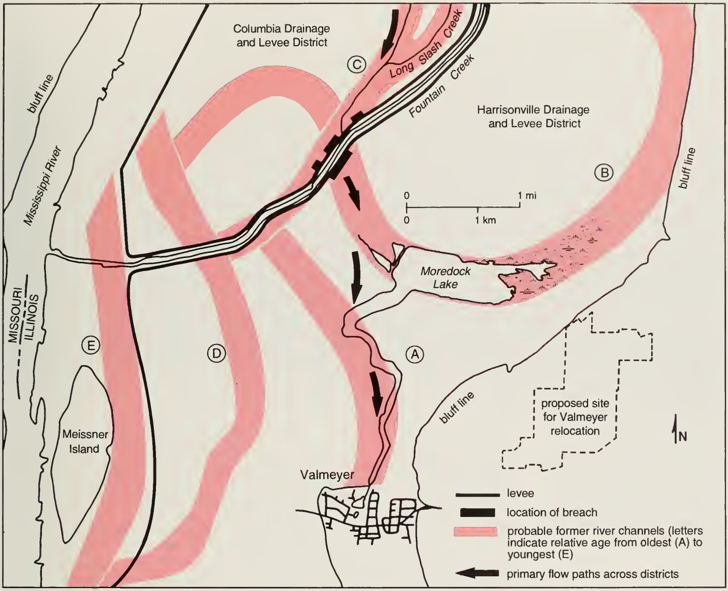
The association of the breaches with ancient channels suggests a strong relationship between subsurface sediments in the channels and materials in the levees. The exact mechanisms of these levee breaks along the Fountain Creek drainage

24 Pike County: Water seepage caused piping of sandy material in the Sny Island levee, at about the place where it failed on July 25, near East Hannibal. The observers are engineers from the U.S. Army Corps and officials of the Sny Island Drainage and Levee District (July 21, 1993).

25 Pike County: Sand boil at the foot of the Sny Island levee. Sandbag ring dike prevents loss of piped sand but lets water flow away, reducing water pressure under the levee (July 21, 1993).

26 Active and inactive sand boils side by side at the foot of the Sny Island levee. Flow paths to the inactive boil (top) were possibly shut off by internal shifting of sediments (July 21, 1993).

channel are uncertain because no monitoring was going on at the time. But from what is known about how these materials respond under similar conditions, it is possible to make a reasonable interpretation of what happened. Sand, which is typically the dominant sediment in ancient channels, became quickly saturated by an abundant water supply. Saturation of the channel sands reduced the support for the overlying levees. The levees sagged, making them vulnerable to overtopping. Once overtopped, the levees were easily eroded, which opened the breach.



27 *Floodplain north of Valmeyer. Four breaches occurred where the levees crossed former river channels. Saturation of the sands in these channels may have reduced support for the levee on the north side of Fountain Creek. Once the levee sagged, it was quickly overtopped and breached in three locations. Water surging through the two southern breaks overtopped and breached the levee on the south side of Fountain Creek and flooded the Harrisonville Drainage and Levee District. The flooding damaged Valmeyer so severely that the town is moving to the top of nearby bluffs.*

GEOLOGIC IMPACTS OF THE 1993 FLOODING

The shape of the land, as well as other geologic factors, controlled the direction, flow rate, and height of flooding along the Mississippi and its tributaries. In turn, the flood changed the shape of the land. The changes to the landscape were generally localized, although they were happening in many locations along the floodplains. The geologic impacts of the flood fall into four categories.

Erosion Flowing water scoured and transported sediments along the river channels, across the floodplains, and through and beneath the levee breaches. The most severe erosion formed deep scour holes, gullies, and troughs.

Deposition As the water slowed, sediments (and considerable debris) settled out along the river channels and across the floodplains. In some places, flood waters buried the former land surface under several feet of sediment.

Groundwater levels and contamination Groundwater recharge increased, which led to flooding. Groundwater systems also collected contaminants from flood water that flowed into unsealed wells and through other conduits.

Ground instability Saturated materials on unstable slopes may cause landslides or slumps. The possibility of flood-induced earthquakes was also a concern.

28 Randolph County: Nearly vertical cut made by waves eroding the inner (landward) side of the southern part of the Kaskaskia Island levee. Note the driftwood and debris where ISGS engineering geologist, Robert Bauer, stands at the base of the erosional cut (October 13, 1993).

EROSION

Erosion Along the High Water Line

In some areas, flood water of the Mississippi and Illinois Rivers submerged the floodplain from bluff to bluff. As a result, temporary lakes formed that were several miles wide (see cover photo). Waves on these lakes eroded the land along the high water lines. In many places, a wave-cut notch ranging from a few inches to 1 foot high was eroded along the high water line. Along bluff slopes, the erosion caused the soils overlying the notch to slump and undermined the foundation of trees and shrubs. Some farmers may face considerable expense in leveling their fields, but in general, the wave erosion had no major consequence. Remedial action will be required, however, along the inner side of the Kaskaskia Island levee, where an erosional cut nearly 5 feet high was formed by severe wave action (fig. 28). Apparently, the abundance of sandy materials in this section of the levee accelerated the wave erosion.

Erosion Along River Channels and Channel Margins

Surveys are needed to evaluate where and to what extent erosion may have modified the bottom of the river channels. (At the writing of this report, such surveys are underway, but have yet to be completed.) Where the river channel runs through bedrock, erosional changes were most likely minimal; but where the channel floor is composed of unconsolidated sediments, the potential for erosional changes was significant. On the flooded margins of the Mississippi channel near Chester, high velocity flow around an abandoned railroad building eroded through compacted crushed rock to a depth of 4 feet. In the same area, flood water lifted and transported large slabs of asphalt pavement (fig. 4).

After the flood subsided, bridge supports were among the first structures to be checked for erosion. Bridge scour is caused by the rapid flow of water around abutments. State and federal agencies conducted surveys at several bridges across the Mississippi that have support structures in the river channel. Although scour holes were found at several bridges, the erosion was not severe enough to compromise the bridge integrity.

29 *Monroe County: Deep erosion in the floodplain near a levee breach (October 12, 1993). The erosional scars may follow old plow furrows; the cuts are about 1 to 2 feet deep. Note pen atop field notebook (arrow) for scale.*

Erosion of Floodplains at Levee Breaches

The worst flood-related erosion occurred near levee breaches. At flood crest, the difference in elevation between the water surface on the outside of a levee and the floodplain on the other side could be 15 to 20 feet or more. Once a levee was overtopped, it was quickly breached by erosion from water flowing over it. The erosional capacity of the flood water was substantial because it poured through the breach in a torrent. Erosion continued until the floodplain inside the levee was inundated up to the flood height at the breach.

Across the floodplain, for a distance of about 1/4 mile from several of the breaches, erosional scars 1 to 2 feet deep mark the flow patterns of the flood water. In many agricultural fields, these erosional scars form a series of parallel, linear cuts suggesting that plow furrows may have concentrated the flood water flow and the erosion (fig. 29). Where flood water was concentrated along topographic depressions such as streams or drainage ditches, the erosion was more intense. Roadways oriented along the direction of flow also facilitated flow, so erosion was greater along the edges and across the surfaces of roads.

Deep scour holes, extending tens of feet below the original floodplain surface, developed at the levee breaches. Figure 30 is a view across the levee breach at Kaskaskia Island; figure 31 shows the depth contours of the scour hole that developed at the breach. The maximum depth, 50 feet, is in the center of the scour hole across the levee axis. The shape of this scour hole and the occurrence of maximum depth across the levee axis is typical of most scouring at levee breaches in Illinois. Figure 32 schematically summarizes the development of a scour hole. At first, the maximum scour occurs on the land beside the levee. As the breach continues to develop and more water flows through it, the highest flow velocity becomes concentrated in the breach and results in maximum erosion across the levee axis.

30 Randolph County: Looking northward across the levee breach in the Kaskaskia Island levee. (Figure 31 shows the depth of scour through this breach.) The Mississippi River channel is to the right beyond the range of the photo. (October 13, 1993).

The scouring at the Kaskaskia Island levee removed about 1 million cubic yards of floodplain sediment (equivalent to a football field covered with a block of sediment nearly six stories high). Equally impressive is the fact that the scour holes at the levee breaches and the nearby erosion across the floodplain occurred in hours, rather than in days or weeks. Typically, the floodplains behind the levees were inundated to the level of the river in about 24 hours, depending on the acreage of the district and the size of the levee breach. The erosion took place during maximum flow. Although some erosion may have occurred later as water drained from the floodplain back to the river, this process was slower and the differences in water elevation were slighter, so erosion was less energetic.

DEPOSITION

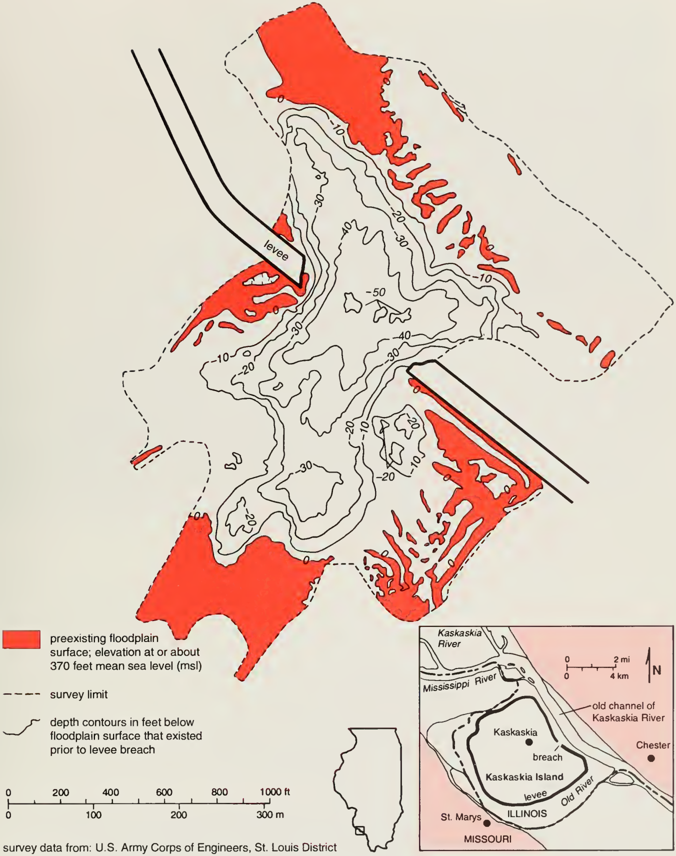
Deposition Along the High Water Line

Along the high water line, the amount of sediment deposited by flood water generally decreased away from the river channel. Where the area of flooding was narrow, moderate to large amounts of sediment were deposited. Where the flood water covered broad areas, little sediment was deposited, especially in the areas farthest from the river channel. Near the confluence of the Mississippi and Illinois Rivers, for example, where the town of Grafton sits on a narrow floodplain between the river and bluffs, as much as 6 inches of fine sand and sandy silt was deposited. By contrast, along the flood margin in inundated levee districts 2 miles or more from the river channel and distant from levee breaches, flood water deposited little if any sediment. What was most often deposited in these areas was corn-plant debris from the inundated corn fields (fig. 33). After the flood subsided, major cleanup campaigns were organized to remove the debris from towns and roadways.

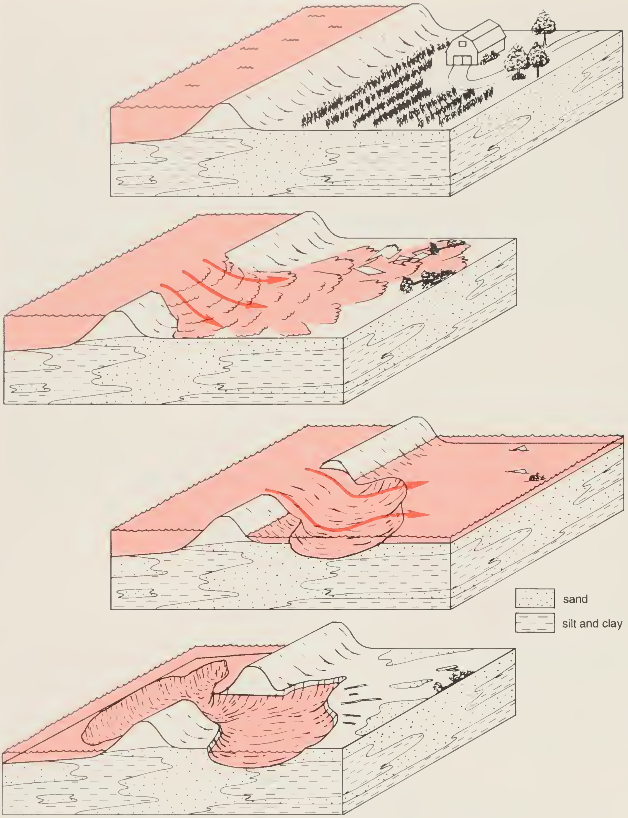
Deposition in River Channels

Floods cause major changes in the distribution of sediments in river channels. Bars (sand and gravel ridges deposited where water slows) and shoals (shallow places in a stream) may change little for a long time. Then suddenly, the extreme energy of a major flood dramatically changes the stream bed.

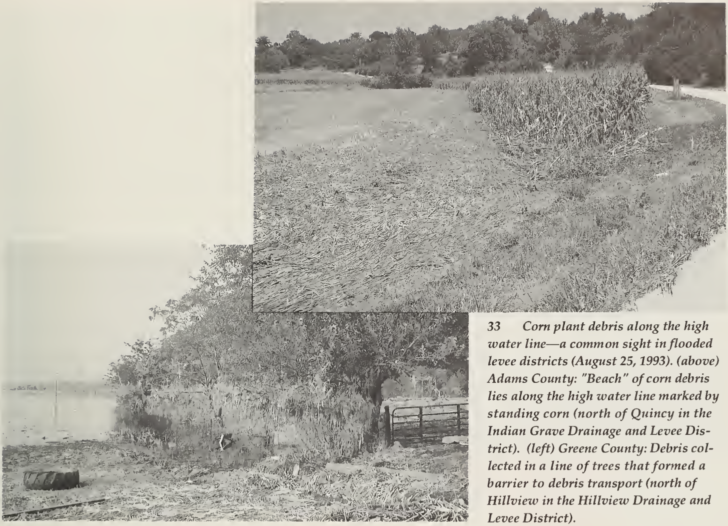
Although surveys of the channel bottom of the Mississippi and Illinois Rivers have yet to be completed and evaluated, preliminary observations indicate that significant deposition occurred in some areas of the channels. Within days after the Illinois segment of the Mississippi River was reopened to barge traffic, sev-



31 Depth of scouring at the Kaskaskia Island levee breach. The maximum depth is located along the axis of the levee. Inset map shows location of the breach in this levee that encircles Kaskaskia Island.



32 *Stages in development of a typical scour hole common to most levee breaches. In the lowermost block, the river is still at flood stage. Depth of the scour holes can be 50 feet or more below the original floodplain surface.*



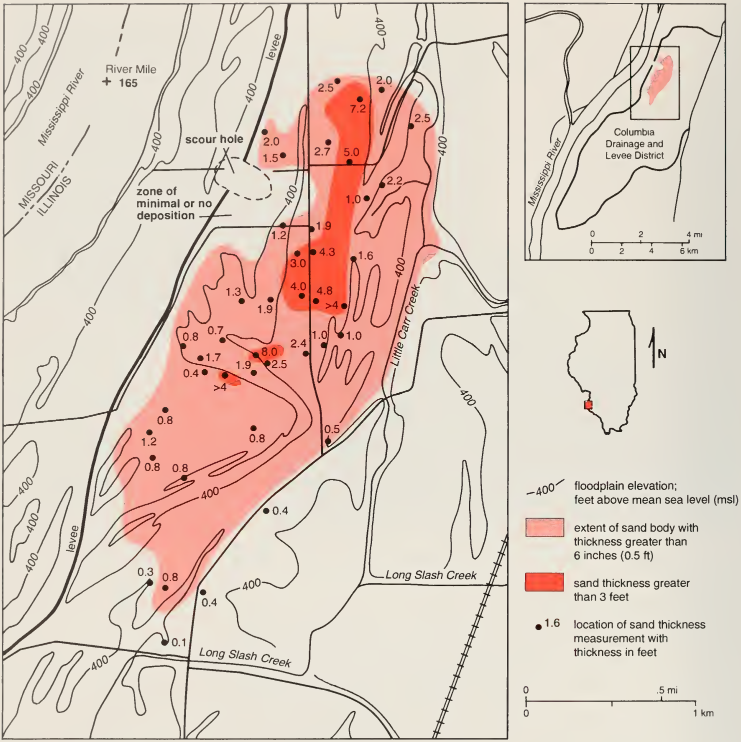
33 Corn plant debris along the high water line—a common sight in flooded levee districts (August 25, 1993). (above) Adams County: "Beach" of corn debris lies along the high water line marked by standing corn (north of Quincy in the Indian Grave Drainage and Levee District). (left) Greene County: Debris collected in a line of trees that formed a barrier to debris transport (north of Hillview in the Hillview Drainage and Levee District).

eral newly developed shoals were identified. They had to be dredged to restore safe navigation.

Deposition Near Levee Breaches

Although the impact of erosion during the 1993 flood was greatest at the levee breaches, the impact of deposition was greatest on the floodplains downcurrent from the levee breaches. The deposits of fine to coarse sand indicated that flood water flowed fast enough to pick up and carry away fine grained sediments. The deposits are large, fan-shaped sand bodies that bury the preexisting floodplain surface for 1 mile or more downvalley from the levee breaches. Although some sediments may have come from the river and some from erosion of the levee, it is likely that most came from scour holes at the levee breaches. The abundance of sand in these deposits is added evidence that the scour holes typically formed in ancient sand-rich channel deposits, and that these underlying deposits have contributed to the occurrence and location of levee breaches.

Figure 34 shows the distribution of at least 6 inches of sand deposited at the breach of the Columbia levee. The characteristics of deposition at this breach are typical. Near the scour hole is a zone where flood water flowed fast enough to prevent deposition. The floodplain in this zone is exposed, revealing erosional scars similar to those shown in figure 29. Beyond this zone, the sand body fans out, extending only slightly upvalley (northward) but primarily spreading downvalley, lobe-shaped, in the direction of major flow. Mapped to a minimum thickness of 6 inches, the sand body covers 760 acres of the floodplain and extends



34 Generalized map of the extent and thickness of the sand body deposited atop the floodplain near the breach of the Columbia levee.

about 1.5 miles beyond the Columbia levee breach. The overall distribution of sand is related to the underlying floodplain topography, which influenced the flow path of the flood water.

This sand deposit looks like a snowdrift (fig. 35) or a desert landscape (fig. 36). Its thickness varies, but a maximum of 8 feet was measured. A band of deposition, about 1,500 to 2,500 feet beyond the levee breach, ranges from about 3 to 7 feet thick; it is essentially a large bar or river dune such as that commonly found along the bottom of river channels.

Localized thick deposits occur on the margins of topographically low areas or on the downcurrent sides of buildings or downed trees, where the current slowed

and sediments settled out of quiet water. The thick sand deposits are unsuitable for farming. Because they are so thick and wide, earth-moving equipment will have to be used to clear them away. These sand deposits are the most dramatic examples of adverse geologic impacts related to flood deposition.

35 Monroe County: Snowdrift-like sand deposits near the Columbia levee breach are as much as 3–5 feet thick (November 23, 1993).

INCREASED GROUNDWATER RECHARGE AND CONTAMINATION

The 1993 flood had an impact on both the quantity and quality of groundwater. Heavy precipitation raised the water table, increasing the groundwater supply. Because groundwater not only provides base flow to all permanent streams in the state, but also supplies drinking water to half the population of Illinois, increased recharge is generally beneficial. The negative aspect is that the change in groundwater quality caused by the flooding was generally detrimental.

Groundwater Recharge

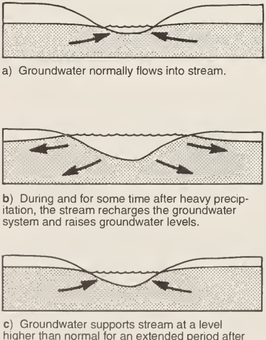
Under normal conditions in Illinois, the base flow to streams, including the Mississippi and Illinois Rivers, is supplied by groundwater, as illustrated in figure 37a. Precipitation produces runoff, which raises the level of the streams, and infiltration, which recharges the groundwater supply and causes the water table to rise. Because runoff occurs faster than infiltration, the water level in the streams rises faster than does the water table. Shortly after a heavy rain, water will move from the stream into the groundwater system, as illustrated in figure 37b.

Groundwater was recharged during the summer of 1993, when the Mississippi and Illinois Rivers were above flood stage, and afterward, when infiltration increased in the flooded levee districts. Such recharge is natural and desirable. Just as the river water level rises faster than the groundwater level does, the river level also falls faster after the flood. The higher groundwater level supports the stream at a higher level for a long time after precipitation ceases (fig. 37c), so the river remains high longer than one might expect. Because the surficial soils in floodplains may remain nearly saturated for months after a flood, the potential

36 Monroe County: Near the Columbia levee breach, the road cuts through sand 3–6 feet thick, deposited like a large sandbar or river dune commonly found along the bottom of river channels. ISGS geologists head for their minivan after a close look at the dune-like sand that buries fertile farmland (November 23, 1993).

for additional heavy precipitation to infiltrate into the soil is low, and the area is more susceptible to flooding than it was before the initial flood.

Groundwater recharge is generally desirable, but heavy rainfalls and flooding can lead to too much of a good thing. Some of the most extensive groundwater-related flooding took place in the Illinois River valley in Mason County at Havana (fig. 16) and across a broad area east of the town. Most of this flooding was not on the floodplain of the Illinois River, but rather on an extensive upland of glacial-age sand dunes. Thick sandy deposits, which allow rapid infiltration, and a shallow water table, make this farmland some of the most heavily irrigated in the state. The excessive precipitation of 1993 reduced the need for irrigation, so less groundwater was extracted than usual. The high water levels in the Illinois River also reduced the usual volume of groundwater flow toward the river. The combined effect was to raise groundwater levels as much as 20 feet to intercept the ground surface. Low-lying areas flooded. Extensive sandbagging was needed to protect roads and buildings; gravel and crushed rock were brought in to raise roadways above flood levels.



a) Groundwater normally flows into stream.

b) During and for some time after heavy precipitation, the stream recharges the groundwater system and raises groundwater levels.

c) Groundwater supports stream at a level higher than normal for an extended period after the heavy precipitation event.

37 Groundwater levels and flow directions for a stream at normal stage and during and after the stream level rises because of heavy precipitation (modified from Driscoll 1986).

Groundwater Contamination

Contamination of groundwater by flood water was also a problem. How much contamination occurred may not be fully known for some time. The flood inundated farmland, landfills, water treatment plants, and industrial sites and added pesticides, industrial chemicals, raw sewage, and fuels to the flood water. Native soils generally filter out much contamination before it reaches the groundwater. Wells inundated by flood water are another matter. They can be contaminated by water entering through poor seals or leaks along the casing.

After flood water receded, owners of private wells were strongly advised to disinfect their wells, then have the water quality tested. Some of the disinfected wells studied by the ISGS remained clean for a while, but were then recontaminated. The cause of the recontamination is unknown. There may still have been some contamination around a leaky well seal, or the infiltrating flood water may have continued to contaminate the groundwater. Groundwater and well contamination may be a persistent problem that requires long-term monitoring. Private wells inundated by the flood may need repeated testing after their initial disinfection.

38 Major faulted zones in southern Illinois and the epicenter of an earthquake that occurred on August 26, 1993, and registered 3.3 on the Richter scale. The slight tremor was not connected with the flood.

GROUND INSTABILITY

Landslides

Whether the flooding might trigger landslides during and after the flood was another concern. The bluffs along the Mississippi floodplain of southern Illinois from Chester southward to near Thebes have a long history of slope instability. Some landslides in this region may have been related to floods since at least late glacial time. Conditions are right for landslides when flood water and elevated water tables saturate the sediments at the base of unstable slopes. As flood water recedes, the saturated, weakened sediments may shift, allowing the overlying materials higher on the slope to slide.

In Illinois, no major landslides were associated with the flood of 1993 along the Mississippi or Illinois Rivers. Small slumps were common, however, along the banks of tributary streams and drainage ditches. These minor slope failures were caused by flood water saturating the bank materials, which then collapsed as the flood receded. The slumped material filled stream and ditch channels, and reduced the amount of water they could carry. Some repair work may be needed to correct the problems and reduce the likelihood of flooding upstream from any restrictions in the channel.

Earthquakes

A slight concern was that the added weight of flood water might trigger an earthquake along several seismically active regions. Minor earthquakes are common in the New Madrid faulted zone and the nearby Ste. Genevieve and Wabash Valley faulted zones (fig. 38). Each year, nearly 200 seismic events are recorded throughout the region, but most are so minor that they can only be detected by instruments. People generally cannot feel any tremors, and damage is rare.

Earthquakes in the region are caused by stresses in the earth's crust. When the crustal rocks are near the point of failure, even a small increase in stress may trigger an earthquake. The concern was that the weight of flood water might add stress along some active faults and trigger an earthquake. Although theoretically possible, there is no evidence for this flood-related, earthquake triggering mechanism, and it is generally considered to be highly improbable.

During July and August 1993, as the flood crests were occurring in southern Illinois, the regional seismic monitoring centers at St. Louis University and Memphis State University did not record any increase in seismic activity. In fact, seismic activity was unusually quiet. Only one tremor, registering 3.3 on the Richter magnitude scale, occurred during the flood on August 26. The epicenter of the tremor was about 40 to 50 miles south of St. Louis (fig. 38). Nothing indicates that this event was in any way related to the flood.

GEOLOGIC RESOURCES FOR FLOOD MITIGATION AND DAMAGE REPAIR

Fighting the flood and making repairs after the flood increased the demand for sand and gravel, crushed rock, riprap, and fill materials. Fill includes a variety of unprocessed earth materials that are free of soft, unstable, or organic components and compact easily. Coarse or fine grained materials, or a mixture of both, can be used to fill holes; but only fine grained cohesive materials that resist slumping and erosion can be used to build levees and other embankments. Riprap, which consists of massive blocks of stone that resist cracking, is placed on stream banks, levees, and embankments to protect them from erosion. The impact of the flood of 1993 on the use of the state's geologic resources was significant.

SAND FOR SANDBAGS

Volunteers filled and placed roughly 10 million sandbags to raise levee elevations and defend roads and buildings throughout the affected areas of Illinois. Each bag contained about 30 pounds of sand, so an estimated 150,000 tons of sand was used. Although considerable, this amount represents only about 0.5% of the amount of construction sand and gravel used every year in Illinois.

The type of sand used in sandbags varied significantly. Much of it had been originally mined, washed, and sized by commercial aggregate producers for use in backfilling of trenches and production of concrete; but a lot of it was too fine for such usage and thus readily available for flood defense. The immediate need for sand supplies also led to the use of unwashed, unprocessed sand from local borrow pits in the river valleys and nearby uplands.

EARTH MATERIALS FOR STREAM BANKS, LEVEES, HIGHWAYS, AND RAILROADS

Much more riprap, fill material, and crushed rock than sand was used to combat the flood. Even more of these materials will be consumed in the immediate and long-term efforts to repair flood damage. For example, an estimated 10 million tons of material will be needed just to repair the scour hole and floodplain erosion at the breach of the Len Small deflection levee near Miller City (fig. 22).

Riprap was placed on stream banks and the river side of levees, and spread on road and railroad embankments to reinforce and protect them from erosion. Some levees and embankments were raised by dumping crushed rock on top of them. Taking this step was faster than placing sandbags, but it took more material. Crushed rock and fill material were used extensively to raise low stretches of road to keep them open (fig. 39). Occasionally, an elevated road was similarly constructed to maintain access to critical sites, such as water or sewage treatment plants.

GEOLOGIC RESOURCES

Sand
Earth Materials

Railroad beds and embankments that were underwater had to be examined carefully after the flood subsided. Substantial volumes of rock resources were needed to repair these facilities. The Union Pacific Railroad brought in 350,000 tons of crushed rock to repair both the embankments and track beds on the Mississippi River floodplain from near East St. Louis south to Thebes. Even more crushed rock was used by the U.S. Army Corps of Engineers during the autumn of 1993

39 *Monroe County: Crushed rock used to raise a roadway across a low-lying, flooded section of the Mississippi River floodplain. (October 12, 1993).*

to build cofferdams across levee breaches to prepare for possible flooding in the spring of 1994.

The flood-impacted areas of Illinois may need up to 1,000 times more sand, riprap, fill material, and crushed rock for repair work than the amount used in sand bags during the fight for control. Repairing flood damage significantly adds to the normal demand for Illinois reserves of sand, gravel, and rock resources. Construction aggregate companies will meet much of the demand by increasing production. Although materials will also be imported from adjacent states, just as they were before the flood, locally excavated fill materials will meet most of the state's needs.

GEOLOGIC INFORMATION FOR FLOOD EMERGENCY MANAGEMENT, RECOVERY, AND DOCUMENTATION

Map resources are especially important in all phases of a geologic event such as the 1993 flood because of the scale of the disaster. Natural disasters such as tornadoes may strike a narrow path no more than 10 to 20 miles long, and ice storms or blizzards may blanket several towns or counties. But floods, extending for tens to hundreds of miles along river valleys, are truly regional.

Government agencies involved in the flood fight required maps showing flooded areas, road closings, locations of weak points in levee systems, and much other helpful data. Maps were also valuable to private property owners who needed to know the elevation of the land where their buildings or water wells are located in relation to predicted flood heights. During the flood of 1993, the Illinois State Geological Survey (ISGS) used new technologies in computerized mapping, map data collection and processing, and map printing to prepare specialized maps that assisted agencies in charge of flood emergency operations.

TOPOGRAPHIC MAPS

One of the most useful map resources for planning flood emergency actions is the 1:24,000-scale topographic map (7.5-minute quadrangle series). Rivers, levees, transportation infrastructure, and buildings all appear on these topographic maps, which depict the elevation and shape of the land surface (topography) by a system of contour lines. As soon as the elevation of a river's flood crest is predicted, the area potentially subject to flooding can be determined by following the contour lines indicating that elevation on the topographic maps.

Topographic maps of Illinois are published by the U.S. Geological Survey (USGS) in cooperation with the ISGS. They can be purchased from both agencies and many private dealers. The appendix tells how to purchase topographic maps from the ISGS. A publication explaining how to read and interpret topographic maps is also available.

Maps of two different scales proved most useful in the work related to this flood and are likely to have similar application in future floods. The maps are at the scale of 1:100,000 (1 inch equals 1.6 miles) and 1:24,000 (1 inch equals approximately 0.4 miles). The 1:100,000-scale maps show a large area on a single map sheet, which is best for regional purposes—to give the "big picture." The 1:24,000-scale maps present information in greater detail.

During the flood of 1993, the ISGS provided topographic maps to the command centers of the Illinois National Guard in Quincy, Springfield, and East St. Louis. The National Guard used the maps to coordinate sandbagging efforts, locate levee breaks, and route vehicles involved in relief work around roads closed by flooding. Maps also were supplied to local and state flood-relief agencies.

THE GIS: GEOGRAPHIC INFORMATION SYSTEM

The flood of 1993 was a catastrophic event lasting so long that map information was generated while the event was still in progress. During the flooding, for example, maps were produced showing the distribution of flooded drainage and levee districts. Satellite imagery and aerial photographs were used to map the extent of flooding as the flood crests continually migrated downstream. Much of this "on-demand" mapping was facilitated with the use of the Geographic Information System, or GIS.

Generally speaking, the GIS is a tool for computer-assisted information analysis and mapping. Various types of information that have been entered into the computer's database can be selected and combined by the user. For example, the GIS can generate a map that superimposes the locations of domestic water wells on a data set delineating the maximum extent of flooding. The result is a GIS map that can be used to identify wells that may be in danger of contamination by flood water.

The ISGS used the GIS during the flood of 1993 to produce a variety of maps requested by several state agencies involved in flood relief. Figures 13 to 16 are page-sized, black-and-white GIS maps similar to the larger-sized color maps produced during the flood event. Experts on the GIS and its data resources can immediately assist those responding to crises such as the flood because they can quickly produce specific information and specialized or customized maps (assuming the necessary data are already in the GIS). Using the GIS, experts can quickly analyze alternatives and examine the impacts of multiple scenarios. The GIS technology also allows rapid transfer of digital data to various agencies involved in the disaster response, and telecommunication lines speed the transfer of data.

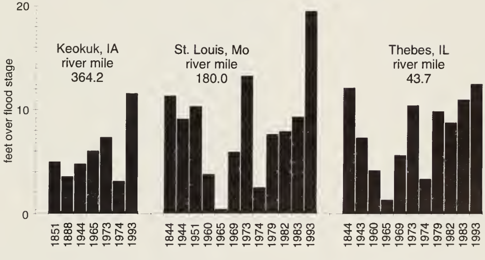
This was the first major flood in Illinois in which GIS capabilities were used so extensively and effectively. In the previous record flood along the Mississippi River in 1973, much of the GIS technology used for information analysis, mapping, and map processing was not yet available. The technology is relatively new, and anticipated advances will make it all the more valuable for dealing with future floods and other natural disasters. In addition to its usefulness in emergencies, the GIS is a tool for ISGS researchers evaluating the surface and subsurface geology of Illinois. Key applications include landfill siting, oil and gas exploration and recovery, and groundwater resource location and protection. The GIS provides a means to store digital data for future use. All GIS data compiled from the 1993 flood will be available for interpreting and evaluating data on future floods.

FLOODING AS A GEOLOGIC EVENT: SUMMARY AND PERSPECTIVES

Excessive precipitation typically causes flooding, but when rivers overflow their banks, the local and regional geology controls the flooding and much of its impact. Geologic controls include (1) the geologic history and landscape evolution, which sets the stage for drainage patterns and floodplain characteristics; (2) topography, which influences the depth and extent of flooding and the flow paths for flood water; and (3) floodplain sediment type and distribution, which determine the permeability and vulnerability of sediments to erosion. In terms of geologic impacts, changes to the landscape are produced by flood-induced erosion, deposition, elevated groundwater levels, and the slumping of flood-saturated slopes. The severest geologic impacts of the 1993 flood in Illinois were landscape changes associated with the levee breaches. The extreme erosion and deposition at levee breaches provide lessons for planning and managing the impacts of future floods of comparable magnitude.

"The Great Flood of 1993" was the most costly, widespread natural disaster in Illinois history. The height of the 1993 flood exceeded the heights of all previous floods for the Mississippi and Illinois Rivers, although the previous record high for the Mississippi was set only 20 years ago. The record of historical floods shows that flood heights have increased by several feet at some locations (figs. 8 and 40). This observation raises the question of whether the region is undergoing climatic change and/or changes in flood dynamics due to human interference.

The severity of the 1993 flood raised many issues concerning management of river channels and floodplains. The issues are not new. Questions are raised after every major flood—about how human modifications of the floodplains and river channels may be contributing to increases in the magnitude of flood events. Because of the magnitude of this flood, new approaches to floodplain management and land use may result. Many property owners, even entire communities such as Valmeyer, are opting to relocate off the floodplains. In addition, debate at the federal level led to the authorization on December 3, 1993, of a $110 million flood package to buy out property on the floodplains. Approximately $21 million was earmarked for Illinois. This flood brought widespread recognition that it will be less expensive in the long term to relocate certain structures off the floodplain than to continually repair and rebuild after each major flood.



40 Flood heights recorded at three gauging stations along the Illinois segment of the Mississippi River (from Sally A. McConkey, Illinois State Water Survey 1993).

New approaches to floodplain land use, considered from the geologist's perspective, must take into account that floodplains are dynamic landscapes formed by repeated changes in the river and the drainage basin for thousands of years. Several major floods can occur during a single human lifetime, and this fact alone provides support for some limits to floodplain development.

The 1993 flood was the first widely recognized disaster in Illinois during which state agencies used the GIS for fast information gathering and assimilation, and map output. It is hoped that this experience will lead to a change in the way disaster responses are planned and managed in Illinois. In the future, information processed with a GIS may be instrumental in decisions related to the placement of people and equipment for disaster relief.

Inundation of floodplains is the natural result of rivers rising above flood stage. Certainly, floods will occur in the future along all rivers and streams in Illinois. We should not assume that "The Great Flood of 1993" will be the most devastating flood that could occur. This flood should be a reference point for evaluating the extent to which present and future land-use practices along floodplains and river valleys are in harmony with the geologic processes that shaped these landscapes.

ACKNOWLEDGMENTS

To observe the geology in flood-impacted areas, members of the ISGS required the cooperation of the Illinois National Guard, the Illinois State Police, and emergency response teams from the various counties and communities in the affected areas. We are especially grateful to the Illinois National Guard and the Illinois Department of Transportation (IDOT) for assisting in helicopter flights for aerial photography. The U.S. Coast Guard provided boat access to some flood sites. Maps, data, and field observations related to the flood impacts were provided by the U.S. Army Corps of Engineers St. Louis District, the U.S. Geological Survey Water Resources Division, and the Union Pacific Railroad. Special appreciation is extended to the many property owners who graciously allowed us access to their land, so that we could examine the impacts of flooding. Other state agencies that contributed to this report include the Illinois State Water Survey, Illinois Natural History Survey, IDOT Division of Water Resources, and Illinois Emergency Management Agency.

Contributing significantly to this report were many members of the ISGS: Joel M. Dexter and Michael J. Chrzastowski are acknowledged for their photography. Curtis Abert prepared the shaded relief map (fig. 12). Pamella K. Carrillo drafted the line illustrations, and designed and assembled the report for printing. E. Anne Latimer and Ellen Wolf co-edited the report. Technical and scientific contributions were made by Michael L. Barnhardt, Richard C. Berg, Leon R. Follmer, Jonathan H. Goodwin, David L. Gross, David R. Larson, E. Donald McKay, Christopher J. Stohr, and C. Brian Trask.

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APPENDIX: TOPOGRAPHIC MAPS

USING TOPOGRAPHIC MAPS

One of the most valuable tools for flood planning, mitigation, and remedial actions is a topographic map showing rivers, streams, and drainage ditches as well as cultural features such as roads, buildings, and levees. The topographic information is conveyed by contour lines, which show the elevations of land surface.

Some skills are needed for a user to be able to read and interpret all the information on such a map, but these skills can be readily learned. The Illinois State Geological Survey (ISGS) offers a publication that describes techniques for reading and interpreting topographic maps:

Cote, William E. (revised by Myrna M. Killey, Paul B. DuMontelle, and David L. Reinertsen), 1978, Guide to the Use of Illinois Topographic Maps: Illinois State Geological Survey, Champaign, Illinois, Educational Extension Publication, 26 p.

PURCHASING MAPS

Topographic maps for Illinois are produced by the U.S. Geological Survey (USGS) in cooperation with the ISGS. The maps may be purchased from the ISGS.

Index sheets showing the names of maps and map coverage across the state are available upon request and at no charge. Map prices may change without notice. For further information, contact

Illinois State Geological Survey
Order Department
615 East Peabody Drive
Champaign, Illinois 61820-6964

Phone (217) 333-ISGS or 333-4747

Fax (217) 333-2830

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