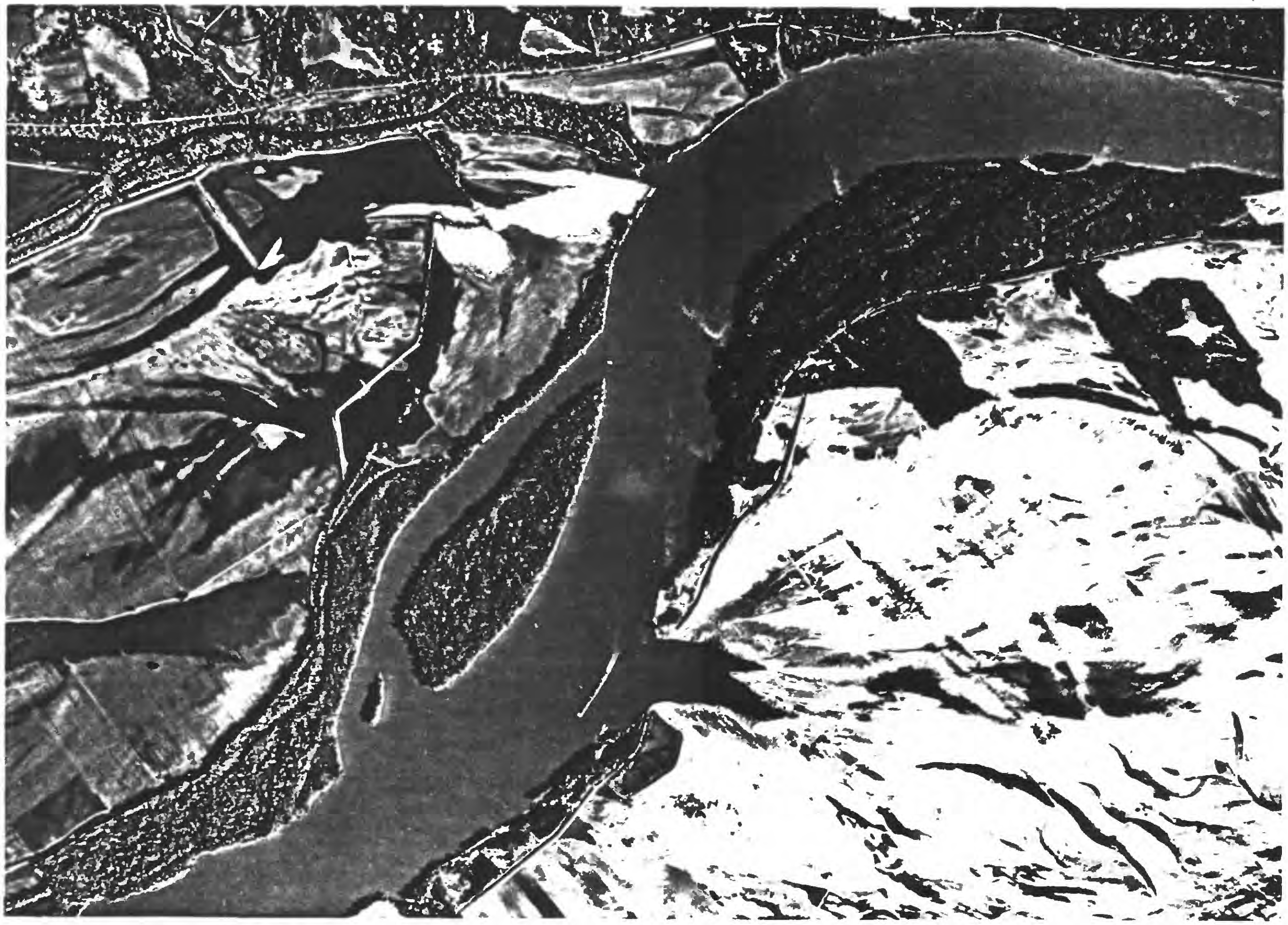
Scour, Sedimentation, and Sediment Characteristics at Six Levee-Break Sites in Missouri from the 1993 Missouri River Flood

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 97–4110



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U.S. GEOLOGICAL SURVEY

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SCOUR AND SEDIMENTATION CAUSED FROM 1993 LEVEE-BREAK SITES ARE DETERMINED

How much of the floodplain was scoured and how much sand and mud were deposited on the Missouri River floodplain from a levee break during the 1993 flood? Those are two of the questions answered in a report released by the U.S. Geological Survey (USGS), U.S. Department of the Interior, prepared in cooperation with the Missouri Department of Natural Resources. The report presents the findings of a study of six levee-break sites along the Missouri River.

Levee failures during the flood released large volumes of water that flowed through constricted openings and onto the floodplain. These flows caused extensive deep scours and deposition of massive amounts of sand and mud on the Missouri River floodplain. According to Gregg K. Schalk, principal author of the report, "The largest levee break in the study, which is 5.5 miles downstream from Hermann, Missouri, scoured the equivalent of 720 acres, 1 foot deep, of the floodplain. The scoured volume was only 15 percent of the total new deposits on the floodplain downstream from the levee break. This was an example where a levee break provided a passage for sediments from the river onto the floodplain. At this site the net mass of flood sediments was between 9.3 to 14.8 million tons, or 10 to 16 percent of the total sediment load transported by the Missouri River during the flood past Hermann. At a levee near Arrow Rock, Missouri, the scour volume was 190 percent of the total new sediment volumes. This was an example where a levee break provided a way for the water to erode more of the floodplain than new sediments deposited."

Also provided in the report are results of soil-chemistry and herbicide analyses of pre-flood soil and flood sediment at two of the levee-break sites. The report concludes that deposition in the levee breaks caused significant changes in particle size, nutrient availability, and organic carbon in the floodplain soils. Herbicide concentrations in the flood sediment were equal to or less than the pre-existing herbicide concentrations in the floodplain soil.

The report "Scour, Sedimentation, and Sediment Characteristics at Six Levee-Break Sites in Missouri from the 1993 Missouri River Flood," by Gregg K. Schalk and Robert B. Jacobson has been released as U.S. Geological Survey Water-Resources Investigations Report 97–4110. Copies are available for inspection at U.S. Geological Survey, 1400 Independence Road, MS 100, Rolla, Missouri 65401 and at most large libraries nationwide. The report may be purchased from the U.S. Geological Survey, Branch of Information Services, Box 25286, Denver, CO 80225-0286 (telephone number 303–202-4700). Orders must include check or money order payable to U.S. Department of the Interior—USGS and must specify report number WRIR 97–4110.

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Scour, Sedimentation, and Sediment Characteristics at Six Levee-Break Sites in Missouri from the 1993 Missouri River Flood

By Gregg K. Schalk *and* Robert B. Jacobson

ABSTRACT

Levee failure during the 1993 Missouri River flood caused discharges with large hydraulic heads to flow through constricted openings. These discharges produced deep, extensive scours and deposited large quantities of sediment on the Missouri River floodplain. Six representative sites were selected to study the effects of levee breaks on floodplain scour and sedimentation. Emphasis was placed on determining whether these sites were net sinks or sources for flood sediment and on documenting particle-size and soil-chemistry characteristics of the sediment. Four of the sites have scours that remain connected to the Missouri River during low flow, whereas two sites have unconnected scours.

Scour volumes ranged from 150 to 720 acre-feet at the connected-scour sites and were 94 acre-feet or less at the unconnected-scour sites. Scour volumes at depths below the pre-flood elevation of the floodplain ranged from 89 to 95 percent of the total scour volumes at the connected-scour sites and were 65 and 89 percent of the total scour volume at the unconnected-scour sites. The maximum scour depths ranged from 20 to 51 feet below the average pre-flood elevation of the floodplain.

The net sediment volumes (total sediment deposited during the 1993 flood minus the scour volume) ranged from -340 to +4,200 acre-feet at the connected-scour sites and were less than 20 acre-feet at the unconnected-scour sites. Deposits thicker than 1 foot consisted mostly of sand. The areas covered with 2 feet or more of sand ranged from 2.3 to 840 acres at the connected-scour sites and were less than 35 acres at the unconnected-scour sites. Sediment volume ranged from 26 to 680 percent of scour volume at the connected-scour sites and from 117 to 162 percent of scour volume at the unconnected-scour sites. Ratios of deposition to erosion at connected-scour sites indicate that some of the sites were net sources for sediment in transport by the flood, whereas others were net sinks. The ratios at the unconnected-scour sites indicate that the volume of sediment deposited downstream from the scours is nearly equal to the volume of the scours. However, flood-sediment deposits are coarser than much of the scoured sediment, so these estimates represent minimum total fluxes of sediment onto the floodplain.

The potential significance of connected-scour levee-break sites as sinks for transported flood sediment is exemplified by a site 5.5 river miles downstream from Hermann, Missouri. The net mass of flood sediments (7.7–12.6 million tons) deposited on the floodplain was estimated to be 10 to 16 percent of the total sediment load transported by the Missouri River past Hermann during the 1993 flood. In contrast, a connected-scour levee-break site near Arrow Rock, Missouri, had a sediment volume that was only 51 percent of the scour. The net loss of sediment from this site may be related to local flow hydraulics or increased sediment transport capacity of

the river because of extensive sedimentation in a levee-break complex immediately upstream from the site.

Pre-flood soil and flood-sediment samples were analyzed for particle-size characteristics, soil chemistry, and herbicide concentrations at two sites. Based on statistical testing, flood-sediment samples were significantly coarser than pre-flood soil samples and had lower cation exchange capacities, extractable acidities, extractable magnesium, extractable potassium, and organic carbon content. Flood-sediment samples had significantly higher extractable calcium and pH values. Flood-sediment samples also had less-negative differences between the sum of the extractable cations and the cation exchange capacity than pre-flood soils, indicating that the flood-sediment samples have more soluble cations readily available for uptake by plants or for leaching. Of the 15 different herbicides or their degradation products analyzed, atrazine had the highest median concentrations in pre-flood soils and flood-sediment samples; atrazine was detected in 23 of 24 pre-flood soil samples and in 23 of 24 flood-sediment samples. Median atrazine concentrations at the two sites were 2.3 and 4.4 micrograms per kilogram in the pre-flood soil samples and 1.4 and 2.3 micrograms per kilogram in the flood-sediment samples.

INTRODUCTION

Most levees along the Missouri River (fig. 1) that protected agricultural land in Missouri either failed or were overtopped during the flood of 1993 when peak discharges exceeded 100-year recurrence intervals (Parrett and others, 1993; Interagency Floodplain Management Review Committee, 1994). Failure of the levees caused discharges with large hydraulic heads to flow through constricted openings. These discharges produced deep, extensive scours and large quantities of sediment on the Missouri River floodplain. More than 500 scour holes were created from levee breaks between Kansas City and St. Louis, Missouri (Interagency Floodplain Management Review Committee, 1994). Between Glasgow and St. Charles, Missouri, 30 percent of the local floodplain were damaged by scour and sedimentation processes (Interagency Floodplain Management Review Committee, 1994). The total suspended sediment load transported measured at the sediment stations at the Mississippi River below Grafton, Illinois, and at the Missouri River at Hermann, Missouri, was 24 million tons greater than the total suspended sediment load transported below the junction of these rivers at St. Louis (Holmes, 1996). Sedimentation on the floodplain downstream from Hermann was assumed to account for most of this "lost" sediment.

A typical levee-break complex consists of a scour at or near the site of the levee break, a stripped zone in which several inches to a foot of topsoil was eroded, and a depositional zone characterized by inches to tens of feet of clay, silt, and sand deposits (fig. 2). The scours, also called blew holes and scour holes, refer to the deep erosion created near a levee break (fig. 3). Exit scours also commonly occurred at the downstream ends of leveed parts of the floodplain.

Knowledge of erosion and sedimentation processes on the floodplain during large floods and characteristics of flood-transported sediments are important for the design of river-control structures, for flood-hazard mitigation policies, and for floodplain-management decisions. The U.S. Geological Survey (USGS), in cooperation with the Missouri Department of Natural Resources, studied selected levee-break complexes (hereinafter referred to as levee-break sites) along the Missouri River floodplain to investigate scour and sedimentation processes. The information gathered in this study is intended for use in evaluating the role of levee-break complexes in sediment routing along the Missouri River and in documenting changes in the floodplain that are possible in levee-break complexes.

The major objectives of the study were to:

- Document and describe the scour and sedimentation characteristics associated with the levee breaks; and
- Evaluate the effects of levee-break complexes on soil characteristics and land-use resources on the Missouri River floodplain.

Secondary objectives were to evaluate flow hydraulics at typical levee-break complexes and to investigate the role of levee-break complexes in sediment routing.

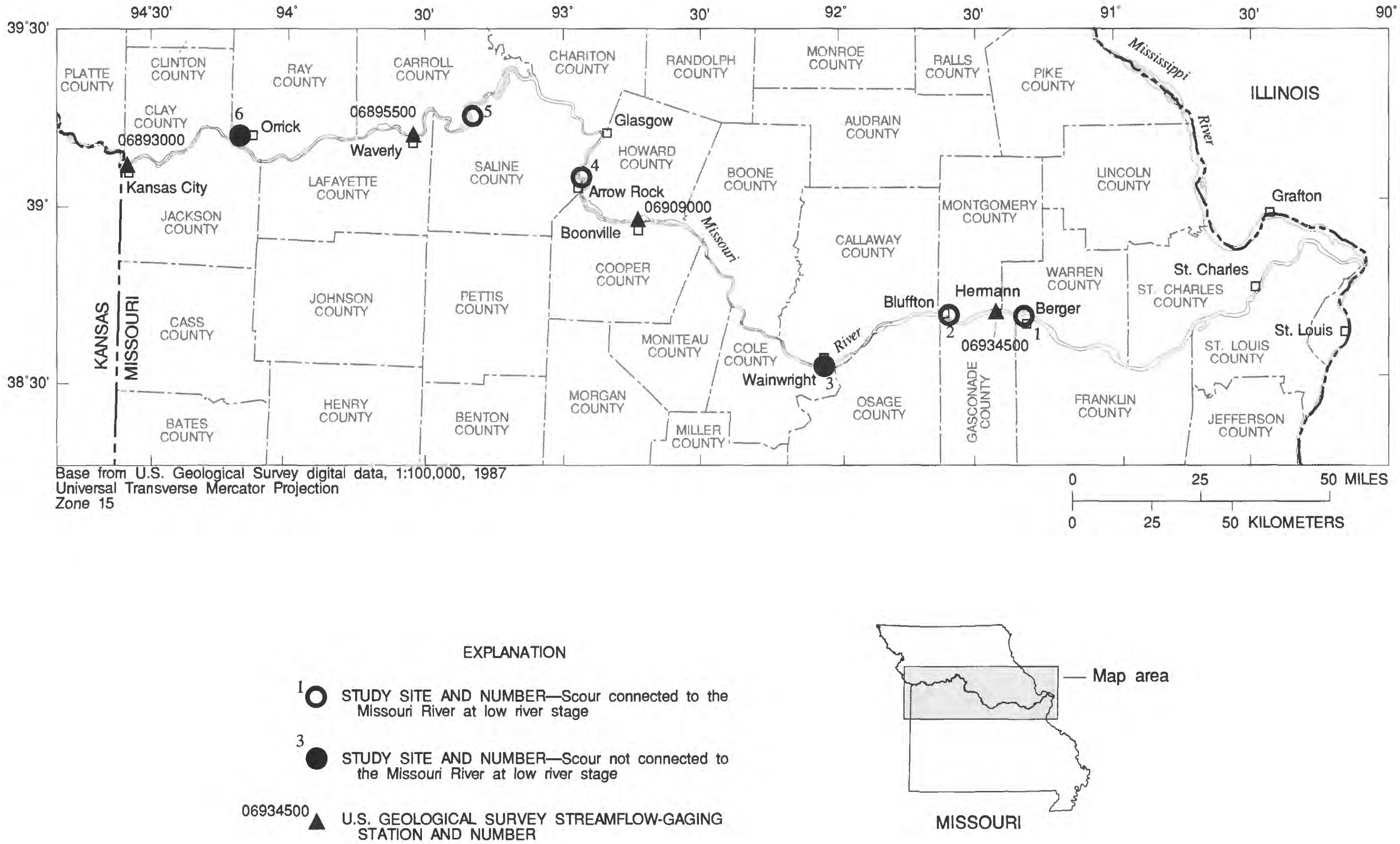


Figure 1. Location of levee-break study sites in the Missouri River floodplain.

Purpose and Scope

This report presents the scour and sedimentation effects at six levee-break sites in the Missouri River floodplain. The six levee-break sites were selected as representative of breaks along the Missouri River. The sites extend from Missouri River mile 92.5 near Berger, Missouri, to Missouri River mile 338.0 near Orrick, Missouri (fig. 1). Four of the sites have scours that remain connected to the Missouri River during low flow, whereas two sites have scours that do not remain connected. A study site includes the levee break and the area of resulting scour and sedimentation at the site. In this report, flood sediments refer to the sediments that were transported and deposited on the floodplain by the 1993 flood.

The scour characteristics described include morphology, depth, and volume; sedimentation features described include morphology, thickness, and volume. The particle-size distribution, chemistry, and herbicide concentrations of flood sediments were determined and compared to those of the pre-flood soil. Also, for one study site, pre-existing sediment characteristics and the extent to which sedimentology and stratigraphy of pre-flood soil affected scour morphology were evaluated based on three core samples. In this report, the term soil refers to pedogenically altered sediments. Post-flood sediments are considered to have no pedogenic alteration; hence they are referred to as sediments. Pre-flood materials consist of sediments (at depths where they have not been pedogenically altered) and soil [within approximately 2 ft (feet) from the surface where pedogenesis is evident].

Geomorphological Setting of Levee-Break Sites

The valley of the Missouri River is cut into nearly flat-lying bedrock composed of dolomite, limestone, shale, and some sandstone (Missouri Division of Geology and Land Survey, 1979). The bedrock is a critical control on valley and channel morphology. Upstream from Glasgow, the river flows in a wide, open valley cut into sedimentary rocks dominated by interbedded shale and limestone of Pennsylvanian and Mississippian age. In this section, the valley is 5 to 10 mi (miles) wide, and the river meanders in broad, sinuous curves. Downstream from Glasgow, the valley is cut into sedimentary rocks dominated by limestone and dolostone of Mississippian and Ordovician age. Here, the valley narrows to 1.5 to 2.5 mi wide, and the river flows in short-wavelength meanders from bluff to bluff. In this constricted part of the Missouri River valley, floodplains[1] have been classified as loop bottoms (a relatively small bottom in which the width and length of the floodplain are about equal) and long bottoms (a relatively large bottom in which the width of the floodplain is much narrower than the length) (Schmudde, 1963). Levee-break complexes were more numerous in this part of the valley as compared to the upstream segment because floodwaters were concentrated in the narrower valley (Interagency Floodplain Management Review Committee, 1994).

Deep and extensive scours and thick sand deposits created by the 1993 flood contrasted dramatically with pre-flood morphology and sedimentology. The present-day (1996) morphology of the Missouri River valley was created from a sequence of events, including aggradation of Pleistocene glacial outwash gravel, migration of braided and meandering channels during the Holocene, and engineered channel-stabilization activities after the 1930's. Pleistocene glacial outwash gravel underlies much of the river valley to depths of 60 to more than 100 ft (Interagency Floodplain Management Review Committee, 1994). Post-glacial meandering and braiding of the Missouri River channel resulted in deposition of a fining-upward sedimentary sequence over and inset against cut-and-fill terraces. The alluvium consists of sand and gravel [bottom stratum, following the usage of Brakenridge (1988)] overlain by 6 to 15 ft of interbedded sand, silt, and clay [top stratum (Brakenridge, 1988)]. Within the top stratum, floods were recorded in discrete sandy units in backswamp deposits, natural levee deposits, and crevasse-splay deposits (Schmudde, 1963). The total thickness of post-glacial alluvium has been estimated at 35 to 45 ft (Interagency Floodplain Management Review Committee, 1994).

In the wide-valley segment upstream from Glasgow, the floodplain consists of a channel meander belt flanked by terraces that rise 3 to 30 ft above it. The terraces occupy more than 50 percent of the valley area (Interagency Floodplain Management Review Committee, 1994). The floodplain has a typical ridge and

[1] The floodplain is the constructional surface created by deposition by the river under its current hydrologic regime. Before river regulation and levee construction, the floodplain was subject to inundation every 1 to 2 years on average. The term floodplain is equivalent to "active high-energy floodplain" of the Interagency Floodplain Management Review Committee (1994).

swale topography that resulted from channel migration and avulsion. In the narrow-valley segment downstream from Glasgow, terraces are less common, and the floodplain occupies 35 to 75 percent of the valley bottom. Before levee construction, margins of the floodplain were occupied by sandy, natural levee deposits; away from the main channel, overflow channels formed sloughs in the floodplain surface (Schmudde, 1963).

The natural features of the Missouri River channel and adjacent floodplain have been progressively altered since the mid-1800's to improve navigation (Hesse and Sheets, 1993). These changes included snagging beginning as early as 1838, reservoir construction beginning in 1909, and channelization beginning in 1912. Closure of mainstem Missouri River dams in 1967 allowed regulation of the water level to minimize floods and prolong the navigation season. Agricultural levees have been built to protect farmland since the mid-1800's and now exist on both banks nearly the entire length of the Missouri River from St. Louis to Kansas City. Typically, these agricultural levees are designed for protection against 5- to 10-year floods. As a result of these alterations, the Missouri River changed from a shallow, dynamic, braided channel to a deeper, more sinuous and stable channel (Hesse and Sheets, 1993; Latka and others, 1993).

The average river slope from site 6 to site 1 is 0.8 ft/mi (foot per mile). River slopes vary locally and range from 0.74 ft/mi near sites 4 and 5 to 1.9 ft/mi immediately downstream from site 1.

Acknowledgment

The authors thank Dr. David Hammer, University of Missouri–Columbia, for reviewing the soil chemistry section of this report.

METHODS FOR DATA COLLECTION AND COMPUTATION

Six levee-break sites were chosen along the Missouri River floodplain from near Berger, Missouri, to near Orrick, Missouri (fig. 1). These sites were selected to document the range of conditions at levee-break complexes along the Missouri River between Kansas City and St. Louis. Additionally, these sites had only minor flood-damage mitigation efforts after the flood and before onsite work was completed.

Scour and sedimentation effects were documented at each site from transects surveyed across the main scour and sediment deposits and with supplementary information from U.S. Army Corps of Engineers (USACE) topographic maps and aerial photographs and USGS topographic maps. Wooded areas, levees, extent of inundation, and additional scours were mapped from aerial photographs. The road network, the Missouri River channel, hydrography, and railroads were mapped from USGS and USACE maps. Flood and pre-flood sediments were sampled for analysis of particle-size distribution, soil chemistry, and herbicide concentrations.

Scour and Sedimentation Features

The depth and aerial extent of scour at each site were determined through transect surveys of the scour. Transects were surveyed using a total-station surveying instrument and a boat-mounted Fathometer to measure depths greater than 8 ft below the water surface. Pre-flood surface elevations were determined at the edge of the scour perimeter. If pre-flood surfaces could not be determined at the main scour perimeter, unpublished USACE 2-ft-contour-interval topographic maps also were used to estimate pre-flood land-surface elevations.

Surveyed transects of topography over flood deposits and excavations through the flood deposits were used to document the thickness and properties of flood sediments. Transects at sites 2, 3, 5, and 6 were surveyed using a total-station surveying instrument. At these sites, location points and deposit depths were recorded at distance intervals of 5 to 300 m (meters) depending on variations in deposit topography. Locations and points of sediment thickness data were located at sites 1 and 4 and 40 percent of the area at site 5 using a hand-held global positioning system (GPS) because of the large size of the survey areas and ongoing agricultural activity that impeded total-station surveying. These points were located at distance intervals of 80 to 300 m; points located with this GPS technique have planform positional accuracies of ± (plus or minus) 15 m; however, sediment thickness was determined with the same accuracy as in the total-station survey, approximately ±0.1 ft. Sediment observations of all points were verified by comparison with USACE post-flood aerial photography.

The pre- and post-flood surfaces were mapped using a triangulated irregular network (TIN) computer technique with surveyed transects and pre-flood elevations from USACE unpublished topographic maps. The scour and sediment volumes were calculated from the difference between the pre- and post-flood TIN surfaces. Elevation contours of the scour and thickness isopachs of the sediments deposited on the floodplain also were created from the TIN surface models. Scour and sediment masses were calculated by multiplying sediment and scour volumes by bulk densities of 85 and 138 lb/ft^3 (pounds per cubic foot). This range of bulk densities was used to include the various types of sediment.

Additional deposition and scour may have occurred during minor floods in September 1993 at all sites and in April 1994 at sites 1 and 2 (fig. 4). The scour at site 2 was surveyed before the April 1994 flood, but the sedimentation was surveyed after the April 1994 flood. The peak stage measured on the Missouri River at Hermann in April 1994 was 5.55 ft less than the 1993 flood peak. Both scour and sedimentation were surveyed at site 1 after the April 1994 flood. Consequently, these data describe the cumulative flood effects. However, the July 1993 flood is thought to have caused the most scour and sedimentation as indicated by aerial photographs, onsite visits, and eyewitness accounts.

Sample Collection and Analytical Procedures

Samples of pre-flood soil and flood sediments were collected at each site for particle-size analyses. At sites 4 and 5, subsets of the samples were analyzed for soil chemistry and herbicide concentrations. Flood sediments were differentiated from pre-flood soil by excavating a hole with a shovel and examining the stratigraphy of the sediment layers. Pre-flood soils were identified based on presence of pedogenic alteration or lack of primary sedimentary structures. Samples for particle-size analyses and soil chemistry were collected in a clean plastic bag and sealed. Samples for herbicide analysis were collected using a clean wooden spoon and latex gloves in 500-mL (milliliter) wide-mouth glass bottles that had been baked at 450 °C (degrees Celsius) and sealed with Teflon-lined lids. Sediment samples collected for herbicide analyses were chilled to 4 °C immediately after sample collection. To minimize cross-contamination between sample locations and pre-flood soil and flood sediments, both gloves and spoons were disposed of after each sample collection.

Core samples were collected using a drill rig at three locations at site 5. Samples were collected with a split spoon sampler in the interval 10 to 15 ft below the ground surface, and samples were collected off drill augers to depths of 40 ft in intervals of non-cohesive sediment.

The University of Missouri Soil Characterization Laboratory in Columbia analyzed the samples using methods described by the Soil Survey Laboratory (1992) for particle-size distribution, inorganic soil chemistry, and soil organic carbon. Particle-size distributions were obtained from a combination of sieve and pipet analysis and reported using conventional U.S. Department of Agriculture particle-size classes.

Soil chemistry analyses included pH, cation exchange capacity (CEC; reported as milliequivalents per 100 grams), extractable base cations [calcium, magnesium, sodium, potassium; reporting limit of 0.1 meq/100 g (milliequivalents per 100 grams)], extractable acidity (reporting limit of 0.1 meq/100 g), and percent organic carbon (reporting limit of 0.1 percent). Soil pH was determined from a water/soil suspension with an equal volume of 0.01 mole calcium chloride and measured with an electronic meter. The CEC was determined using ammonia acetate with ammonium as the replacing cation at a pH adjusted to 7.0. The quantity of ammonia acetate, determined by hydrochloric acid titration, used to displace the cations was considered to be the CEC. The extractable bases were extracted with ammonia acetate, buffered at pH 7.0, and measured by atomic absorption spectrophotometer. To determine extractable acidity, a soil sample was leached using a mechanical vacuum extractor and a barium chloride-triethanolamine solution buffered at a pH of 8.2. The difference between a blank and the extract was the extractable acidity. Organic carbon was determined from the release of carbon dioxide after combustion. The carbon dioxide gas was measured using an infrared detector in a carbon analyzer.

Samples for herbicides were analyzed at the USGS laboratory in Lawrence, Kansas, for acetochlor, alachlor, ametryn, atrazine, cyanazine, cyanazine amide (cyanazine metabolite), deethylatrazine and deisopropylatrazine (atrazine metabolites), metolachlor, metribuzin, prometon, prometryn, propazine, simazine, and terbutryn. The herbicides and metabolites were extracted from the soils with methanol. The solvent mixture was then extracted onto disposable C-18 solid-phase extraction cartridges followed by gas chromatography/mass spectrometry analysis (Thurman and others,

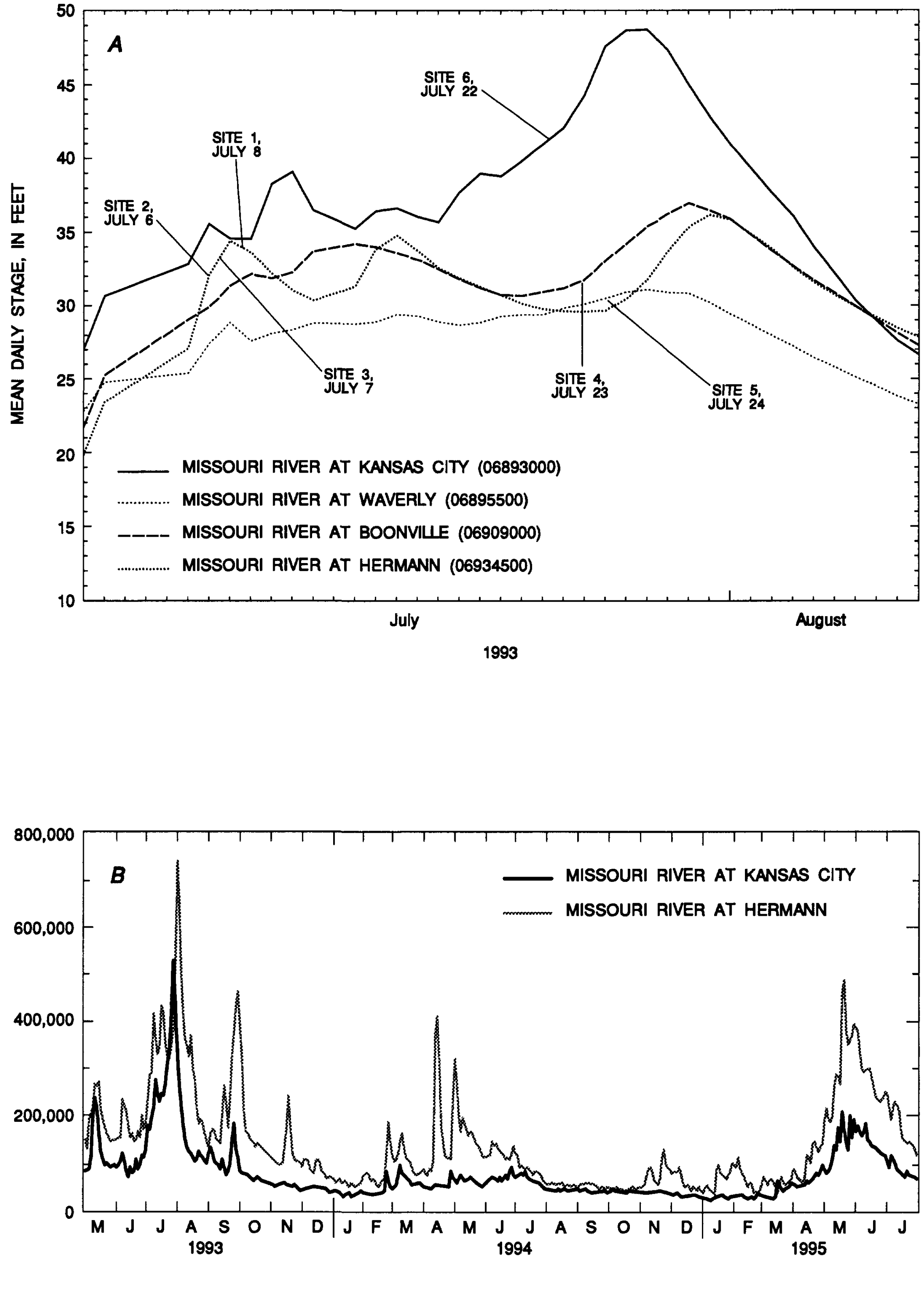


Figure 4. (*A*) Levee-break dates and associated stage at the nearest Missouri River gaging station; (*B*) 1993 flood and post-flood hydrographs, May 1993 through July 1995.

1990; Mills and Thurman, 1992; Meyer and others, 1993). The analytical reporting limit for these herbicides and metabolites was 0.2 μg/kg (microgram per kilogram).

Quality control measures for this study included onsite replicate sample sets to assess the precision of sample collection and duplicate sample sets to assess the precision of laboratory procedures (table 1). Replicates were collected at the same location onsite. Duplicates were created from a single sample by splitting at the laboratory. For nine replicate sample sets collected for particle-size analysis, seven sample sets had less than a 6 percent difference between the median particle sizes. All sample sets had less than a 30 percent difference between the median particle sizes. The replicate set for herbicide analyses had a 12 μg/kg difference in the atrazine concentration and an average difference of 0.3 μg/kg for three other herbicides detected in the sample set.

Two standard reference soil samples were analyzed for every set (20 samples) of soil samples at the University of Missouri Soil Characterization Laboratory. The results of the reference samples were compared with the mean and standard deviation computed for the standard reference soil samples with known particle-size distribution and soil chemistry. If a large deviation occurred in the laboratory quality control procedures, the sample was reanalyzed. The USGS laboratory quality control procedures included an analysis of a standard reference sample for every 20 samples, 2 to 3 standards for calibrating the gas chromatography/mass spectrometry, and 2 reagent blanks analyzed immediately after the calibration standards.

SCOUR AND SEDIMENTATION FEATURES AT LEVEE-BREAK SITES

This section describes the scour and sedimentation features resulting from levee breaks at six selected sites, flood history, description of the levee break, and general site characteristics. Information about the levee breaks and flood-peak elevations is presented in table 2. The difference between the average floodplain elevation and the top of the levee was considered to be the minimum difference between the floodplain and the water-surface elevation. This elevation criterion will be used for the sites where the floodplain was not inundated before the levee break.

New sediments were likely deposited in scours that were connected to the Missouri River channel at low flow during the recession of the 1993 flood and during subsequent high flows during 1994 and 1995 that affected sites 1, 2, 4, and 5. Also, sediments may have been added to the floodplain during these floods. Therefore, volumes and masses calculated in tables 3 and 4 estimate the net scour and sedimentation from the time of the levee break to the time of the survey.

Site 1

The levee break at site 1 (figs. 1, 5) is located in Franklin County in the floodplain locally known as the Berger Bottoms. This is a long bottom (Schmudde, 1963) that extends from bluff to bluff across the river and for more than 6 mi downstream from the levee break. Maps of the 1879 Missouri River channel (Scientific Assessment and Strategy Team, 1994) indicate that the pre-regulation channel had multiple mid-channel islands upstream and near the downstream end of Berger Bottoms.

An eyewitness account from a local resident specified that the levee (fig. 5) failed by overtopping on July 8, 1993, near the first peak of the flood (fig. 4). The levee broke after the floodplain had backfilled with floodwater from breaks in the same levee downstream from the main break on July 6 and 7. By eyewitness account, the water elevation in the floodplain was approximately 5 ft below the water elevation in the main river channel before failure. This estimate corresponds to approximately 6 to 7 ft of backflooded water. Once the levee was overtopped, it was quickly breached. The main levee break occurred at the upstream end of Berger Bottoms where the distance from the levee to the main channel was at a minimum (fig. 5). The maximum measured scour depth of 46 ft (table 3) occurred on the upstream side of the scour between the channel and the levee center line. The perimeter of the scour (fig. 6) was characterized by nearly vertical scarps in cohesive sediment. The scarps decreased in height from the channel to the interior of the floodplain. Some sediment accumulated in the scour during recession of the 1993 flood and subsequent high flows that occurred before the scour was surveyed. Cohesionless sand was deposited 1 to 3 ft thick in the downvalley end of the scour; the thickness in the upvalley end of the scour was unknown. Because of post-1993 flood sedimentation, the measured scour volume is a net or minimum estimate. The estimated scour volume was 720 acre-ft (acre-feet) with an area of 41.7 acres. Twenty-five percent of the

Table 1. Soil-chemistry and herbicide differences in the replicate and duplicate sample sets

[n, number of samples; CEC, cation exchange capacity; meq/100 g, milliequivalents per 100 grams; sum of bases, ammonia acetate extractable bases (calcium, magnesium, sodium, and potassium); ND, constituent not detected in either sample]

Property or constituent	Range of differences between samples: Replicate	Duplicate
pH (standard units)	0–0.1, n = 5	0 and 0.1, n = 2
CEC (meq/100 g)	0.1–0.4, n = 5	0.1, n = 2
Sum of bases (meq/100 g)	0–155, n = 5	55 and 88, n = 2
Extractable acidity (meq/100 g)	0.3–0.8, n = 5	0 and 0.5, n = 2
Organic carbon (percent by weight)	0–0.1, n = 5	0 and 0.1, n = 2
Herbicides (micrograms per kilogram), n = 4		
Acetochlor	ND	ND
Alachlor	ND–0.8	0.3–1.0
Ametryn	ND–0.3	ND
Atrazine	ND–12	0–2.1
Cyanazine	ND	ND–1.5
Cyanazine amide	ND	ND
Deethylatrazine	ND–0.1	ND–0.5
Deisopropylatrazine	ND	ND
Metolachlor	ND–0.3	0–1.7
Metribuzin	ND	ND
Prometon	ND	ND
Prometryn	ND	ND
Propazine	ND	ND
Simazine	ND	ND
Terbutryn	ND	ND

Table 2. Site information and estimated flood-peak elevations in the vicinity of the levee-break sites

[ft, feet; --, not determined]

Site number (fig. 1)	River mile at levee break	Minimum distance from levee center line to main channel at the levee break (ft)	Average floodplain elevation (ft above sea level)	Elevation difference from floodplain to the top of levee (ft)	Estimated flood-peak elevation near levee break (ft above sea level)
1	92.5	250	501	12.8	--
2	108.5	690	514	10.9	527.0
3	136.8	[a]5,800	536	10.0	552.7
4	214.7	110	604	5.5	615.0
5	272.3	180	651	9.3	658.8
6	338.0	7,920	705	10.8	722.3

[a]The levee center line extends perpendicular to the Missouri River.

Table 3. Morphologic characteristics, net volume, and estimated mass of the scour at levee-break sites

[ft, feet; acre-ft, acre-feet; NC, scour not connected to the Missouri River at low flow; lb/ft^3, avoirdupois pounds per cubic foot]

Site number (fig. 1)	Width at levee center line (ft)	Width at river (ft)	Maximum length (ft)	Perimeter (ft)	Area (acres)	Maximum measured depth (ft)[a]
1	1,200	1,500	2,390	8,240	41.7	46
2	350	100	2,120	6,870	17.9	46
3	[b]430, [c]350	NC	1,240	4,520	9.7	37
4	1,270	750	3,180	10,800	59.3	51
5	950	840	990	3,660	16.6	32
6	325	NC	535	1,840	3.1	20

Site number (fig. 1)	Volume (acre-ft)	Estimated mass (million tons)		Range of scour yield (tons per acre)
		Using bulk density of 85 lb/ft^3	Using bulk density of 138 lb/ft^3	
1	720	1.33	2.16	31,900–51,800
2	150	.28	.45	15,600–25,100
3	94	.17	.28	17,500–28,900
4	700	1.30	2.10	21,900–35,400
5	310	.57	.93	34,300–56,000
6	27	.050	.081	16,100–26,100

[a]Measured from the average floodplain elevation listed in table 1.
[b]Measured at the west levee center line (fig. 12).
[c]Measured at the east levee center line (fig. 12).

scour volume originated at depths greater than 15 ft below the average floodplain elevation, 50 percent originated greater than 9 ft below, and 75 percent originated greater than 4 ft below (fig. 7).

The total volume of flood sediments was 4,900 acre-ft covering 7,000 acres. Twenty-five percent of the sediment volume was deposited between 1.6 and 7.7 ft (maximum measured thickness) deep, and 75 percent was deposited greater than 0.3 ft deep (fig. 8). The average thickness (50 percent of the sediment by volume deposited at this depth or greater) was 0.7 ft. Fifty percent of the sedimentation area was covered by sediments at least 0.3 ft thick (fig. 8). The sedimentation area was considered the floodplain area covered by flood sediments and is illustrated in figure 5. The scour volume was 15 percent of the sediment volume (table 4).

Of the 28 flood-sediment samples collected (fig. 5), the median particle-size diameter ranged from 0.011 to 0.593 mm (millimeter); however, 95 percent of the median particle-size diameters were less than 0.20 mm. The thicker areas of the deposit were sand-size particles, and the farthest downvalley sample (sample 27) had the smallest median particle-size diameter. The sample with the largest median particle-size diameter (sample 3) was located near the scour.

Site 2

The levee at site 2 (fig. 9) broke on the upstream side of a loop bottom in Montgomery County, Missouri (fig. 1). The break occurred on the rising limb of the first flood peak on June 2, 1993 (fig. 4), when the stage was at least 10.9 ft above the floodplain (table 2).

Table 4. Morphologic characteristics, net volume, and estimated mass of sedimentation at levee-break sites

[ft, feet; acre-ft, acre-feet; lb/ft^3, avoirdupois pounds per cubic foot]

Site number (fig. 1)	Length (ft)	Perimeter (ft)	Area (acres)	Maximum measured thickness (ft)	Average thickness (ft)	Volume (acre-ft)	Scour/ sediment volume percentage	Net volume (acre-ft)[a]
1	39,700	110,00	7,000	7.7	0.7	4,900	15	4,200
2	2,870	14,300	57	4.1	.7	40	390	-110
3	3,890	14,800	210	4.0	.5	110	87	14
4	10,800	36,500	550	4.0	.6	360	190	-340
5	15,800	49,500	2,300	6.2	.3	850	36	500
6	2,600	7,900	70	5.0	.6	44	61	17

	Estimated mass (million tons)				Net mass (million tons)[a]	
Site number (fig. 1)	Using bulk density of 85 lb/ft^3	Using bulk density of 138 lb/ft^3	Sediment yield range (tons per acre)	Scour/ sediment mass percent range	Using bulk density of 85 lb/ft^3	Using bulk density of 138 lb/ft^3
1	9.07	14.8	1,300–2,110	9–23	7.7	12.6
2	.074	.12	1,300–2,120	240–620	-.22	-.34
3	.20	.32	980–1,550	53–139	.031	.04
4	.66	1.08	1,200–1,960	119–318	-.63	-1.0
5	1.57	2.55	680–1,100	22–59	1.00	1.6
6	.081	.13	1,200–1,860	38–100	.031	.049

[a]Sedimentation volume minus scour volume.

Before the break, the floodplain at site 2 was not flooded.

The levee was constructed across a slough that was part of the Missouri River channel during 1879 (fig. 9). Unpublished USACE contour maps indicate the base of the slough was approximately 6 ft below the average floodplain elevation. The distribution of sediments may have been controlled in part by the slough because the slough evidently controlled the direction of flow once the levee had broken.

The scour at site 2 is unique among the scours surveyed because two distinct, connected scours developed (fig. 10). One scour (A, fig. 10) formed in the zone between the levee and the channel. Before the flood, this zone was a wooded riparian corridor. Scour A had a maximum depth of 30 ft below the floodplain near the center line of the natural levee and a maximum width of 390 ft. Tree tops were evident at the eventual site of this scour in aerial photography taken near the peak of the flood on August 2, 1993. This observation indicates that scour A was altered substantially by flows after the flood peak.

The second distinct scour (B, fig. 10) extends from near the channel side of the levee base approximately 1,550 ft into the floodplain. At the levee center line it is approximately 350 ft wide. The maximum measured depth, 46 ft below the average floodplain elevation (table 3), occurred near the levee center line. The total volume of the two scours was 150 acre-ft, covering 17.9 acres, and the mass of sediment removed was estimated to be between 0.28 and 0.45 million tons. Twenty-five percent of the scour volume originated at depths greater than 15 ft below the average floodplain elevation, 50 percent of the scour volume originated greater than 7 ft below, and 75 percent originated greater than 2 ft below (fig. 7). Fresh

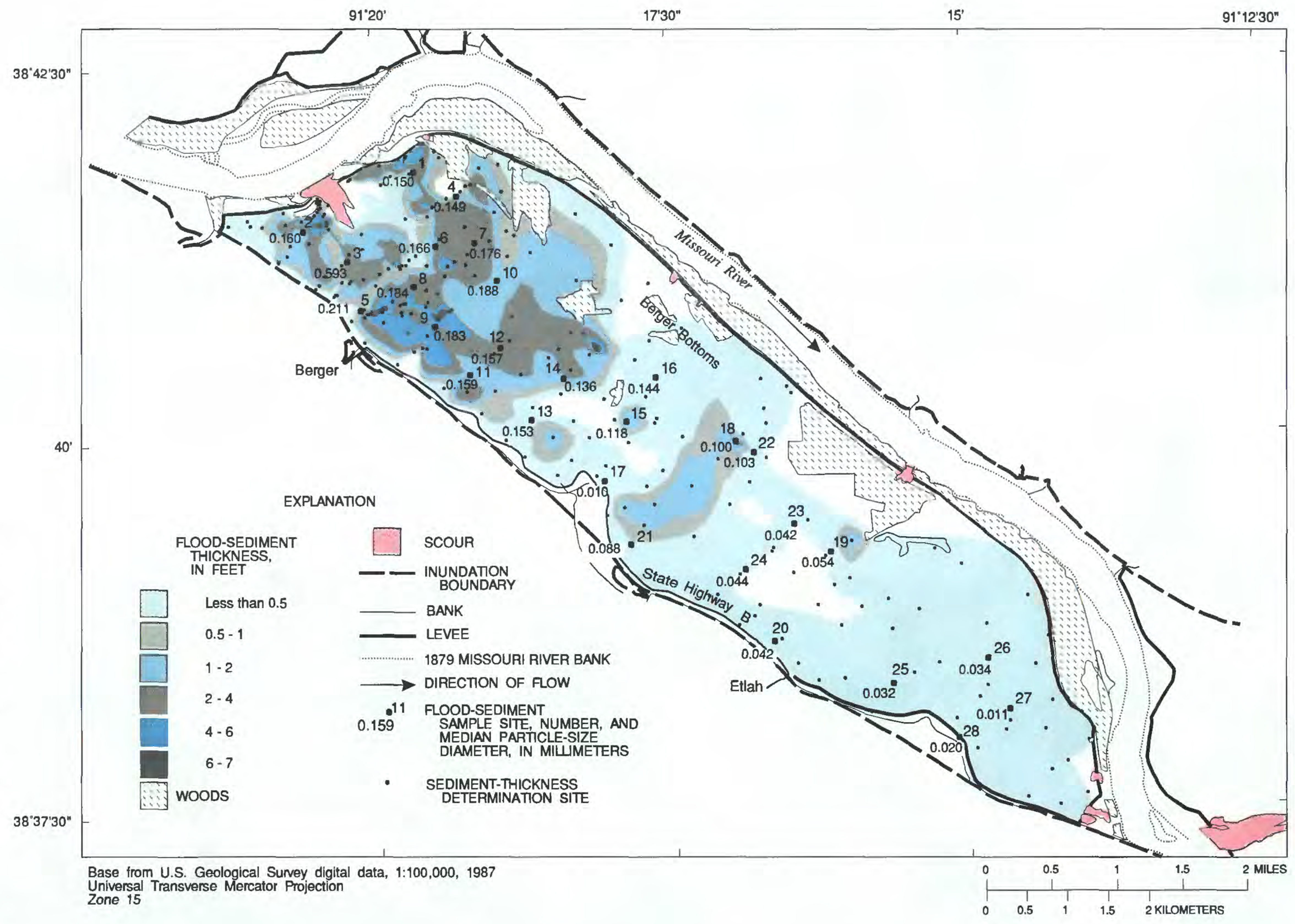


Figure 5. Scour and sedimentation resulting from the levee break in the Missouri River floodplain at site 1 at Berger, Missouri.

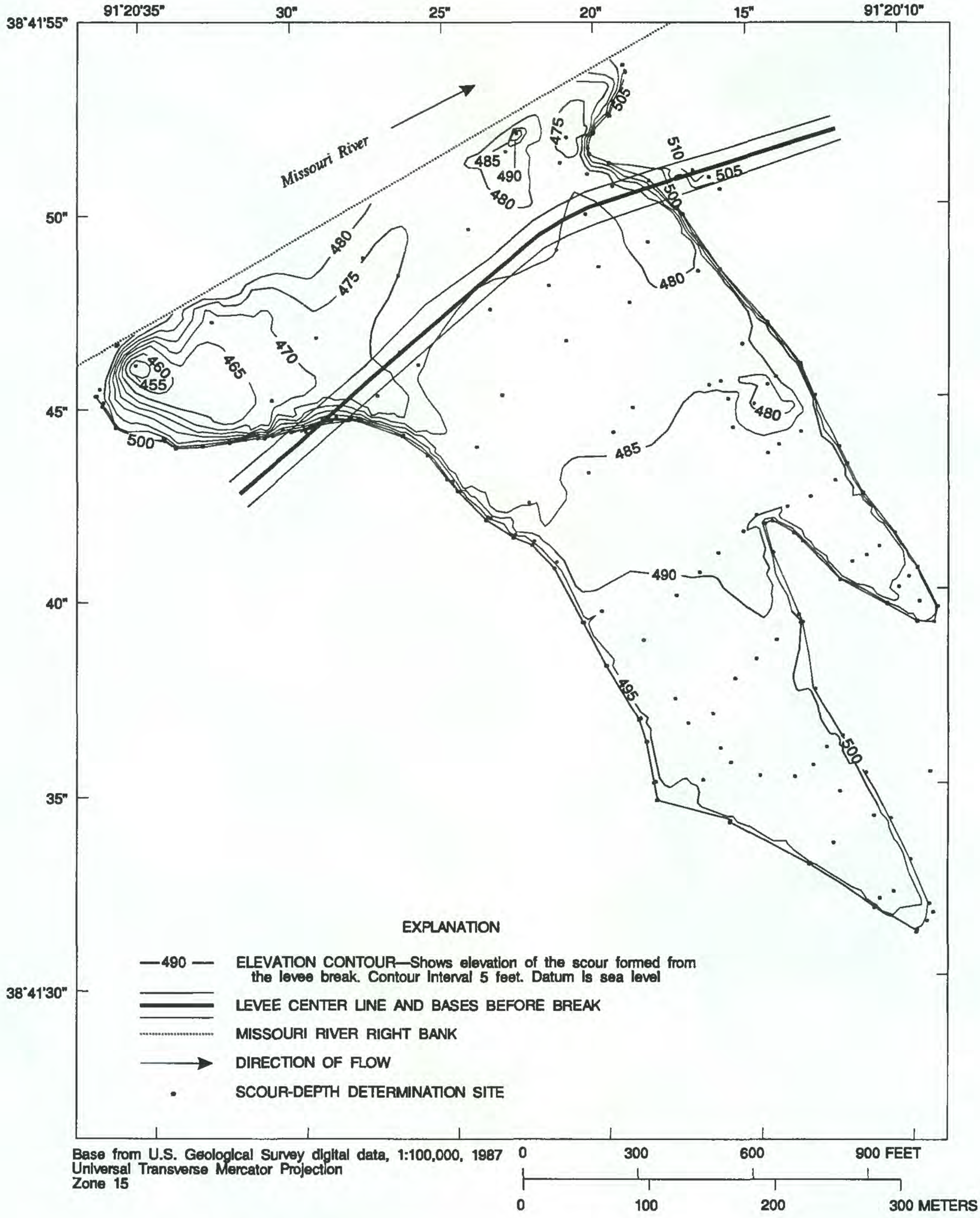


Figure 6. Elevation contours of the scour resulting from a levee break in the Missouri River floodplain at site 1 at Berger, Missouri.

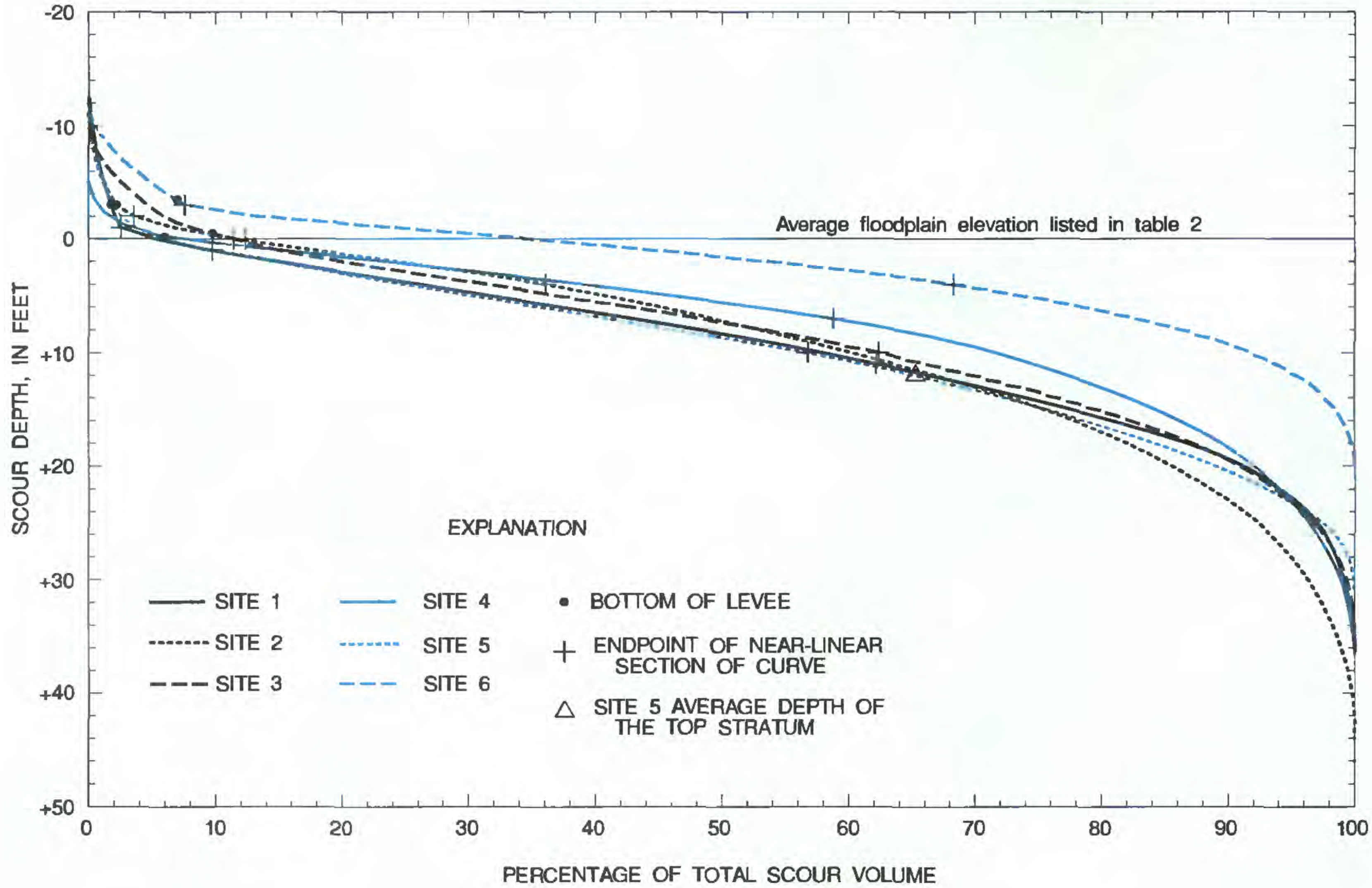


Figure 7. Depth-volume curves of scours at levee-break sites.

slumping of the steep sides of the scour was observed after the April 1994 flood; hence, the scour (surveyed in the spring of 1994) probably was altered by previous flooding during September 1993.

The areal boundary of sedimentation surveyed at site 2 was arbitrary because of mixing of sediment from other levee breaks in the areas upstream and downstream. The boundaries were determined by sediment patterns that indicated the main levee break was the only possible source of the sediment. This boundary results in a minimum volume estimate because concentration of flow in the slough and the narrow area between the levee and the valley wall (fig. 9) apparently resulted in high velocities and extensive downvalley sediment transport. Sedimentation patterns indicate that some sediment from the main levee break and other levee breaks accumulated in a tree line approximately 8,700 ft downstream from the main break. Sediment thicknesses of as much as 4 ft were observed in the tree line.

The total volume of flood sediments deposited was 40 acre-ft, covering 57 acres (table 4). Twenty-five percent of the sediment volume was deposited between 0.8 to 4.1 ft (maximum measured thickness) deep, and 75 percent was deposited greater than 0.2 ft deep (fig. 8). The average thickness was 0.5 ft. Fifty percent of the sedimentation area was covered by sediments at least 0.6 ft thick (fig. 8). The scour volume was 390 percent of the sediment volume (table 4).

Of 12 flood-sediment samples, the median particle-size diameter ranged from 0.015 to 1.007 mm (fig. 9); 95 percent of the median particle-size diameters were less than 0.70 mm. Fine sediments were deposited immediately inside the levee and to the left of the main flow. Coarse sediments were concentrated at the downstream end of the scour and along the main flow direction.

Site 3

The two levee breaks at site 3 (fig. 11) are located approximately 6,000 ft north of the Missouri River channel in the middle of a long bottom in Callaway County, Missouri. The bottom is approximately 8,600 ft wide at the levee breaks. The levees are along

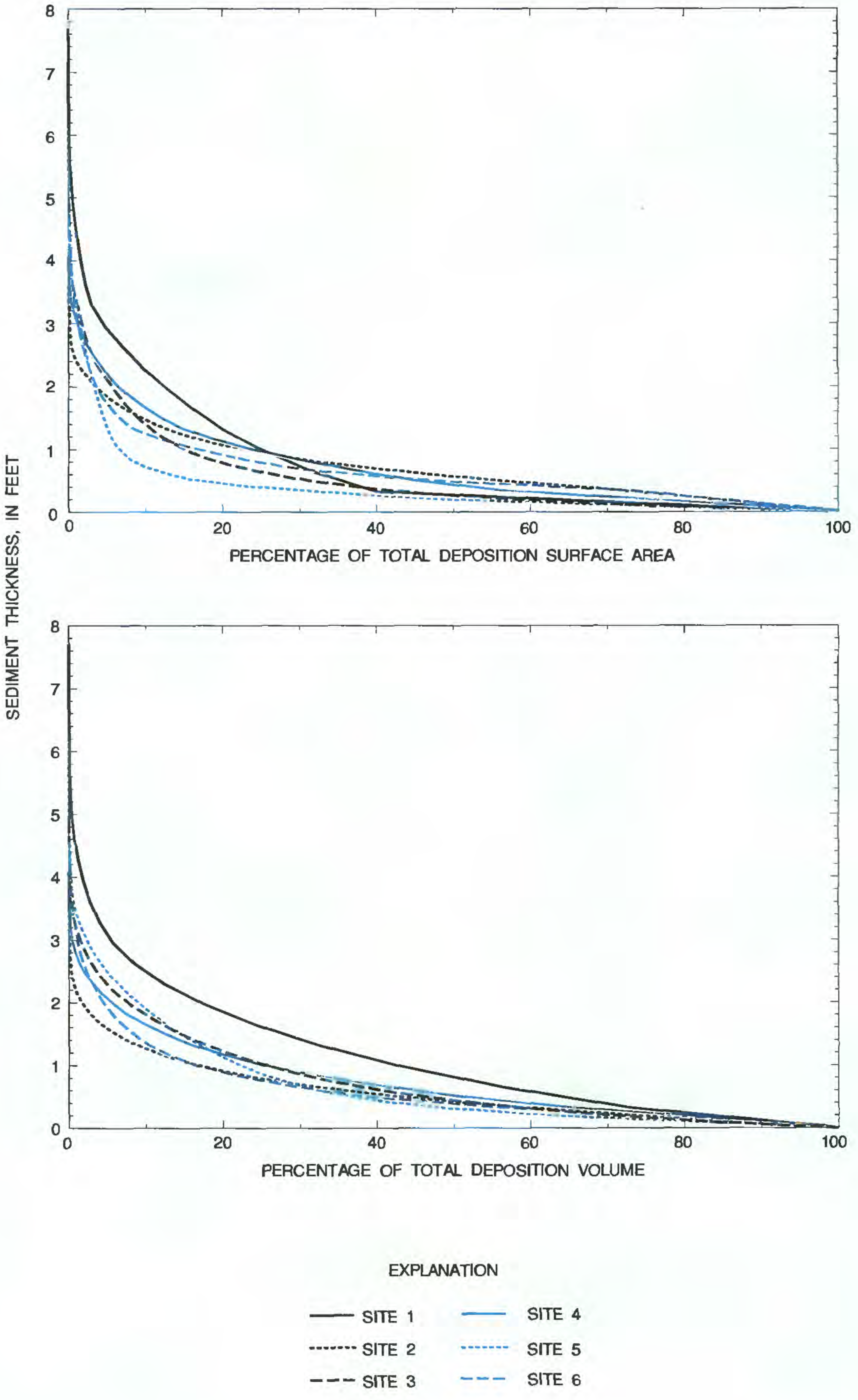
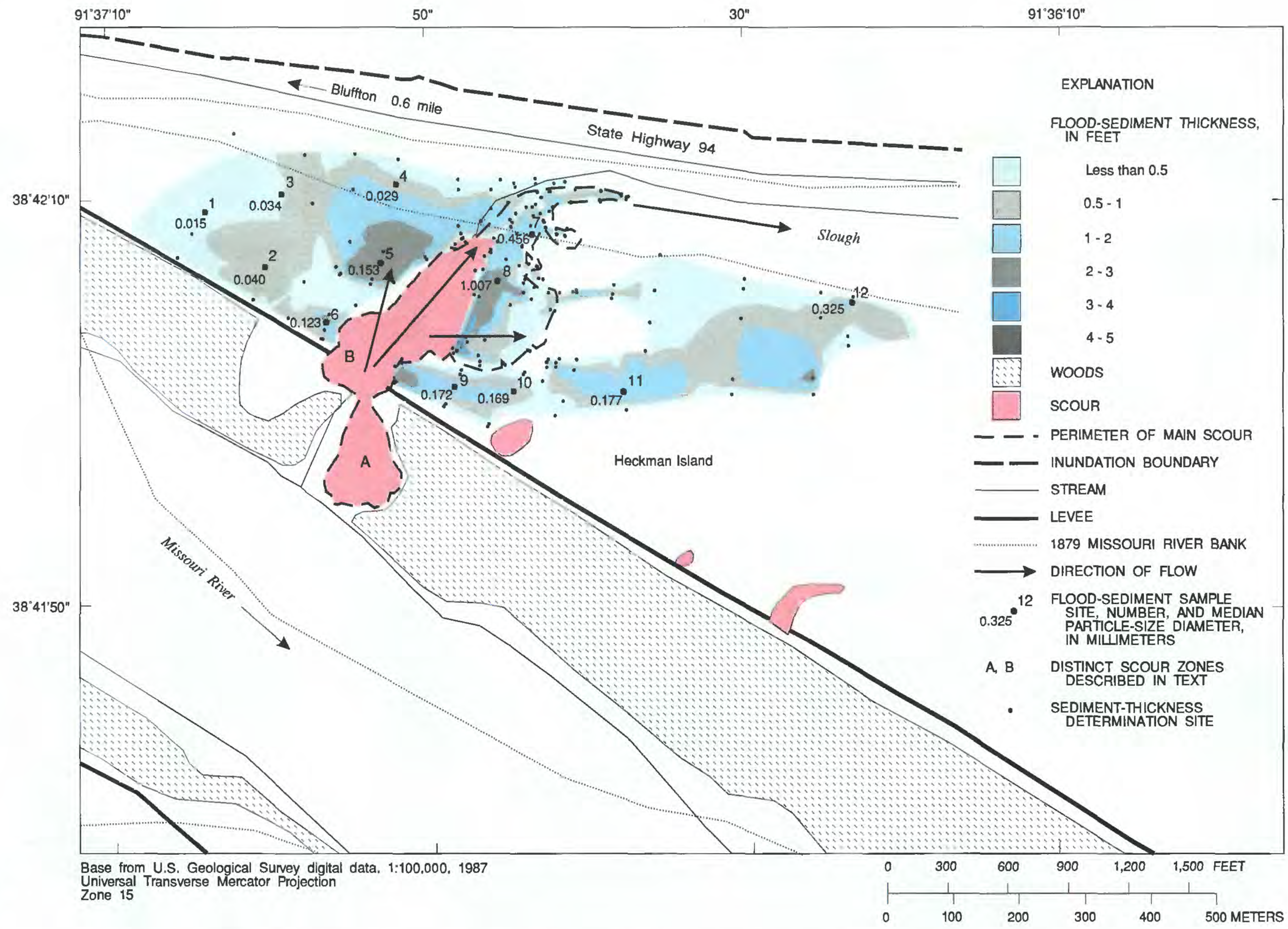


Figure 8. Depth-area and depth-volume curves for sediments deposited on the floodplain at levee-break sites.



Base from U.S. Geological Survey digital data, 1:100,000, 1987
Universal Transverse Mercator Projection
Zone 15

Figure 9. Scour and sedimentation resulting from a levee break in the Missouri River floodplain at site 2 near Bluffton, Missouri.

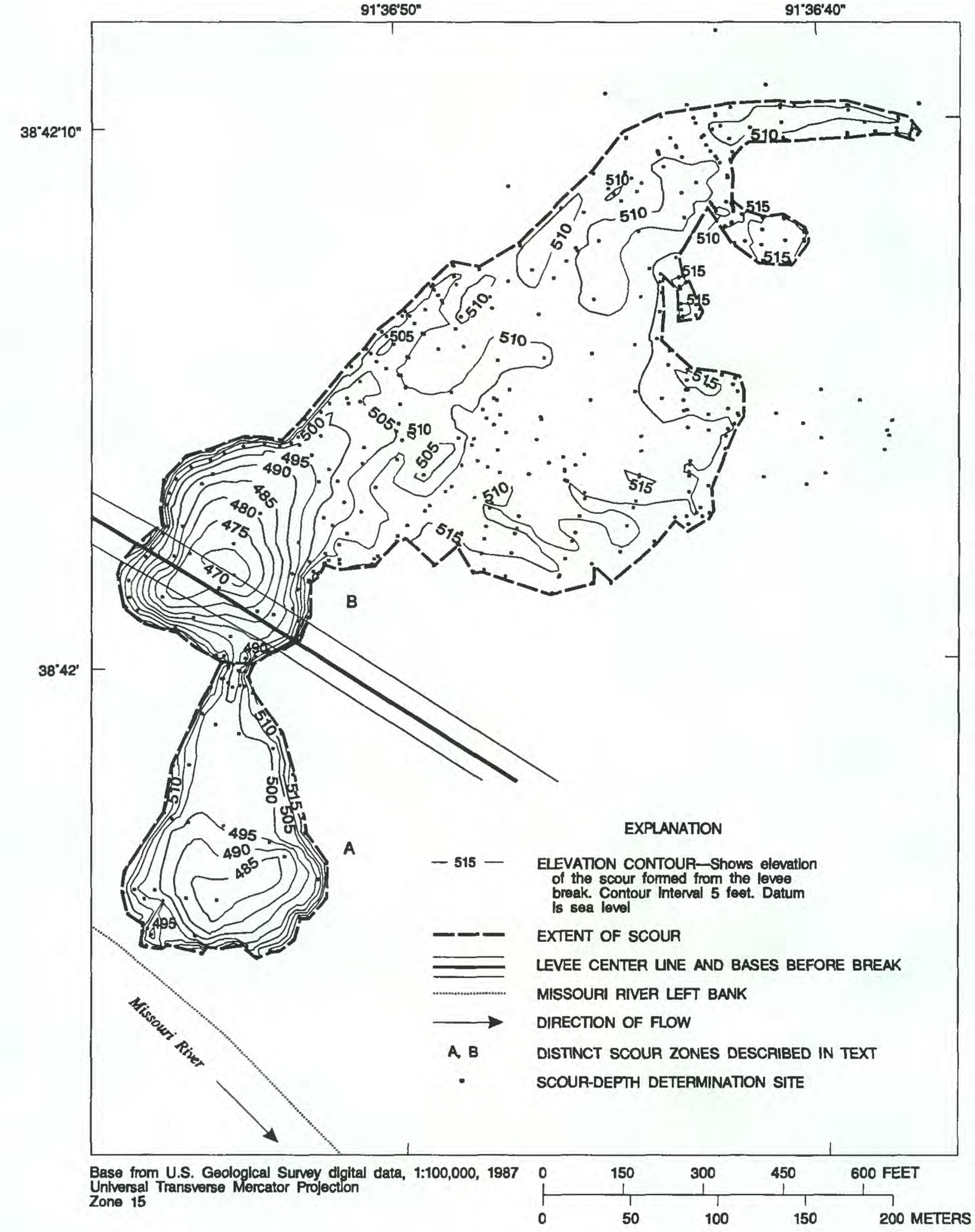


Figure 10. Elevation contours of the scours resulting from a levee break in the Missouri River floodplain at site 2 near Bluffton, Missouri.

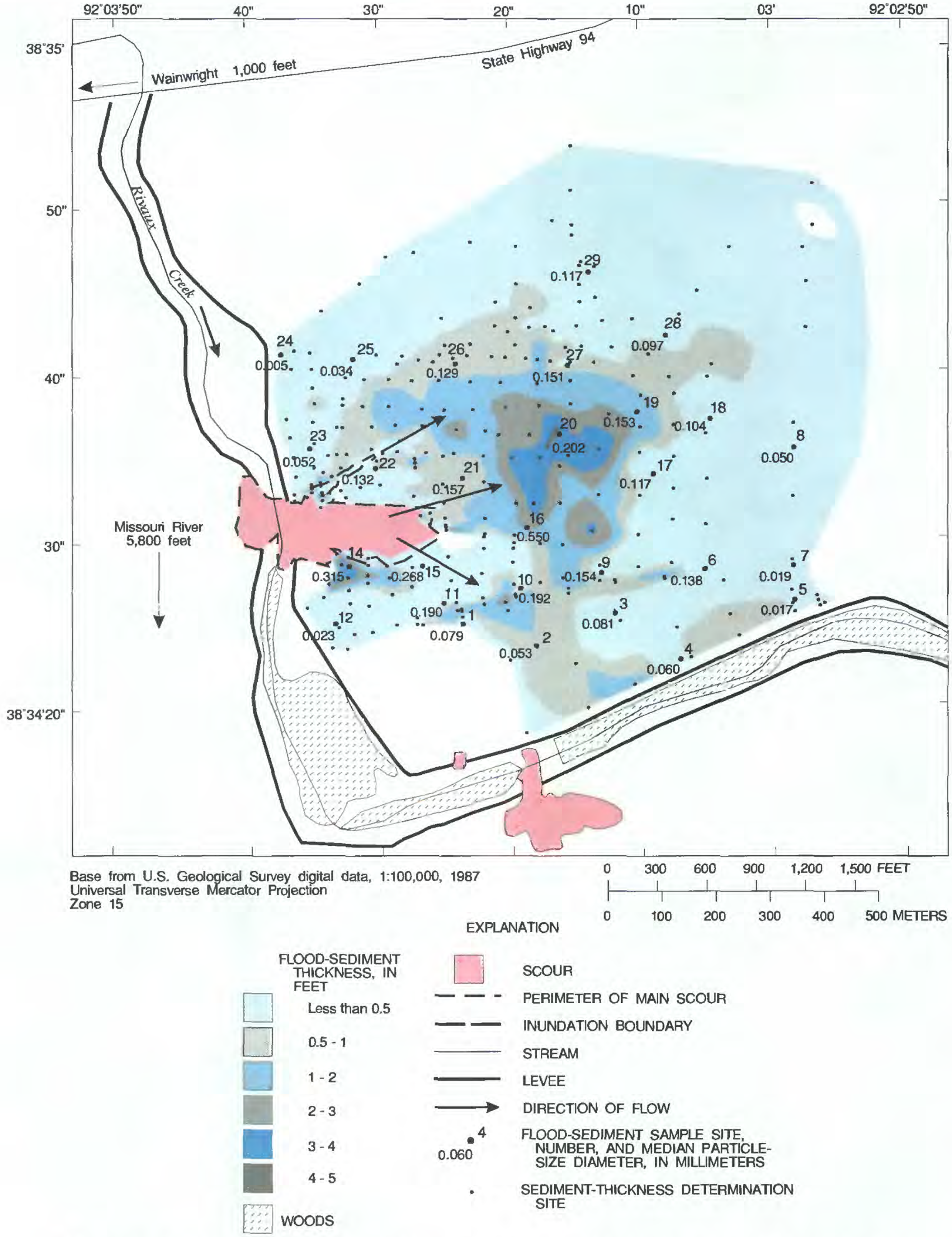


Figure 11. Scour and sedimentation resulting from two levee breaks in the Missouri River floodplain at site 3 near Wainwright, Missouri.

Rivaux Creek and were designed to control backwater from the Missouri River in the creek. Small remnant scours created from previous floods also are evident at the site.

From anecdotal information, the two levees at site 3 failed from overtopping because of substantial flow on the floodplain on July 7, 1993 (fig. 4). Before the levee failures, the floodplain downvalley of the breaks had not been flooded. At the time the levees were overtopped, the water elevation upvalley from Rivaux Creek was at least 10 ft above the floodplain (table 2).

The maximum measured scour depth of 37 ft (table 3) occurred at the center line of the western levee (fig. 12). The total volume of the scour was 94 acre-ft, covering 9.7 acres. Twenty-five percent of the scour area volume originated at depths greater than 14 ft below the average floodplain elevation, 50 percent of the scour volume originated greater than 7 ft below, and 75 percent originated greater than 3 ft below (fig. 7).

The total volume of flood sediments was 110 acre-ft, covering 210 acres (table 4). Twenty-five percent of the sediment volume was deposited between 1.1 to 4.0 ft (maximum measured thickness) deep, and 75 percent was deposited greater than 0.2 ft deep (fig. 8). The average thickness was 0.5 ft. Fifty percent of the sedimentation area was covered by sediment at least 0.3 ft thick (fig. 8). The scour volume was 87 percent of the sediment volume (table 4).

Of 28 flood-sediment samples, the median particle-size diameter ranged from 0.005 to 0.550 mm (fig. 11); 95 percent of the median particle-size diameters were less than 0.30 mm. Fine sediments were deposited preferentially adjacent to the levee on both sides of the scour. Coarse sediments were deposited preferentially adjacent to the downvalley end of the scour and in the area of thickest sediment accumulation along the main flow direction (indicated by arrows, fig. 11).

Site 4

Site 4 is located in Saline County in a 10,400 ft-wide loop bottom that is divided by a chute cutoff[2] (figs. 1, 13). The river meander amplitude is longer than the length of the chute cutoff at the levee break. The affected floodplain is bounded on the east by a levee adjacent to the chute; to the west, the floodplain is bordered by the valley wall. The break occurred on a concave bank where the levee-to-riverbank width was at a local minimum.

Although no eyewitness accounts of the levee break at site 4 were available, hydrographic evidence indicates that the levee failed from overtopping on the rising limb of the flood hydrograph. Another levee break occurred on the downstream end of the floodplain, allowing floodwaters to flow through. Three smaller levee breaks occurred on the levee near the river upstream from the main break, causing minor scouring near the main break (fig. 13).

The maximum measured scour depth of 51 ft (table 3) occurred at the levee center line (fig. 14). The total volume scoured was 700 acre-ft, covering 59.3 acres. Twenty-five percent of the scour volume originated at depths greater than 11 ft below the average floodplain elevation, 50 percent originated greater than 6 ft below, and 75 percent originated greater than 2 ft below (fig. 7).

The total volume of flood sediments was 360 acre-ft, covering 550 acres (table 4). Twenty-five percent of the sediment volume was deposited between 1.1 to 4.0 ft (maximum measured thickness) deep, and 75 percent was deposited greater than 0.2 ft deep (fig. 8). The average thickness was 0.6 ft. Fifty percent of the sedimentation area was covered by sediments at least 0.4 ft thick (fig. 8). The scour volume was 190 percent of the sediment volume (table 4).

Of 20 flood-sediment samples, the median particle-size diameter ranged from 0.005 to 0.569 mm (fig. 13); 95 percent of the median particle-size diameters were less than 0.41 mm. Fine sediments were deposited preferentially adjacent to the levee and directly west of the scour and in the extreme southeast levee-bounded corner of the flooded area. Coarse sediments were deposited preferentially immediately downstream from the two arms of the main scour and in the zone of thick sediment accumulation along the main flow direction.

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[2] A chute cutoff is an overflow channel across a meander, formed during a period of high discharge when flow is diverted to the inside of the bend.

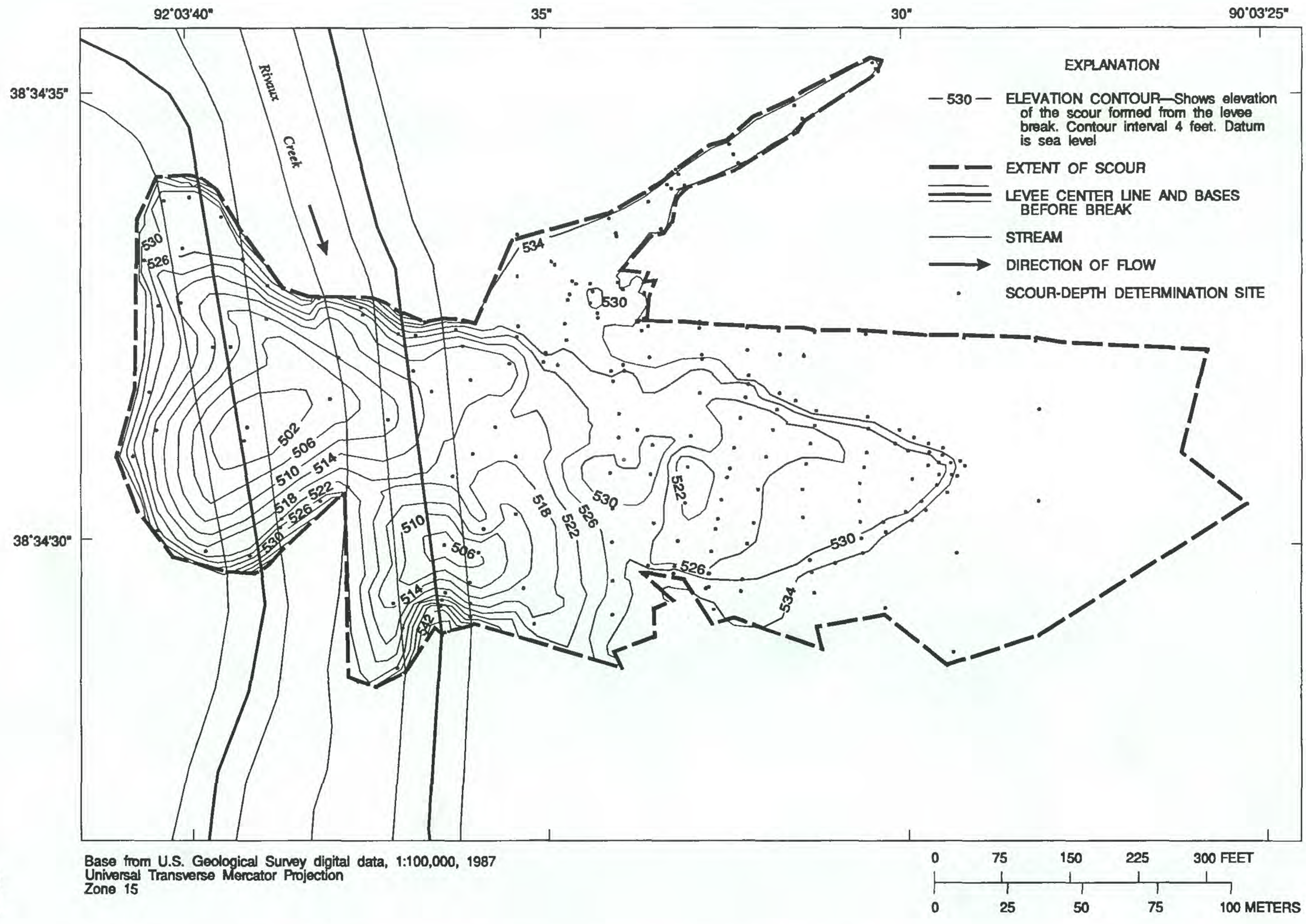


Figure 12. Elevation contours of the scour resulting from two levee breaks in the Missouri River floodplain at site 3 near Wainwright, Missouri.

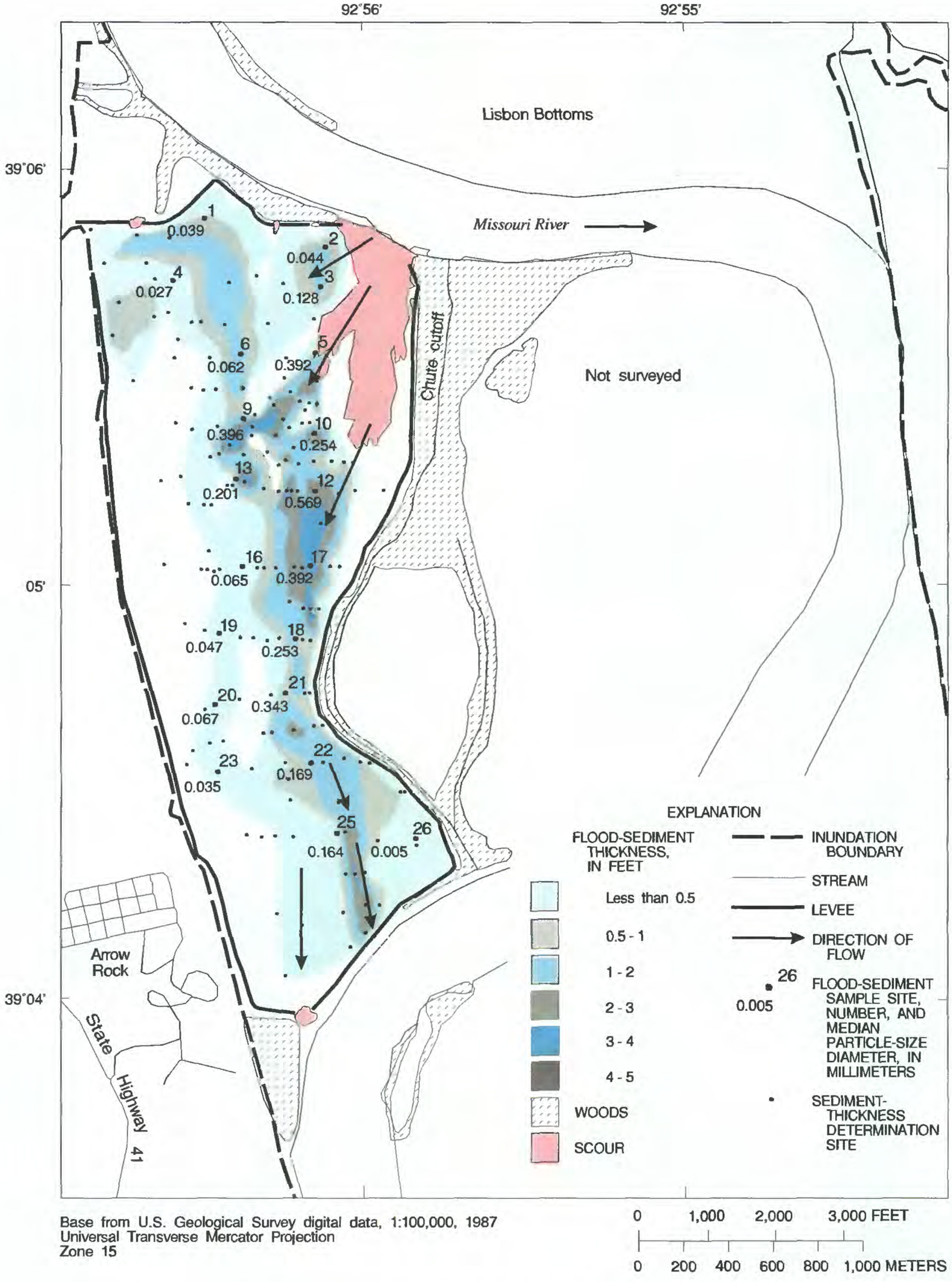
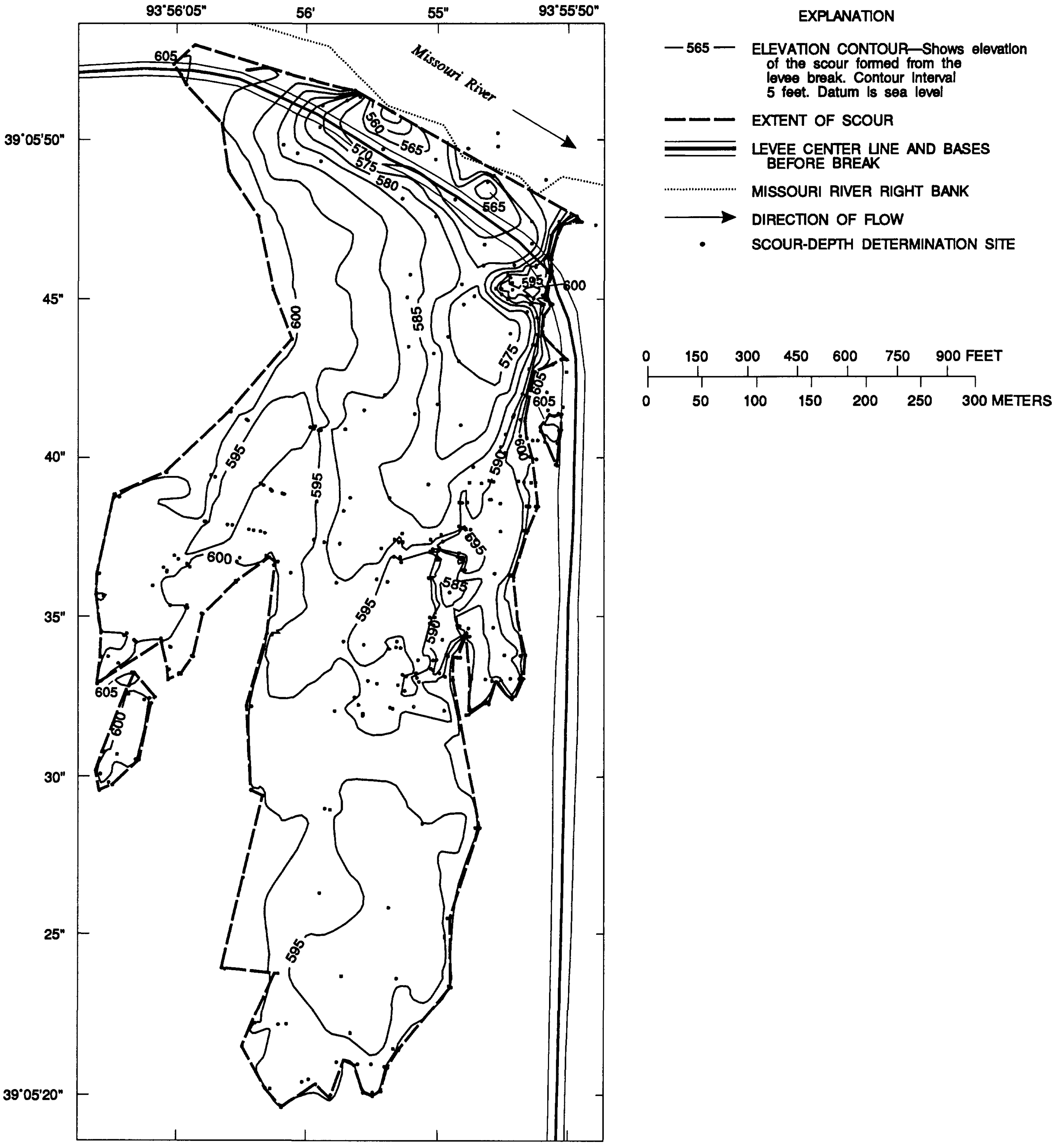


Figure 13. Scour and sedimentation resulting from a levee break in the Missouri River floodplain at site 4 at Arrow Rock, Missouri.



Base from U.S. Geological Survey digital data, 1:100,000, 1987
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Zone 15

Figure 14. Elevation contours of the scour resulting from a levee break in the Missouri River floodplain at site 4 at Arrow Rock, Missouri.

Site 5

The levee break at site 5 was located on the concave bank of a long meander loop in Saline County (figs. 1, 15). The levee probably failed from overtopping near the peak on July 24, 1993 (fig. 4). Aerial photography on July 29, 1993, indicated a tree line was still visible along the levee break, except for a 400-ft opening on the upstream end of the break (fig. 15). However, aerial photography on October 22, 1993, indicated the levee break was fully developed. The levee break occurred at a site that was 180 ft from the water during low-flow conditions. This site apparently was unaffected by navigation structures. Shifting of the channel boundary since 1879 indicates that the break occurred in a naturally dynamic part of the river bottom. Before the main levee break, backwater from a downstream levee break on July 14, 1993, extended upstream as far as the Missouri Department of Conservation office (fig. 15).

A second flood during September 1993 destroyed more of the levee to produce the condition at the time of the survey in May 1994; this flood deposited an additional quantity of silt northeast of the Missouri Department of Conservation office (fig. 15; Robb Leonard, Missouri Department of Conservation, oral commun., 1994). More silt apparently was deposited from the September 1993 flood than from the July to August 1993 flood.

The maximum measured scour depth was 32 ft (table 3) and occurred at the levee center line (fig. 16). The total volume scoured was 310 acre-ft and covered 16.6 acres. Twenty-five percent of the scour volume originated at depths greater than 15 ft below the average floodplain elevations, 50 percent originated greater than 9 ft below, and 75 percent originated greater than 4 ft below (fig. 7).

The spatial distribution of sediment flowing from and through the levee break was controlled by a low river terrace to the south and a system of levees used to manage the area as a wetland and wildlife refuge. Downstream movement of sediment apparently was restricted by the leveed wetland compartments (fig. 15). The total volume of flood sediments was 850 acre-ft, covering 2,300 acres (table 4). Twenty-five percent of the sediment volume was deposited between 0.9 to 6.2 ft (maximum measured thickness) deep, and 75 percent was deposited greater than 0.1 ft deep (fig. 8). The average thickness was 0.3 ft. Fifty percent of the sedimentation area was covered by sediments at least 0.2 ft thick (fig. 8). The scour volume was 36 percent of the sediment volume (table 4).

Of 33 flood-sediment samples, the median particle-size diameter ranged from 0.004 to 0.332 mm (fig. 15); 95 percent of the median particle-size diameters were less than 0.226 mm. The spatial distribution of particle-size diameters apparently was affected by the wetland-management levee system at this site. Fine sediments were preferentially deposited in areas where flow pooled upstream from the levee. Coarse sediments were concentrated about 2,000 ft downstream from the end of the scour where the main flow encountered the first of the wetland-management levees.

The sediment thicknesses discussed for site 5 do not include the sediments deposited in the wetland distribution channels (fig. 15). The sediment volume in the main wetland distribution channel, computed using a survey by the Missouri Department of Conservation, was 46.3 acre-ft, or 5.4 percent of the total volume of sediments on the floodplain. An additional volume of 5 to 10 acre-ft of sediment, not reported in table 4, was estimated to be deposited in the rest of the distribution channels. Because of the levees around the distribution channels and the depths of the channels, these distribution channels acted as energy dissipaters, reducing the flow velocities and, therefore, allowing the sediments to be deposited.

Site 6

The levee break at site 6 was on the concave side of Jackass Bend Slough (an oxbow lake connected to the main channel at high flow) in Ray County (figs. 1, 17). The levee break occurred adjacent to a pre-existing remnant scour located on the oxbow side of the levee.

Before the levee break, the floodplain north of the levee was not flooded. According to an eyewitness account, the levee break at site 6 resulted from overtopping on July 22, 1993, on the rising limb of the flood hydrograph (fig. 4). The water elevation was about 11 ft above the floodplain at the time of overtopping (table 2). This levee break was the first of four breaks on the levee surrounding Jackass Bend. The flow initially was north onto the floodplain, but examination of aerial photographs taken during the peak of the flood on July 29, 1993, indicates that water was flowing south from the floodplain into the oxbow lake through the levee break. Small lobes of sand project-

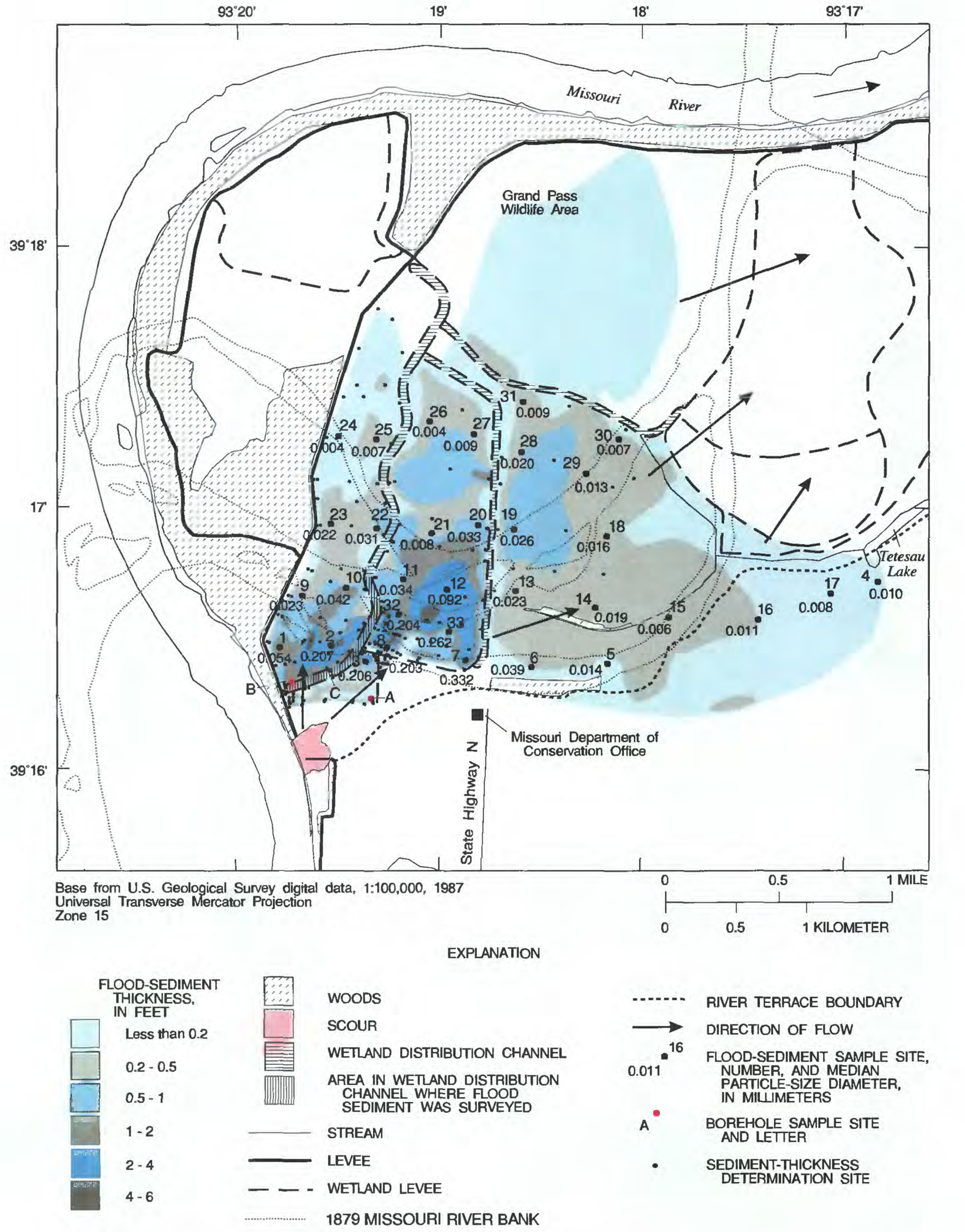


Figure 15. Scour and sedimentation resulting from a levee break in the Missouri River floodplain at site 5 in Saline County, Missouri.

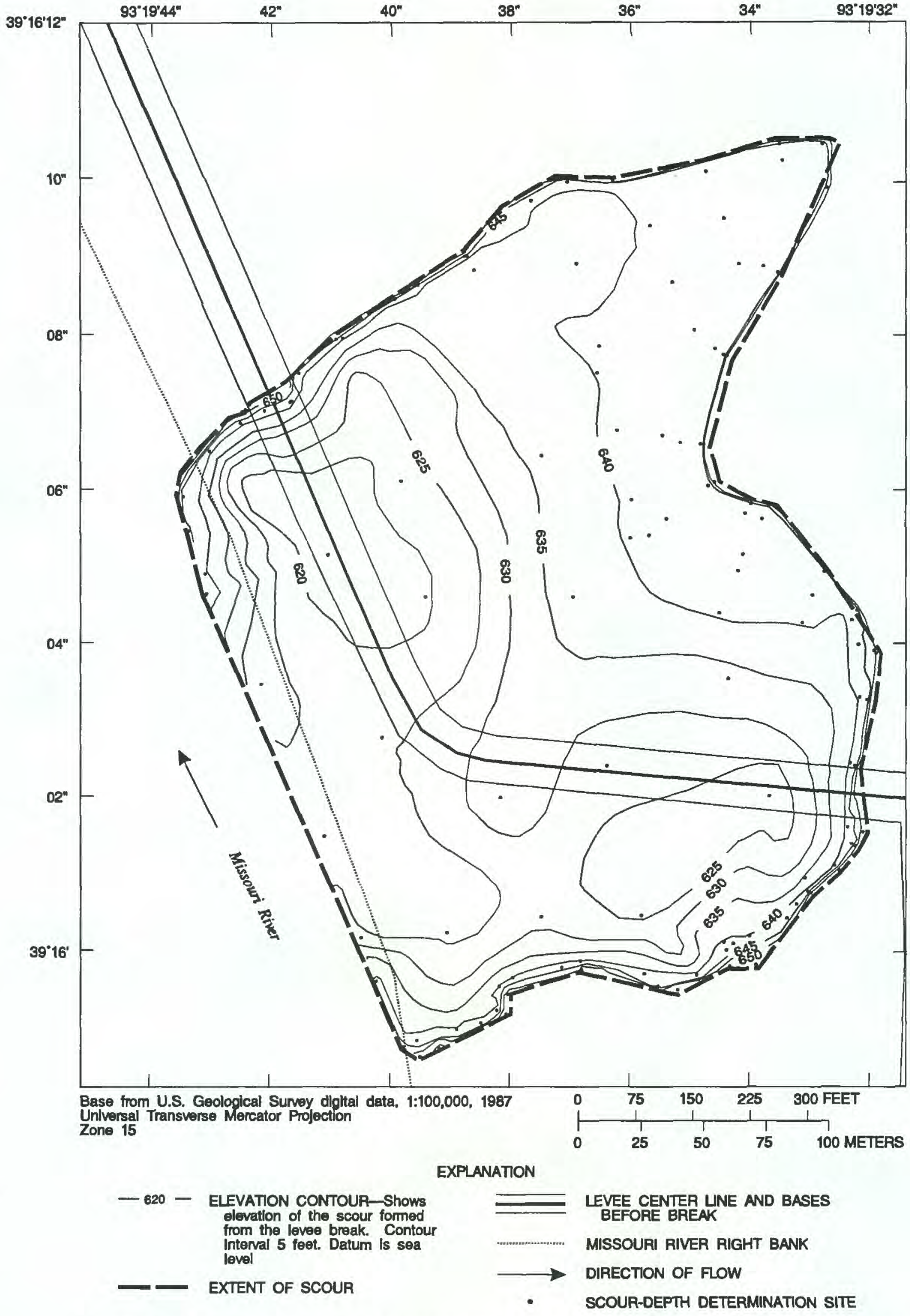


Figure 16. Elevation contours of the scour resulting from a levee break in the Missouri River floodplain at site 5 in Saline County, Missouri.

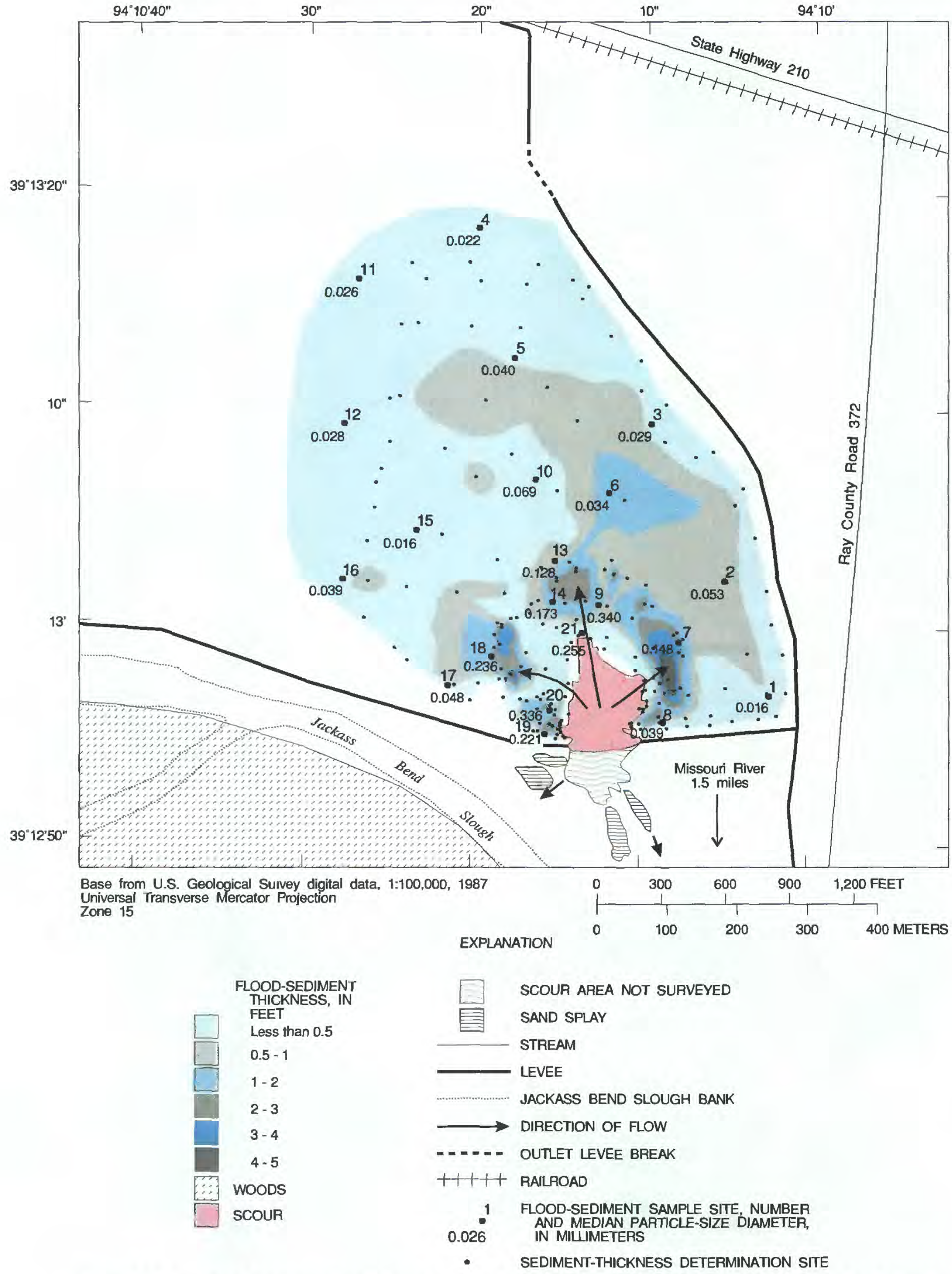


Figure 17. Scour and sedimentation resulting from a levee break in the Missouri River floodplain at site 6 near Orrick, Missouri.

ing south toward the oxbow lake also indicate some floodwaters flowed toward the oxbow lake (fig. 18).

The entire scour at site 6 could not be surveyed. However, the non-surveyed part of the scour (fig. 17) was relatively small and shallow, so the error introduced is not considered to be large. The maximum measured scour depth of 20 ft (table 3) occurred at the levee center line (fig. 19). The total volume scoured was 27 acre-ft, covering 3.1 acres. Twenty-five percent of the scour volume originated at depths greater than 5 ft below the average floodplain elevations, 50 percent originated greater than 2 ft below, and 75 percent originated approximately 1 ft above to 18 ft below (fig. 7). Scour volume above the average pre-floodplain level originated mainly from the levee.

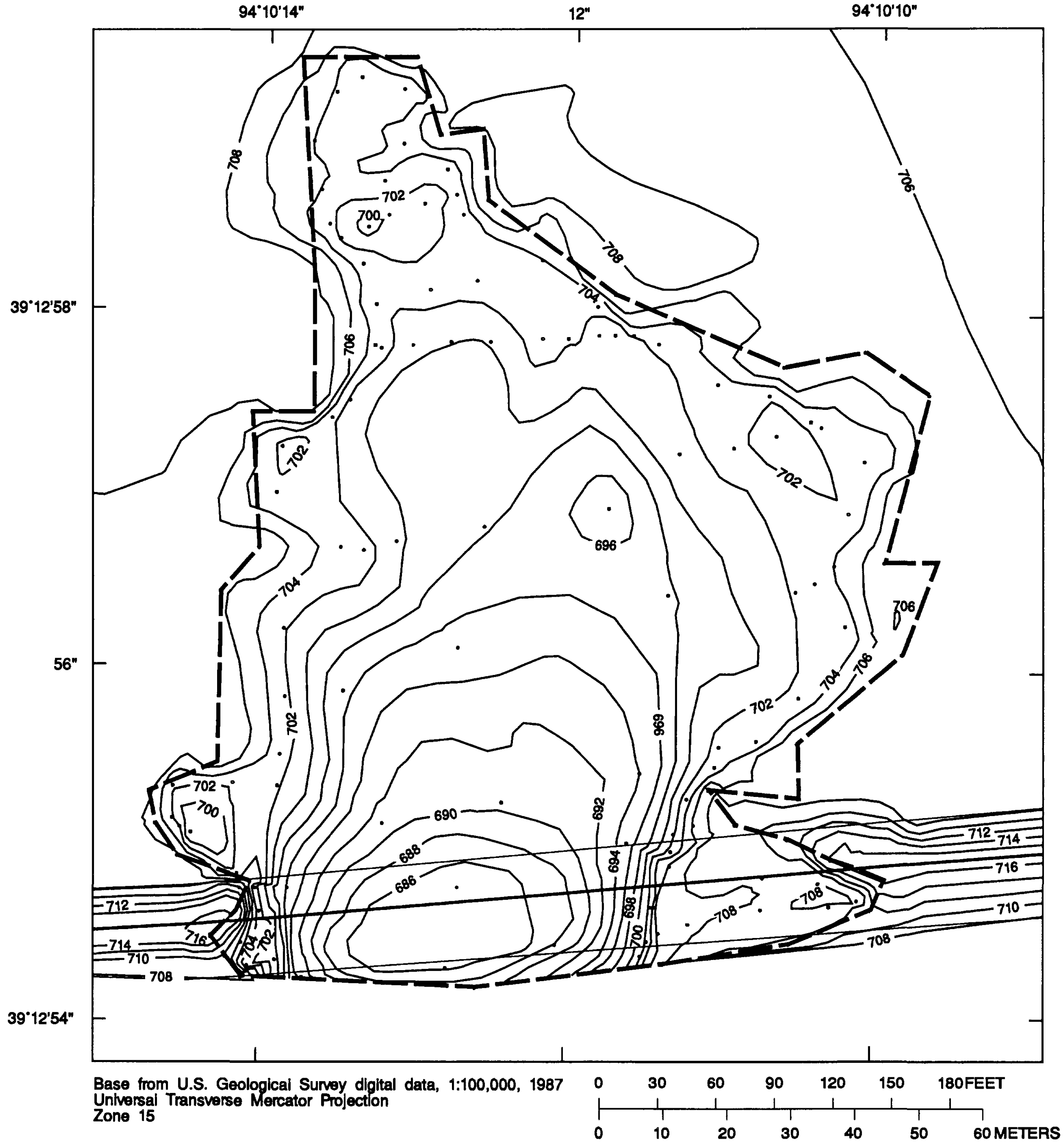
The total flood sediment volume was 44 acre-ft, covering 70 acres (table 4). Twenty-five percent of the sediment volume was deposited from 0.8 to 5.0 ft (maximum measured thickness) deep, and 75 percent was deposited greater than 0.2 ft deep (fig. 8). The average thickness was 0.4 ft. Fifty percent of the sedimentation area was covered by sediments at least 0.4 ft thick (fig. 8). The scour volume was 61 percent of the sediment volume (table 4).

Of 21 flood-sediment samples, the median particle-size diameter ranged from 0.016 to 0.340 mm (fig. 17); 95 percent of the median particle-size diameters were less than 0.336 mm. Fine sediments were deposited preferentially adjacent to the levee and directly east of the scour in a corner formed by the levee system. Coarse sediments were deposited immediately downstream from the main scour and in the zone of thick sediment accumulation along the three main flow directions.

PROCESSES AND MORPHOLOGIC CHARACTERISTICS OF LEVEE-BREAK SITES

Flow over and through a levee break is characterized by steep water-surface slopes and high velocities. Part of the energy of water passing through a levee break is dissipated in turbulence adjacent to the break, resulting in deep scours. Other energy is dissipated in sediment transport and in turbulence as the water flows over the floodplain. Constriction of flow through the levee break generally is followed by expansion of the flow and sediment deposition, forming the characteristic fan shape of levee-break deposits. Details of the sediment distribution are controlled to some extent by other features on the floodplain that guide flow or dissipate energy, including vegetation, roads, secondary levees, and natural topographic features such as scarps and swales (Jacobson and Oberg, 1997). This section discusses the inferred processes of erosion and deposition and the morphologic characteristics of the six levee-break sites examined in the study.

Figure 18. Scour with lobes of sand extending in the opposite flow direction during the levee break at site 6 near Orrick, Missouri (view is looking south).



EXPLANATION

—702— ELEVATION CONTOUR—Shows elevation of the scour formed from the levee break. Contour interval 2 feet. Datum is sea level

— — EXTENT OF SCOUR

LEVEE CENTER LINE AND BASES BEFORE BREAK

• SCOUR-DEPTH DETERMINATION SITE

Figure 19. Elevation contours of the scour resulting from a levee break in the Missouri River floodplain at site 6 near Orrick, Missouri.

Scour

Generally, levee-break scours vary in shape from round to elongated, and they vary in size from several acres to tens of acres. Of many hundreds of scours examined during this study, all were characterized by steep scarps composed of cohesive sediments. Steep scarps and slump blocks have been interpreted as evidence that the cohesive sediments function as a protective cap above erodible non-cohesive sediments; once the cap is breached by turbulent, high-velocity floodwater, expansion of the scour continues by undermining of the lower, non-cohesive sediment (Jacobson and Oberg, 1997).

The maximum depths of scour measured in this study ranged from 20 to 51 ft below the average floodplain elevation at each location (table 3). Maximum scour depths were at or near the levee center line at all sites except at site 1, where the maximum depth was on the upstream side of the scour between the channel and the levee center line. Location of the maximum depth at the levee center line indicates that the steep water-surface slopes and high velocities over and through the constricted levee break created the conditions for greatest scour. Observations of levee breaks indicate that flow velocities greater than 10 ft/s (feet per second) and water surface slopes of several percent were possible (Jacobson and Oberg, 1997).

The depth-to-percent volume curves (fig. 7) are similar for each scour, even though the scours vary in shape and volume. These curves indicate the percentage of the scour that was removed at a given depth. Zero depth was considered to be the average floodplain elevation (table 2). A negative depth represents parts of the floodplain above the average floodplain elevation, including parts of the levee. These curves help distinguish the quantity of material that came from varying depths. The percentage of the scour volume removed below the average floodplain elevation at each site was 95 at site 1, 89 at sites 2 and 3, 92 at site 4, 94 at site 5, and 65 at site 6.

The percentage volume corresponding to the bottom elevation of the levee (fig. 7) was calculated as the quantity of levee removed. Extremely little of the pre-flood topography in the vicinity of the scours was at elevations above the levee base; therefore, this approximation is considered reasonable. The levee bottom elevations were determined from onsite surveys. The percentage of the total scour removed from the levees was 2 at site 1, 3 at site 2, 10 at site 3, 6 at site 4, 2 at site 5, and 7 at site 6. The double levee system at site 3 (figs. 11, 12) accounts for the larger levee percentage at this site.

Most of the scour volume originated from parts of the scours where the scour depth increased almost linearly with percent volume, except the scour at sites 2 and 5 (fig. 7). The percent volume originating from the section in which the relation was linear was 60 at site 1, 32 at site 2, 51 at sites 3 and 4, 47 at site 5, and 61 at site 6. The linear sections of the relation correspond closely to the depths with nearly vertical scarps at each site. The scarps are indicated as the steep slopes along the perimeter of the scour (figs. 6, 10, 12, 14, 16, 19).

The scarps (fig. 20) are composed of interbedded cohesive silt, clay, and sand. These sediments are typical of the top stratum of alluvial sediments of large rivers (Brakenridge, 1988). The range of depths in the near linear section of the curves in figure 7 may be an indication of the average thickness of the top stratum. At site 5, for example, the base of the top stratum (12-ft average depth as determined from borehole data) corresponds approximately to the end of the nearly linear section point (approximately 9 ft depth) on the curve in figure 7. Based on this estimate, average thicknesses of the top stratum, except for site 2, ranged from 6 ft at site 4 to about 12 ft at site 1.

The depths below the linear section (fig. 7) contributed about 32 to 64 percent of the total scoured volume. These depths may represent parts of the floodplain eroded from the bottom stratum. The bottom stratum is the relatively coarse sediment deposited on a previous channel bed and subsequently buried by overbank deposition during the lateral migration of the channel (Brakenridge, 1988). At site 5, the borehole samples revealed fine to coarse sand about 10 to 14 ft below the floodplain surface, indicating that 35 percent of the scour volume eroded from the bottom stratum. The cohesionless material at greater depths tends to slump as depicted by the bowl-shaped areas of the scours (figs. 6, 10, 12, 14, 16, 19). In summary, more scour volume had been eroded from the top stratum than from the bottom stratum in scours.

Sedimentation

The varying thicknesses and particle sizes of sediment deposited indicate the general patterns of flow and energy dissipation of the floodwaters on the floodplain (Jacobson and Oberg, 1997). Areas of thick sand deposits result from transport of sediment from

Figure 20. Nearly vertical scarps of the scour at site 2 near Bluffton, Missouri.

the river into leveed areas by high-energy floodwaters. When this flow expands or encounters areas of ponded water, sediment is deposited (fig. 21). Sediment transport capacity can decrease because of flow expansions, local increases in hydraulic roughness, changes in topography, or because of the effects of structures, such as roads and buildings, on the flow pattern.

Generally, coarse deposits (sand) were thicker than fine deposits (silt and clay) at the study sites (fig. 22). These observations indicate that the general decrease in energy and transport capacity in the floodplain downstream from levee-break sites reached critical levels that caused deposition of sand, but that much of the silt and clay was transported through the levee-break sites.

Levee-Break Sites as Sources and Sinks for Sediment

Sediment transport data indicate that during the 1993 flood, total sediment load decreased between Hermann and St. Louis, Missouri (Holmes, 1996). The total suspended sediment load transported past Hermann from June 26 to September 14, 1993, was 70 million metric tons, whereas during the same period only 7 million metric tons were transported past Grafton, Illinois, on the Mississippi River upstream from St. Louis, and only 55 million metric tons were transported past St. Louis downstream from the junction of the Missouri and the Mississippi Rivers. The load transported past St. Louis was 22 million metric tons less than the 77 million metric tons expected by adding the loads transported past Hermann and Grafton.

Holmes (1996) concluded that levee-break complexes on the Missouri River may have extracted substantial quantities of sediment from the total flood load. Volumes of net sedimentation calculated in this study supports the theory that large, connected levee-break complexes had the potential to be substantial sediment sinks. The net mass (flood sediment mass minus the scoured mass) of sediment deposited on the floodplain at site 1, which is 5.5 river miles downstream from Hermann, was between 36 and 57 percent of the 22 million metric tons of sediment thought to have been deposited during the flood. In other terms, the net mass of flood sediment deposited at site 1 was 11 to 18 percent of the total sediment load transported by the Missouri River past Hermann during the 1993 flood. At a larger levee-break complex near Miller City, Illinois, 22 to 36 percent of the total sediment load transported by the Mississippi River past Thebes, Illinois, was estimated to have been deposited on the floodplain (Jacobson and Oberg, 1997).

Levee-break complex sites varied in their function as sources or sinks for sediment depending on size, location, and other factors. For example, although they had scours of similar volume, the levee-break complex at site 1 had a sediment gain, whereas site 4 had a net loss. The scour volume at site 1 was only 15 percent of the sediment volume on the flood-

Figure 21. Thick sand deposits on the floodplain at site 1 at Berger, Missouri.

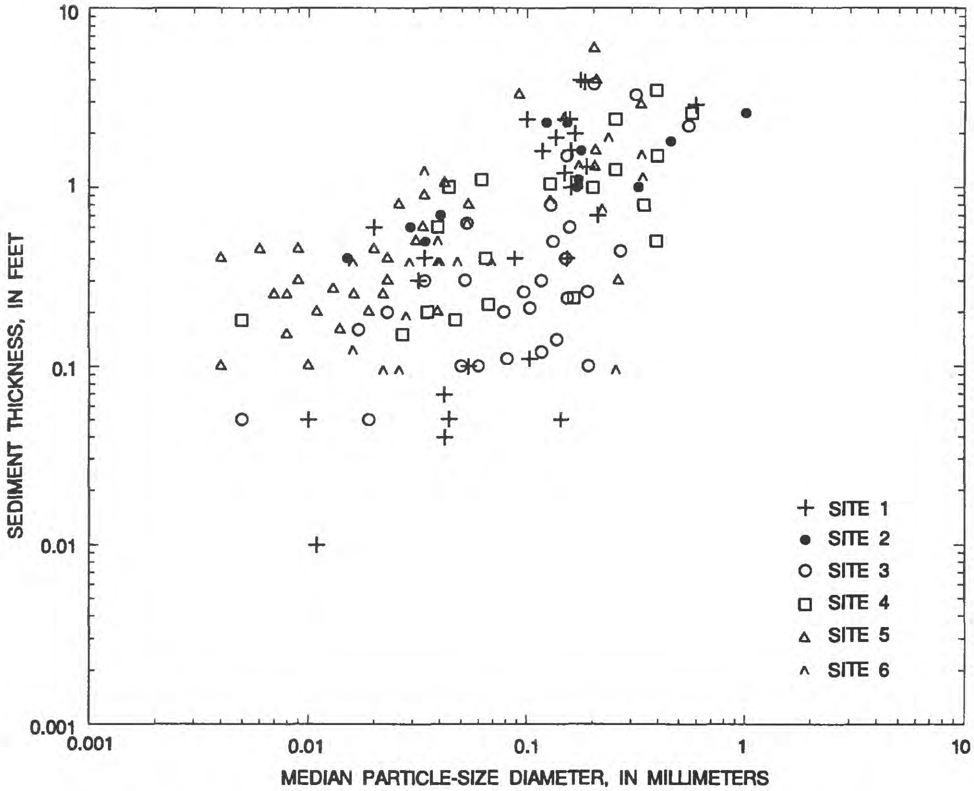


Figure 22. Thickness and median particle-size diameter for sediment samples collected at levee-break sites (site locations are shown in figure 1).

plain, whereas the scour volume at site 4 was 190 percent of the sediment volume (table 4). Several factors may have contributed to this phenomenon. First, the floodplain at site 1 is a long bottom with an approximate floodplain slope of 1.8 ft/mi and a floodplain width ranging from 7,000 to 10,000 ft. The floodplain at site 4 is a loop bottom with an approximate floodplain slope of 2.5 ft/mi and a floodplain width ranging from 2,300 to 5,000 ft. With a greater floodplain slope at site 4, the floodwater had a greater capacity to transport sediment down the floodplain and out of the levee-break complex. This study did not evaluate sediment volumes transported out of the levee-break complex.

Second, a large quantity of sand (figs. 23, 24) was deposited on the loop bottom (Lisbon Bottoms) immediately upstream from site 4 (fig. 13). Deposition of sand upstream from the site may have caused depletion of sediment supplied to the floodplain at site 4.

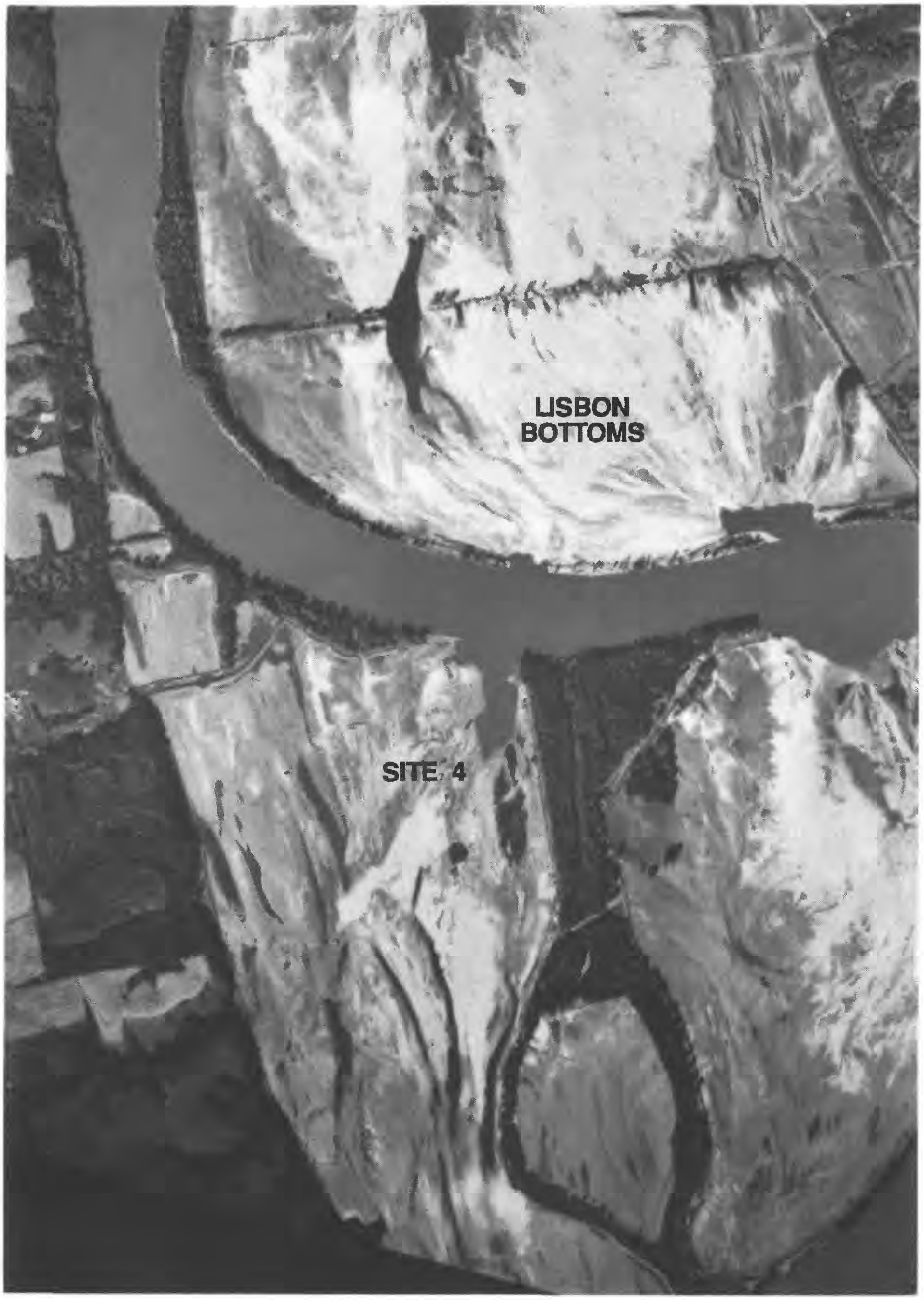
Third, as noted by Schmudde (1963), "the greater lengths of long bottoms dissipate active currents within the overflow." The longer the floodplain, the more likely the sediment load coming into the floodplain will be deposited. At site 1, sediment deposits are concentrated in the upstream one-third of the floodplain. In contrast, continuous deposits of sand as much as 3 ft thick along the floodplain at site 4 indicate that sand was being transported the entire length of the floodplain, and, presumably, some exited through the downstream levee break. Areal trends in particle-size distributions for all levee-break sites are indicated by median particle-size data (figs. 5, 9, 11, 13, 15, 17). The general velocity dissipation trends downstream and transverse to the levee break at each site are illustrated by gradation of particle sizes from medium and coarse sand to finer, thinner deposits of silt and clay.

Sources of Levee-Break Sediment Indicated by Particle-Size Distributions

Particle-size distributions of levee-break complex sediments also may indicate whether the bulk of sediment deposited was from bedload or suspended load. Sediment load commonly is classified into two general categories, suspended load and bedload. The suspended load is the sediment that is carried mostly in suspension within the water column; the bedload is sediment that moves by rolling, sliding, or skipping close to the streambed (Meade and others, 1990). Suspended load also can be classified into two subcategories, washload and bed-material load. Washload consists of suspended, fine particles that are uncommon on the bed of the river; conversely, bed-material load consists of suspended particles that are present in appreciable quantities on the streambed surface (Meade and others, 1990). Within the water column, bed-material particles are concentrated nearer the streambed, whereas washload tends to be uniform vertically.

The alluvial stratigraphy of meandering rivers often is classified according to facies associations as bottom stratum and top stratum. The bottom stratum

Figure 23. Massive sand deposits on Lisbon Bottoms immediately upstream from site 4 at Arrow Rock, Missouri.



Flow is from top left to bottom right

Figure 24. Vertical aerial photograph of site 4 and Lisbon Bottoms at Arrow Rock, Missouri (photograph courtesy of the U.S. Army Corps of Engineers, Kansas City, Missouri).

consists of relatively coarse sediment (sand and gravel) deposited on channel and point bars; the top stratum consists of interbedded sand, silt, and clay deposited in overbank environments (Brakenridge, 1988). Bottom-stratum deposits are dominated by bedload sediments and top-stratum deposits are dominated by suspended-load sediments. Hence, the particle-size distribution of pre-flood alluvial strata also provides information against which flood sediment data can be compared. Descriptions of the pre-flood alluvial sediment and soil from 3 boreholes at site 5 are given in table 5 and particle-size data are given in table 6.

Particle-size characteristics of pre-flood soil and flood sediments are summarized in figure 25 and table 7 (at the back of this report). Particle-size distributions of bottom-stratum samples from site 5 and typical bed-sediment and suspended-sediment samples (Holmes, 1996) are shown for comparison in figure 25. Generally, the flood sediments are (1) coarser and better sorted than pre-flood soil; (2) much coarser and much better sorted than the suspended-sediment samples; (3) finer and better sorted than the bottom-stratum samples; and (4) substantially finer and better sorted than the bed-material samples.

The intermediate particle-size distributions of flood-sediment samples may be related to three factors alone or in combination; the relative contributions of these factors to the observed particle-size distributions cannot be ascertained from available data. First, some of the finer particles (for example, less than 0.05 mm) may have been deposited during subsequent, smaller floods when the velocity of water through the levee breaks was less than that during the major flood. Mixing or sampling of these particles would bias the results toward finer distributions.

Second, flood sediment may accurately represent bedload transport particle-size distributions. Unfortunately, technical problems prevented sampling of bedload transport during the 1993 flood (Holmes, 1996), so there are no samples for comparison of sediment known to be transported as bedload. The reference bed-material samples shown in figure 25 were collected from the beds of the Missouri and Mississippi Rivers from July 29 to August 12, 1993. Because the rivers were sampled after more than a month of flood conditions, the samples may represent a coarse lag remaining after depletion of finer, more transportable bedload. Hence, actual bedload particle-size distributions may be finer and more similar to the reference bottom-stratum sediment samples. Jacobson and Oberg (1997) proposed that connected levee-break scours created efficient ramp-like features that could convey bedload through levee breaks and onto the floodplain.

Third, the sediment deposited in the levee-break complexes may be representative of the sandy, bed-material-load fraction of the suspended-sediment load. The samples shown for reference in figure 25 are vertically integrated samples representative of the entire water column and, therefore, include both washload and bed-material load. In addition, conventional suspended-sediment samplers do not sample all the way to the streambed, typically leaving the zone of coarsest sediment and highest concentration unsampled (Guy and Norman, 1970). Therefore, actual suspended load may be somewhat coarser than indicated in the suspended-load reference samples (fig. 25), and the levee-break complex sediment may include a large proportion of the unsampled suspended sediment and the bed-material-load suspended sediment. According to this model, the washload fraction of the suspended load would have been largely transported through the floodplain without deposition.

The general differences in particle-size distribution between pre-flood soils and flood sediments also indicate that the net accumulations of sediment calculated for the sites (tables 3, 4) are minimum estimates of sediment flux onto the floodplain. These data indicate that the sites lost fine top-stratum sediment and preferentially gained sandy sediment from bedload transport or from the bed-material-load fraction of suspended sediment.

SCOUR AND SEDIMENTATION EFFECTS ON FLOODPLAIN RESOURCES

Levee breaks during the 1993 flood affected floodplain resources by eroding extensive areas and depositing large quantities of sediment. Degradation of floodplain resources resulted from changes in chemical and physical characteristics of floodplain materials as well as from alteration of the land surface. This section summarizes magnitudes of scour and sedimentation and changes to characteristics of the floodplain materials, including particle size, inorganic soil chemistry, soil organic carbon, and herbicide concentrations.

Table 5. Lithologic description of pre-flood sediment and soil from three boreholes at site 5 in Saline County, Missouri

[ft, feet]

Elevation of top of lithology (ft above sea level)	Thickness (ft)	Description
		Borehole A (fig. 15)
649.60	0.42	Light gray, loamy, coarse sand (1993 flood deposit)
649.18	.18	Dark grayish brown, very fine sandy loam
649.00	.05	Very dark grayish brown, laminated silt loam
648.95	.04	Black silt
648.91	.14	Very dark gray, silt loam (A horizon)
648.77	.25	Very dark gray, silt loam
648.52	.42	Very dark grayish brown, silty clay loam
648.10	.17	Dark grayish brown, fine sandy loam
647.93	.41	Black, silty clay
647.52	.25	Black, silty clay (A horizon; plow horizon)
647.27	4.25	Dark gray to grayish brown, silty clay with laminations toward the bottom
643.02	4.17	Interbedded gray clay and dark grayish brown, micacous, sandy silt
638.85	2.25	Gray to dark grayish brown, interbedded silty clay and micacous fine sand with bedded fine sand toward the bottom (end of top stratum)
636.60	27.0	Dark gray, coarse sand (bottom stratum)
609.60 (bottom of hole)		
		Borehole B (fig. 15)
652.80	0.20	Light brownish gray, fine sand (1993 flood deposit)
652.60	.13	Very dark grayish brown, silt loam with some laminations (1993 flood deposit)
652.47	.54	Brown, fine sand to dark grayish brown, loamy, fine sand
651.93	.02	Very dark grayish brown silt
651.91	.53	Dark grayish brown, very fine sandy loam
651.38	.12	Dark to very dark brown silt
651.26	.46	Dark grayish brown, silty, clay loam (A horizon; plow horizon)
650.80	.33	Very dark grayish brown, silty clay
650.47	.34	Dark gray, silty, clay loam, A horizon
650.13	1.41	Very dark grayish brown, silty, clay loam to dark grayish brown, silty clay
648.72	.09	Dark yellowish brown, loamy, fine sand
648.63	3.75	Dark grayish brown, silty, clay loam and silty clay interbedded toward the top
644.88	6.66	Interbedded silty clay to loamy sand (end of top stratum)
638.22	25.34	Loamy sand to sand becoming coarser downward (bottom stratum)
612.88 (bottom of hole)		
		Borehole C (fig. 15)
652.40	1.00	Light yellowish brown, gravelly, fine sand (1993 flood deposit)
651.40	1.42	Bedded, yellowish brown to brown, loamy, fine sand with olive gray loam at the bottom
649.98	.29	Olive gray, silty clay (A horizon)
649.69	8.87	Mainly black, dark olive gray, or grayish brown, silty clay with dark grayish brown clay and silty clay loam (end of top stratum)
640.82	27.75	Mainly fine sand with medium to coarse sand in the middle (bottom stratum)
613.07 (bottom of hole)		

Table 6. Cumulative particle-size distribution data for three boreholes at site 5 in Saline County, Missouri

[ft, feet; mm, millimeters; >, greater than]

Depth below land surface (ft)		Percent finer than the indicated particle size								
Beginning	Ending	0.002 mm	0.02 mm	0.05 mm	0.1 mm	0.25 mm	0.5 mm	1 mm	2 mm	>2 mm
Borehole A (fig. 15)										
0.0	0.4	5.3	9.5	12.8	15.7	41.3	64.1	84.6	93.2	100
.4	.6	6.9	12.1	33.5	83.8	99.4	99.6	99.8	100	100
1.1	1.3	30.8	58.4	86.2	96.7	99.6	99.7	99.8	100	100
1.8	2.0	48.3	85.6	99.1	99.6	99.8	99.8	99.9	100	100
2.8	3.0	54.7	89.2	98.5	99.2	99.5	99.6	99.8	100	100
4.8	5.0	47.7	81.1	98.8	99.4	99.6	99.7	99.8	100	100
6.8	7.0	19.1	38.4	83.7	99.1	99.6	99.8	99.9	100	100
8.8	9.0	43.6	80.1	96.8	99.1	99.4	99.5	99.7	100	100
10.8	11.2	12.6	38.6	91.3	98.4	98.9	99.0	99.2	100	100
11.4	11.7	26.6	60.7	93.3	98.5	99.0	99.2	99.5	100	100
26.0	26.3	2.2	3.7	5.1	7.2	36.6	53.7	78.9	99.0	100
39.8	40.0	3.3	5.1	7.7	11.8	55.9	72.4	86.8	96.7	100
Borehole B (fig. 15)										
0.0	0.2	1.8	2.7	7.4	10.1	82.9	99.5	100	100	100
.2	.3	10.3	23.6	73.4	91.0	97.9	99.8	99.9	100	100
.6	.8	6.0	10.4	22.4	56.0	99.2	99.6	99.7	100	100
1.2	1.4	7.8	15.2	44.2	91.6	99.4	99.5	99.7	100	100
1.7	1.9	31.7	63.7	87.3	94.8	98.4	99.1	99.4	100	100
2.8	3.0	28.0	54.3	80.9	93.7	98.6	99.8	99.9	100	100
5.8	6.0	49.0	81.9	99.0	99.6	99.8	99.9	99.9	100	100
7.7	7.9	39.0	79.6	98.7	99.5	99.7	99.8	99.9	100	100
13.8	14.0	7.3	16.7	56.7	92.8	99.7	99.9	100	100	100
39.1	39.3	3.2	6.4	12.2	25.8	62.9	79.2	91.2	99.5	100
Borehole C (fig. 15)										
0.0	0.6	2.8	4.7	8.7	13.5	57.4	68.6	75.3	81.0	100
.6	1.0	3.2	5.5	8.6	16.5	90.4	95.4	97.8	99.6	100
1.0	1.3	6.5	10.4	16.2	31.6	97.2	99.2	99.8	100	100
1.9	2.2	10.5	19.1	56.8	90.6	99.6	99.7	99.8	100	100
2.7	2.9	43.5	74.6	94.2	98.5	99.7	99.8	99.9	100	100
4.3	4.6	59.9	89.1	97.0	98.9	99.8	99.8	99.9	100	100
6.9	7.2	51.0	83.1	97.9	98.9	99.6	99.8	99.9	100	100
9.0	9.3	27.6	51.0	87.5	98.7	99.5	99.7	99.9	100	100
10.7	10.8	51.8	87.4	97.8	98.8	99.7	99.9	100	100	100
20.6	20.8	3.1	5.5	9.0	17.1	86.7	97.3	99.7	100	100
38.2	38.5	2.4	4.2	7.6	16.1	79.6	92.4	95.5	99.2	100

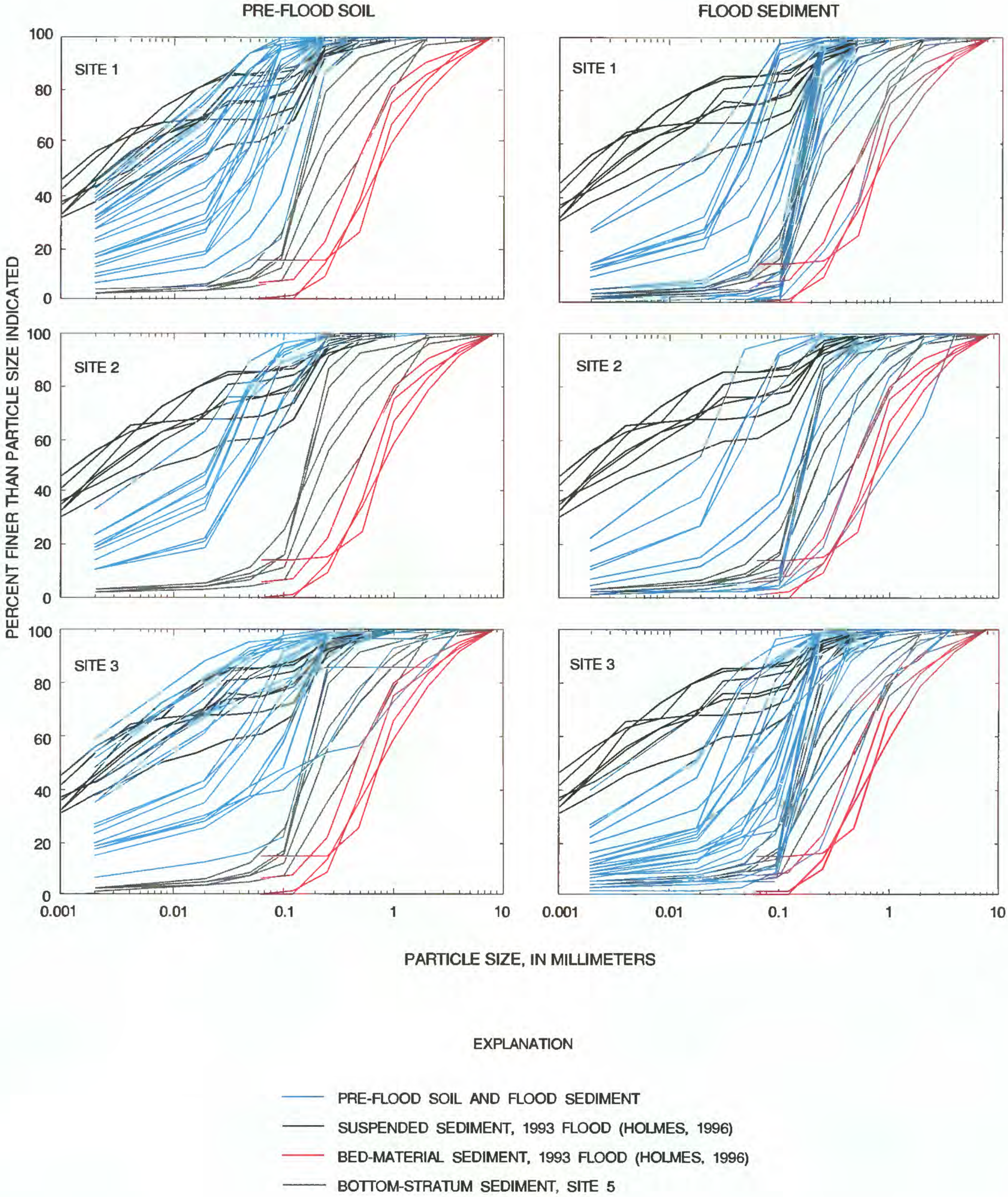


Figure 25. Cumulative particle-size distributions for pre-flood soil and flood-sediment samples at levee-break sites, with comparisons to typical suspended sediment, bed-material sediment, and bottom-stratum sediment from the 1993 flood.

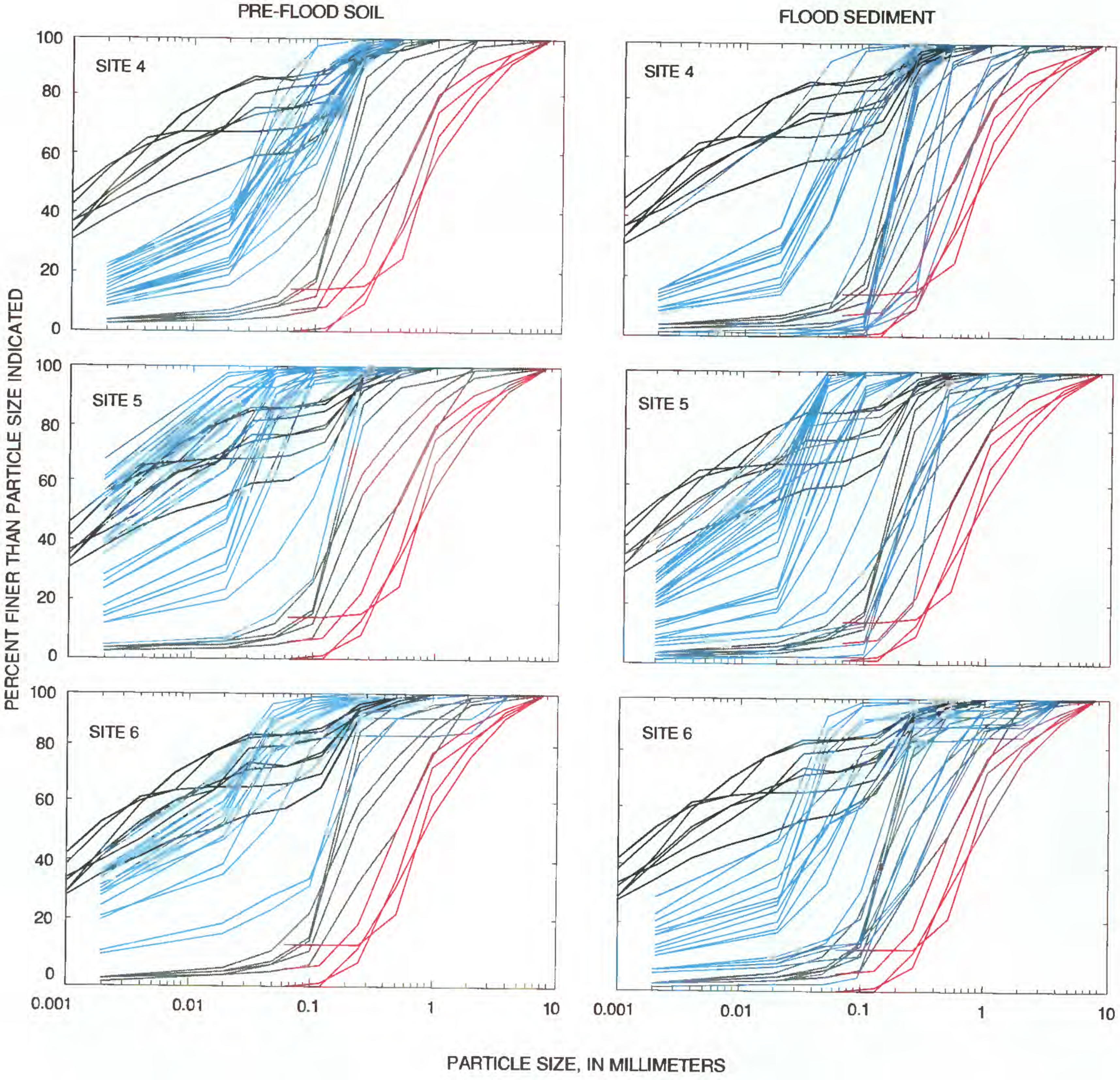


Figure 25. Cumulative particle-size distributions for pre-flood soil and flood-sediment samples at levee-break sites, with comparisons to typical suspended sediment, bed-material sediment, and bottom-stratum sediment from the 1993 flood—Continued.

Scoured Areas and Sedimentation Volumes and Areas

The levee breaks resulted in erosion of substantial areas of floodplain at the levee breaks (table 3). The maximum area scoured in this study was 59.3 acres at site 4, even though site 1 had a larger scour by volume (fig. 7; table 3). The smallest scour was 3.1 acres at site 6, an unconnected-scour site.

Areas of scour generally were completely lost for agricultural production. Stripped areas generally lost part or all of the plow (Ap) horizon of the soil, leaving a dense plow pan at the surface (Jacobson and Oberg, 1997). Loss of the plow horizon in stripped areas may have involved loss of some fertility, organic content, and tilth (workability) of the soil. However, underlying sediments generally could be used for agricultural production if fertility and tilth were restored.

Documented thicknesses of flood-sediment deposits ranged from 0.04 (the minimum measurable) to 7.7 ft. Sediment deposits greater than 1 ft thick were composed mainly of sand-size particles (fig. 22). Areas at each site with at least 1 ft or greater of sand were 1,800 acres at site 1, 13 acres at site 2, 32 acres at site 3, 132 acres at site 4, 138 acres at site 5, and 12 acres at site 6.

Sand deposits 2 or more feet thick have been considered to have a substantial detrimental effect on the agricultural productivity of the floodplain. According to Vance (1994), an area covered with 2 ft of sand would cost $5,000 per acre to reclaim for agricultural purposes. The areas covered with 2 ft or more of sand at the study sites were 840 acres at site 1, 2.3 acres at site 2, 13 acres at site 3, 33 acres at site 4, 69 acres at site 5, and 2.1 acres at site 6.

Soil Chemistry of Pre-Flood Soil and Flood-Sediment Samples

The chemistry of new sediments deposited on the floodplain also may affect floodplain resources. Soil chemistry is sensitive to particle size because of particle-size controls on surface area, water-holding capacity, and charge-to-surface ratio. Chemical activity in a soil mainly is attributed to the clay, fine silt, and organic material content, whereas sand and coarse silt particles—although necessary for tilth—are relatively inactive chemically (Brady, 1984). Increases in sand percentages at the expense of silt and clay may decrease the water- and nutrient-holding capacity of floodplain soils. In some cases, sand increases in levee-break complexes may improve the tilth of the soil. Most sites had net increases in sand and decreases in clay content as a result of flooding and sedimentation (fig. 26).

Pre-flood soil and flood sediment were sampled and analyzed for selected macronutrient base cations (calcium, magnesium, sodium, and potassium), CEC, organic carbon, and pH at sites 4 and 5 (table 8, at the back of this report). Macronutrients are soil elements needed for plants in relatively large quantities and are in the form of ions that can be adsorbed by the plants from the soil solution, the liquid phase of the soil (Mengel and Kirkby, 1982). For soil/plant relations, macronutrient availability in the soil is more important than the total mineral element content in the soil (Brady, 1984). Macronutrient availability is determined by extracting the cation from the soil with ammonium acetate at a pH of 7.0. The concentration of the available cation is then determined from the soil extractant. The extractant contains cations that were adsorbed on the negatively charged surfaces of the soil particles (that is, cation exchange sites on colloidal soil particles), as well as the dissolved cations in the soil solution. The results of the analysis are termed extractable because both the exchangeable and soluble cations are included.

The extractable base cations calcium, magnesium, sodium, and potassium generally are assumed to be the major exchangeable cations on the cation exchange sites of the soil (Soil Survey Laboratory, 1992). The exchangeable cations include the nonhydrogen species, which are collectively called the exchangeable bases (generally calcium, magnesium, sodium, and potassium), and the acidic species including hydrogen ions and aluminum ions, which are referred to collectively as the exchangeable acidity (Birkeland, 1974). The cations adsorbed on the cation exchange sites of the soil particles can be exchanged by other cation species, usually between the liquid and solid soil phases. The CEC is the sum of the exchangeable cations and is a measure of the macronutrient-holding capacity of the soil (Mengel and Kirkby, 1982).

The soil chemistry data were analyzed in three ways. Boxplots showing the median, quartiles, and extreme data for pre-flood soil and flood-sediment samples for sites 4 and 5 are shown in figure 27. These plots depict the characteristics of the pre-flood soil and flood-sediment sample sets.

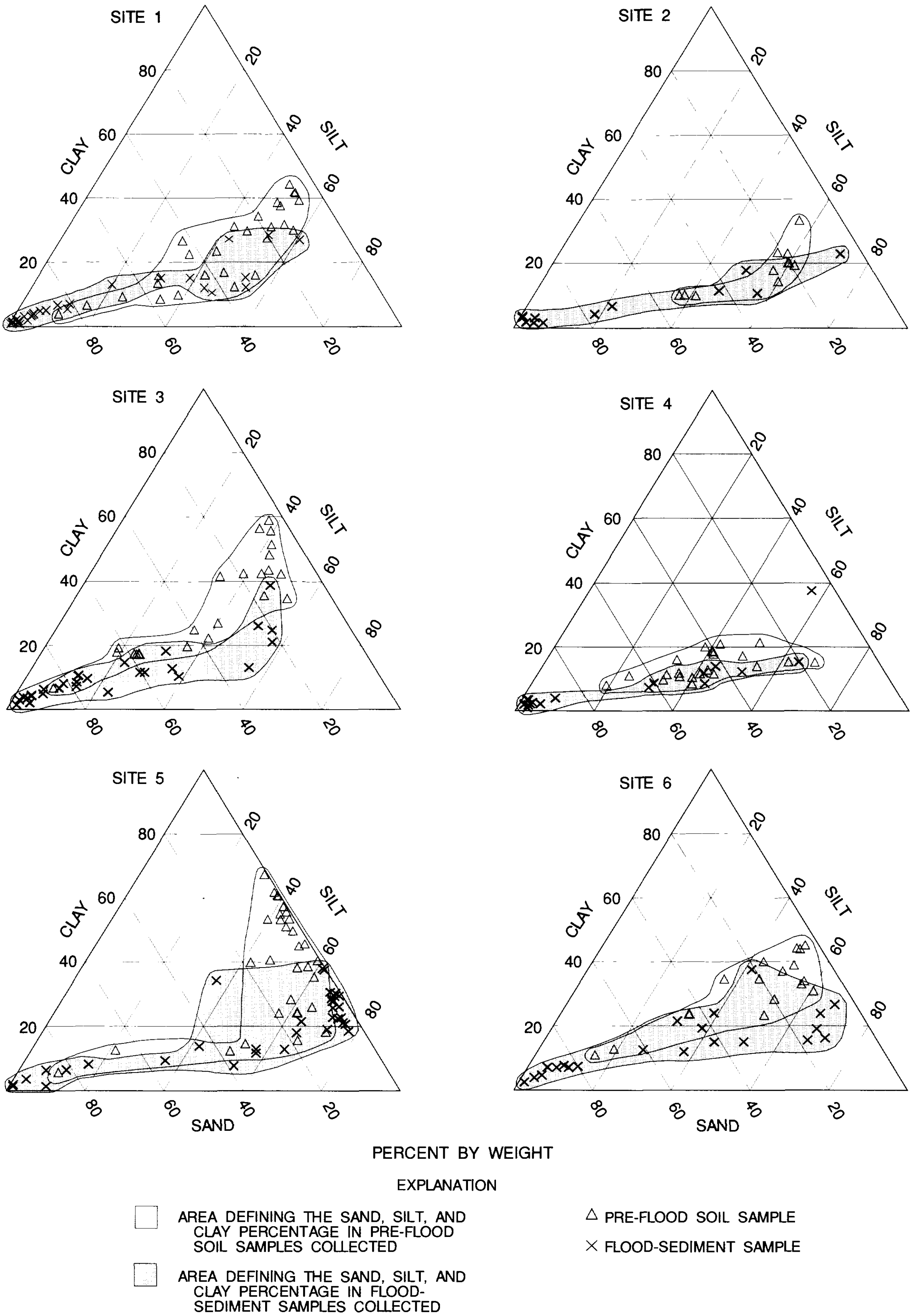


Figure 26. Percent by weight of sand, silt, and clay in pre-flood soil and flood-sediment samples at levee-break sites.

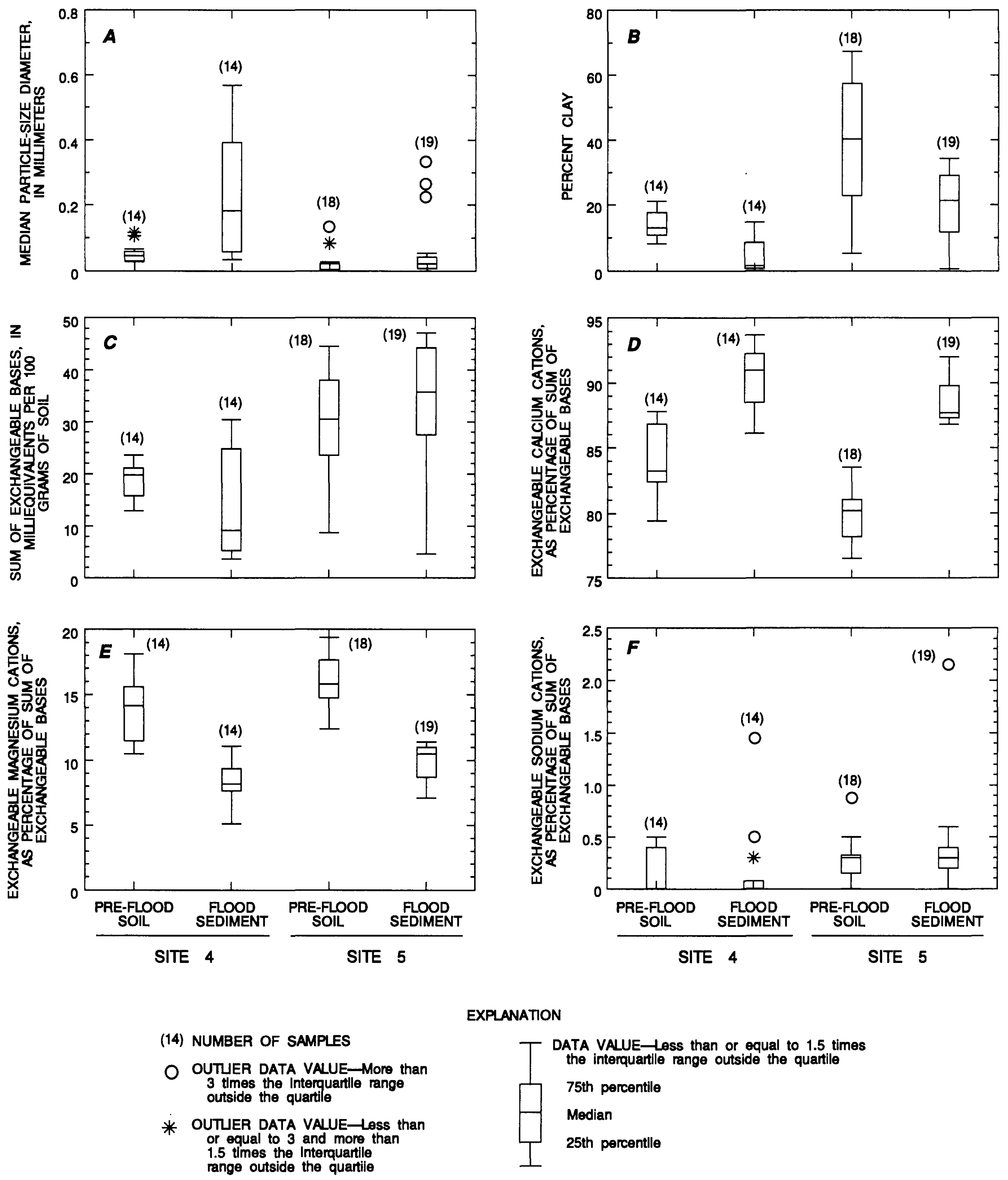


Figure 27. Soil chemistry data for pre-flood soil and flood-sediment samples at sites 4 and 5.

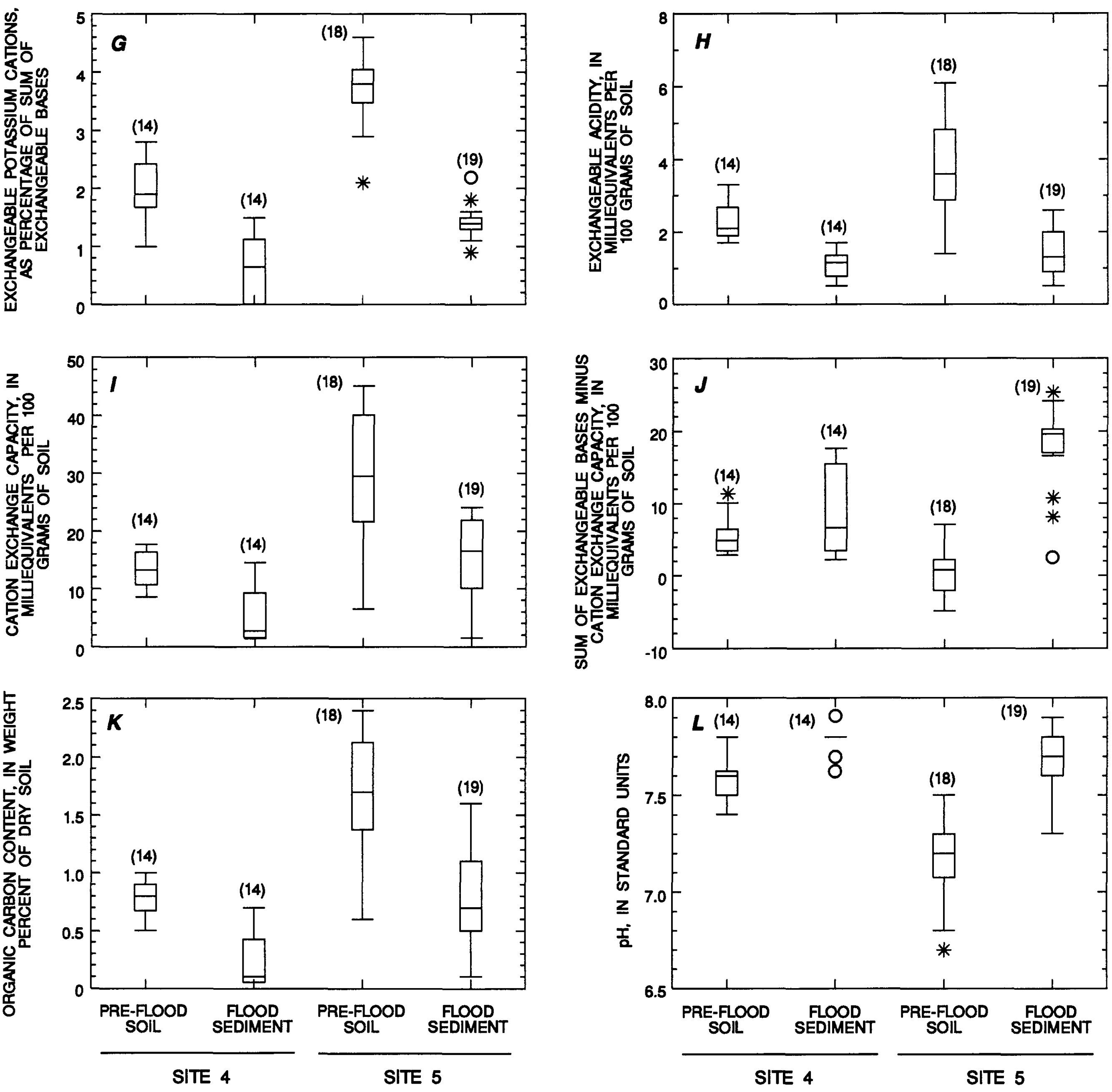


Figure 27. Soil chemistry data for pre-flood soil and flood-sediment samples at sites 4 and 5—Continued.

The sample sets were subjected to simple statistical tests to identify significant differences between pre-flood soil and flood-sediment samples at each site. The untransformed data were compared in median tests (Helsel and Hirsch, 1992) with the null hypothesis that the pre-flood soil and flood-sediment samples have identical medians for the particular analyses. The Kruskal-Wallis median test requires no assumptions about the shape of the data distribution. Significant differences were determined at the $\alpha = 0.05$ level; that is, for those comparisons noted as significant in table 9, the probability that the sample sets actually have the same median is $\alpha = 0.05$ or less.

The data also were subjected to nonparametric comparisons of the distribution characteristics of the samples. First, the four data sets (two pre-flood soil data sets and two post-flood sediment data sets) were subjected to a Kruskal-Wallis one-way analysis of variance (Helsel and Hirsch, 1992) to determine if the four combinations of pre- and post-flood sites had identical distributions. All of these tests (table 9) indicated that there were significant departures from identical distributions; that is, the probabilities that all sample sets had identical distributions for each of the measured properties were less than 0.05 ($\alpha = 0.05$). The data were then subjected to Tukey's non parametric multiple comparison on ranks (Helsel and Hirsch, 1992) to determine specific differences among distributions for pre-flood soil and flood-sediment samples at each site (table 9). Differences were considered significant if the probability that two samples came from the same distribution was 0.05 or less.

In addition, soil chemistry data were plotted by median particle-size diameter for each site, distinguishing between pre-flood soil and flood-sediment samples (figs. 28, 29). These plots show the variations between sample sets and the association of soil chemistry data with particle-size diameter.

Particle-size characteristics of pre-flood soil and flood-sediment samples were discussed in a previous section. For the subset of samples used for soil chemistry data, the median particle-size diameter was significantly finer for pre-flood soil than for flood-sediment samples at both sites (fig. 27A; table 9). Correspondingly, the percent clay (particle-size diameter less than 0.002 mm) was significantly greater for pre-flood soil than for flood-sediment samples (fig. 27B; table 9).

The CEC of pre-flood soil was significantly higher than that of flood-sediment samples at both sites (fig. 27C; table 9). Cation exchange capacities of pre-flood soil and flood-sediment samples increased similarly with decreasing median particle size (figs. 28, 29).

The sum of exchangeable bases did not vary significantly for sample sets between sites or between pre-flood soil and flood-sediment samples (fig. 27D; table 9). When plotted by median particle-size diameter (figs. 28, 29), the sum of exchangeable bases for a given particle-size diameter is higher for flood sediment than for pre-flood soil samples.

Exchangeable acidity and percentages of calcium, magnesium, and potassium (as percentages of the sum of extractable bases) varied significantly (fig. 27E-G, 27I; table 9) between pre-flood soil and flood-sediment samples. Flood sediment was relatively enriched in extractable calcium cations and poor in magnesium and potassium extractable cations. The pH of flood-sediment samples was significantly higher than that for pre-flood soil samples (fig. 27; table 9) and was relatively insensitive to particle size (figs. 28, 29).

Organic carbon content was significantly lower for flood sediment compared to pre-flood soil samples (fig. 27K; table 9). Generally, organic carbon content was inversely related to median particle-size diameter (figs. 28, 29). However, even for a given particle-size diameter, pre-flood soil samples tended to have higher organic carbon contents. Some of the greatest variation between pre-flood soil and flood-sediment samples at sites 4 and 5 was in the difference obtained from subtracting the CEC from the sum of the exchangeable bases (fig. 27L; table 9). Values greater than zero (excess bases) result mainly from free cations in the soil solution. Free cations probably result from soluble minerals like calcium carbonate. Values less than zero indicate the part of the CEC occupied by acidic cations, or exchangeable acidity (Buol and others, 1989). When acidity is added to the sum of extractable bases, the abscissa values in figures 28 and 29 are moved upward so no differences are less than zero; the relations between pre-flood soil and flood-sediment samples do not change, however.

The difference between the sum of the exchangeable bases and the CEC is substantially larger for flood sediment as compared to pre-flood soil samples (fig. 27L; table 9); the difference is statistically significant at site 5. The difference increases in flood-sediment samples as the median particle-size diameter decreases, probably indicating greater free

Table 9. Results of statistical tests of soil-chemistry data for pre-flood soil and flood-sediment samples

[**, differences in pre-flood soil and flood-sediment samples are significant at $\alpha = 0.05$ level; ‡, differences are not significant at the $\alpha = 0.05$ level]

Site number	Median particle-size diameter	Clay content	Cation exchange capacity	Sum of exchange-able bases	Exchange-able acidity	Percentage of sum of exchangeable bases				pH, water suspension	Organic carbon content	Sum of bases minus cation exchange capacity
						Calcium cations	Magnesium cations	Sodium cations	Potassium cations			
Kruskall-Wallis median test												
4	**	**	**	‡	**	**	**	‡	**	**	**	‡
5	‡	‡	**	‡	**	**	**	‡	**	**	**	**
Kruskal-Wallis one-way analysis of variance by ranks												
4 and 5	**	**	**	**	**	**	**	**	**	**	**	**
Tukey's nonparametric multiple comparison on ranks												
4	**	**	**	‡	**	**	**	‡	**	**	**	‡
5	**	**	**	‡	**	**	**	‡	**	**	**	**

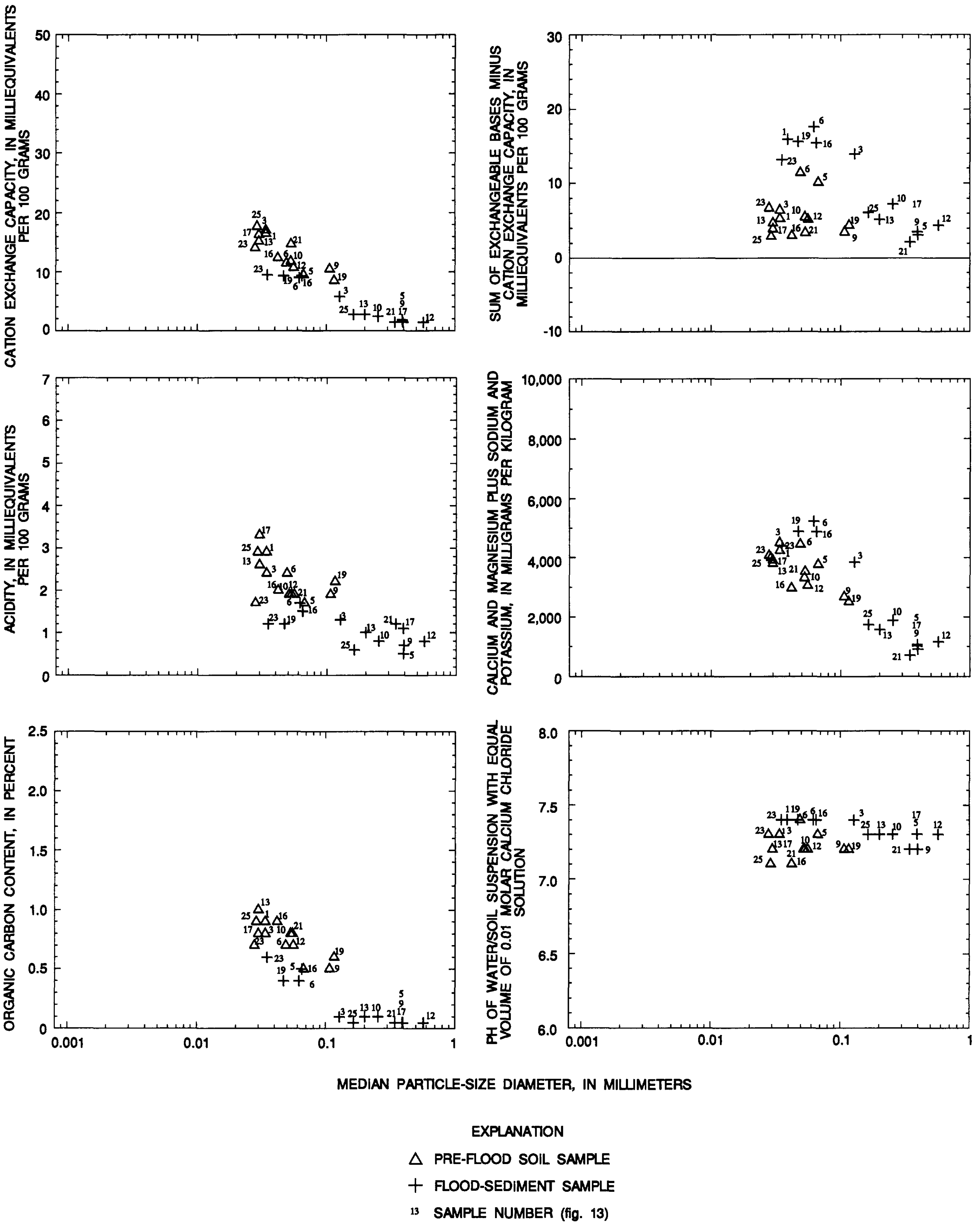


Figure 28. Soil chemistry and sample median particle-size diameter at site 4 at Arrow Rock, Missouri.

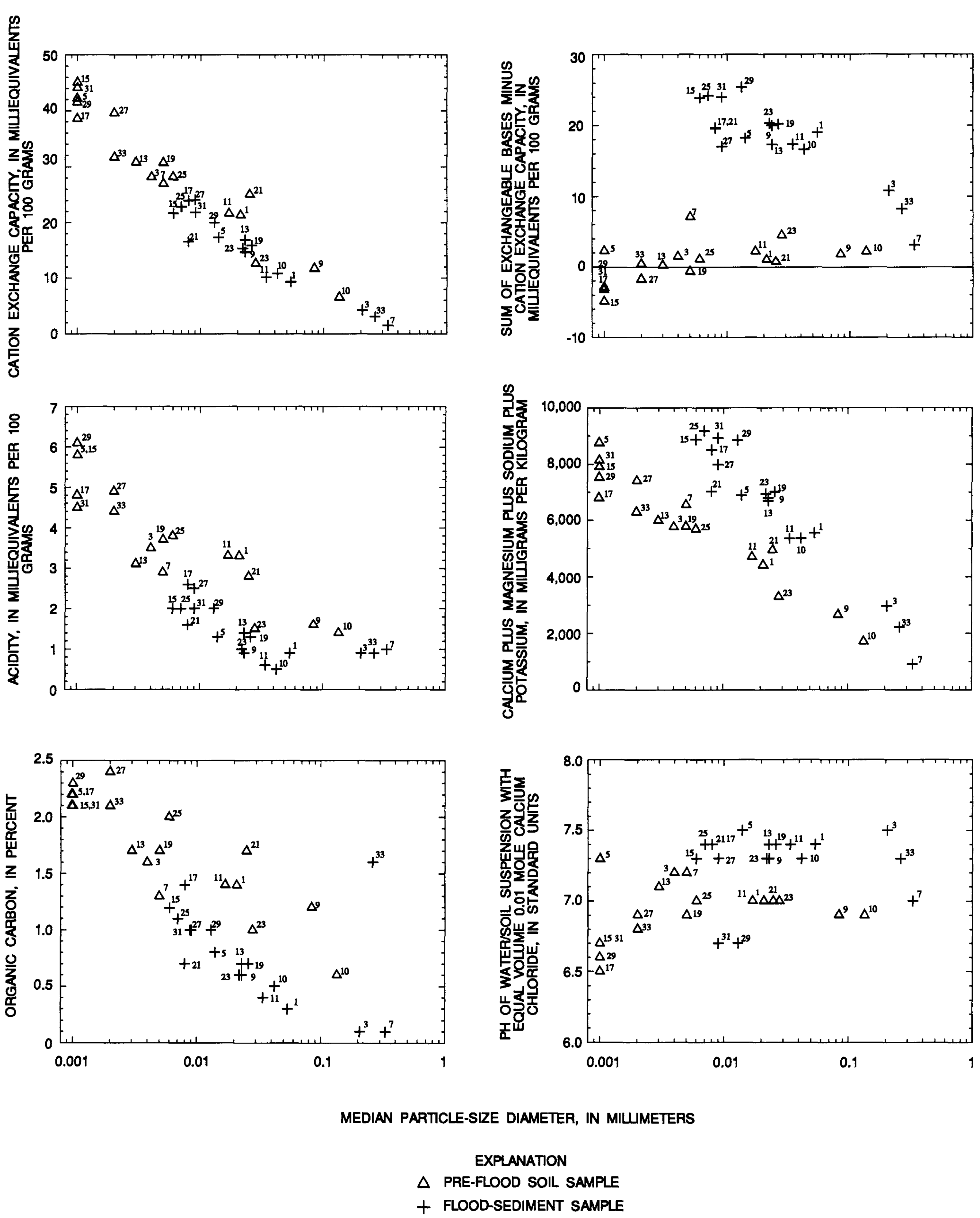


Figure 29. Soil chemistry and sample median particle-size diameter at site 5 in Saline County, Missouri.

cations in the soil solution in fine-grained samples (figs. 28, 29). The difference in the pre-flood soil samples decreases at site 5 as particle-size diameter decreases, even to the point where the CEC is larger than the sum of the extractable cations for seven samples. Thus, the flood sediments have more soluble cations readily available for uptake by plants or leaching. This availability increases as the median particle-size diameter decreases.

Because these sites were not subject to agricultural application of lime, high concentrations of extractable calcium, high pH values, and large differences in the sum of extractable cations and the CEC in the flood sediment indicate that the sediment was enriched by a source of relatively unweathered, limestone- or carbonate-rich sediment. Scour of floodplains and the channel bed during the 1993 flood may have eroded previously unweathered materials and allowed transport of the unweathered material onto the floodplain. Alternatively, scour of the floodplains may have exhumed sediments that had accumulated agriculturally applied lime.

Herbicide Concentrations in Pre-Flood Soil and Flood-Sediment Samples

Herbicides are used for weed and grass control for crops such as corn, soybeans, and milo. During the 1993 flood, large quantities of herbicides were flushed from fields into the Missouri River and tributary streams (Goolsby and others, 1993). The Missouri River Basin was flooded during and just after the peak application time for herbicides, so the potential existed for large quantities of herbicides to be transported during the flood.

The transport and fate of herbicides depend on factors such as solubility, soil sorption, and half life in the soil and water (Goolsby and others, 1993). For sediments in the levee-break complexes to have appreciable herbicides concentrations, the herbicide compounds would have to be present in floodwaters or sorbed onto sediment particles, the compounds would have to be deposited from floodwaters or with flood sediment, and the herbicide compounds would have to be sufficiently stable so that they could be detected when the samples were obtained nearly 1 year after the flood.

The presence of large quantities of common herbicides transported during the 1993 flood has been documented by Goolsby and others (1993). The most common herbicides in the upper Midwest—alachlor, atrazine, cyanazine, and metolachlor—have relatively low soil sorption coefficients and are considered to be transported mainly in the dissolved phase. Hence, most of the herbicides in levee-break complexes would be expected to come from floodwaters rather than being transported into the sites in association with sediment particles. The soil half life for these major herbicides ranges from 14 to 75 days (Goolsby and others, 1993); therefore, in the 240 days between the end of the flood and sampling at site 5 and the 300 days that elapsed before sampling at site 4, considerable quantities of herbicides could have been lost by degradation. The effect of degradation can be accounted for in part by comparing herbicide concentrations in pre-flood soil with those of the flood-sediment samples. This comparison does not take into account leaching of herbicides from flood sediment into underlying pre-flood soil, nor does it take into account possible differences in rates of degradation. For example, smaller particle sizes, higher organic matter content, and greater biological activity of pre-flood soil might lead to faster herbicide degradation rates than rates in flood-sediment samples. Although the comparison is imperfect, it should suffice to show substantial trends in herbicide concentrations, if such trends exist.

Herbicide concentrations were analyzed in 10 pre-flood soil and flood-sediment samples collected at site 4 and 14 pre-flood soil and flood-sediment samples collected at site 5 (table 10). The purpose of these analyses was to document herbicide concentrations in the levee-break complex sediments and to compare them with pre-flood soil concentrations. The herbicide samples are a subset of the soil chemistry and particle-size samples.

Summary statistics of the herbicide concentrations for all samples are presented in table 11. At site 4, ametryn, cyanazine amide, deethylatrazine, and deisopropylatrazine were detected in pre-flood soil samples, but not in flood-sediment samples. Only alachlor, atrazine, and metolachlor were detected in the flood-sediment samples at site 4, and these herbicides had smaller median concentrations than the pre-flood soil samples. Atrazine was the most frequently detected herbicide, with nine detections out of 10 samples in both the pre-flood soil and flood-sediment samples. The maximum detected herbicide concentrations in the pre-flood soil samples were greater than the maximum detected concentrations in the flood-sedi-

Table 10. Herbicide concentrations in pre-flood soil and flood-sediment samples at sites 4 and 5

[Herbicide concentrations reported in micrograms per kilogram; <, less than]

Site number (figs. 13, 15)	Aceto-chlor	Ala-chlor	Ame-tryn	Atra-zine	Cyan-azine	Cyanazine amide	Deethyl-atrazine	Deisopropyl-atrazine	Metol-achlor	Metribu-zin	Pro-meton	Pro-metryn	Prop-azine	Sim-azine	Terb-utryn
Site 4—Pre-flood soil samples, June 2 and 3, 1994															
1	<0.2	<0.2	1.1	2.3	<0.2	<0.2	<0.2	<0.2	5.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
3	<.2	.6	<.2	2.9	<.2	<.2	<.2	<.2	.8	<.2	<.2	<.2	<.2	<.2	<.2
5	<.2	<.2	<.2	4.0	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
9	<.2	<.2	<.2	5.0	<.2	4.8	<.2	.8	<.2	<.2	<.2	<.2	<.2	<.2	<.2
13	<.2	1.2	1.9	4.8	<.2	<.2	<.2	<.2	1.1	<.2	<.2	<.2	<.2	<.2	<.2
17	<.2	3.9	<.2	5.0	<.2	<.2	<.2	<.2	1.7	<.2	<.2	<.2	<.2	<.2	<.2
[1]17	<.2	2.9	<.2	5.6	<.2	<.2	<.2	<.2	2.1	<.2	<.2	<.2	<.2	<.2	<.2
19	<.2	.8	<.2	1.3	<.2	<.2	<.2	<.2	1.8	<.2	<.2	<.2	<.2	<.2	<.2
21	<.2	3.2	<.2	11	<.2	<.2	1.7	<.2	1.2	<.2	<.2	<.2	<.2	<.2	<.2
23	<.2	<.2	<.2	6.0	<.2	<.2	4.2	<.2	.6	<.2	<.2	<.2	<.2	<.2	<.2
25	<.2	3.8	<.2	<.2	<.2	<.2	1.7	<.2	2.5	<.2	<.2	<.2	<.2	<.2	<.2
[2]25	<.2	3.0	<.2	12	<.2	<.2	1.8	<.2	2.4	<.2	<.2	<.2	<.2	<.2	<.2
Site 4—Flood-sediment samples, June 2 and 3, 1994															
1	<0.2	1.1	<0.2	2.1	<0.2	<0.2	<0.2	<0.2	0.9	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
[b]1	<.2	1.3	.5	2.0	<.2	<.2	<.2	<.2	1.2	<.2	<.2	<.2	<.2	<.2	<.2
3	<.2	<.2	<.2	2.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
5	<.2	<.2	<.2	1.1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
9	<.2	<.2	<.2	1.1	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
13	<.2	<.2	<.2	1.6	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
17	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
19	<.2	.7	<.2	1.9	<.2	<.2	<.2	<.2	.8	<.2	<.2	<.2	<.2	<.2	<.2
21	<.2	<.2	<.2	.8	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
23	<.2	.7	<.2	3.1	<.2	<.2	<.2	<.2	.9	<.2	<.2	<.2	<.2	<.2	<.2
25	<.2	<.2	<.2	.7	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Site 5—Pre-flood soil samples, April 28 and 29, 1994															
1	<0.2	<0.2	<0.2	1.4	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.20	<0.2	<0.2
1	<.2	<.2	<.2	2.3	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
3	<.2	<.2	<.2	2.1	4.0	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
5	<.2	<.2	<.2	2.2	5.0	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
9	<.2	<.2	<.2	2.5	2.9	<.2	<.2	<.2	2.1	<.2	<.2	<.2	<.2	<.2	<.2
10	<.2	<.2	<.2	2.8	6.7	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2

Table 10. Herbicide concentrations in pre-flood soil and flood-sediment samples at sites 4 and 5—Continued

Site number (figs. 13, 15)	Aceto-chlor	Ala-chlor	Ame-tryn	Atra-zine	Cyan-azine	Cyanazine amide	Deethyl-atrazine	Deisopropyl-atrazine	Metol-achlor	Metribu-zin	Pro-meton	Pro-metryn	Prop-azine	Sim-azine	Terb-utryn
Site 5—Pre-flood soil samples, April 28 and 29, 1994—Continued															
11	<0.2	<0.2	<0.2	1.3	3.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
13	<.2	<.2	<.2	21	<.2	<.2	2.4	<.2	19	<.2	<.2	<.2	.5	<.2	<.2
15	<.2	<.2	<.2	16	1.4	<.2	3.3	1.1	4.7	<.2	<.2	<.2	<.2	<.2	<.2
17	<.2	<.2	<.2	1.4	1.5	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
19	<.2	<.2	<.2	2.1	1.5	<.2	1.1	<.2	2.0	<.2	<.2	<.2	<.2	<.2	<.2
21	<.2	<.2	<.2	2.3	1.3	<.2	.5	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
27	<.2	<.2	<.2	9.3	1.5	<.2	1.6	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
29	<.2	<.2	<.2	9.3	1.6	<.2	2.9	.9	39	<.2	<.2	<.2	<.2	<.2	<.2
31	<.2	<.2	<.2	.7	1.6	<.2	.8	<.2	2.5	<.2	<.2	<.2	<.2	<.2	<.2
Site 5—Flood-sediment samples, April 28 and 29, 1994															
1	<0.2	<0.2	<0.2	5.8	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
[b]1	<.2	<.2	<.2	3.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
3	<.2	<.2	<.2	1.5	<.2	<.2	<.2	<.2	.5	29	<.2	<.2	<.2	<.2	<.2
5	<.2	<.2	<.2	2.4	2.6	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
9	<.2	1.3	<.2	2.9	4.0	<.2	<.2	<.2	1.3	<.2	<.2	<.2	<.2	<.2	<.2
[a]9	<.2	1.0	<.2	2.9	3.2	<.2	<.2	<.2	1.2	<.2	<.2	<.2	<.2	<.2	<.2
10	<.2	<.2	<.2	1.4	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
11	<.2	<.2	<.2	2.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
13	<.2	.8	<.2	1.9	1.7	<.2	<.2	<.2	1.2	<.2	<.2	<.2	<.2	<.2	<.2
15	<.2	<.2	<.2	1.4	1.4	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
17	<.2	.6	<.2	2.4	1.5	<.2	<.2	<.2	1.1	<.2	<.2	<.2	<.2	<.2	<.2
[a]17	<.2	<.2	<.2	2.4	1.6	<.2	<.2	<.2	1.1	<.2	<.2	<.2	<.2	<.2	<.2
19	<.2	<.2	<.2	2.4	1.3	<.2	<.2	<.2	3.1	<.2	<.2	<.2	<.2	<.2	<.2
21	<.2	1.7	<.2	1.9	1.6	<.2	<.2	<.2	1.5	<.2	<.2	<.2	<.2	<.2	<.2
27	<.2	<.2	<.2	2.7	1.5	<.2	.5	<.2	.9	<.2	<.2	<.2	<.2	<.2	<.2
29	<.2	.8	<.2	3.2	1.4	<.2	<.2	<.2	2.2	<.2	<.2	<.2	<.2	<.2	<.2
31	<.2	1.5	<.2	3.1	1.7	<.2	.7	<.2	3.0	<.2	<.2	<.2	<.2	<.2	<.2
[a]31	<.2	.9	<.2	1.0	<.2	<.2	<.2	<.2	1.3	<.2	<.2	<.2	<.2	<.2	<.2

[1]Duplicate sample.
[2]Replicate sample.

Table 11. Summary statistics of herbicide concentrations, percent clay, and percent organic carbon in pre-flood soil and flood-sediment samples at sites 4 and 5

[Concentrations are reported in micrograms per kilogram; <, less than; --, not applicable; median values only computed for the herbicides with 50 percent or greater detections; clay particle sizes are less than 0.002 millimeter in diameter]

Summary statistics	Ala-chlor	Ame-tryn	Atra-zine	Cyan-azine	Cyanazine amide	Deethyl-atrazine	Deisopropyl-atrazine	Metol-achlor	Metribu-zin	Prop-azine	Clay content percent	Organic carbon content percent
Site 4—Pre-flood soil samples (sample size = 10)												
Number of detections	6	2	9	0	1	3	1	8	0	0	10	10
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	8.2	.5
Maximum	3.9	1.9	11	<.2	4.8	4.2	.8	5.1	<.2	<.2	21	1
Median	.7	<.2	4.4	<.2	<.2	<.2	<.2	1.1	<.2	<.2	16	.8
Site 4—Flood-sediment samples (sample size = 10)												
Number of detections	3	0	9	0	0	0	0	3	0	0	10	10
Minimum	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	.1	<.1
Maximum	1.1	<.2	3.1	<.2	<.2	<.2	<.2	.9	<.2	<.2	14	.7
Median	<.2	<.2	1.4	<.2	<.2	<.2	<.2	<.2	<.2	<.2	1.2	.08
Site 5—Pre-flood soil samples (sample size = 14)												
Number of detections	0	0	14	12	0	7	2	6	0	1	14	14
Minimum	<.2	<.2	.7	<.2	<.2	<.2	<.2	<.2	<.2	<.2	5.3	.6
Maximum	<.2	<.2	21	6.7	<.2	3.3	1.1	40	<.2	.5	67	2.4
Median	<.2	<.2	2.3	1.5	<.2	.3	<.2	<.2	<.2	<.2	43	1.7
Site 5—Flood-sediment samples (sample size = 14)												
Number of detections	6	0	14	10	0	2	0	9	1	0	14	14
Minimum	<.2	<.2	1.4	<.2	<.2	<.2	<.2	<.2	<.2	<.2	6.1	.1
Maximum	1.7	<.2	5.8	4.0	<.2	.7	<.2	3.1	29	<.2	34	1.4
Median	<.2	<.2	2.4	1.5	<.2	<.2	<.2	1.1	<.2	<.2	21	.7

ment samples. Herbicide concentrations in pre-flood soil samples were dependent mainly on whether herbicides were applied to that field and the factors that govern degradation and leaching of the herbicide in the period between application and sampling; data on the type and quantity of herbicides applied to the fields and the factors affecting loss of the herbicide were not collected as part of this study.

Atrazine was detected in all pre-flood soil and flood-sediment samples from site 5 (table 10). The median atrazine (2.3 μg/kg) and metolachlor (less than 0.2 μg/kg) concentrations in the pre-flood soil samples were less than the median concentrations for the flood-sediment samples (2.4 and 1.1 μg/kg; table 11). Median concentrations of cyanazine were 1.5 μg/kg in both pre-flood soil and flood-sediment samples. Only the median deethylatrazine concentration was greater in the pre-flood soil samples than in the flood-sediment samples. However, the maximum concentrations of all herbicides except alachlor and metribuzin were greater in the pre-flood soil samples than in the flood-sediment samples. Alachlor was not detected in the pre-flood soil samples, but was detected in six flood-sediment samples. Metribuzin was detected in only one flood-sediment sample.

Statistical analyses were performed on the atrazine concentration data sets. The Kruskal-Wallis nonparametric analysis of variance (Helsel and Hirsch, 1992) was used to test for significant differences ($\alpha = 0.05$) among the ranks of atrazine concentrations in the pre-flood soil and flood-sediment samples at sites 4 and 5. The test results indicated a significant difference ($\alpha = 0.025$). Because a significant difference was detected among data sets and sites, a nonparametric multiple comparison analysis of variance was used on the ranks of the atrazine concentrations to determine which data sets were significantly different. For the analyses between sites and pre-flood soil and flood-sediment samples, the only significant difference in ranks was obtained for pre-flood soil and flood-sediment samples at site 4 (Tukey's test, $\alpha = 0.05$), where the pre-flood soil concentrations of atrazine (4.4 μg/kg, median concentration) were significantly greater than the flood-sediment concentrations (1.4 μg/kg, median concentration).

The atrazine concentrations detected at all sites for pre-flood soil and flood-sediment samples were small relative to concentrations that are possible in agricultural fields. The small concentrations probably result from dilution with flood sediment that had low atrazine concentrations and degradation between application and sample analysis. Concentrations of atrazine in silty loam topsoil samples in Kansas (Perry, 1991) were 20 μg/kg in a sample collected from a field with an atrazine application of 1.5 pounds per acre and 22 and 31 μg/kg in samples collected from a field with an atrazine application of 3.0 pounds per acre. These samples were collected 1 year after application, and the concentrations detected were considered to be small (Perry, 1991). In comparison, the maximum concentration of atrazine in the data used for this report was 21 μg/kg in pre-flood soil samples.

SUMMARY AND CONCLUSIONS

Levee failure during the 1993 Missouri River flood allowed large volumes of floodwaters and flood sediment to enter the Missouri River floodplain. Scour of pre-flood soils and deposition of flood sediments caused extensive physical changes to the land surface and substantially altered the physical and chemical characteristics of the floodplain. The six levee-break complexes documented in this report exhibited a wide range of characteristics representative of levee-break complexes formed by the 1993 flood.

All six levee breaks probably were caused by overtopping. The levee breaks occurred from July 6 to 8, 1993, at sites 1, 2, and 3 and from July 22 to 24, 1993, at sites 4, 5, and 6. Geomorphic changes were caused by the large hydraulic heads that had been maintained by the levees until they were overtopped. The minimum hydraulic head estimated at the sites ranged from 5 (sites 1 and 4) to 11 feet (sites 2 and 6).

Scour volumes ranged from 150 to 720 acre-feet at the connected-scour sites and were less than 94 acre-feet at the unconnected-scour sites. Scour volumes at depths below the pre-flood elevation of the floodplain ranged from 89 to 95 percent of the total scour volumes at the connected-scour sites and were 65 and 89 percent of the total scour volume at the unconnected-scour sites. Maximum scour depths were at or near the levee center line at all sites except site 1, where the maximum depth was on the upstream side of the scour between the channel and the levee center line. The maximum measured scour depths ranged from 20 to 51 feet below the average floodplain elevation.

The net sediment volumes (total sediment volume minus the scour volume) ranged from -340 to +4,200 acre-feet at the connected-scour sites and were less than 20 acre-feet at the unconnected-scour sites. Sediment volume ranged from 26 to 680 percent of scour volume at the connected-scour sites and ranged from 117 to 162 percent of scour volume at the unconnected-scour sites. Sediment volume ranged from 26 to 680 percent of scour volume at the connected-scour sites and ranged from 117 to 162 percent of scour volume at the unconnected-scour sites. The average sediment thickness ranged from 0.3 foot at site 5 to 0.7 foot at site 1, whereas maximum measured thicknesses ranged from 3.1 to 7.7 feet.

Generally, connected levee-break complexes provided substantial potential sinks for sediment in transport. The net mass of flood sediments at site 1 (7.7 to 12.6 million tons) was 10 to 16 percent of the total sediment load transported by the Missouri River past Hermann, Missouri, during the flood. At this site, the scour volume was 15 percent of the sediment volume on the floodplain. In contrast, the scour volume at site 4 was 190 percent of the sediment volume. Net sediment loss from site 4 may have been because of sedimentation on a floodplain upstream from site 4 and subsequent depletion of sediment supply in the river, or the floodplain hydraulics at site 4. Unconnected scours were likely to be sources of sediment or have net contributions of zero. Of the unconnected scours, scour volume was 87 percent (site 3) and 61 percent (site 6) of the sediment volume; the scour to sediment mass ranged from 53 to 139 percent at site 3 and from 38 to 100 percent at site 6. These volumes are within the range to indicate that most of the sediments deposited on the floodplain came from the scour.

Conclusions about net scour at connected sites, however, must additionally take into account differences in particle-size distributions between what was eroded and what was deposited. Flood-sediment particle-size distributions are intermediate between those of bed material and suspended load. At sites where sedimentation was greater than erosion, this distribution indicates an origin of the bulk of levee-break complex sediment from either bedload (which was not sampled during the 1993 flood and may have been substantially finer than sampled bed material) or the coarsest fraction of suspended load. In addition, 32 to 61 percent of the volume of sediment eroded from these sites consisted of silt-to-clay top stratum with particle-size distributions similar to suspended load, whereas most of the sediment deposited was sand. Hence, the calculations of net sedimentation represent minimum fluxes of sand-sized sediment onto the floodplain at connected-scour sites.

Physical and chemical characteristics of floodplain soils were substantially affected by deposition in levee-break complexes. The large depths and volumes of sand deposits were the most dramatic effect of levee breaks. Deposits greater than 1 foot thick consisted mostly of sand. The area affected by 2 feet or more of sand at the study sites ranged from 2.3 acres at site 2 to 840 acres at site 1.

Changes in soil-chemistry characteristics were related to the overall coarser particle size, enrichment in extractable calcium, and lack of organic material in flood-sediment samples compared to pre-flood soil samples. Statistical testing indicated that cation exchange capacities and extractable acidities of the flood-sediment samples were significantly smaller than in the pre-flood soil samples. The sums of extractable cations in the pre-flood soil and flood-sediment samples were similar; however, the calcium percentage was larger and the magnesium and potassium plus sodium percentage was smaller in the flood-sediment samples than in the pre-flood soil samples. The pH of the flood-sediment samples was statistically higher than in pre-flood soil samples, and the organic carbon content was statistically lower. The differences between summed extractable bases and cation exchange capacity was statistically larger for flood-sediment samples than for pre-flood soil samples, probably indicating a source of soluble base cations in the soil solution of flood sediments.

The net effect of changed soil chemistry where appreciable deposition occurred in levee-break complexes depends on the balance of competing trends at particular locations. Increased pH and available calcium in flood sediments may have a somewhat ameliorative effect on soil fertility available on the floodplain, and additions of sand at some locations may increase the workability of heavy, clay-rich pre-flood soils. These benefits may be canceled by decreases in water-holding capacity, cation exchange capacity, extractable magnesium and potassium, and organic carbon content, especially at sites where sand was deposited at thicknesses of 1 foot and greater.

Concentrations of common herbicides or their degradation products (including acetochlor, alachlor, ametryn, atrazine, cyanazine, cyanazine amide, deethylatrazine, deisopropylatrazine, metolachlor, metribuzin, prometon, prometryn, propazine, simazine, and terbutryn) in pre-flood soil and flood-sediment samples were uniformly low or nondetectable. Among the tested herbicides, atrazine had the highest median concentrations in all four data sets and was detected in all samples except one pre-flood soil sample from site 4 and one flood-sediment sample from site 4. Median atrazine concentrations at sites 4 and 5 were 2.3 and 4.4 micrograms per kilogram in the pre-flood soil samples and 1.4 and 2.3 micrograms per kilogram in the flood-sediment samples. Atrazine concentrations at site 4 were statistically higher in pre-flood soil (median value of 4.4 micrograms per kilogram) than in flood-sediment samples (median value of 1.4 micrograms per kilogram); atrazine concentrations at site 5 were statistically similar in pre-flood soil and flood-sediment samples. The maximum atrazine concentration measured (21 micrograms per kilogram in a pre-flood soil sample at site 5) was low compared to atrazine concentrations possible in agricultural fields.

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TABLES

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Table 7. Particle-size characteristics for pre-flood soil and flood-sediment samples at levee-break sites

[<, less than; mm, millimeter; >, greater than; --, data not available]

Sample number	Total clay, <0.002 mm (percent)	Total silt, 0.002–0.05 mm (percent)	Total sand, 0.05–2 mm (percent)	Fine silt, 0.002–0.02 mm (percent)	Coarse silt, 0.02–0.05 mm (percent)	Very fine sand, 0.05–0.1 mm (percent)	Fine sand, 0.1–0.25 mm (percent)	Medium sand, 0.25–0.5 mm (percent)	Coarse sand, 0.5–1 mm (percent)	Very coarse sand, 1–2 mm (percent)	Total gravel, >2 mm (percent)	Median particle size (mm)
Site 1—Pre-flood soil												
1	9.9	38.3	51.8	8.7	29.6	35.2	16.0	0.4	0.1	0.1	0.0	0.052
[a]1	9.9	35.4	54.7	8.4	27.0	36.4	17.5	.5	.2	.1	.0	.055
2	3.6	11.1	85.3	1.8	9.3	8.8	62.6	12.5	1.3	.1	.0	.147
3	34.1	45.9	19.1	29.1	16.7	2.2	10.4	3.4	2.5	.7	.9	.007
4	8.7	34.3	57.0	8.7	25.6	31.1	25.5	.3	.1	.0	.0	.058
5	13.6	31.2	55.2	12.8	18.4	13.9	40.5	.5	.2	.1	.0	.065
6	9.4	24.4	66.2	7.8	16.6	36.3	29.2	.5	.1	.1	.0	.2068
8	6.3	16.9	76.8	6.4	10.5	16.1	57.2	2.8	.5	.2	.0	.119
9	15.7	30.4	53.9	13.9	16.5	18.2	30.8	4.4	.4	.1	.0	.058
10	41.7	51.9	6.4	36.7	15.2	3.4	1.9	.9	.1	.1	.0	.003
11	38.6	49.1	12.3	29.8	19.3	8.2	3.6	.3	.1	.1	.0	.005
12	31.2	41.8	27.0	22.8	19.0	15.1	11.2	.5	.1	.1	.0	.013
13	41.8	52.0	6.2	32.8	19.2	5.4	.6	.1	.1	.0	.0	.004
14	23.5	41.2	35.3	18.7	22.5	26.5	8.2	.3	.1	.2	.0	.027
15	30.0	57.5	12.5	28.4	29.1	9.5	2.3	.2	.2	.3	.0	.010
16	17.0	46.3	36.7	15.6	30.7	25.7	10.6	.2	.1	.1	.0	.034
17	39.4	54.2	6.4	35.7	18.5	3.5	1.6	.7	.3	.3	.0	.004
18	22.5	34.9	42.6	14.9	20.0	34.2	7.8	.4	.1	.1	.0	.036
19	37.4	50.2	11.9	30.2	20.0	6.9	3.4	.7	.5	.5	.5	.005
20	27.1	51.9	20.6	27.1	24.8	15.3	4.1	.4	.3	.5	.4	.014
[a]20	27.5	51.2	20.9	25.6	25.6	15.1	4.3	.3	.5	.7	.4	.015
21	44.4	49.3	6.3	34.2	15.1	4.3	1.7	.1	.1	.1	.0	.003
22	16.0	54.7	29.3	16.4	38.3	24.7	3.9	.2	.2	.3	.0	.030
23	12.4	51.2	36.4	13.0	38.2	32.1	3.9	.1	.1	.2	.0	.036
24	16.2	41.9	41.9	14.6	27.3	39.0	2.6	.1	.1	.1	.0	.038
25	26.7	31.0	42.3	18.0	13.0	23.7	17.9	.4	.2	.1	.0	.029
26	31.0	51.3	17.7	29.1	22.2	14.2	3.3	.0	.1	.1	.0	.009
27	31.8	54.3	13.9	29.1	25.2	13.0	.7	.0	.0	.2	.0	.008
28	29.7	45.9	24.4	23.2	22.7	19.4	4.7	.2	.0	.1	.0	.015

Table 7. Particle-size characteristics for pre-flood soil and flood-sediment samples at levee-break sites—Continued

Sample number	Total clay, <0.002 mm (percent)	Total silt, 0.002–0.05 mm (percent)	Total sand, 0.05–2 mm (percent)	Fine silt, 0.002–0.02 mm (percent)	Coarse silt, 0.02–0.05 mm (percent)	Very fine sand, 0.05–0.1 mm (percent)	Fine sand, 0.1–0.25 mm (percent)	Medium sand, 0.25–0.5 mm (percent)	Coarse sand, 0.5–1 mm (percent)	Very coarse sand, 1–2 mm (percent)	Total gravel, >2 mm (percent)	Median particle size (mm)
Site 1—Flood sediment												
1	2.3	2.9	94.8	1.3	1.6	6.2	87.5	1.0	0.1	0.0	0.0	0.150
[a]1	2.5	3.0	94.5	1.3	1.7	6.0	87.3	1.1	.1	.0	.0	.150
2	1.9	2.7	95.4	.6	2.1	7.4	73.8	11.9	2.0	.3	.0	.160
3	1.1	.6	93.8	.6	.0	.3	17.4	19.7	44.2	12.3	4.4	.593
4	3.6	7.4	88.9	1.5	5.9	10.0	66.6	11.1	1.0	.2	.1	.149
5	1.0	1.1	97.1	.6	.5	.3	58.3	28.5	6.7	.3	.8	.211
6	.6	1.2	97.9	.6	.6	1.4	84.6	10.0	1.5	.4	.3	.166
7	.5	.1	99.4	.0	.1	.5	79.4	18.9	.5	.1	.0	.176
8	.4	1.6	97.7	1.5	.1	3.6	66.6	19.9	6.7	.9	.3	.184
9	.8	.3	98.9	.0	.3	.4	73.3	24.3	.9	.0	.0	.183
10	2.1	2.8	95.0	2.6	.2	1.1	63.8	27.1	2.7	.3	.1	.188
11	.7	.2	99.1	.2	.0	1.6	94.4	2.9	.1	.1	.0	.159
12	1.8	1.6	96.6	1.3	.3	3.0	88.7	4.6	.2	.1	.0	.157
13	1.1	2.5	96.4	.9	1.6	4.3	90.8	1.2	.1	.0	.0	.153
14	3.1	6.7	90.2	3.3	3.4	14.9	74.8	.3	.1	.1	.0	.136
15	4.9	12.9	82.2	4.0	8.9	21.0	60.7	.3	.1	.1	.0	.118
16	3.1	5.7	91.2	2.5	3.2	8.6	81.9	.5	.1	.1	.0	.144
17	26.9	60.7	12.4	32.4	28.3	7.3	4.7	.1	.1	.2	.0	.010
18	5.6	9.9	84.5	2.5	7.4	34.4	49.7	.1	.1	.2	.0	.100
19	15.0	31.4	53.6	13.2	18.2	33.9	18.4	.7	.3	.3	.0	.054
20	12.0	43.9	44.1	12.0	31.9	35.7	8.0	.2	.1	.1	.0	.042
[a]20	12.9	44.8	42.3	12.9	31.9	33.7	8.1	.2	.1	.2	.0	.040
21	13.1	19.9	67.0	10.9	9.0	20.7	45.9	.1	.1	.2	.0	.088
22	5.8	12.8	81.2	3.5	9.3	29.5	51.5	.1	.0	.1	.2	.103
23	10.6	46.5	42.9	10.1	36.4	37.0	5.3	.2	.2	.2	.0	.042
24	15.1	38.7	46.2	12.1	26.6	33.3	12.5	.2	.1	.1	.0	.044
25	15.2	52.7	32.1	16.8	35.9	27.0	4.5	.3	.2	.1	.0	.032
26	12.2	54.3	33.5	15.1	39.2	31.1	2.4	.0	.0	.0	.0	.034
27	28.3	52.1	19.6	28.9	23.2	17.1	2.3	.1	.0	.1	.0	.011
28	27.0	42.7	30.3	22.5	20.2	25.5	4.7	.0	.0	.1	.0	.020

Table 7. Particle-size characteristics for pre-flood soil and flood-sediment samples at levee-break sites—Continued

Sample number	Total clay, <0.002 mm (percent)	Total silt, 0.002–0.05 mm (percent)	Total sand, 0.05–2 mm (percent)	Fine silt, 0.002–0.02 mm (percent)	Coarse silt, 0.02–0.05 mm (percent)	Very fine sand, 0.05–0.1 mm (percent)	Fine sand, 0.1–0.25 mm (percent)	Medium sand, 0.25–0.5 mm (percent)	Coarse sand, 0.5–1 mm (percent)	Very coarse sand, 1–2 mm (percent)	Total gravel, >2 mm (percent)	Median particle size (mm)
Site 2—Pre-flood soil												
1	20.3	59.6	20.1	21.4	38.2	12.6	7.0	0.1	0.2	0.2	0.0	0.024
2	10.2	41.1	48.7	12.4	28.8	23.3	24.4	.2	.4	.3	.0	.048
3	23.5	55.3	21.2	23.4	31.9	15.4	5.2	.2	.2	.2	.0	.022
4	33.4	55.8	10.7	30.0	25.8	7.2	2.8	.2	.3	.3	.0	.007
5	19.4	61.6	18.9	23.8	37.8	8.3	5.4	3.1	1.5	.7	.0	.024
6	14.5	59.9	25.6	18.9	41.0	12.9	7.5	3.5	1.4	.3	.0	.029
9	10.3	37.0	52.8	10.9	26.1	20.9	31.0	.5	.1	.2	.0	.055
10	10.4	38.3	51.4	8.6	29.6	27.9	22.3	.4	.4	.4	.0	.052
11	23.2	58.0	18.9	23.8	34.2	12.3	5.6	.5	.2	.2	.0	.022
12	18.0	57.0	25.1	17.5	39.4	21.4	2.9	.3	.3	.2	.0	.028
Site 2—Flood sediment												
1	22.9	71.3	5.7	30.5	40.9	3.7	1.7	0.1	0.1	0.1	0.0	0.015
2	11.6	46.2	42.1	15.0	31.3	33.3	8.0	.3	.2	.3	.0	.040
3	10.8	56.3	32.8	16.6	39.7	26.0	6.5	.1	.1	.2	.0	.034
4	17.9	49.9	32.1	20.1	29.8	12.0	19.6	.2	.0	.4	.0	.029
5	4.4	18.3	77.5	6.7	11.5	12.0	33.2	19.7	11.4	1.1	.0	.153
6	6.8	21.5	71.7	7.8	13.7	10.5	49.6	9.5	1.7	.4	.0	.123
7	2.2	.2	93.7	.2	.0	1.2	15.4	35.8	28.8	12.6	3.9	.456
8	1.4	1.5	66.4	.8	.8	.3	9.4	18.9	18.2	19.6	30.7	1.007
9	1.1	3.9	94.9	3.7	.2	4.1	68.9	15.7	4.9	1.4	.0	.172
10	1.2	1.3	97.5	.9	.4	4.1	75.6	13.5	3.6	.7	.0	.169
11	2.1	.3	97.6	.3	.0	1.8	73.8	19.0	2.7	.3	.0	.177
12	1.1	2.5	95.6	1.4	1.1	.7	29.0	44.3	15.1	6.5	.8	.325

Table 7. Particle-size characteristics for pre-flood soil and flood-sediment samples at levee-break sites—Continued

Sample number	Total clay, <0.002 mm (percent)	Total silt, 0.002–0.05 mm (percent)	Total sand, 0.05–2 mm (percent)	Fine silt, 0.002–0.02 mm (percent)	Coarse silt, 0.02–0.05 mm (percent)	Very fine sand, 0.05–0.1 mm (percent)	Fine sand, 0.1–0.25 mm (percent)	Medium sand, 0.25–0.5 mm (percent)	Coarse sand, 0.5–1 mm (percent)	Very coarse sand, 1–2 mm (percent)	Total gravel, >2 mm (percent)	Median particle size (mm)
Site 3—Pre-flood soil												
1	14.8	21.6	51.3	10.8	10.8	9.0	8.2	3.2	16.7	14.2	12.3	0.167
2	16.9	23.8	59.3	12.1	11.7	6.7	50.0	1.6	.5	.5	.0	.105
3	16.8	24.2	59.0	10.8	13.4	19.4	39.0	.2	.2	.2	.0	.069
4	27.1	40.1	32.8	16.5	23.6	25.0	7.3	.2	.1	.2	.0	.026
5	42.4	43.4	14.1	24.4	19.0	10.9	2.8	.1	.2	.2	.0	.004
6	22.5	40.0	37.4	18.6	21.4	25.4	11.5	.2	.1	.3	.0	.029
7	54.5	34.8	7.2	24.4	10.4	6.1	.8	.0	.1	.2	3.5	.001
8	54.1	38.1	5.0	26.4	11.8	3.7	1.0	.0	.1	.2	2.7	.001
9	19.8	36.0	44.2	15.7	20.3	20.5	22.9	.5	.1	.2	.0	.038
10	25.1	35.1	39.8	18.2	16.9	12.5	17.3	7.6	1.7	.7	.0	.029
11	35.4	47.2	16.7	25.3	21.9	6.4	7.7	1.5	.5	.5	.8	.008
12	58.9	37.1	4.0	29.1	8.0	1.2	1.5	.6	.4	.3	.0	.001
15	18.9	18.3	60.1	11.1	7.2	2.9	15.9	20.3	17.2	3.8	2.7	.177
17	37.3	38.4	10.1	25.5	12.9	5.8	3.9	.2	.1	.2	14.2	.006
18	51.4	41.5	7.0	29.2	12.3	4.2	2.5	.1	.1	.2	.0	.002
22	6.8	8.6	84.4	5.6	3.1	6.2	62.0	11.6	3.4	1.3	.0	.152
23	18.0	19.1	62.9	10.2	8.9	19.9	41.1	1.3	.3	.3	.0	.078
24	48.3	42.5	9.2	33.8	8.7	2.5	5.6	.4	.3	.4	.0	.002
25	41.6	33.4	25.1	26.4	6.9	3.6	15.7	3.0	2.1	.7	.0	.004
26	42.4	38.8	18.7	24.5	14.3	6.5	10.0	1.6	.2	.5	.0	.004
28	42.4	48.5	9.2	32.3	16.2	6.9	2.0	.0	.1	.1	.0	.003
29	34.9	53.8	11.3	35.6	18.2	5.3	5.6	.1	.1	.2	.0	.005

Table 7. Particle-size characteristics for pre-flood soil and flood-sediment samples at levee-break sites—Continued

Sample number	Total clay, <0.002 mm (percent)	Total silt, 0.002–0.05 mm (percent)	Total sand, 0.05–2 mm (percent)	Fine silt, 0.002–0.02 mm (percent)	Coarse silt, 0.02–0.05 mm (percent)	Very fine sand, 0.05–0.1 mm (percent)	Fine sand, 0.1–0.25 mm (percent)	Medium sand, 0.25–0.5 mm (percent)	Coarse sand, 0.5–1 mm (percent)	Very coarse sand, 1–2 mm (percent)	Total gravel, >2 mm (percent)	Median particle size (mm)
						Site 3—Flood sediment						
1	11.8	28.3	59.9	7.7	20.6	15.0	40.8	3.1	0.5	0.5	0.0	0.079
2	12.5	36.4	51.2	11.3	25.1	14.4	18.0	11.0	6.9	.8	.0	.053
3	15.3	23.2	61.5	9.2	14.0	16.4	40.9	2.8	.7	.7	.0	.081
4	11.8	29.0	59.2	9.2	19.8	35.9	22.0	.7	.2	.4	.0	.060
5	25.0	55.1	20.0	26.6	28.4	8.8	10.7	.2	.1	.2	.0	.017
6	7.3	14.2	78.5	5.2	9.0	6.4	62.9	7.0	1.5	.7	.0	.138
7	26.3	50.9	22.9	24.3	26.6	10.3	12.1	.2	.1	.1	.0	.019
8	18.4	31.4	50.2	13.2	18.2	31.5	17.6	.2	.3	.6	.0	.050
9	3.9	3.7	92.4	1.6	2.1	1.8	86.6	3.5	.3	.2	.0	.154
10	4.1	3.7	92.3	1.8	1.9	1.2	57.6	21.2	10.7	1.5	.0	.192
11	3.2	3.1	93.6	1.3	1.9	.7	61.0	29.7	1.8	.4	.0	.190
12	21.2	57.0	21.8	23.2	33.8	10.9	10.0	.2	.1	.6	.0	.023
14	4.6	6.2	78.9	2.3	3.9	1.9	31.3	18.1	16.8	11.0	10.2	.315
15	9.5	11.5	66.8	6.2	5.4	2.9	23.9	21.0	13.1	6.0	12.2	.268
16	3.2	1.9	88.8	1.0	.8	.2	11.8	28.1	35.3	13.3	6.3	.550
17	8.2	10.5	81.2	5.1	5.5	20.9	59.2	.7	.1	.3	.0	.117
18	9.8	15.8	74.5	6.8	8.9	22.3	51.6	.2	.1	.3	.0	.104
19	1.1	1.3	97.6	.0	1.3	5.7	90.2	1.2	.0	.5	.0	.153
20	2.6	1.3	96.1	.6	.7	.9	59.0	31.1	4.2	.9	.0	.202
21	6.4	6.4	86.6	2.2	4.2	9.2	56.6	14.8	4.6	1.3	.7	.157
22	6.7	10.2	82.8	2.8	7.4	17.7	50.8	7.3	4.6	2.3	.4	.132
23	11.0	38.0	50.8	11.4	26.7	20.6	28.9	.8	.2	.4	.0	.052
24	38.9	47.5	13.6	29.5	18.0	7.6	4.9	.5	.3	.3	.0	.005
25	13.3	55.1	31.7	11.9	43.2	28.2	2.6	.2	.2	.4	.0	.034
26	5.6	23.1	71.4	6.0	17.1	7.8	48.6	13.9	.7	.3	.0	.129
27	1.7	4.3	94.0	2.2	2.1	4.0	88.5	1.2	.1	.2	.0	.151
28	8.7	13.6	77.6	6.5	7.1	29.1	47.8	.3	.1	.4	.0	.097
29	10.7	13.0	76.4	6.3	6.7	16.2	59.6	.2	.1	.2	.0	.117

Table 7. Particle-size characteristics for pre-flood soil and flood-sediment samples at levee-break sites—Continued

Sample number	Total clay, <0.002 mm (percent)	Total silt, 0.002–0.05 mm (percent)	Total sand, 0.05–2 mm (percent)	Fine silt, 0.002–0.02 mm (percent)	Coarse silt, 0.02–0.05 mm (percent)	Very fine sand, 0.05–0.1 mm (percent)	Fine sand, 0.1–0.25 mm (percent)	Medium sand, 0.25–0.5 mm (percent)	Coarse sand, 0.5–1 mm (percent)	Very coarse sand, 1–2 mm (percent)	Total gravel, >2 mm (percent)	Median particle size (mm)
						Site 4—Pre-flood soil						
1	18.7	40.8	40.5	17.6	23.2	14.1	23.2	2.7	0.4	0.1	0.0	0.034
[a]1	18.9	41.0	40.1	18.2	22.8	14.0	22.9	2.7	.4	.1	.0	--
2	11.5	32.9	55.6	11.3	21.6	21.2	31.8	2.3	.2	.1	.0	.060
3	20.2	38.2	41.6	18.3	19.9	12.7	22.9	5.3	.6	.1	.0	.034
4	8.6	40.7	50.7	10.1	30.6	24.1	25.1	1.2	.2	.1	.0	.051
5	9.9	32.8	57.3	9.0	23.8	17.2	38.0	1.6	.3	.2	.0	.067
6	10.7	39.7	49.6	12.4	27.3	18.2	26.9	3.9	.5	.1	.0	.049
9	11.1	23.5	65.4	10.7	12.8	11.8	45.8	6.9	.8	.1	.0	.107
10	12.0	35.7	52.3	10.1	25.6	25.6	23.8	2.3	.4	.2	.0	.053
12	10.9	36.4	52.7	11.3	25.1	15.5	34.8	1.8	.5	.1	.0	.056
13	14.1	54.4	31.5	20.6	33.8	18.8	12.0	.6	.1	.0	.0	.030
14	18.0	41.4	40.6	16.4	25.0	14.8	22.6	2.7	.4	.1	.0	.035
16	11.7	44.7	43.6	12.3	32.4	30.3	12.8	.3	.1	.1	.0	.042
17	17.4	49.0	33.6	19.8	29.2	17.2	15.3	.6	.3	.2	.0	.030
18	13.0	42.5	44.5	16.3	26.2	9.5	30.0	4.6	.3	.1	.0	.041
19	8.2	19.1	72.7	6.9	12.2	14.2	52.1	5.1	1.1	.2	.0	.116
20	11.8	41.1	47.1	13.1	28.0	31.8	15.0	.2	.1	.0	.0	.045
[a]20	11.8	40.9	47.3	12.0	28.9	31.6	15.3	.2	.1	.1	.0	--
21	16.3	33.0	50.7	15.2	17.8	7.6	34.9	7.3	.9	.0	.0	.053
22	21.6	51.4	27.0	22.9	28.5	13.4	11.9	1.6	.1	.0	.0	.024
23	15.5	61.7	22.8	18.6	43.1	20.0	2.5	.2	.1	.0	.0	.028
25	21.1	41.6	37.3	19.8	21.8	10.2	24.6	2.4	.1	.0	.0	.029
[a]25	21.8	40.9	37.3	18.4	22.5	10.0	24.7	2.4	.2	.0	.0	--
[b]25	21.4	41.1	37.5	17.7	23.4	9.9	25.0	2.4	.2	.0	.0	--
26	15.4	68.4	16.2	21.7	46.7	13.6	2.3	.1	.1	.1	.0	.026

Table 7. Particle-size characteristics for pre-flood soil and flood-sediment samples at levee-break sites—Continued

Sample number	Total clay, <0.002 mm (percent)	Total silt, 0.002–0.05 mm (percent)	Total sand, 0.05–2 mm (percent)	Fine silt, 0.002–0.02 mm (percent)	Coarse silt, 0.02–0.05 mm (percent)	Very fine sand, 0.05–0.1 mm (percent)	Fine sand, 0.1–0.25 mm (percent)	Medium sand, 0.25–0.5 mm (percent)	Coarse sand, 0.5–1 mm (percent)	Very coarse sand, 1–2 mm (percent)	Total gravel, >2 mm (percent)	Median particle size (mm)
Site 4—Flood sediment												
1	14.1	43.8	42.1	13.7	30.1	13.9	26.3	1.7	0.1	0.1	0.0	0.039
[a]1	14.8	45.7	39.5	14.9	30.8	12.0	25.4	1.9	.1	.1	.0	--
[b]1	14.9	45.1	40.0	15.2	29.9	12.2	25.9	1.7	.1	.1	.0	--
2	12.0	41.9	46.1	12.2	29.7	16.7	25.2	3.8	.3	.1	.0	.044
3	2.6	6.5	90.9	2.3	4.2	23.9	63.1	3.7	.2	.0	.0	.128
4	15.5	64.2	20.3	20.8	43.4	17.7	2.2	.2	.1	.1	.0	.027
5	.6	1.0	96.1	1.0	.0	.5	16.9	47.8	25.3	5.7	2.3	.392
6	8.8	30.8	60.4	8.1	22.7	34.5	25.2	.5	.1	.1	.0	.062
9	.7	.3	98.4	.3	.0	.5	17.1	47.3	29.4	4.1	.6	.396
10	1.1	1.4	97.5	1.3	.1	2.4	44.1	43.8	7.0	.2	.0	.254
12	1.6	.4	95.1	.4	.0	.3	7.6	32.2	42.4	12.6	3.0	.569
13	.8	2.7	96.5	1.5	1.2	3.1	56.9	34.9	1.6	.0	.0	.201
16	8.6	30.8	60.6	4.9	25.9	28.6	29.2	2.6	.1	.1	.0	.065
17	.8	1.2	97.8	.3	.9	.5	18.3	44.9	32.9	1.2	.2	.392
19	8.7	43.8	47.5	8.6	35.2	32.1	14.6	.6	.1	.1	.0	.047
20	7.4	30.2	62.4	7.4	22.8	29.6	32.4	.2	.1	.1	.0	.067
[a]20	9.6	45.7	44.7	9.9	35.8	24.1	20.2	.2	.1	.1	.0	--
21	.1	1.1	98.8	.0	1.1	.6	11.7	80.1	6.4	.0	.0	.343
22	.8	.4	98.8	.0	.4	.6	84.1	14.0	.1	.0	.0	.169
23	12.4	51.4	36.2	15.7	35.7	20.9	14.8	.4	.1	.0	.0	.035
25	1.6	.6	97.8	.0	.6	1.8	85.1	10.8	.1	.0	.0	.164
[a]25	.6	1.6	97.8	1.2	.4	1.9	84.8	10.9	.2	.0	.0	--
[b]25	.5	1.5	98.0	1.2	.3	2.0	83.8	12.1	.1	.0	.0	--
26	37.7	56.3	6.0	33.6	22.7	4.2	1.4	.2	.1	.1	.0	.005

Table 7. Particle-size characteristics for pre-flood soil and flood-sediment samples at levee-break sites—Continued

Sample number	Total clay, <0.002 mm (percent)	Total silt, 0.002–0.05 mm (percent)	Total sand, 0.05–2 mm (percent)	Fine silt, 0.002–0.02 mm (percent)	Coarse silt, 0.02–0.05 mm (percent)	Very fine sand, 0.05–0.1 mm (percent)	Fine sand, 0.1–0.25 mm (percent)	Medium sand, 0.25–0.5 mm (percent)	Coarse sand, 0.5–1 mm (percent)	Very coarse sand, 1–2 mm (percent)	Total gravel, >2 mm (percent)	Median particle size (mm)
Site 5—Pre-flood soil												
1	24.4	61.8	13.8	22.7	39.1	11.4	2.0	0.3	0.1	0.0	0.0	0.021
3	40.7	46.6	12.7	30.5	16.1	6.3	3.1	2.2	.9	.2	.0	.004
4	26.0	64.6	9.4	26.9	37.7	8.8	.3	.1	.1	.1	.0	.016
5	61.9	37.0	1.1	33.9	3.1	.4	.1	.1	.3	.2	.0	.001
6	55.8	43.2	1.0	33.3	9.9	.7	.1	.0	.1	.1	.0	.001
7	38.2	54.8	7.0	30.6	24.2	3.6	1.2	1.8	.3	.1	.0	.005
8	24.1	57.1	18.8	22.2	34.9	15.3	3.1	.4	.0	.0	.0	.022
9	12.6	21.4	66.0	8.2	13.2	21.2	42.8	1.8	.2	.0	.0	.084
10	5.3	9.8	84.9	2.1	7.7	12.6	67.5	4.6	.2	.0	.0	.135
11	28.4	58.0	13.6	23.4	34.6	12.6	.7	.1	.1	.1	.0	.017
13	45.1	51.8	3.1	30.6	21.2	2.5	.2	.1	.1	.2	.0	.003
14	55.1	41.9	3.0	31.8	10.1	2.6	.2	.1	.1	.0	.0	.001
15	67.4	31.7	.9	30.7	1.0	.3	.3	.1	.2	.0	.0	.001
16	40.4	58.8	.8	40.6	18.2	.5	.1	.0	.1	.1	.0	.003
17	57.5	41.6	.9	35.2	6.4	.5	.1	.1	.1	.1	.0	.001
18	49.7	47.9	2.4	33.6	14.3	1.3	.9	.1	.1	.0	.0	.002
19	39.9	42.1	18.0	25.0	17.1	5.1	12.5	.2	.1	.1	.0	.005
20	53.6	45.1	1.3	33.1	12.0	1.0	.2	.0	.0	.1	.0	.002
21	18.3	71.9	9.8	20.1	51.8	6.4	3.3	.0	.0	.1	.0	.025
22	12.4	50.6	37.0	11.6	39.0	36.1	.6	.1	.1	.1	.0	.037
23	15.7	66.1	18.2	16.5	49.6	18.0	.2	.0	.0	.0	.0	.028
24	38.6	57.3	4.1	30.8	26.5	3.5	.2	.1	.1	.2	.0	.005
25	35.4	60.5	4.1	28.6	31.9	3.5	.2	.1	.1	.2	.0	.006
26	45.7	52.9	1.4	34.4	18.5	1.1	.1	.0	.1	.1	.0	.003
27	53.4	42.9	3.7	29.9	13.0	2.3	.8	.1	.2	.3	.0	.002
28	51.1	45.5	3.4	32.8	12.7	2.9	.2	.1	.1	.1	.0	.002
29	57.4	41.6	1.0	29.6	12.0	.5	.2	.1	.1	.1	.0	.001

Table 7. Particle-size characteristics for pre-flood soil and flood-sediment samples at levee-break sites—Continued

Sample number	Total clay, <0.002 mm (percent)	Total silt, 0.002–0.05 mm (percent)	Total sand, 0.05–2 mm (percent)	Fine silt, 0.002–0.02 mm (percent)	Coarse silt, 0.02–0.05 mm (percent)	Very fine sand, 0.05–0.1 mm (percent)	Fine sand, 0.1–0.25 mm (percent)	Medium sand, 0.25–0.5 mm (percent)	Coarse sand, 0.5–1 mm (percent)	Very coarse sand, 1–2 mm (percent)	Total gravel, >2 mm (percent)	Median particle size (mm)
Site 5—Pre-flood soil—Continued												
30	60.9	38.3	0.8	32.0	6.3	0.3	0.2	0.1	0.1	0.1	0.0	0.001
31	60.8	38.6	.6	31.6	7.0	.2	.1	.1	.1	.1	.0	.001
32	14.6	53.3	32.1	15.3	38.0	26.9	3.7	.7	.4	.4	.0	.032
33	53.5	39.5	7.0	39.5	.0	5.4	.6	.5	.3	.2	.0	.002
Site 5—Flood sediment												
1	9.5	35.7	54.8	8.5	27.2	39.0	15.5	0.1	0.1	0.1	0.0	0.054
2	1.6	.3	97.8	.3	.0	.7	59.8	34.4	2.5	.4	.4	.207
3	6.1	11.4	81.6	4.8	6.6	14.1	23.4	28.6	12.0	3.5	1.0	.206
4	27.4	70.2	2.4	33.3	36.9	1.9	.3	.1	.1	.0	.0	.010
5	21.3	76.3	2.4	34.2	42.1	2.0	.1	.1	.1	.1	.0	.014
6	7.9	53.9	38.2	10.2	43.7	32.2	5.8	.1	.1	.0	.0	.039
7	1.1	.4	98.5	.4	.0	.5	17.5	74.2	6.3	.0	.0	.332
8	5.9	6.2	85.4	3.8	2.4	1.2	47.5	22.9	8.4	5.4	2.5	.203
9	19.7	72.5	7.8	21.8	50.7	7.3	.2	.1	.1	.1	.0	.023
10	14.0	42.1	43.9	8.6	33.5	36.5	7.1	.1	.1	.1	.0	.042
11	11.8	57.5	30.7	12.3	45.2	22.0	8.6	.1	.0	.0	.0	.034
12	7.8	16.3	75.9	4.1	12.2	29.2	42.3	4.1	.3	.0	.0	.092
13	21.6	64.2	14.2	22.8	41.4	13.0	1.0	.1	.1	.0	.0	.023
14	21.7	75.4	2.9	28.8	46.6	2.6	.2	.1	.0	.0	.0	.019
15	29.6	70.0	.4	41.6	28.4	.3	.1	.0	.0	.0	.0	.006
16	27.6	71.0	1.4	29.5	41.5	1.1	.1	.1	.1	.0	.0	.011
17	29.5	69.4	1.1	34.4	35.0	.9	.1	.0	.1	.0	.0	.008
18	23.0	73.5	3.5	29.7	43.8	3.3	.2	.0	.0	.0	.0	.016
19	18.2	64.7	17.1	18.7	46.0	16.6	.5	.0	.0	.0	.0	.026
20	13.0	56.9	30.1	12.2	44.7	25.2	4.7	.1	.0	.1	.0	.033
21	34.4	36.2	29.4	25.2	11.0	21.1	7.9	.1	.1	.2	.0	.008

Table 7. Particle-size characteristics for pre-flood soil and flood-sediment samples at levee-break sites—Continued

Sample number	Total clay, <0.002 mm (percent)	Total silt, 0.002–0.05 mm (percent)	Total sand, 0.05–2 mm (percent)	Fine silt, 0.002–0.02 mm (percent)	Coarse silt, 0.02–0.05 mm (percent)	Very fine sand, 0.05–0.1 mm (percent)	Fine sand, 0.1–0.25 mm (percent)	Medium sand, 0.25–0.5 mm (percent)	Coarse sand, 0.5–1 mm (percent)	Very coarse sand, 1–2 mm (percent)	Total gravel, >2 mm (percent)	Median particle size (mm)
						Site 5—Flood sediment—Continued						
22	13.0	64.3	22.7	13.4	50.9	22.1	0.3	0.1	0.1	0.1	0.0	0.031
23	19.2	78.1	2.7	25.9	52.2	2.5	.1	.0	.1	.0	.0	.022
24	38.6	61.1	.3	40.2	20.9	.2	.0	.0	.0	.1	.0	.004
25	30.1	69.2	.7	36.1	33.1	.6	.1	.0	.0	.0	.0	.007
26	38.2	61.7	.1	39.1	22.6	.1	.0	.0	.0	.0	.0	.004
27	28.7	69.6	1.7	33.4	36.2	1.6	.1	.0	.0	.0	.0	.009
28	23.4	72.0	4.6	25.4	46.6	4.4	.1	.0	.1	.0	.0	.020
29	23.3	74.2	2.5	33.0	41.2	2.4	.0	.0	.1	.0	.0	.013
30	30.3	68.3	1.4	36.1	32.2	1.1	.1	.0	.1	.1	.0	.007
31	29.1	69.1	1.8	32.4	36.7	1.6	.1	.0	.1	.0	.0	.009
[a]32	3.2	2.6	90.2	.9	1.7	.9	55.6	25.2	5.9	2.6	4.1	.204
33	.6	9.1	90.3	3.6	5.5	3.4	34.2	40.6	11.7	.4	.0	.262
[a]35	28.6	69.5	1.9	35.5	34.0	1.7	.1	.1	.0	.0	.0	.008
						Site 6—Pre-flood soil						
1	23.8	32.5	43.6	15.0	17.6	25.0	16.9	0.9	0.4	0.4	0.0	0.036
2	32.1	33.4	27.0	18.7	14.7	8.9	17.3	.6	.1	.1	7.5	.018
3	38.9	51.7	9.4	28.4	23.3	5.9	3.1	.1	.1	.2	.0	.005
4	40.0	43.4	16.5	27.2	16.2	8.1	6.9	1.2	.2	.2	.0	.005
5	44.1	50.7	5.2	28.3	22.4	4.0	.9	.1	.1	.1	.0	.003
6	37.1	49.8	13.1	26.6	23.2	7.7	5.1	.1	.1	.1	.0	.006
7	11.1	15.0	73.9	7.6	7.4	8.9	57.1	7.1	.6	.2	.0	.127
8	12.7	18.6	66.8	9.0	9.6	5.7	39.6	14.9	5.3	1.3	1.9	.135
10	33.1	56.4	10.4	25.9	30.5	7.9	2.1	.2	.2	.1	.0	.009
11	45.3	51.5	3.4	28.5	22.9	2.6	0.5	.0	.1	.1	.0	.003
12	34.1	56.7	9.2	27.4	29.3	4.5	4.3	.2	.1	.1	.0	.008
13	28.3	51.9	19.7	22.9	29.0	11.7	7.7	.1	.1	.2	.0	.018

Table 7. Particle-size characteristics for pre-flood soil and flood-sediment samples at levee-break sites—Continued

Sample number	Total clay, <0.002 mm (percent)	Total silt, 0.002–0.05 mm (percent)	Total sand, 0.05–2 mm (percent)	Fine silt, 0.002–0.02 mm (percent)	Coarse silt, 0.02–0.05 mm (percent)	Very fine sand, 0.05–0.1 mm (percent)	Fine sand, 0.1–0.25 mm (percent)	Medium sand, 0.25–0.5 mm (percent)	Coarse sand, 0.5–1 mm (percent)	Very coarse sand, 1–2 mm (percent)	Total gravel, >2 mm (percent)	Median particle size (mm)
Site 6—Pre-flood soil—Continued												
15	34.7	45.0	20.3	20.6	24.4	6.9	6.4	2.8	3.1	1.1	0.0	0.011
16	30.9	60.6	8.5	25.2	35.4	7.1	1.1	.1	.1	.1	.0	.011
17	38.4	43.1	5.2	25.6	17.5	3.3	1.3	.1	.2	.3	13.3	.006
19	23.3	51.9	24.8	18.4	33.5	15.3	8.2	.6	.4	.3	.0	.025
Site 6—Flood sediment												
1	26.7	68.0	5.3	25.6	42.4	4.2	0.4	0.4	0.2	0.1	0.0	0.016
2	11.8	36.3	49.6	10.0	26.4	23.5	25.5	.3	.1	.2	2.2	.053
3	15.3	64.9	17.1	15.2	49.7	12.1	4.5	.3	.1	.2	2.6	.029
4	23.9	65.8	10.3	22.1	43.6	8.7	1.1	.3	.1	.2	.0	.022
5	18.9	37.1	41.4	12.7	24.2	26.3	14.6	.1	.1	.4	2.7	.040
6	22.0	35.4	34.0	17.6	17.8	6.7	23.5	3.3	.4	.2	8.5	.034
7	7.0	11.4	73.8	5.1	6.4	6.5	58.5	7.7	.8	.3	7.7	.148
8	15.0	42.9	41.2	12.5	30.4	5.9	21.6	9.9	3.2	.6	.9	.039
9	6.2	4.5	87.5	2.5	1.9	1.3	24.1	31.5	26.7	3.9	1.9	.340
10	12.0	25.1	57.5	8.3	16.7	28.2	28.1	.5	.3	.4	5.5	.069
11	19.2	67.2	13.6	16.6	50.5	12.1	.6	.2	.2	.6	.0	.026
12	15.4	67.0	12.2	14.4	52.5	11.0	.7	.2	.1	.2	5.5	.028
13	7.1	10.0	80.5	3.3	6.6	17.9	56.9	4.6	.7	.5	2.4	.128
14	3.1	2.8	93.7	.6	2.2	10.4	56.6	21.1	5.2	.4	.4	.173
15	32.9	36.4	18.3	18.9	17.5	11.4	5.3	.4	.4	.7	12.5	.016
16	13.9	46.2	31.1	10.4	35.8	17.4	13.0	.2	.1	.4	8.8	.039
17	21.0	29.8	46.3	11.8	17.9	20.5	24.8	.2	.1	.7	3.0	.048
18	1.7	1.0	97.2	.6	.4	2.0	48.3	26.3	18.0	2.6	.1	.236
19	7.2	7.2	85.6	3.2	4.0	3.0	37.7	27.4	15.6	1.9	.0	.221
20	7.3	8.1	77.3	4.2	4.0	1.3	21.3	28.0	23.6	3.2	7.1	.336
21	3.8	4.4	91.9	1.6	2.8	2.3	38.3	40.1	10.4	.7	.0	.255

[a]Duplicate sample.
[b]Replicate sample.

Table 8. Soil chemistry data for pre-flood soil and flood-sediment samples at sites 4 and 5

[Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; meq/100 g, milliequivalents per 100 grams; $CaCl_2$, calcium chloride; H_2O, water; TR, trace; --, data not available or not analyzed]

Sample number	Exchangeable bases: Ca (meq/100 g)	Mg (meq/100 g)	Na (meq/100 g)	K (meq/100 g)	Sum of bases	Ca (percentage of sum of bases)	Mg (percentage of sum of bases)	Na (percentage of sum of bases)	K (percentage of sum of bases)	Exchangeable acidity (meq/100 g)	Cation exchange capacity (meq/100 g)	Base saturation (percent)	Organic carbon content (percent)	pH (standard units) $CaCl_2$	pH (standard units) H_2O
Site 4—Pre-flood soil															
1	18	3.2	TR	0.6	21.8	83	15	--	3	2.9	16.5	100	0.9	7.3	7.5
3	19.4	3.6	0.1	.4	23.5	83	15	0	2	2.4	17.1	100	.8	7.3	7.5
5	16.9	2.4	.1	.2	19.6	86	12	1	1	1.7	9.5	100	.5	7.3	7.6
6	20.1	2.4	.1	.3	22.9	88	10	0	1	2.4	11.5	100	.7	7.4	7.8
9	11.3	2.4	TR	.3	14	81	17	--	2	1.9	10.5	100	.5	7.2	7.6
10	14.3	2.7	TR	.3	17.3	83	16	--	2	1.9	11.8	100	.8	7.2	7.5
12	13.2	2.4	TR	.3	15.9	83	15	--	2	1.9	10.7	100	.7	7.2	7.6
13	15.8	3.6	TR	.5	19.9	79	18	--	3	2.6	15.2	100	1	7.2	7.6
16	12.6	2.4	0	.4	15.4	82	16	0	3	2	12.4	100	.9	7.1	7.5
17	17.1	2.7	TR	.4	20.2	85	13	--	2	3.3	16.3	100	.8	7.2	7.5
19	11.2	1.5	TR	.2	12.9	87	12	--	2	2.2	8.5	100	.6	7.2	7.7
21	15.8	2	TR	.3	18.1	87	11	--	2	1.9	14.7	100	.8	7.2	7.6
23	18.1	2.3	TR	.4	20.8	87	11	--	2	1.7	14.1	100	.7	7.3	7.7
25	17.2	2.8	.1	.5	20.6	83	14	0	2	2.9	17.7	100	.9	7.1	7.4
[a]25	16.6	2.7	TR	.5	19.8	84	14	--	3	2.6	17.3	100	.8	7.2	7.4
[b]25	16.7	2.8	.1	.5	20.1	83	14	0	2	2.6	17.4	100	.9	7.2	7.5
Site 4—Flood sediment															
[a]1	26.9	3.1	0.1	0.3	30.4	88	10	0	1	1.7	14.5	100	0.7	7.4	7.6
[b]1	26.5	2.8	.1	.3	29.7	89	9	0	1	2	14.2	100	.7	7.4	7.6
3	17.9	1.6	.1	.1	19.7	91	8	1	1	1.3	5.8	100	.1	7.4	7.8
5	4.9	.4	0	TR	5.3	92	8	0	--	.5	1.8	100	TR	7.3	7.8
6	23.4	2.4	.4	.4	26.6	88	9	2	2	1.7	9	100	.4	7.4	7.8
9	4.1	.4	TR	TR	4.5	91	9	--	--	.7	1.4	100	TR	7.2	7.8
10	8.7	.8	TR	TR	9.6	91	8	--	--	.8	2.4	100	.1	7.3	7.7
12	5.4	.4	TR	TR	5.8	93	7	--	--	.8	1.4	100	TR	7.3	7.8
13	7.4	.4	0	.1	7.9	94	5	0	1	1	2.7	100	.1	7.3	7.9

Table 8. Soil chemistry data for pre-flood soil and flood-sediment samples at sites 4 and 5—Continued

Sample number	Exchangeable bases Ca (meq/100 g)	Mg (meq/100 g)	Na (meq/100 g)	K (meq/100 g)	Sum of bases	Ca (percentage of sum of bases)	Mg (percentage of sum of bases)	Na (percentage of sum of bases)	K (percentage of sum of bases)	Exchange-able acidity (meq/100 g)	Cation exchange capacity (meq/100 g)	Base saturation (percent)	Organic carbon content (percent)	pH (standard units) $CaCl_2$	pH (standard units) H_2O
Site 4—Flood sediment—Continued															
16	22.5	1.9	TR	0.3	24.7	91	8	--	1	1.5	9.3	100	0.5	7.4	7.8
17	4.7	.4	0	TR	5.1	92	8	0	--	1.1	1.6	100	TR	7.3	7.8
19	22.7	2	TR	.2	24.9	91	8	--	1	1.2	9.3	100	.4	7.4	7.8
21	3.1	.4	TR	TR	3.6	86	11	--	--	1.2	1.4	100	TR	7.2	7.8
23	20	2.4	TR	.2	22.6	88	11	--	1	1.2	9.5	100	.6	7.4	7.8
25	7.9	.8	TR	.1	8.8	90	9	--	1	.6	2.7	100	TR	7.3	7.9
[a]25	7.3	.8	TR	.1	8.2	89	10	--	1	1	2.5	100	.1	7.4	7.9
[b]25	7.1	.4	TR	.1	7.6	93	5	--	1	1.5	2.4	100	TR	7.3	7.9
Site 5—Pre-flood soil															
1	18.6	3	TR	0.8	22.4	83	13	--	4	3.3	21.4	100	1.4	7	7.3
3	23.2	5.2	0.1	1.2	29.7	78	18	0	4	3.5	28.2	100	1.6	7.2	7.4
5	36.9	5.9	.1	1.6	44.5	83	13	0	4	5.8	42.2	100	2.2	7.3	7.5
7	27.6	5.5	.3	.7	34.1	81	16	1	2	2.9	27	100	1.3	7.2	7.5
9	11	2	TR	.5	13.5	81	15	--	4	1.6	11.7	100	1.2	6.9	7.2
10	6.8	1.5	TR	.4	8.7	78	17	--	5	1.4	6.5	100	0.6	6.9	7.2
11	19.3	3.5	.1	1	23.9	81	15	0	4	3.3	21.7	100	1.4	7	7.3
13	23.7	5.9	.1	1.3	31	76	19	0	4	3.1	30.8	100	1.7	7.1	7.3
15	32.4	6	.1	1.7	40.2	81	15	0	4	5.8	45.1	89	2.1	6.7	6.9
17	27	6.8	.1	1.4	35.3	76	19	0	4	4.8	38.6	91	2.2	6.5	6.7
19	23.9	5.1	.1	.9	30	80	17	0	3	3.7	30.7	98	1.7	6.9	7.1
21	19.8	5	.1	.9	25.8	77	19	0	3	2.8	25.1	100	1.7	7	7.2
23	13.5	3.1	TR	.5	17.1	79	18	--	3	1.5	12.6	100	1	7	7.3
25	23.5	4.7	.1	1	29.3	80	16	0	3	3.8	28.2	100	2	7	7.2
27	30.3	5.8	.2	1.5	37.8	80	15	1	4	4.9	39.6	95	2.4	6.9	7.1
29	31.1	6	.1	1.4	38.6	81	16	0	4	6.1	41.5	93	2.3	6.6	6.8
31	34.3	5.1	.1	1.6	41.1	83	12	0	4	4.5	44.1	93	2.1	6.7	7
33	25.7	5	.1	1.3	32.1	80	16	0	4	4.4	31.7	100	2.1	6.8	7.1

Table 8. Soil chemistry data for pre-flood soil and flood-sediment samples at sites 4 and 5—Continued

Sample number	Exchangeable bases Ca (meq/100 g)	Mg (meq/100 g)	Na (meq/100 g)	K (meq/100 g)	Sum of bases	Ca (percentage of sum of bases)	Mg (percentage of sum of bases)	Na (percentage of sum of bases)	K (percentage of sum of bases)	Exchange-able acidity (meq/100 g)	Cation exchange capacity (meq/100 g)	Base saturation (percent)	Organic carbon content (percent)	pH (standard units) $CaCl_2$	pH (standard units) H_2O
						Site 5—Flood sediment									
1	25.6	2.3	0.1	0.3	28.3	90	8	0	1	0.9	9.3	100	0.3	7.4	7.8
3	13.6	1.2	TR	.2	15	91	8	--	1	.9	4.2	100	.1	7.5	7.9
5	30.8	4	.2	.5	35.5	87	11	1	1	1.3	17.3	100	.8	7.5	7.8
7	4	.4	.1	.1	46	87	9	2	2	1	1.5	100	.1	7	7.7
9	30.9	3.2	.1	.5	34.7	89	9	0	1	.9	14.7	100	.6	7.3	7.7
10	24.7	2.3	.1	.3	27.4	90	8	0	1	.5	10.8	100	.5	7.3	7.7
11	24.6	2.4	.1	.3	27.4	90	9	0	1	.6	10.1	100	.4	7.4	7.7
13	30	3.5	.1	.6	34.2	88	10	0	2	1.4	16.9	100	.7	7.4	7.7
15	40.1	4.8	.1	.6	45.6	88	11	0	1	2	21.7	100	1.2	7.3	7.6
17	38.1	4.8	.1	.7	43.7	87	11	0	2	2.6	24	100	1.4	7.4	7.7
19	31.5	4	.1	.5	36.1	87	11	0	1	1.3	15.9	100	.7	7.4	7.7
21	31.6	4	.1	.5	36.2	87	11	0	1	1.6	16.6	100	.7	7.4	7.8
23	31.2	3.9	.1	.5	35.7	87	11	0	1	1	15.4	100	.6	7.3	7.6
25	41.3	5	.1	.7	47.1	88	11	0	1	2	22.9	100	1.1	7.4	7.6
27	35.7	4.7	.1	.6	41.1	87	11	0	1	2.5	24.1	100	1	7.3	7.6
29	40	4.7	.1	.6	45.4	88	10	0	1	2	20	100	1	6.7	7.5
31	40.1	5	.1	.7	45.9	87	11	0	2	2	21.9	100	1	6.7	7.3
33	10.4	.8	--	.1	11.3	92	7	--	1	.9	3.1	100	1.6	7.3	7.8
35	38.6	4.8	.1	.7	44.2	87	11	0	2	1.8	24	100	1.1	7.4	7.6

[a]Duplicate sample.
[b]Replicate sample.