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

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;

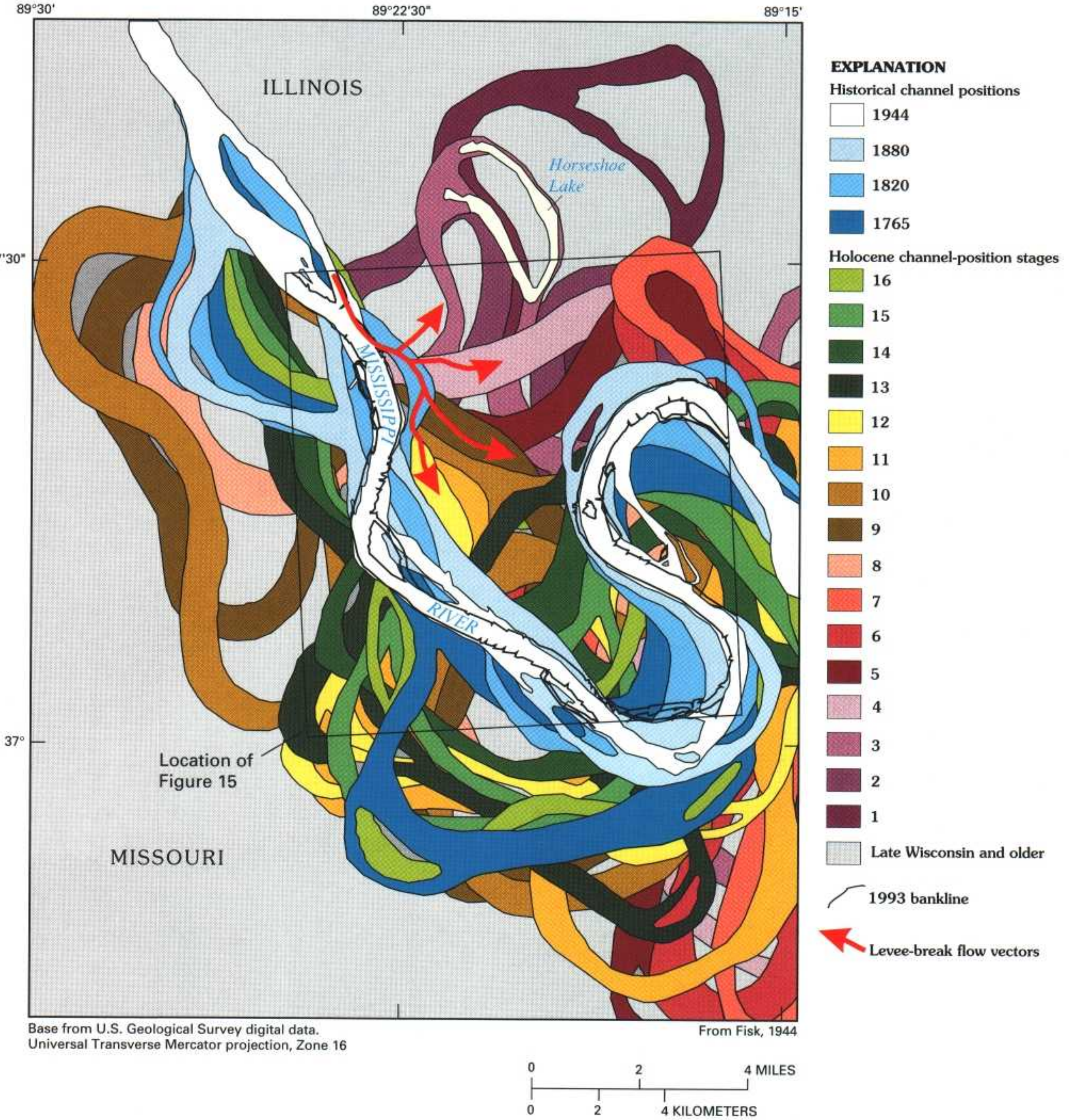

Figure 10. Historical channel positions and Holocene channel-position stages in the Miller City, Illinois, area.

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

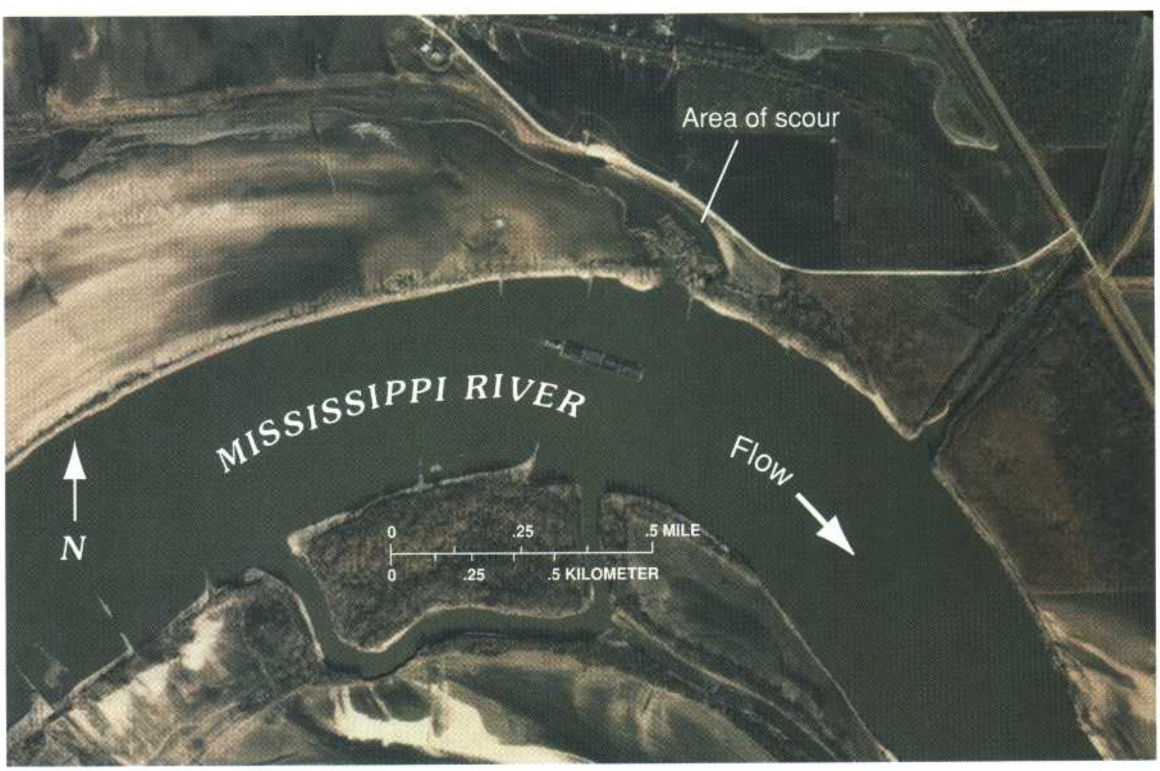

Figure 11. Reentry scour east of Roth, Illinois. (Aerial photograph January 8, 1994;U.S. Army Corps of Engineers, St. Louis).

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

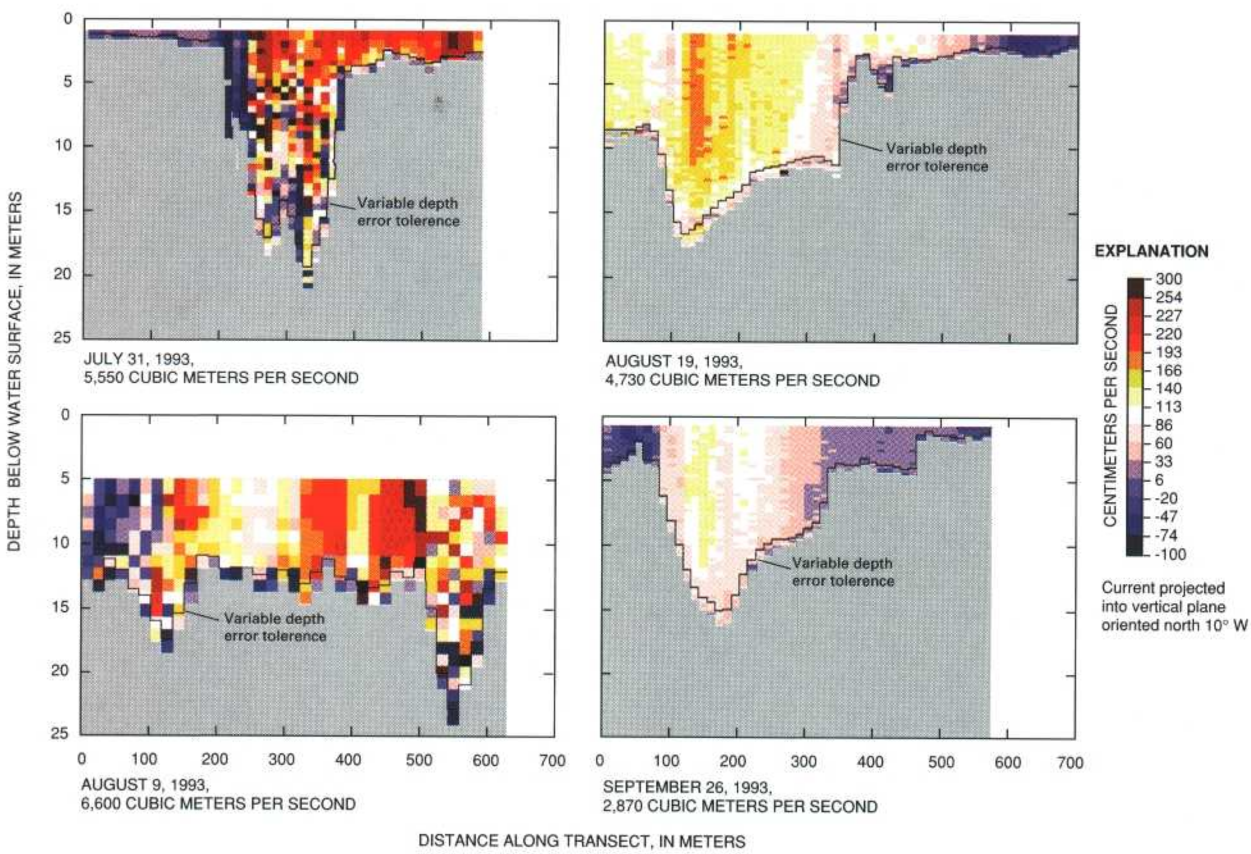

Figure 12. Acoustic Doppler current profile transects measured in the main levee break, Miller City, Illinois.

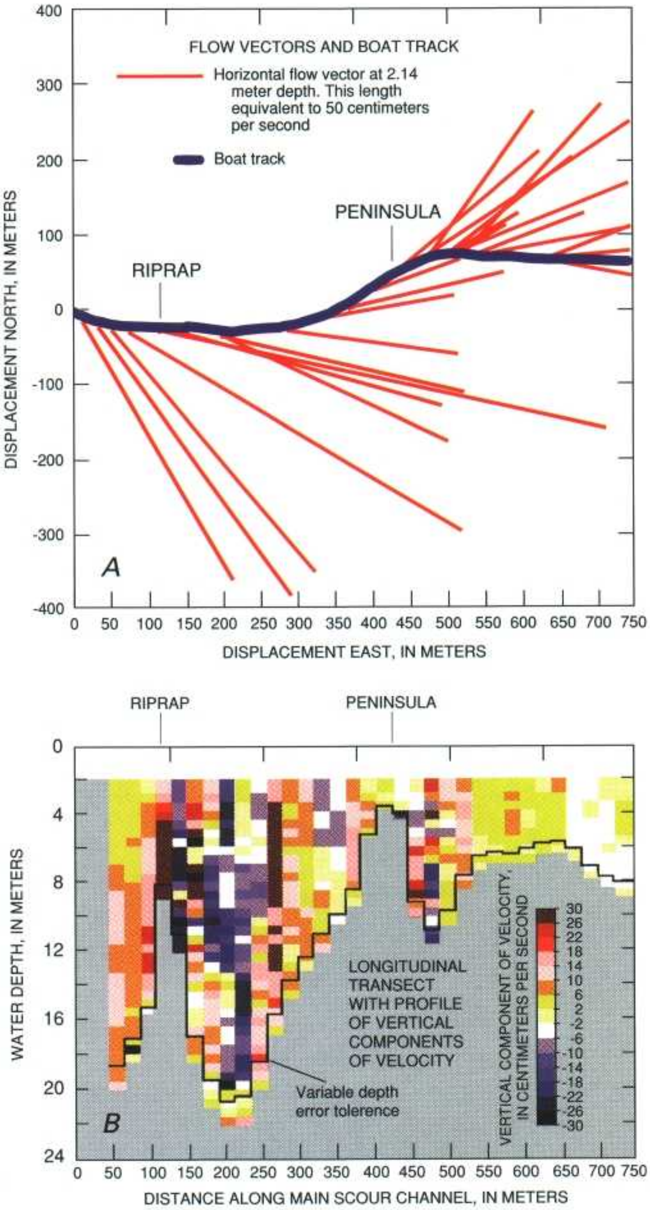

Figure 13. Levee break, Miller City, Illinois. *A*, Boat track and flow vectors; *B*, Longitudinal transect with profile of vertical components of velocity.

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.

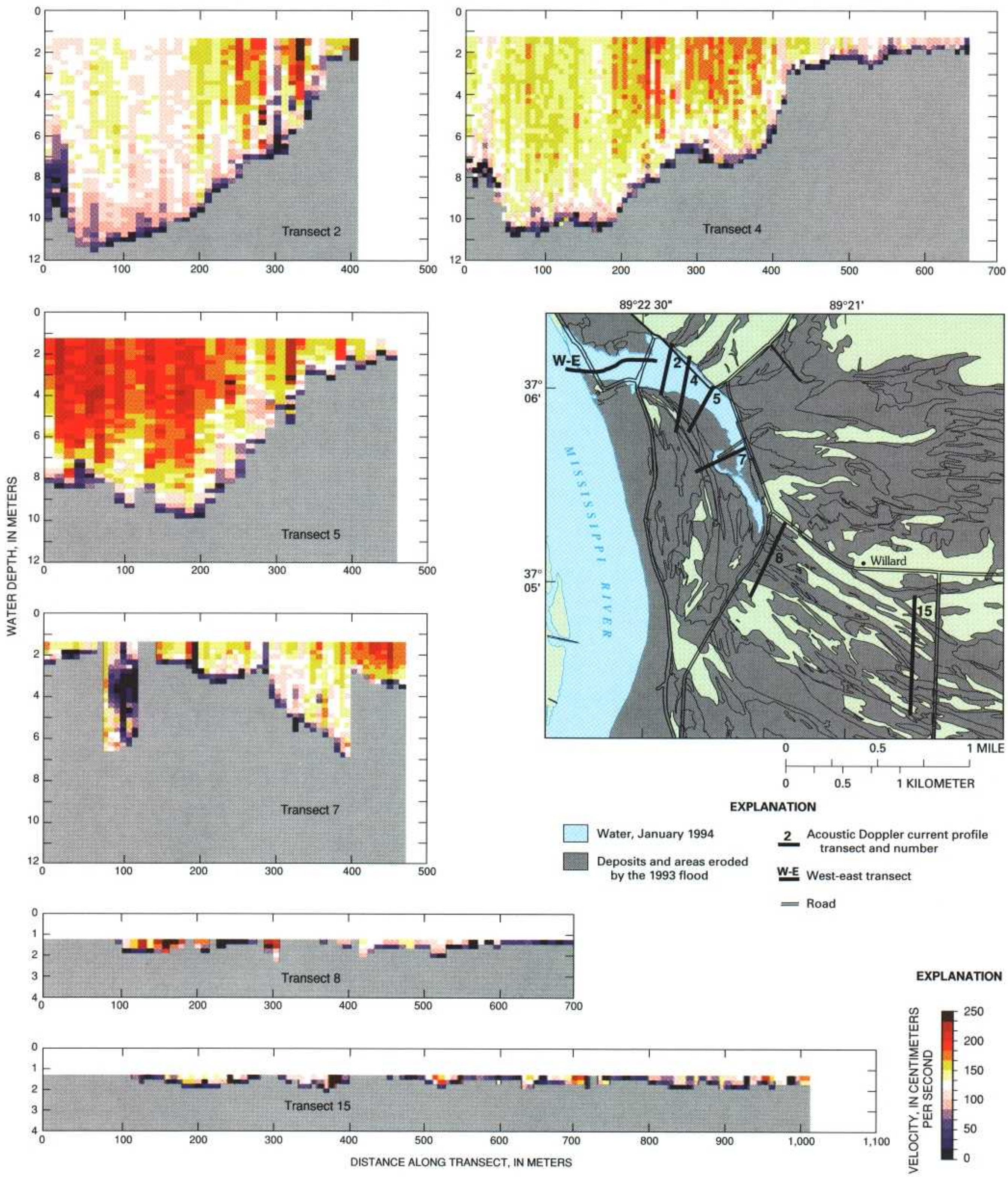

Figure 14. Acoustic Doppler current profile transects along the main scour, Miller City, Illinois, leve-break complex.

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.

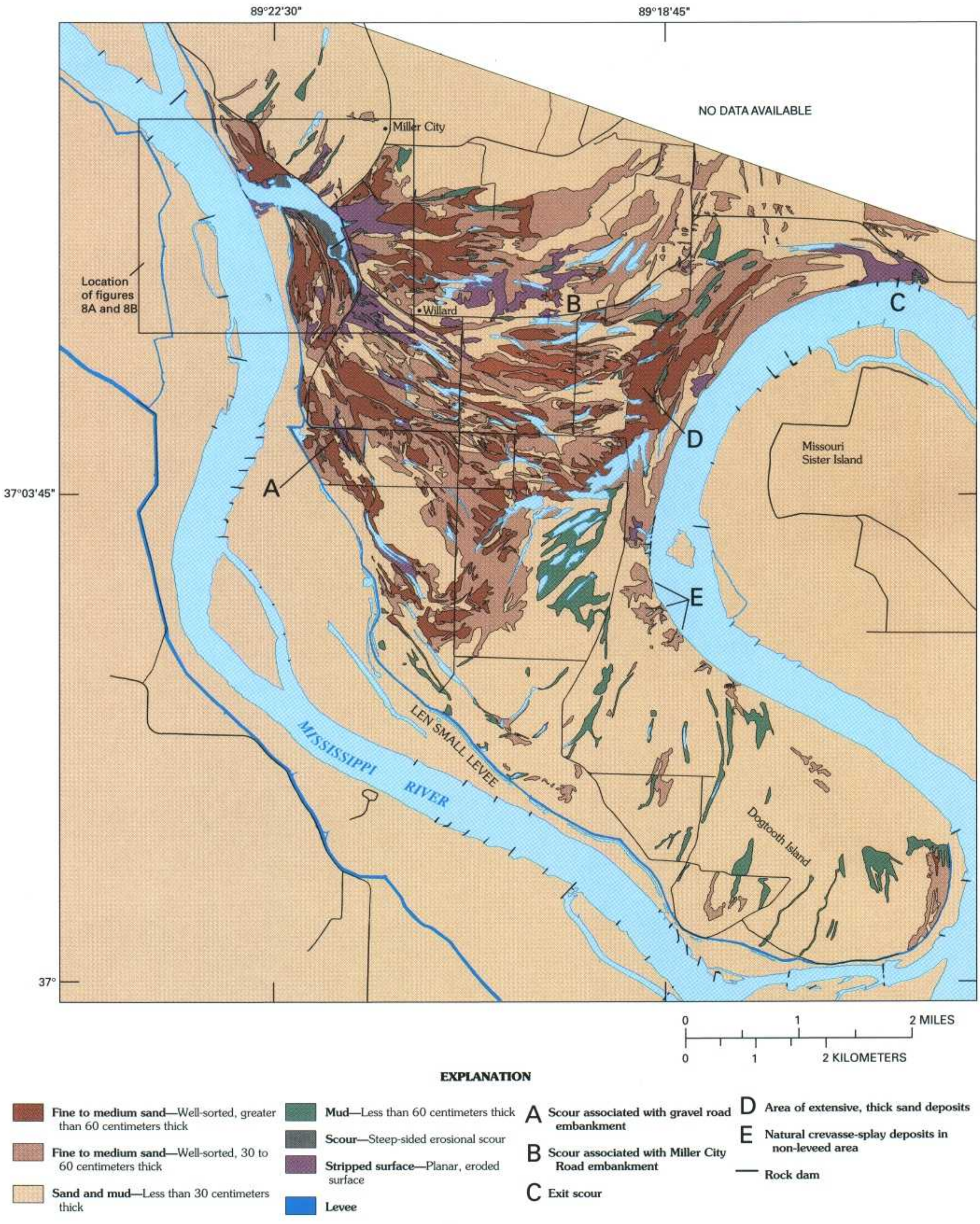

Figure 15. Geomorphic features created in the Miller City, Illinois, levee-break complex.

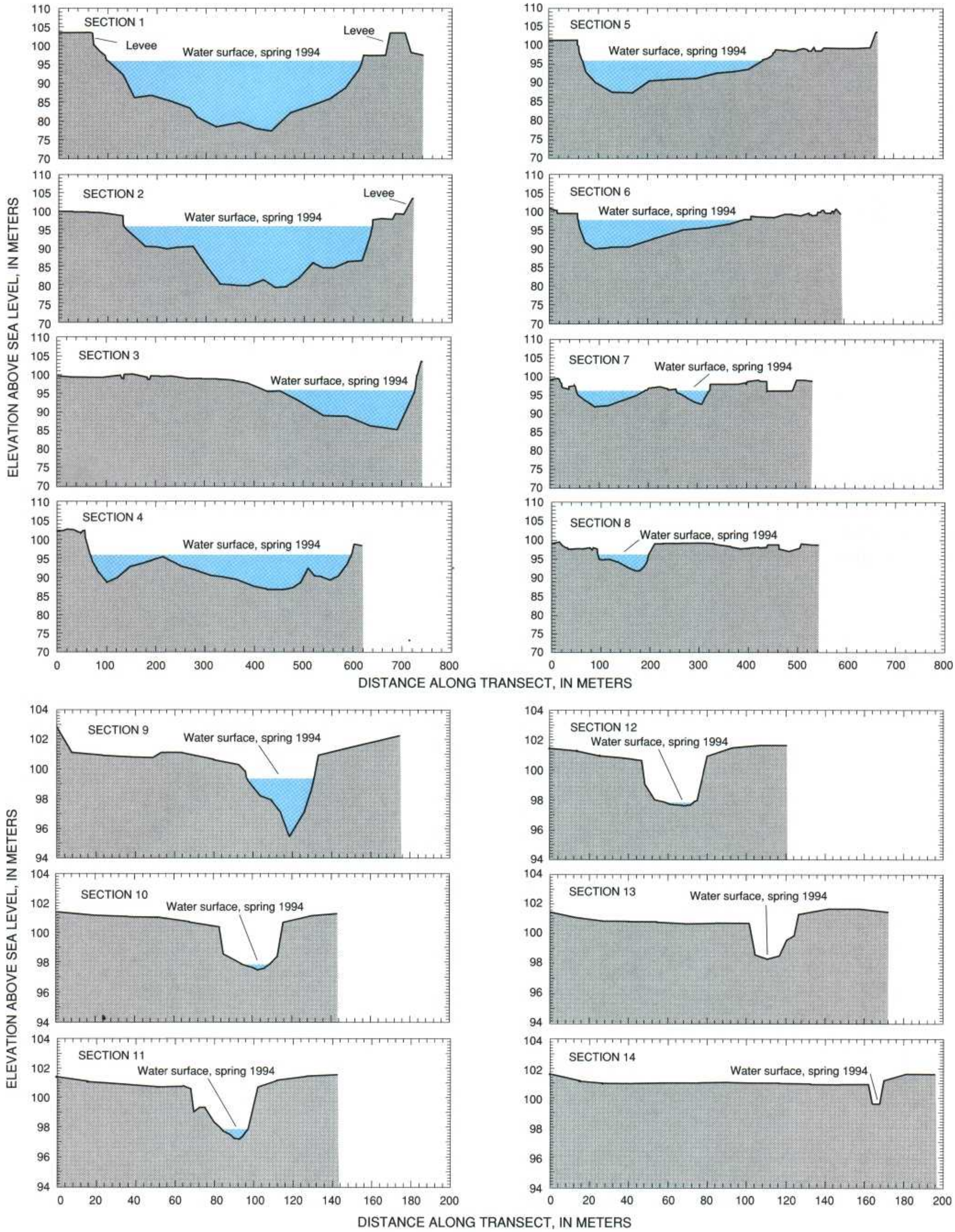

Figure 16. Cross sections in the main and secondary scours, Miller City, Illinois, levee-break complex.

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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