GEOMORPHIC CHANGES ON THE MISSISSIPPI RIVER FLOOD PLAIN

AT MILLER CITY, ILLINOIS AS A RESULT OF THE FLOOD OF 1·9·9·3

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U.S. GEOLOGICAL SURVEY CIRCULAR 1120–J

Front Cover—View of Miller City, Illinois levee break, August 1993. (U.S. Geological Survey)

Back Cover— Field Hydrologist making streamflow measurements (U.S. Geological Survey)

View of Spirt of St. Louis Airport, Chesterfield,Mo. (Srenco Photography, St. Louis, Mo.)

GEOMORPHIC CHANGES ON THE MISSISSIPPI RIVER FLOOD PLAIN AT MILLER CITY, ILLINOIS, AS A RESULT OF THE FLOOD OF 1993

By Robert B. Jacobson and Kevin A. Oberg

Floods in the Upper Mississippi River Basin, 1993

U.S. GEOLOGICAL SURVEY CIRCULAR 1120–J

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FOREWORD

During spring and summer 1993, record flooding inundated much of the upper Mississippi River Basin. The magnitude of the damages—in terms of property, disrupted business, and personal trauma—was unmatched by any other flood disaster in United States history. Property damage alone is expected to exceed $10 billion. Damaged highways and submerged roads disrupted overland transportation throughout the flooded region. The Mississippi and the Missouri Rivers were closed to navigation before, during, and after the flooding. Millions of acres of productive farmland remained under water for weeks during the growing season. Rills and gullies in many tilled fields are the result of the severe erosion that occurred throughout the Midwestern United States farmbelt. The hydrologic effects of extended rainfall throughout the upper Midwestern United States were severe and widespread. The banks and channels of many rivers were severely eroded, and sediment was deposited over large areas of the basin's flood plain. Record flows submerged many areas that had not been affected by previous floods. Industrial and agricultural areas were inundated, which caused concern about the transport and fate of industrial chemicals, sewage effluent, and agricultural chemicals in the floodwaters. The extent and duration of the flooding caused numerous levees to fail. One failed levee on the Raccoon River in Des Moines, Iowa, led to flooding of the city's water treatment plant. As a result, the city was without drinking water for 19 days.

As the Nation's principal water-science agency, the U.S. Geological Survey (USGS) is in a unique position to provide an immediate assessment of some of the hydrological effects of the 1993 flood. The USGS maintains a hydrologic data network and conducts extensive water-resources investigations nationwide. Long-term data from this network and information on local and regional hydrology provide the basis for identifying and documenting the effects of the flooding. During the flood, the USGS provided continuous streamflow and related information to the National Weather Service (NWS), the U.S. Army Corps of Engineers, the Federal Emergency Management Agency (FEMA), and many State and local agencies as part of its role to provide basic information on the Nation's surface- and ground-water resources at thousands of locations across the United States. The NWS has used the data in forecasting floods and issuing flood warnings. The data have been used by the Corps of Engineers to operate water diversions, dams, locks, and levees. The FEMA and many State and local emergency management agencies have used USGS hydrologic data and NWS forecasts as part of the basis of their local flood-response activities. In addition, USGS hydrologists are conducting a series of investigations to document the effects of the flooding and to improve understanding of the related processes. The major initial findings from these studies will be reported in this Circular series as results become available.

U.S. Geological Survey Circular 1120, *Floods in the Upper Mississippi River Basin, 1993*, consists of individually published chapters that will document the effects of the 1993 flooding. The series includes data and findings on the magnitude and frequency of peak discharges; precipitation; water-quality characteristics, including nutrients and man-made contaminants; transport of sediment; assessment of sediment deposited on flood plains; effects of inundation on ground-water quality; flood-discharge volume; effects of reservoir storage on flood peaks; stream-channel scour at selected bridges; extent of flood-plain inundation; and documentation of geomorphologic changes.

Gordon P. Eaton
Director

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
centimeter (cm)	0.3937	inch
square kilometer (km^2)	0.3861	square mile
cubic meter (m^3)	35.31	cubic foot
centimeter per second (cm/s)	0.0328	foot per second
cubic meter per second (m^3/s)	35.31	cubic foot per second
metric tons	1.102	short tons

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Geomorphic Changes on the Mississippi River Flood Plain at Miller City, Illinois, as a Result of the Flood of 1993

By Robert B. Jacobson *and* Kevin A. Oberg

Abstract

During the flood of 1993 on the upper Mississippi and Missouri Rivers, the most dramatic changes to flood plains resulted at levee-break complexes. At these sites, large discharges were concentrated through narrow levee breaks, which resulted in high water-surface slopes and intensely turbulent flow. These conditions created extensive, deep scours and permitted sediment-laden water to flow into areas behind the levees. As a result, large areas of formerly productive bottom land were eroded or covered by thick deposits of sand.

The levee break at Miller City, Illinois, created a typical large levee-break complex. As much as 28 percent of the Mississippi River discharge flowed through the break during the peak of the flood. With velocities as great as 300 centimeters per second, the flow through the levee break was able to scour an area 2,200 meters long to a maximum depth of more than 20 meters. Transport of sediment from the main channel, through the break, resulted in net deposition of at least 8.2 million cubic meters of sand.

Although the history of this part of the Mississippi River Valley indicates that channel changes have been extensive and frequent, the geomorphic changes that resulted from the 1993 flood seem to be unprecedented during the last 10,000 years or so. The large geomorphic changes at Miller City during the 1993 floods are attributable to the magnitude of the flood, the hydraulic head artificially increased by the levee, and the lack of energy dissipation on the agricultural flood plain relative to presettlement, forested conditions.

INTRODUCTION

Large amounts of rainfall in the upper Mississippi River Basin through winter, spring, and summer 1992–93 produced widespread and persistent flooding (Parrett and others, 1993; Wahl and others, 1993). The flood of 1993 on the upper Mississippi and Missouri Rivers set record discharges at many streamflow-gaging stations (Parrett and others, 1993). More than 26,000 km^2 of urban and agricultural land were inundated; total costs of the flood exceeded $12 billion (Interagency Floodplain Management Review Committee, 1994).

More than $1.2 billion in losses were attributed to actual flooding of agricultural bottomland (Interagency Floodplain Management Review Committee, 1994). Along the Missouri River, more than an estimated 1,800 km^2 of prime agricultural land was severely affected by erosion and deposition (Interagency Floodplain Management Review Committee, 1994). More than 300 km^2 of this prime agricultural land was covered with sand deposits that were more than 60 cm thick. The costs to remove this sand and return the soil to its former productivity levels have been estimated to be about $1.2 million per square kilometer (Vance, 1994). The most severe erosion and sedimentation damages by far were associated with breaks of agricultural levees.

Purpose and Scope

This report documents the geomorphic changes associated with a levee break typical of those created by the 1993 flood. The geomorphic effects at levee breaks are of concern because erosion and sedimentation at levee-break complexes are substantial public safety and economic hazards. Furthermore, routing of sediment to and from storage in flood plains has the potential to redistribute sediment-borne contaminants. The levee-break complex chosen for documentation here occurred on the Mississippi River at river mile 34, which is near Miller City, Illinois (fig. 1). A chronology of events during the levee break, measurements of discharge and velocity in the main channel and the break, maps of erosion and deposition, descriptions of erosional features and sediments, and a comparison of the levee break to the Holocene history of the Mississippi channel are presented. Although it is one of the larger levee-break complexes created during the flood, the Miller City levee-break complex contains features typical of many of the levee-break complexes of the Mississippi and the Missouri Rivers.

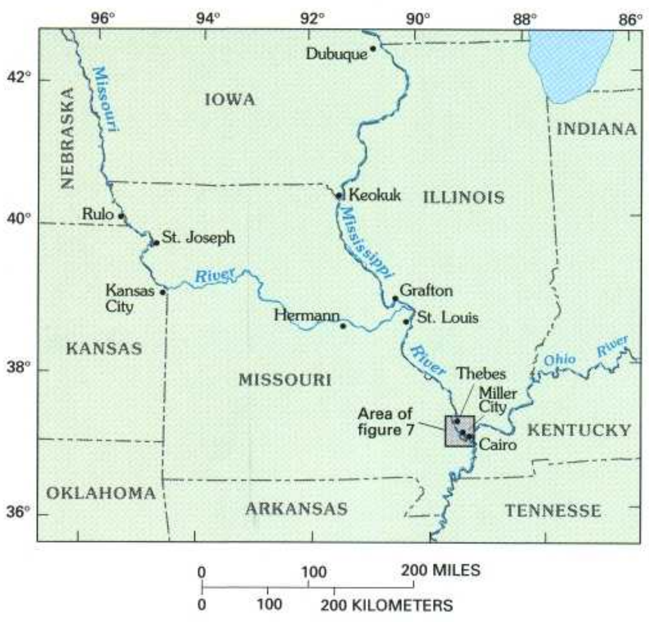

Figure 1. Part of the upper Mississippi and Missouri Rivers.

Levee-Break Complexes

Levees may break as a result of a variety of mechanisms, which include overtopping by floodwater, liquefaction of the levee or foundation material, or mass failure. The term "levee break" in this report describes levee sections where the levee was completely removed or eroded at least to ground level, regardless of the erosion mechanism.

The 1993 flood resulted in breaks of 1,082 levees in the upper Mississippi and Missouri River Basins (Bhowmik and others, 1994). As many as 604 separate levee breaks were identified on the Missouri River between Kansas City and St. Louis, Missouri (J.C. Dohrenwend, U.S. Geological Survey, oral commun., 1994). Large hydraulic heads and flow constriction through narrow openings in the levee breaks created zones of intense scour downstream and upstream from typical breaks. Flow through the levee breaks also transported large quantities of sediment onto the flood plain.

A levee-break complex consists of the levee break and associated erosional and depositional features. Although erosion and deposition patterns in levee-break complexes can be quite complicated, they generally consist of scour, stripped, and depositional zones (fig. 2). The scour zone (locally called blue, blew, blow, or blown holes) is an area of deep erosion, usually more than 1 to 2 m deep, with steep sides. Detached blocks of cohesive sediment are common along the margins of the scours, which attest to erosion by gravitational slumping and toppling. The planform of scours ranges from circular to elongated; many scours extend upstream and downstream from the break to form elongated channels. In cases where the scour channels connect with the main channel upstream, the scours are efficient structures for funneling water and sediment onto the flood plain (fig. 2). Exit scours were formed when floodwater overtopped the levees or descended the banks as it reentered the main channel.

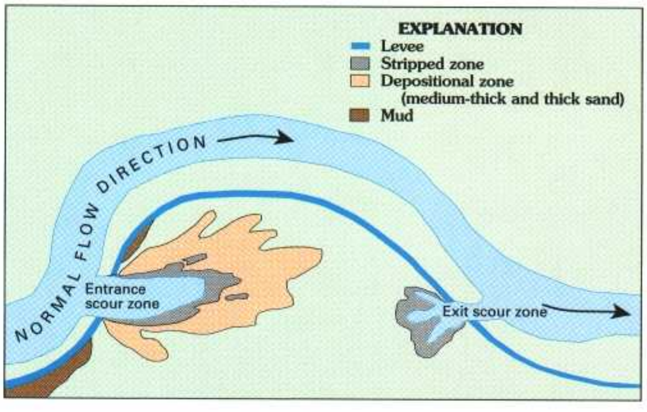

Figure 2. Definition of features in a typical levee-break complex.

Downstream from the levee break, the scour zone is skirted with a zone where erosion generally is less than 50 cm deep. This zone is referred to as the "stripped zone" (figs. 2, 3) because the plow horizons and rooted horizons of the soil are typically stripped, which leaves less erodible B-horizons and plow pans. Stripped zones commonly have shallow, rounded scours near their upstream margin and are characterized by abundant grooves (fig. 3). Some grooves are parallel to flow directions and seem to have been carved by debris carried by the floodwaters, whereas other grooves are evidently related to preexisting weaknesses in the soil, such as those caused by plowing (fig. 3).

A

B

Figure 3. Examples of stripped surfaces from the Miller City, Illinois, levee-break complex. *A*, Flow was toward the viewer; *B*, Flow was from left to right; with grooves.

Downstream from the stripped zone, there is a transition into the depositional zone that consists of sediment deposits of varying thicknesses. Because of the sequence of flooding at any particular site, sand and mud (silt- and clay-sized sediment) may have been deposited over stripped zones or may partially fill scours. Generally, sand deposits are thickest and coarsest closer to the scour. Sedimentary features include sand waves, dunes, and current ripples; commonly, areas of dunes and current ripples are draped with mud that was deposited during recession of the floodwaters or by subsequent floods (fig. 4). Extensive areas of the flood plain used for agriculture were covered with sand deposits, some of which were as much as 4 m thick; according to Vance (1994), some sand deposits were as much as 6 m thick on the Missouri River flood plain. Mud deposition seemed to be minor in extent. Mostly, mud was left as thin deposits in eddies or slackwater areas or was deposited during recession of the floodwaters in low areas that existed before the flood. The geomorphic effects of mud deposition were minor.

A

B

Figure 4. Sand dunes on the Missouri River flood plain between Kansas City and Hermann, Missouri, and in the Miller City, Illinois, levee-break complex. *A*, Missouri River Flood plain between Kansas City and Hermann, Missouri. View is to the north; flow was from left to right; *B*, Miller City, Illinois, levee-break complex. View is to the northwest; flow was from right to left.

Scour zones and sand deposits in levee-break complexes are by far the most dramatic geomorphic effects of the 1993 flood. In contrast, geomorphic changes in nonleveed areas consisted of minor bank erosion and sedimentation in natural levees and crevasse-splay features (fig. 5). Natural-levee sedimentation was prominent in nonleveed bank areas with dense woody vegetation. Crevasse-splay features, which consist of a scour (crevasse) and associated sand deposits (splay), are similar but much smaller natural analogs for levee-break complexes. Crevasse splays occur where a weakness in the natural levee, or flow concentration, results in erosion of a crevasse channel through which sediment is transported from the channel onto the flood plain (Collinson, 1978).

A

B

Figure 5. Natural levee and crevasse splays on the Missouri River flood plain between Kansas City and Hermann, Missouri. *A*, Natural levee; *B*, Crevasse splay.

Acknowledgments

The authors thank Ronald Eastwood, Illinois Department of Transportation (IDOT), for logistical support and access to video and photographic data. The U.S. Army Corps of Engineers (COE), St. Louis District, provided aerial photography, discharge-measurement data, and levee-break width data. Roger Edinson, IDOT, Department of Water Resources, provided postflood survey data of the extent of erosional scour at the Miller City, Illinois, levee-break complex.

THE FLOOD OF 1993 AND THE MILLER CITY, ILLINOIS, LEVEE-BREAK COMPLEX

The flood of 1993 on the upper Mississippi and Missouri Rivers was notable for the extreme discharge and long duration. Discharges in excess of the estimated 100-year flood were recorded on the Missouri River from Rulo, Nebraska, to Hermann, Missouri, and on the Mississippi River at Keokuk, Iowa, and St. Louis (Parrett and others, 1993; fig. 1). At Thebes, Illinois, the peak discharge was 28,200 m^3/s on August 7, 1993 (Reed and others, 1994); the estimated recurrence interval was from 10 to 50 years (Parrett and others, 1993). The daily mean discharge at Thebes is shown in figure 6.

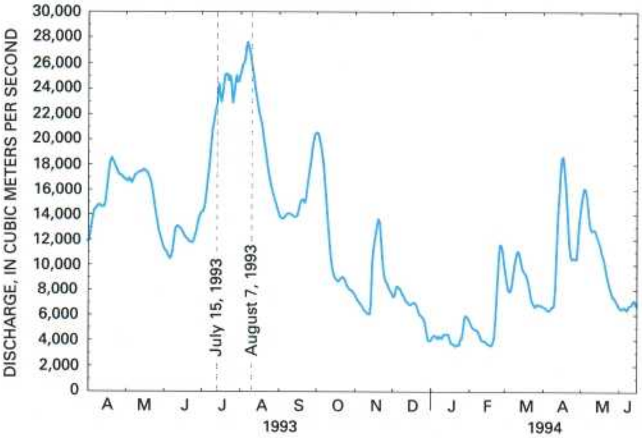

Figure 6. Daily mean discharge of the Mississippi River at Thebes, Illinois, April 1993–June 1994.

In addition to large discharges, the flood of 1993 was notable for its long duration. At St. Louis, the Mississippi River was above flood stage for more than 2 months. At Thebes, several smaller floods occurred from April 1993 through May 1994 in addition to the main flood of July through August 1993.

Downstream from the junction of the Ohio and the Mississippi Rivers (fig. 1), the magnitude of the flood was not severe because of low flows on the Ohio River in July and August 1993.

History of the Miller City Levee-Break Complex

The levee near Miller City, which is locally called the Len Small levee, was designed and constructed by local landowners to protect agricultural land in Dogtooth Island bend of the Mississippi River (fig. 7). The levee is continuous along the left bank (facing downstream) of the Mississippi River from Fayville, Illinois, to past the apex of Dogtooth Island bend. The levee was designed to deflect high-velocity floodwaters of the Mississippi River away from agricultural land at the upstream part of the bend. The downstream part of Dogtooth Island bend is not protected by a levee, so low-velocity backflooding has occurred in the area south of the Miller City Road during many floods. The Len Small levee

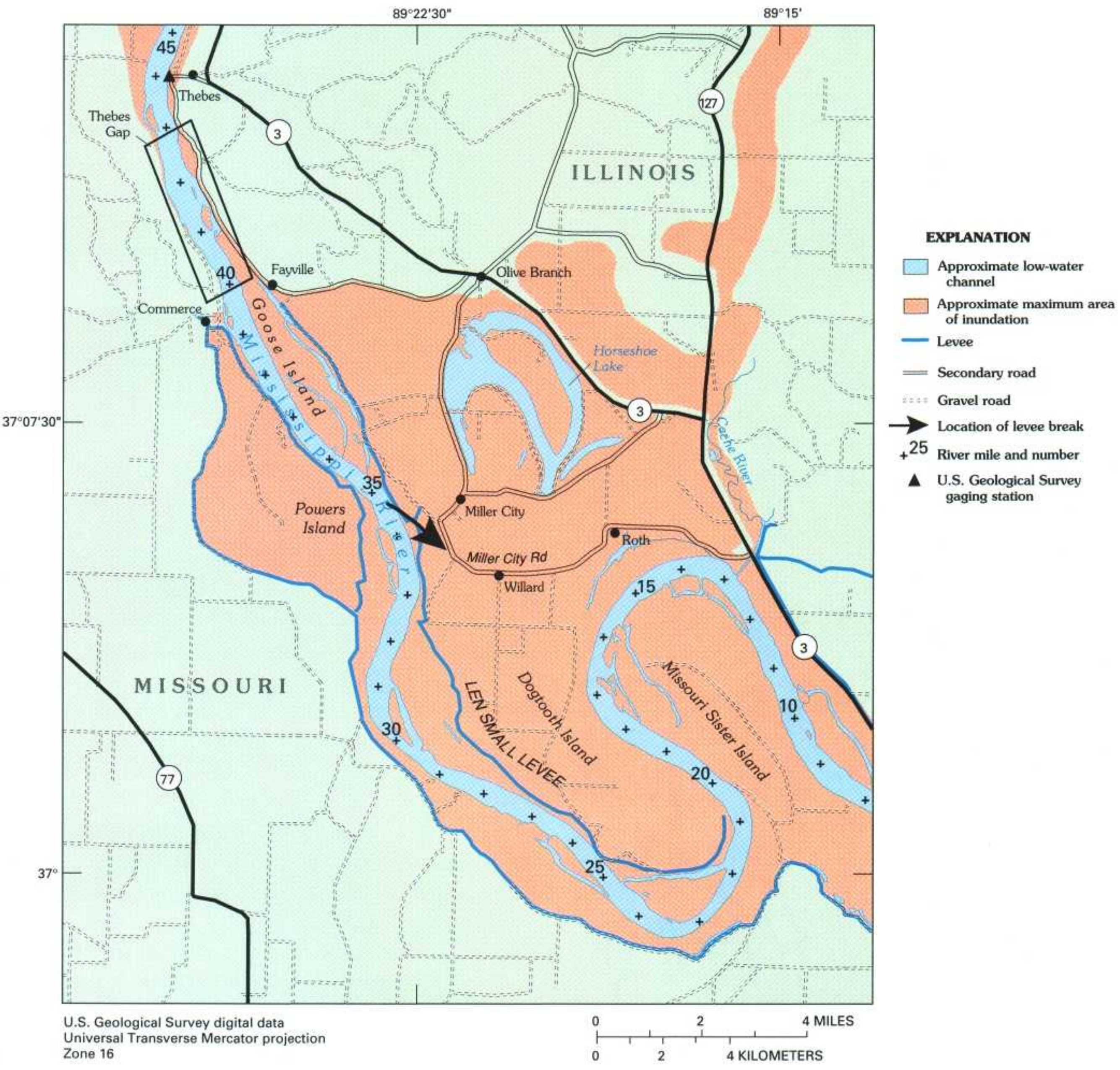

Figure 7. Features of the Miller City, Illinois, levee-break complex area.

was constructed from locally available materials by using draglines and scrapers. Most of the levee material is uncompacted top soil. Internal stratigraphy of levee remnants showed that black top soil was interbedded with clean, white sand units. The river side of the levee was protected with riprap at the site of the break and for some distance upstream and downstream. The riprap and numerous wing-dams located in this reach of the Mississippi River are maintained by the COE to improve navigation.

The levee broke on July 15, 1993, at about 1:00 p.m. local time. According to anecdotal evidence from several witnesses, the levee was inspected 15 minutes before the break. At the time of the break, the water level on the channel side of the levee was estimated to be as much as 2 m below the levee crest. [For comparison, at the U.S. Geological Survey (USGS) streamflow-g.aging station at Thebes, which is about 16 km upstream, the daily mean stage was 104.68 m on July 15; on July 20 and August 7, the daily mean stage at Thebes peaked at 105.24 m (table 1)]. An eyewitness related that a loud noise drew his attention at 12:50 p.m. When he looked at the levee from a distance of about 500 m, he saw a near-horizontal, 15- to 30-cm-diameter fountain of water gushing out of the side of the levee. The hole quickly enlarged, and a section of the levee failed. As the levee eroded and widened, water began to fill the area between the main levee and a cross levee (fig. 8*A*). During the first few days after the break, flow through the break was extremely turbulent (fig. 9) with standing waves[1] that were about 1 m high.

The area between the main levee and the cross levee is the upstream end of a channel that the Mississippi River occupied during 1820 (fig. 10). The extension of the 1820 channel formed an arcuate trough to the east and south with about 1.5 m of relief before the 1993 flood. The 1820 channel was bounded to the north and east by a terrace scarp that cut laterally into alluvial deposit of late Wisconsin and presumed early Holocene age (Fisk, 1944). The scarp ranged from about 2 to 3 m high. As the low area between the two levees filled, water flowed northward and eastward over the scarp, and followed low areas of former channels that extended toward Horseshoe Lake (figs. 8*A*, 10). As water levels rose in the Horseshoe Lake area, flow began to move southward along former channels, descended the scarp, and reentered the 1820 channel to the east and downstream of the cross levee (fig. 8*A*). By July 17, water that reentered the 1820 channel had eroded a secondary scour at least 400 m long by upstream (northward) migration of a steep head cut (location A, fig. 8*A*). Most of the area of Dogtooth Island bend south of the Miller City Road was inundated by backflooding or seepage by this time.

Much of the early floodwater followed low areas directly to Horseshoe Lake. Subsequent overflow of Horseshoe Lake to the south and east caused water to flow across the Miller City Road between Willard and Roth, Illinois (fig. 7), and down 0.5- to 1-m-high scarps that separate paleochannels of the Mississippi River, notably the scarp between deposits of Holocene channel-position stage 2 and those of channel-position stages 5 and 9 (fig. 10). Observations during the flood indicated that flow over the road and down the terrace scarps typically was fast, highly turbulent, and characterized by standing waves.

Aerial videotape from July 17 indicated small areas of flow over the cross levee at the extreme northern and southern ends. Larger quantities of overflow were noted on July 19. Because the area had been evacuated, the precise time and mechanism of failure of the cross levee are not known. However, by July 20, a substantial part of the cross levee had broken, and by July 31, the entire 400 m of the cross levee was removed.

After the cross levee was breached, flow through the main levee was concentrated in the 1820 channel, and floodwater that moved through the secondary scour immediately downstream of the cross levee (location A, fig. 8*A*) reversed direction and flowed northeastward. By July 26, flow was 5,570 m^3/s from the Mississippi River main channel into the break, and 8,000 m^3/s of flow was measured near the peak discharge on August 7. From July 17 through August 10, the northern (left) bank of the main scour eroded laterally more than 60 m (location B, fig. 8*A*). In the process, more than 680 m of a county road was removed, as well as a house, a machine shed, and the front yard and front porch of another house (fig. 9).

[1]Standing waves are stationary wave forms indicative of critical flow, which occurs in flows with large ratios of velocity to depth.

Table 1. Daily mean discharge and stage of the Mississippi River at Thebes, Illinois, upstream from the Miller City, Illinois, levee-break complex, discharge upstream from and at the levee-break complex, and width of the levee break, July 15 to August 25, 1993

[m^3/s, cubic meters per second; m, meters; --, not measured]

Date	Daily mean discharge at Thebes, Illinois (m^3/s)	Daily mean stage at Thebes, Illinois (meters above sea level)	Discharge at river mile 35, immediately upstream of the Miller City levee break (m^3/s)[1]	Discharge measured in the levee break at river mile 34 (m^3/s)	Surveyed width of the levee break (m)
07-15	24,451	104.68	--	--	--
07-16	23,687	104.81	--	--	--
07-17	23,065	104.88	--	--	--
07-18	23,659	105.01	--	--	113
07-19	24,508	105.15	--	--	120
07-20	25,159	105.24	--	--	--
07-21	25,159	105.15	--	--	--
07-22	25,215	105.09	--	--	--
07-23	24,734	104.93	--	--	--
07-24	25,046	104.92	--	--	--
07-25	24,480	104.78	--	--	--
07-26	22,980	104.53	--	5,570	472
07-27	23,602	104.67	--	4,920	478
07-28	24,423	104.74	--	5,480	484
07-29	25,102	104.79	--	--	--
07-30	24,621	104.75	--	5,580	532
07-31	24,649	104.83	24,000	5,550	--
08-01	25,074	104.95	--	6,720	539
08-02	25,442	105.00	--	--	--
08-03	25,923	105.03	--	6,930	558
08-04	26,008	104.97	--	--	--
08-05	26,432	105.04	--	--	--
08-06	27,338	105.18	--	7,100	587
08-07	27,677	105.24	--	8,000	--
08-08	27,253	105.14	--	--	--
08-09	26,913	105.09	--	6,600	--
08-10	26,149	104.95	22,900	7,560	--
08-11	25,555	104.85	--	6,090	618
08-12	24,904	104.71	--	--	--
08-13	24,083	104.58	--	--	--
08-14	23,489	104.45	--	--	--
08-15	22,895	104.34	--	--	--
08-16	22,272	104.23	--	--	--
08-17	21,819	104.12	--	--	--
08-18	21,423	104.04	19,500	5,130	--
08-19	20,829	103.91	18,200	4,730	--
08-20	20,008	103.75	--	--	--
08-21	19,386	103.60	--	--	--
08-22	18,735	103.41	--	--	--
08-23	17,942	103.22	--	--	--
08-24	17,291	103.03	--	--	--
08-25	16,782	102.87	--	2,890	625

[1]Discharges measured in main channel upstream from the levee break are somewhat lower than those measured at the U.S. Geological Survey gage at Thebes, Illinois, possibly because of unmeasured flow to the west of Powers Island (fig. 7).

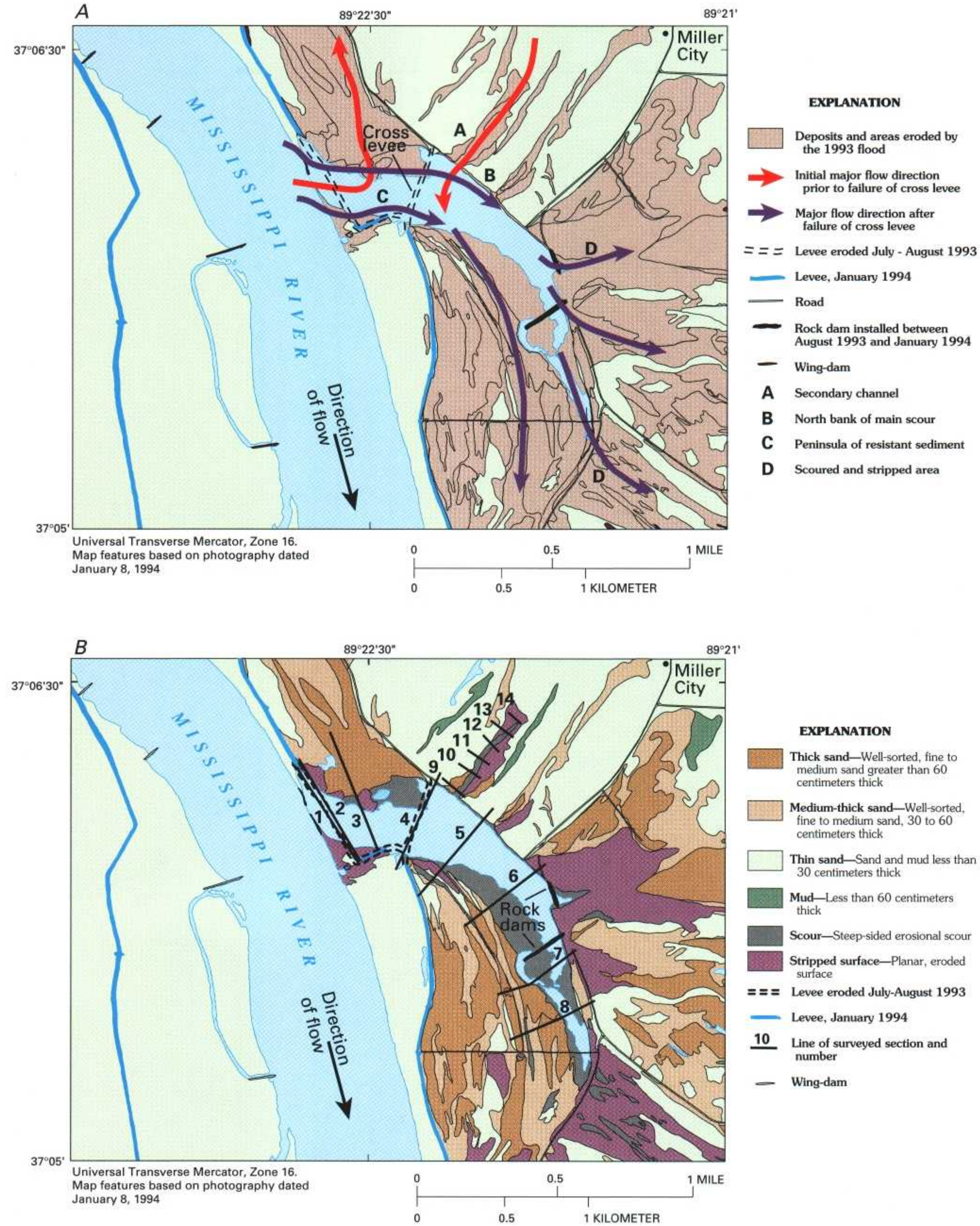

Figure 8. Upstream end of the Miller City, Illinois, levee-break complex. *A*, Flow directions and locations; *B*, Erosional and depositional features.

A

B

C

Figure 9. Miller City, Illinois, levee-break complex. *A*, Turbulence at northern end (Illinois Department of Transportation); *B*, Turbulence and vortices in center (Illinois Department of Transportation), and; *C*, Northern margin of main scour, October 1993.

Observations from water and aerial reconnaissance from July 26 through August 8 indicated that the main-flow vectors were oriented along the 1820 channel with divergence to the northeast and southeast (fig. 8*A*). To the north of the Miller City Road, in the area between Willard and Roth, flow vectors were to the east and northeast; secondary flow diverged southward across the Miller City Road (fig. 7). All the Dogtooth Island bend area south of the Miller City Road was inundated at this time, although water that flowed at higher velocities seemed to be confined to the northern one-half of the area. Floodwater diverged to the south and followed the 1820 channel until it encountered the levee. Then it concentrated in a low area defined by channel-position stage 12 (Fisk, 1944) and flowed to the southeast until ponded water forced the flow to the east and back into the main channel near river mile 16 (fig. 7).

Because of the wide angle of divergence of flow, it is impossible to define the degree to which flow around Dogtooth Island bend was cut off as a result of flow through the levee break. The location of flow back into the Mississippi River channel ranged from about river mile 20 as determined by the downstream extent of the Len Small levee, to about river mile 13.3, which is immediately upstream from the Cache River cutoff (fig. 7).

Floodwaters slowly receded after the peak on August 7 (table 1). As higher areas became dry, flow concentrated in the 1820 channel and the newly scoured areas. Flow in secondary scours oriented to the north and northeast once again reversed and moved into the 1820 channel. Probably the most dramatic change during this time was about 3 km east of Roth where large volumes of water were continuing to drain from Horseshoe Lake (fig. 7). As the water level dropped in the main channel of the Mississippi River, a reentry scour was created by upstream migration of the headcut (fig. 11). Erosion processes were still continuing during the last week of August 1993.

Subsequent to the summer flooding during 1993, the Miller City area was affected substantially by three additional floods (fig. 6). During late September and early October 1993, intense rainfall in Missouri resulted in another rise on the Mississippi River; the peak discharge of 20,600 m^3/s was at Thebes. In mid-November 1993, intense rain in Missouri and southern Illinois created a flood with a peak discharge of about 13,500 m^3/s at the streamflow-gaging station at Thebes. Both floods were sufficient to create a high volume of flow through the levee break with subsequent inundation of most of Dogtooth Island bend south of the Miller City Road. Before the November flood, construction had begun on a new levee alignment, and rock dams had been built across the main scour and one of the secondary scours (fig. 8*B*). The November flood caused increased erosion around the southwestern corner of the dam that had been constructed across the main scour. Another flood in April 1994 had a peak discharge of 18,500 m^3/s at Thebes. This flood created extensive changes, which included erosion of as much as 100 m of the southern margin of the main scour and extensive reworking of sand deposits in the area of the 1820 channel. The April 1994 flood also destroyed about 1,000 m of newly reconstructed levee.

Measurements

Measurements of discharge, velocity, and bathymetry in the levee break were made by the U.S. Army Corp of Engineers (COE) and the USGS from July 26 through September 9, 1993. The USGS measurements were made in cooperation with the Illinois Department of Transportation (IDOT). Discharge and velocity were measured in the Mississippi River upstream from the levee break and in the levee break. The COE measured discharge by the moving-boat technique (Smoot and Novak, 1969) and bathymetry by use of a digital echo-sounder and range–range positioning system. The range of the COE boat was limited by its draft;

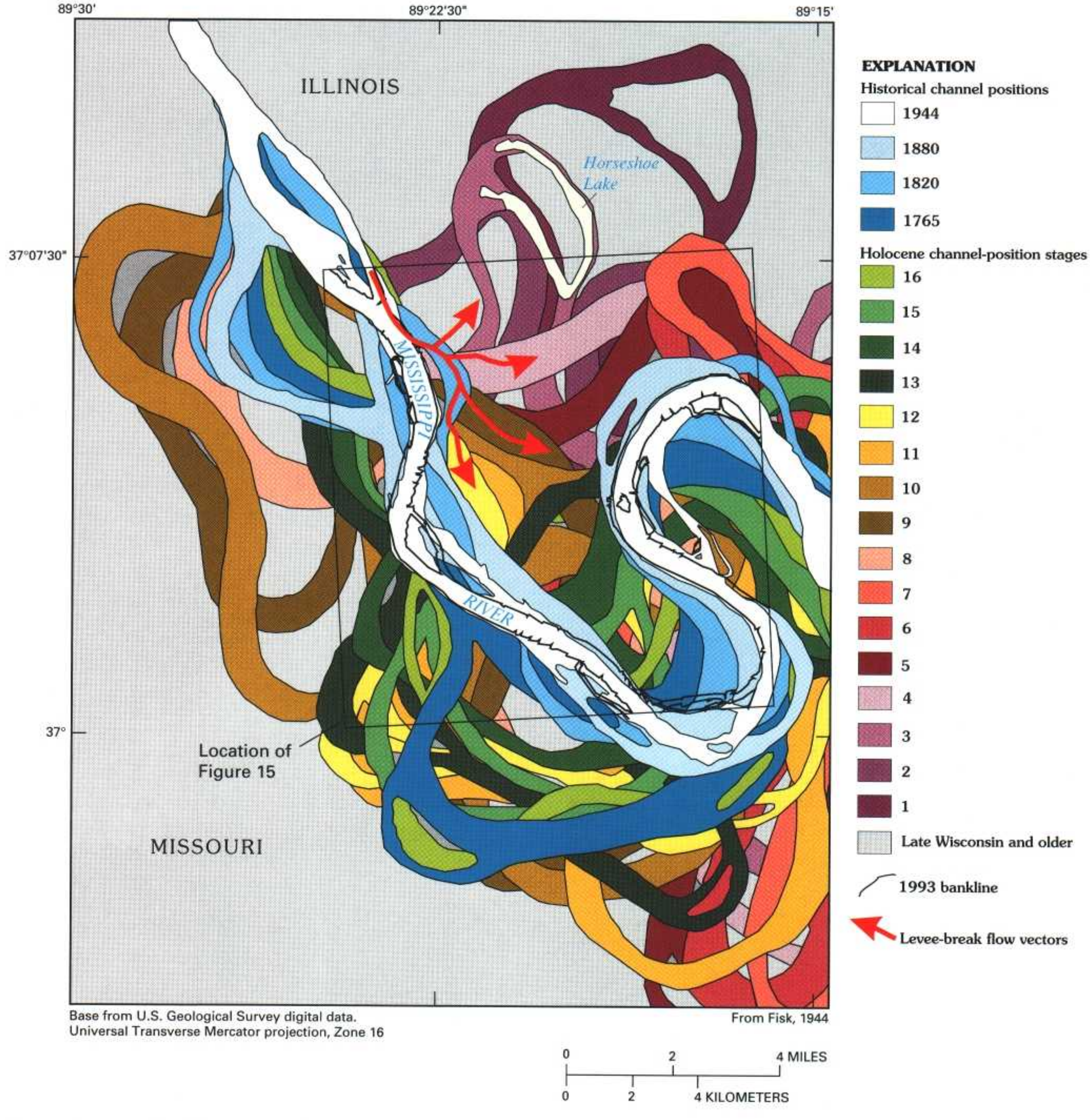

Figure 10. Historical channel positions and Holocene channel-position stages in the Miller City, Illinois, area.

therefore, it could be used to measure velocity and bathymetry only in the immediate vicinity of the break.

The USGS used an acoustic Doppler current profiler (ADCP) on an 8-m boat to measure discharge and velocity in and near the levee break. An ADCP may be used to measure vertical profiles of water velocity in three dimensions from a moving boat. The technique used for ADCP measurements is similar to the moving-boat technique except that the ADCP can measure water velocity every 25 cm in the water column, rather than at a single depth, and requires no external positioning system for computing boat velocity. Gordon (1989), Simpson and Oltman (1993), and Oberg and Mueller (1994) provided detailed descriptions of the ADCP and its application to streamflow measurements. Bathymetry measurements also were made by combining depths measured by using the ADCP with concurrent horizontal position data from a global positioning system (Oberg and Mueller, 1994).

An ADCP equipped with a 300-kilohertz (kHz) transducer was used to measure discharge and velocity in the Mississippi River upstream from the levee break, downstream from the levee break, and, in some instances, in the levee break. However, most measurements of discharge and velocity in the levee break were made by using an ADCP equipped with a 1,200-kHz transducer because the 300-kHz ADCP could not be used to measure water velocities in less than 5 m depth; the minimum recordable depth for the 1,200-kHz ADCP was about 1.3 m. Discharges measured by the COE and the USGS upstream from and in the levee break are shown in table 1.

The 1,200-kHz ADCP also was used to collect velocity and bathymetry data downstream from the levee break along the scour. These measurements were used to determine changes in water velocities along the main scour and the extent of scour formation. A small subset of the velocity data collected by using the ADCP is presented here to illustrate the range of velocities measured in and downstream from the levee break. Velocity profiles in the cross section for transects made in the levee break on July 31, August 9, August 19, and September 26, 1993, are shown in figure 12. These transects were located approximately along the former levee alignment.

Turbulence in and near the levee break made some measurements of water velocities and discharge difficult. Large (1- to 3-m diameter) vortices were present in the levee break, especially in the area immediately riverward of the original levee (fig. 9). This turbulence may have been associated with flow over the remains of riprap. In some instances, the ADCP was not able to measure velocities because of the turbulent flow conditions. Velocities measured by the ADCP in the levee break may be subject to errors because of the

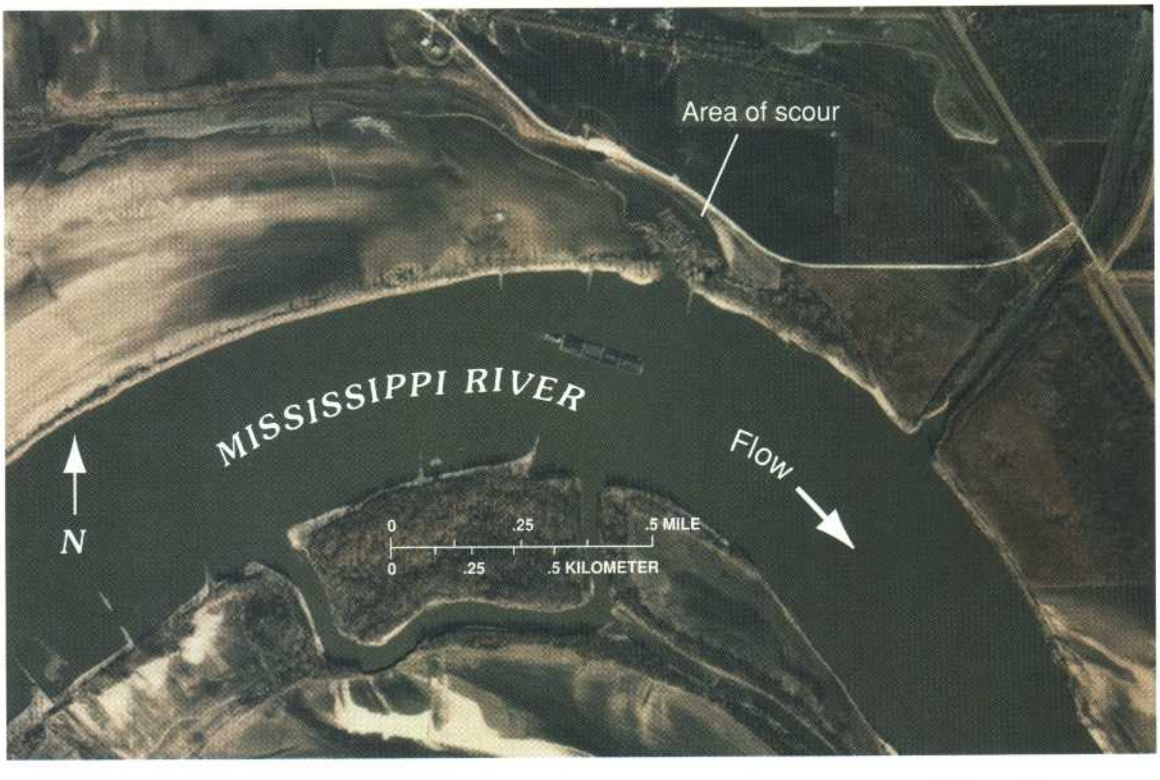

Figure 11. Reentry scour east of Roth, Illinois. (Aerial photograph January 8, 1994;U.S. Army Corps of Engineers, St. Louis).

unsteady, turbulent flow between the northern and southern end of the levee. High turbulence also was noted in an area about 200 m downstream of the break. When the water receded, it was revealed that this second area was above a peninsula of extremely compact, cohesive, and resistant sediment (location C, fig. 8*A*).

On July 31, 1993, an ADCP transect was made through the approximate center of the levee break from west (Mississippi River) to east (flood plain). The longitudinal transect of the scour and vertical components of velocities measured by the ADCP are shown in figure 13. This transect shows the flow up and over the riprap that lined the low-water channel and the large scour hole that formed immediately east (downstream) of the riprap. The vertical velocities measured with the ADCP generally correspond to the scour morphology. The vertical velocity is predominantly positive (upward) as flow moves up and over the riprap and predominantly negative as flow descends into the scour hole. About 300 m downstream from the levee, flow ascends over an area of resistant sediment referred to as the "peninsula" (location C, fig. 8*A*). Velocity components that fluctuate upward and downward are indicative of high turbulence in this area. Velocity vectors veer from west/east to southwest/northeast around the peninsula, which indicates that it also was effective in steering flow in planform.

The ADCP velocity and bathymetry measurements also were made downstream (inland) from the break on August 1, 1993. Cross sections and location of velocity-profile transects are shown in figure 14. Results of these measurements indicate that water velocities tended to increase downstream of the levee break until the downstream end of the scour channel was reached. This increase in velocity may be explained by the narrowing of the scour channel downstream of the levee break and the consequent loss of conveyance.

GEOMORPHIC CHANGES

Geomorphic changes on the flood plain include erosional and depositional alterations of the surface. Erosion and deposition are primary evidence for the spatial distribution of energy and sediment transport related to the levee break. Therefore, geomorphic changes can be used to evaluate the pattern of energy and sediment transport on the flood plain. Furthermore, the economic effect of the substantive geomorphic changes that occurred as a result of the 1993 flood was large. Many areas with deep scours and thick sand deposits may be uneconomical to repair, and natural

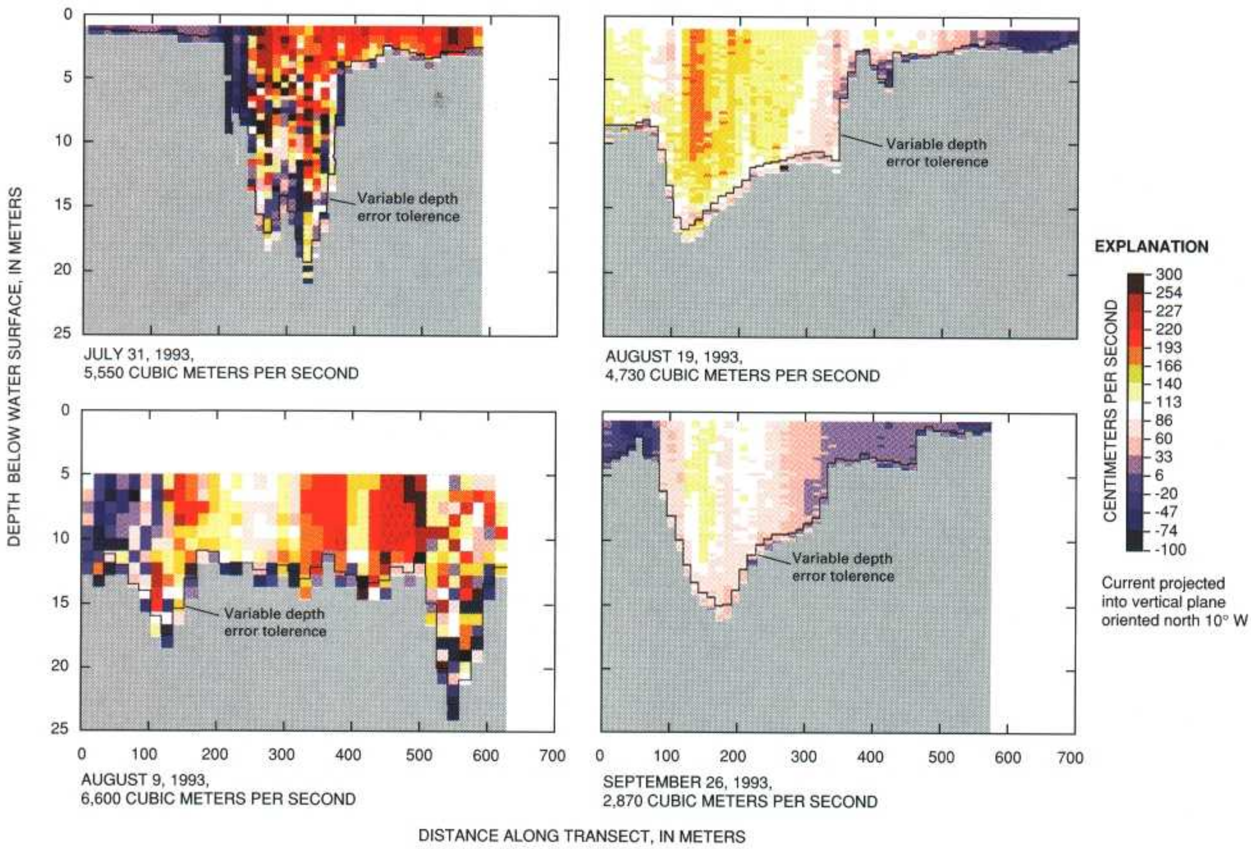

Figure 12. Acoustic Doppler current profile transects measured in the main levee break, Miller City, Illinois.

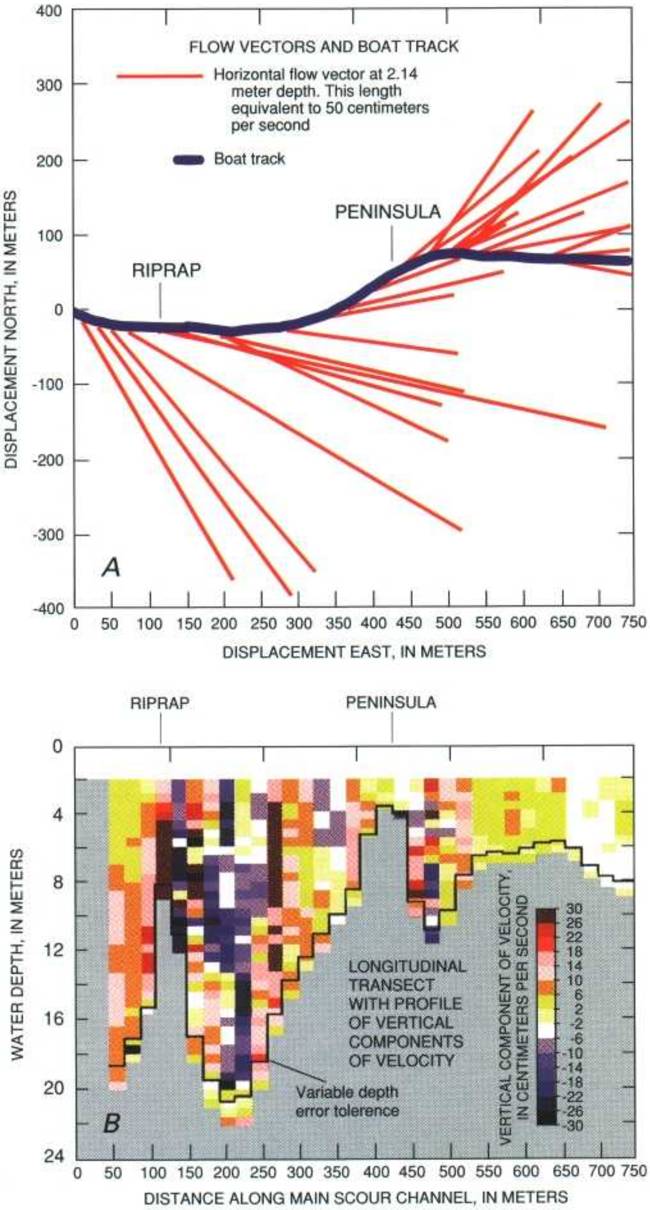

Figure 13. Levee break, Miller City, Illinois. *A*, Boat track and flow vectors; *B*, Longitudinal transect with profile of vertical components of velocity.

geomorphic processes would require hundreds to thousands of years to erase the damage.

Geomorphic Features

Geomorphic features in the Miller City levee-break complex were documented through aerial photographic interpretation, supplemented with onsite visits to obtain ground-truth information. The magnitude of the changes described in this report are determined, in part, by the scale of aerial photography, date of photography, and methods used to transfer photographic data to a map. Information on aerial photography is given in table 2.

The map of geomorphic features (fig. 15) was prepared by using the following procedure. First, control points identifiable on preflood photographs and USGS 1:24,000 scale topographic maps of the area (Cache, Thebes SW, Thebes, Charleston, and Tamms) were digitized. These data were projected into a universal transverse mercator, zone 16, and then used for absolute orientation of the preflood photographs. The absolute accuracy of the location of the control points and all subsequent points is constrained by the accuracy of the information on the topographic maps from which the data were digitized, or about 12 m horizontal and 0.8 m vertical. However, additional control points were digitized from the preflood photography and used for absolute orientation of the postflood photography, thereby diminishing the estimated interphotographic accuracy to about 2 m horizontal. Once control points were established, they were used for absolute orientation of stereomodels by using a photogrammetric stereoplotter and a photogrammetric computer software program.

For preflood conditions, 16 photogrammetric stereomodels were used to map channel margins, wooded areas, ponded water, roads, levees, and structures. For postflood conditions, 12 stereomodels were used to map 6 geomorphic mapping units (table 3) and navigation structures that were more apparent at the lower water level during January 1994. Digital map files for each stereomodel were imported to a geographic information system format where they were edge matched, edited, plotted, and analyzed.

The geomorphic units (table 3) were developed through onsite checking and evaluation of how much interpretation was possible given the scale and resolution of the postflood photography. Onsite checks involved spot determinations of thickness, stratigraphy, and sedimentology of sediments and descriptions of eroded areas. Vertical resolution of the photography was not adequate for mapping topography of the sand units, but it was sufficient to distinguish between thicker and thinner deposits. The thickness values given in table 3 are conservative to avoid overestimation of sediment volume.

The main scour channel (figs. 8, 15) follows the 1820 channel mapped by Fisk (1944; fig. 10). Total scour-channel length is about 2,200 m; the maximum width is about 400 m. Thick sand within the scour was deposited either on the receding limb of the hydrograph or during subsequent floods before the January 8, 1994, photography.

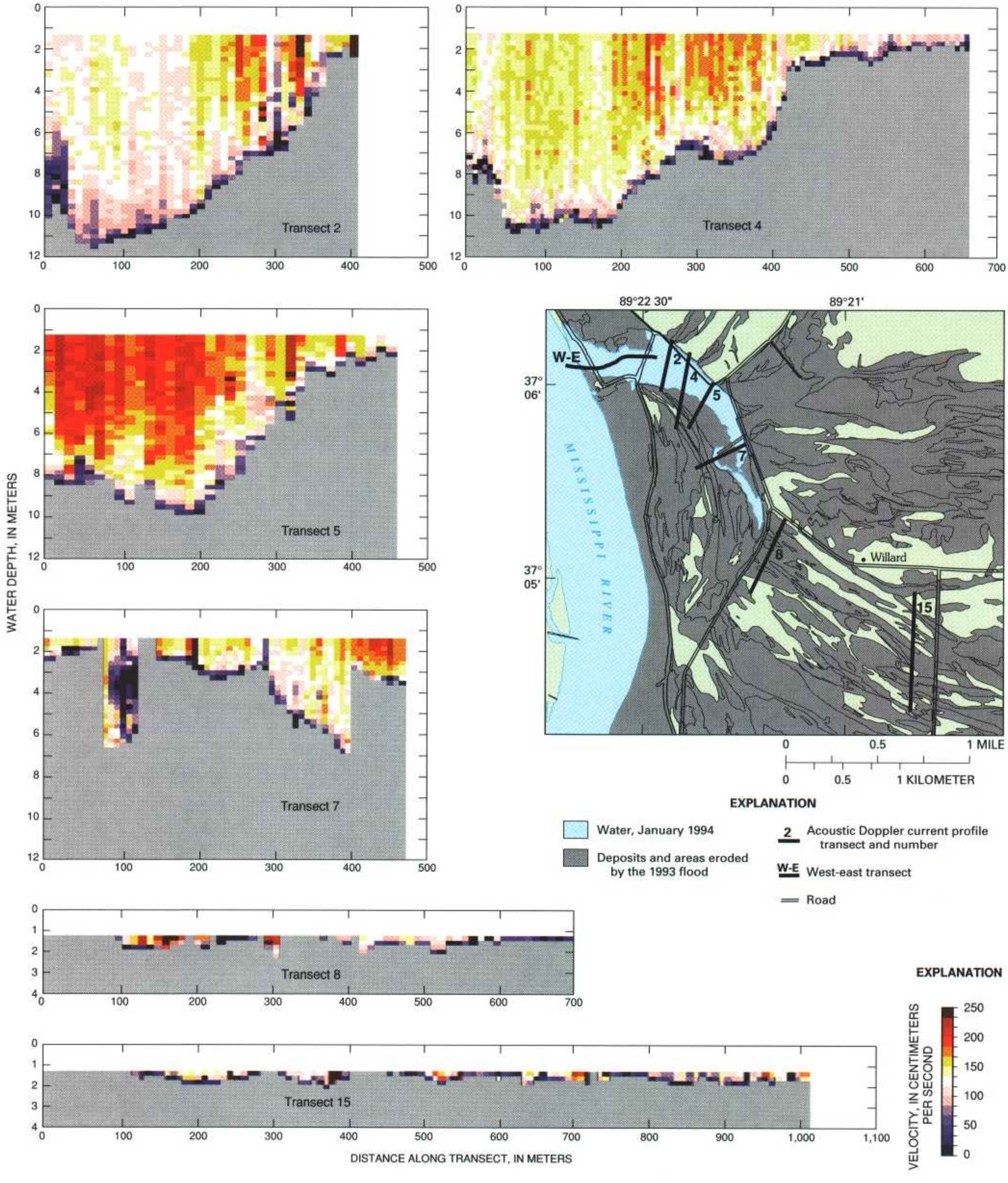

Figure 14. Acoustic Doppler current profile transects along the main scour, Miller City, Illinois, leve-break complex.

Table 2. Aerial photographic information for documenting geomorphic changes at the Miller City, Illinois, levee-break complex

[U.S. Army Corps of Engineers, St. Louis District]

Date of photography	Application of photography	Approximate scale and type of photography
July 7, 1993	Map prelevee-break conditions in Dogtooth Island bend.	1:24,000, black and white.
August 7, 1993	Evaluate flow vectors and inundated area.	Do.
January 8, 1994	Map geomorphic effects in levee-break complex, low-water channel, and navigation structures.	1:24,000, color.

or during subsequent floods before the January 8, 1994, photography.

Additional areas of scour occur as narrow secondary channels on the margins of the main scour and as elongated features downstream from the main scour. These smaller scours usually are surrounded by stripped areas (fig. 8*B*). Scoured and stripped areas are most extensive to the east and southeast of the downstream end of the main scour (locations D and E, fig. 8*A*). Smaller areas of scouring and stripping are described as follows:

- A long, narrow, southeast-trending region (1.7–4.3 km) directly south of the downstream end of the main channel. This was an area of concentrated flow, and the scour seems to have started where the flow overtopped a road embankment (location A, fig. 15) that crossed a preexisting channel.
- North of and crossing the Miller City Road where floodwaters flowed southward and down a prominent scarp (location B, fig. 15).
- At an exit scour, immediately upstream of the Cache River cutoff (location C, fig. 15).
- Directly south and parallel to the main scour. These are long, narrow scours that were partially refilled with sand after the flood. Such a scour can be seen on the right side of ADCP profile 7 (fig. 15).

Medium-thick and thick sand deposits are distributed in a complex pattern. They generally consist of elongated, somewhat streamlined bodies aligned parallel to flow direction. Thick sand units are most common close to the main scour and at the eastern edge of Dogtooth Island bend (location D, fig. 15) where much of the flow reentered the main channel of the Mississippi River. At this location, the main-channel flow apparently caused a hydraulic damming effect, which allowed the deposition of a large quantity of sand; thicknesses of greater than 4 m were measured. Some locations of deposition of medium-thick and thick sand seemed to be controlled by fencelines and woody vegetation. Thick sand deposits were common in densely vegetated fencelines along the upstream margins of wooded areas. Several medium-thick sand deposits were mapped along the channel margin of the nonleveed part of Dogtooth Island bend (location E, fig. 15); these were interpreted to be natural crevasse-splay deposits from water that overtopped the natural levee and flowed from northeast to southwest onto Dogtooth Island bend.

Mud deposits were limited in extent and detected mainly in the southern one-third of Dogtooth Island bend. This was an area of low-velocity flow, situated between the levee-break and the main flows, and protected by the remains of the Len Small levee. Mud generally accumulated in low areas of paleochannels and typically attained thicknesses that ranged from 20 to 40 cm.

Scour Morphology and Volume

Cross sections of the main scour and two smaller scours were surveyed onsite by the IDOT during February 1994 (fig. 16). These surveys were completed after the flood of November 17 to 22, 1993, and before the flood of April 13 to 21, 1994. Surveyed depths are minimum, or net, scour depths because of probable redeposition of sediment by the receding floodwaters at the end of the 1993 summer floods and by the November 1993 flood.

The main scour channel is 2,200 m long and forms an arc that follows the preexisting 1820 channel. The channel ranges in width from about 100 m to more than 600 m and averages about 350 m. In the cross section, the scour is wide and deep at the levee break where the maximum net depth is 19.1 m (section 1, fig. 16). Immediately downstream of the break, a prominent shelf is evident on the left bank (sections 2, 3, fig. 16). This shelf was located near an area of intense turbulence during the levee break. Onsite observations indicate that it was formed of extremely dense, cohesive, and resistant silt and clay that eroded to form vertical scarps and long, narrow grooves (fig. 17). Subsequent to scour of the main channel, thick sand was deposited downstream and toward the left bank of the shelf (fig. 8*B*; section 4, fig. 16). Apparently, the less-erodible sediment of the shelf deflected the flow to the right bank, which caused greater velocity and deepening on that side (figs. 13, 14). Downstream of the shelf, the deepest part of the channel shifts to the left bank (sections 5 through 8). During

Table 3. Characteristics of geomorphic map units used in preparation and interpretation of the Miller City, Illinois, levee-break complex map

[km^2, square kilometers; cm, centimeters; m, meters; >, greater than; <, less than; NA, data not applicable]

Geomorphic map unit	Area (km^2)	Unit characteristics	Estimated thickness (cm)
Thick sand deposits . . .	7.1	Forms sand waves and dunes with amplitudes of 0.5 to 3 m; wavelengths of 2 to 10 m. Thickness is sufficient to obscure all underlying, preflood topography on the scale of crop rows to road embankments. Usually little or no mud drape is present, and reflectivity on photography is high. Generally well-sorted, fine to medium sand. May have discontinuous, thin, interbedded mud layers. Internal sedimentary structures include wave ripple cross lamination, climbing ripple cross lamination, dune-scale crossbedding, and planar bedding.	> 60
Medium-thick sand deposits.	15.2	Forms low-amplitude dunes and extensive areas with little or no surface topography. Amplitudes of dunes range from 10 to 30 cm; wavelengths of 2 to 4 cm. Thickness is sufficient to obscure all underlying preflood topography on the scale of crop rows. Mud drapes are common and tend to obscure underlying sand; reflectivity is often low, but mud is usually dry and light brown. Overlying mud drapes may be as much as 30 cm thick. Generally well-sorted, fine to medium sand with common interbedded mud layers. Internal sedimentary structures include wave ripple cross lamination, climbing ripple cross lamination, planar bedding, and minor dune-scale crossbedding.	30–60
Thin sand deposits. . . .	52.5	Forms extensive areas of sand conforming to preexisting topography. Identification for aerial photography depends on presence of areas of highly reflective sediment that does not obscure crop rows. Mud drapes are extremely common and tend to obscure this unit, although because of underdraining by the sand, the mud tends to be dry and a lighter brown on photographs. Generally well-sorted, fine to medium sand with common interbedded mud layers. Internal sedimentary structures include wave ripple cross lamination, climbing ripple cross lamination with minor planar bedding, and dune-scale crossbedding.	0–30
Mud deposits	2.5	Forms dark, low-reflective areas in low spots. Does not obscure crop-row topography and is often associated with standing water and patchy ice in January 1994 photography.	< 60
Stripped surfaces	2.1	Has distinctive grooved topography, has ledges with 5 to 100 cm of relief, and lacks preflood crop stubble and vegetation. Sharp boundaries at edge of stripped units indicate 30 to 50 cm of stripping. Red colors of B-horizon are prominent (where older terrace sediments are stripped). May have subsidiary shallow scours. Some areas have been covered with subsequently deposited sand and mud.	NA
Scours	.5	Equant to elongate, steep-sided features with evident depths of greater than about 1 m. Often partially filled with water; commonly partially filled with sand deposited subsequent to erosion.	Do.

1993 flood, an additional area was scoured to the south (right) of the rock dam constructed for the new levee alignment, and additional sand was deposited just downstream from the rock dam (section 7, fig. 16).

The secondary scour represented in sections 9 through 14 (fig. 16) was much narrower than the scour of the main channel. The maximum depth at the downstream end is about 5 m. A small amount of sand was deposited in the secondary scour subsequent to the main flood, so the cross section is eroded almost entirely in cohesive silt and clay.

The volume of sediment eroded from the main scour was estimated by approximating the channel segments between cross sections (fig. 16) as solid, rectangular bodies and multiplying the area of stripped surfaces by an estimated mean erosion depth of 30 cm. The estimated volume (table 4) ignores some minor scours and is based on the net depth of the two surveyed scours; hence, the calculation may underestimate the total eroded volume.

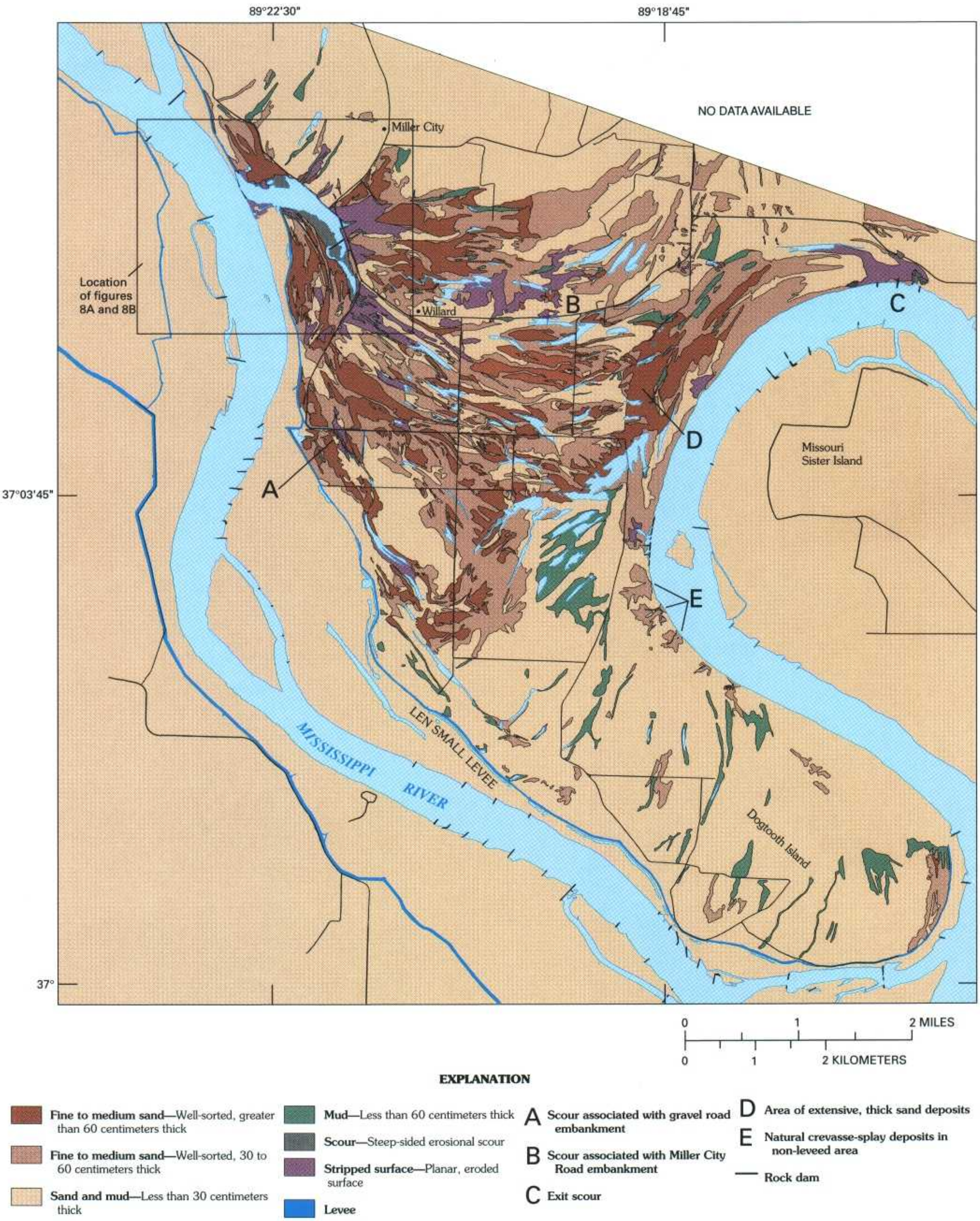

Figure 15. Geomorphic features created in the Miller City, Illinois, levee-break complex.

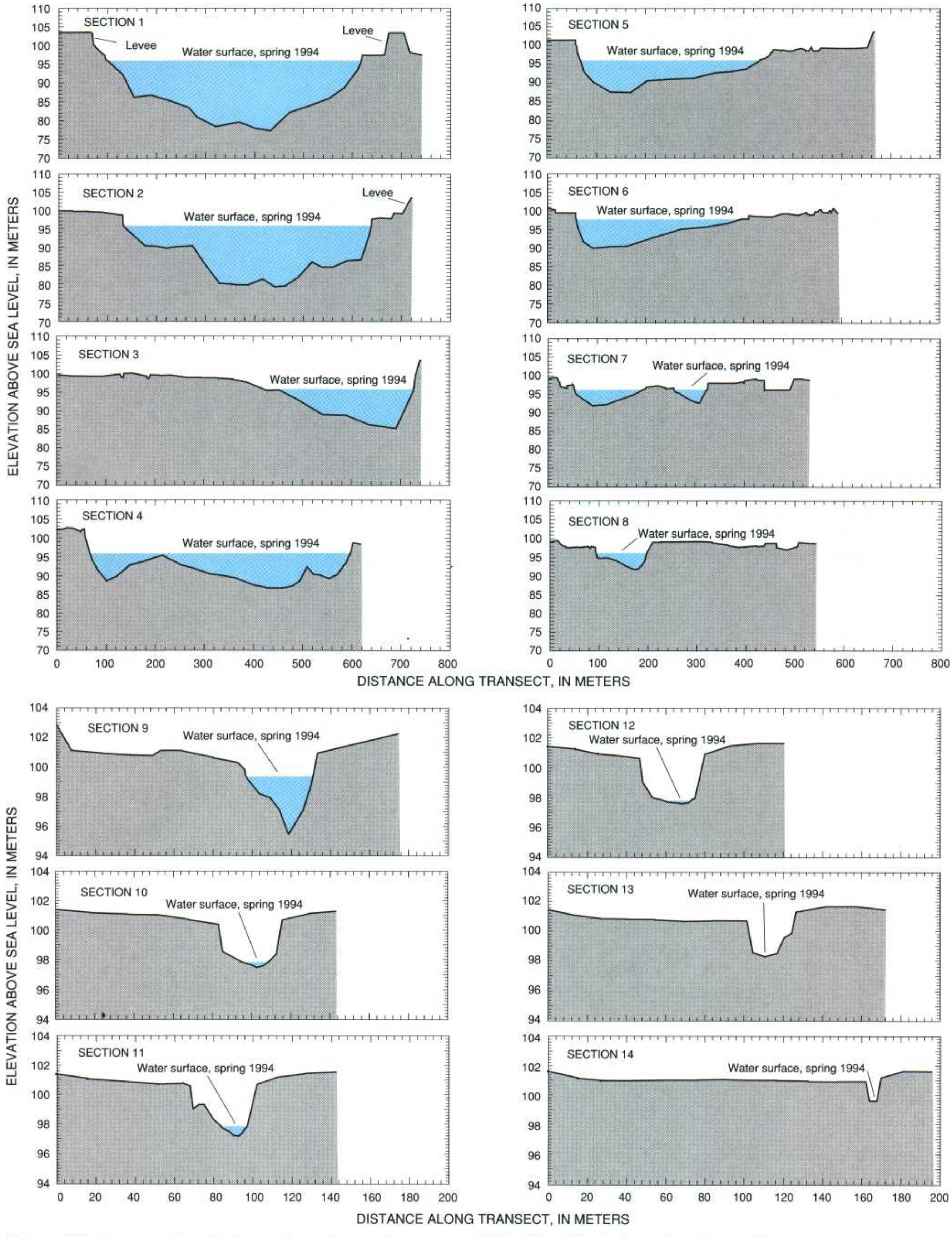

Figure 16. Cross sections in the main and secondary scours, Miller City, Illinois, levee-break complex.

Figure 17. Groves and vertical walls at the peninsula, Miller City, Illinois, levee-break complex. View is to the Southeast, downstream along the main scour channel.

Volumes of eroded soil and estimated areas of deposition in the thin, medium-thick, and thick geomorphic map units were used to calculate the net volume of sediment delivered to the flood plain (table 4). The volumes of sand were conservatively estimated because the lower limit of the thickness range was used for the calculation. The mass of sediments eroded and deposited was calculated by using a range of typical bulk densities to cover the range of materials present. These estimates provide an indication of the importance of the Miller City levee-break complex as a net source or sink of sediment during the flood.

Even with the range in uncertainties, the Miller City levee-break complex was clearly a sink for sediment in transport, thus accumulating a net volume of 8.2 million m^3 and a mass from 11.4 to 18.4 million metric tons. The mass of sediment deposited on the flood plain at Miller City is from 22 to 36 percent of the total sediment load that passed Thebes, during the flood (Holmes, 1966). This mass of sediment also is equivalent from 8 to 13 percent of the mean annual suspended sediment load of the Mississippi River at Thebes.

PROCESSES, MAGNITUDE, AND FREQUENCY OF GEOMORPHIC CHANGES IN THE MILLER CITY, ILLINOIS, LEVEE-BREAK COMPLEX

A detailed analysis of the causes of the Miller City levee break is beyond the scope of this report. However, some discussion is warranted because geometric aspects of the break are directly related to geomorphic processes in the levee-break complex. Anecdotal accounts of local residents attribute the break to poor levee maintenance that allowed weakening of the structure by groundhog burrows. On a broader scale, it may be significant that the Miller City

Table 4. Summary of erosion and deposition estimates in the Miller City, Illinois, levee-break complex

[km^2, square kilometers; cm, centimeters; m^3, cubic meters; kg/m^3, kilograms per cubic meter; NA, not applicable]

Geomorphic mapping unit	Area (km^2)	Depth used for calculation (cm)	Estimated volume (millions of m^3)	Estimated mass (millions of metric tons using minimum bulk density of 1,362 kg/m^3)	Estimated mass (millions of metric tons using maximum bulk density of 2,211 kg/m^3)
Thick sand deposits	7.1	60	4.2	5.8	9.4
Medium-thick sand deposits	15.2	30	4.6	6.3	10.1
Thin sand deposits	52.5	10	5.2	7.1	11.5
Stripped surfaces	1.8	30	.5	-.7	-1.1
Scours	5.8	Variable[1]	5.2	-7.1	-11.5
Net deposition	NA	NA	8.2	11.4	18.4
Percentage of flood sediment load at Thebes, Illinois.[2]	....do...	....do....	NA	22.3	36.1

[1]Variable depths were used for surveyed cross sections to estimate scour volume.

[2]51,000,000 metric tons [estimated by Holmes (1996)].

levee broke downstream from Thebes Gap (fig. 1), which is an area where the Mississippi River Valley is constricted between bedrock bluffs. From the exit of Thebes Gap near Fayville to the downstream end of Goose Island, the agricultural levees on both sides of the channel converged to create a local constriction, or neck, exactly where the Len Small levee failed (fig. 7). In addition, the low-water channel of the Mississippi River, which carried a high percentage of the discharge during the flood, curves around Goose Island and into the levee at the site of the levee break. Constriction of the flow at the neck and channel geometry that directed the thread of high-velocity flow at the levee may have been partial factors in determining the location of the levee break.

Once the break occurred, the geomorphic effectiveness of flow through the levee break was affected by several factors, which include the direction of flow through the break. From July 15 through August 25, 1993, as much as 28 percent of the discharge of the Mississippi River flowed through the Miller City levee break. Depths in the upstream part of the levee break were comparable to those in the main channel. Local water-surface slope through the break exceeded 5 percent just after the break. During ADCP discharge measurements in late July, the water-surface drop through the break was estimated to be 1 m over a distance of about 20 m for a slope of about 5 percent. The slope across Dogtooth Island bend averaged about 0.04 percent, or twice the normal slope of 0.02 percent along the low-water channel. High flow concentrated in a narrow region with a large water-surface slope created conditions sufficient to erode the preexisting flood plain sediments.

The characteristic steep walls and the presence of slumped and toppled blocks of cohesive sediment attest to erosion by a combination of hydraulic and gravitational forces. Observations at Miller City and from other locations on the Mississippi and the Missouri Rivers support a model of scour formation in which highly turbulent flow in or near the levee break erodes through a top stratum of cohesive muddy sediment. The initial piercing of the cohesive layer may result from vertical components of velocity in the turbulent flow or by scour around objects like tree trunks or both. Once the cohesive top-stratum is breached, noncohesive sediment under the top stratum is undermined, thus maintaining steep walls in the top stratum and leading to slumping or toppling. Undermining and toppling lead to extension of the scour upstream and downstream. In cases like the Miller City levee-break complex where the scour extends far enough upstream from the levee to intersect the main channel, the scour forms a ramp that expedites the transport of bedload and near-bed suspended load from the channel, through the levee break, and onto the flood plain.

Vertical components of velocity are evident in the west-to-east ADCP transect through the levee break (fig. 13). The overall ramp structure of the scour is interrupted by a ridge at the remains of the riprap. Upstream from the riprap, substantial components of velocity are directed vertically upward (positive values), and downstream, downward components are evident. The downward components probably caused the large scour hole between the riprap and the peninsula. Upward and downward fluctuating velocity components are evident around the peninsula, which indicated high turbulence in that area.

In the break, velocities of as much as 300 cm/s were common on July 31 and August 9 (fig. 12). Downstream from the break, velocities on August 1 initially slowed in the area of expanding flow, then accelerated toward the downstream end (transects 2, 4, 5, fig. 14). Acceleration of flow probably was related to the narrower channel at the downstream end of the scour where channel width and depth were continuing to adjust to the imposed discharge by actively eroding banks and channel bed. Downstream from transect 5 (fig. 14), ADCP data indicate transition through a more poorly defined channel (transect 7, fig. 14) to an area of multiple, shallow threads of highly variable velocity (transects 8, 15, fig. 14). Bottom topography in ADCP profile 8, (fig. 14) shows several narrow channels from 2 to 3 m deep; these probably became the isolated, small scours mapped in the stripped zone downstream from the main scour (figs. 8*B*, 15). Some of the irregular bottom topography in transect 15 (fig. 14), however, probably resulted from deposition of longitudinal sand dunes (fig. 15).

The map pattern of the main scour, stripped zones, and depositional zones at Miller City indicates the effects of topography and structures on geomorphic changes in the levee-break complex. Initial flow directions were determined by the 1820 channel and the cross levee that blocked water from flowing to the south and east. After the cross levee was broken, flow directions were affected mainly by the scarp between the 1820 channel and older sediments. The larger secondary scours to the north and east of the main scour occur in preexisting low areas where flow was concentrated. Long, narrow scours to the south of the main scour (fig. 8*B*) are not clearly related to topography or structure and may have been caused by scour around grounded tree boles or other debris carried by the flood.

Stripped areas were formed preferentially at topographic breaks. Most stripping occurred where flow from the main channel ascended the scarp that separates the 1820 channel from older deposits. Stripping was extensive where shallow flow crossed the topographically high area along and north of the Miller City Road. A large area also was stripped during the flood recession where flow out of Horseshoe Lake descended the scarp into the low-water channel (location C, fig. 15). Also, stripping was commonly observed downstream, but not upstream, from fairly subtle topographic breaks, such as low road embankments or even wheel ruts. Association of stripped areas with topographic breaks indicates that turbulence induced by such features is a key control for initiation of shallow erosion.

Flow diverged from the 1820 channel to the northeast and southeast and followed preexisting low spots defined by paleochannels and around topographic highs of older channel positions. Water that flowed southward parallel to the levee encountered ponded water in the southern one-half of Dogtooth Island bend and was forced to the northeast. Where flow that was eastward and northeastward across the bend converged with flow in the main channel (about river miles 15–17), decelerating current velocity resulted in particularly thick sand deposits. The patterns of thick sand deposits north of the Miller City Road indicate that wooded areas also slowed current velocities sufficiently to create deposition sites.

The net amount of sediment deposited in the Miller City levee-break complex was conservatively estimated to be from 22 to 36 percent of the total flood-sediment load. From this estimate, it is possible to conclude that levee-break complexes could be substantial sinks for sediment in transport during the flood. Holmes (1996) speculated that levee-break complexes on the Missouri River were, in part, responsible for a 21-percent decrease in flood-sediment load between Hermann and St. Louis. Onsite observations indicate that the effectiveness of levee-break complexes to extract sediment from transport is controlled, in part, by the extent to which the scour connects to the main channel at a favorable angle to funnel flow directly onto the flood plain. At Miller City, the levee break and main scour were almost perfectly aligned with the direction of flow guided by the low-water channel along the western side of Goose Island (fig. 7).

Erosion from the 1993 flood created many extensive exposures of preexisting flood-plain sediments (figs. 17, 18). Of the many exposures scattered throughout the Miller City area, none contained thick sand deposits like those that resulted from the 1993 flood. Although the history of channel changes in the Miller City area attests to an extremely dynamic channel system (fig. 10), the apparent lack of thick sand in the stratigraphic record indicates that the geomorphic effects of the 1993 flood were unprecedented during the Holocene. The geomorphic effectiveness of the 1993 flood in the levee-break complex was far greater than would be expected from either the estimated 100-year recurrence interval of the flood at St. Louis (Parrett and others, 1993) or the 75- to 300-year recurrence intervals estimated for the precipitation conditions that created the flood (Interagency Floodplain Management Review Committee, 1994; Kunkel and others, 1994). The large hydraulic head artificially maintained by the levee and the lack of energy dissipation on the dominantly agricultural land probably contributed to much greater geomorphic change in the levee-break complex than would have resulted from a flood of comparable magnitude on wooded, nonleveed bottomland.

Figure 18. Typical pre-1993 flood sediment deposit, Miller City, Illinois, levee-break complex.

SUMMARY

Geomorphic changes at levee-break complexes were the most dramatic geomorphic effects of the 1993 flood on the Mississippi and the Missouri Rivers. Erosion and sedimentation at the levee-break complexes severely damaged large areas of formerly productive agricultural land. Discharge through the Miller City levee-break complex was as much as 28 percent of the total Mississippi

River flow during the peak of the 1993 flood. Measured velocities in the levee break were as high as 300 cm/s.

The levee-break complex at Miller City is one of the larger features created during the 1993 flood and has many characteristics that are typical of levee-break complexes on the upper Mississippi and Missouri Rivers. Erosion created a steep-sided scour as much as 20 m deep that extended for more than 2,000 m downstream from the levee break. Deep, narrow secondary scours radiated outward in areas of concentrated flow. Concentric around the downstream end of the scour were areas where from 10 to 45 cm of soil had been stripped; these areas accounted for about 1.8 km^2. Sand deposits in excess of 30 cm thickness covered slightly more than 22 km^2.

Net deposition on the flood plain at Miller City was estimated conservatively to be from 11.3 to 18.4 million metric tons, or from 22 to 36 percent of the 1993 flood sediment load measured at Thebes. Although the history of the Mississippi River channel in this area attests to frequent, dynamic channel changes, the stratigraphic record does not seem to contain sand units comparable to those deposited during 1993. The extensive erosion and even greater deposition may be attributable to the magnitude of the flood, the hydraulic head artificially increased by the levee, and the lack of energy dissipation on the agricultural flood plain relative to presettlement, forested conditions.

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