Simulation of the Effect of Traffic Barricades on Backwater along U.S. Highway 54 at Jefferson City, Missouri—1993 Flood on the Missouri River

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 97–4213

Prepared in cooperation with the
MISSOURI DEPARTMENT OF TRANSPORTATION

Rolla, Missouri
1997

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ABSTRACT

During the summer of 1993, major flooding along the Missouri River caused extensive damage to homes, businesses, and agricultural properties in the Jefferson City, Missouri, area. To analyze the possible backwater effects of temporary traffic barricades placed along U.S. Highway 54 on 1993 flood elevations, a two-dimensional finite-element surface-water model was used to simulate flood flows in the vicinity of the U.S. Highway 54 crossing of the Missouri River floodplain near Jefferson City. These analyses were used to determine how much additional backwater was created upstream from the crossing because of the barricades and what effects the barricades had on the flow distribution.

The model was calibrated using flood-peak elevations collected during and after the 1993 flood. A discharge of 750,000 cubic feet per second was estimated from nearby streamflow-gaging stations for use in the model. Two 1993 flood-flow simulations along the Missouri River floodplain were run to determine the backwater conditions for existing conditions (traffic barricades along U.S. Highway 54) and alternative conditions (without traffic barricades along U.S. Highway 54).

Simulation of existing flow conditions indicates that 98.5 percent of the 1993 discharge flowed under the main channel bridges and less than 1 percent flowed over U.S. Highway 54. Also, the maximum velocity was 12.5 feet per second in the main channel. Comparing the existing and alternative conditions, the results of the alternative simulation indicate that the discharge increased from 7,110 to 12,500 cubic feet per second over the U.S. Highway 54 roadway embankment and discharge decreased from 738,700 to 733,000 cubic feet per second under the main channel bridges. Backwater elevations increased about 0.1 foot to a distance of about 2,000 feet upstream from U.S. Highway 54, primarily between U.S. Highway 63 and the Missouri River main channel bridges with the temporary traffic barricades. Also, in the vicinity of the U.S. Highway 63 interchange, 0.1 to 0.6 foot of additional backwater occurred along the temporary traffic barricades.

INTRODUCTION

The flood of 1993 in the Central United States was one of the most devastating floods in U.S. history. Losses are estimated to range from $15 to $20 billion, making the flood of 1993 the costliest flood event in

U.S. history and second only to Hurricane Andrew in damages from a weather-related disaster (National Oceanic and Atmospheric Administration, 1994).

The flood of 1993 on the Missouri River near Jefferson City resulted from above average precipitation in the Missouri River Basin in the spring and early summer. From January through July 1993, large areas of the basin received more than 150 percent of their normal rainfall, and some areas received more than 200 percent of their normal rainfall (Parrett and others, 1993). In July 1993, the weather station in Kansas City, Missouri, reported 10.90 in. (inches) of rainfall, which was 249 percent of normal for the same period from 1961 to 1990 (Wahl and others, 1993). With surface-water elevations well above flood stage on the Missouri River, the persistent intense rainfall in July increased floodwaters to record elevations and discharges at many streamflow-gaging stations. At 154 streamflow-gaging stations in the upper Mississippi River Basin, flood-peak discharges equaled or exceeded that of the 10-year recurrence interval (recurrence interval is the average interval of time within which a given flood will be equaled or exceeded once). At 46 of these stations, flood-peak discharges exceeded that of the 100-year recurrence interval. Also, along the lower Missouri River, 1993 flood-peak discharges exceeded the 100-year recurrence interval at five U.S. Geological Survey (USGS) streamflow-gaging stations from Rulo, Nebraska, to Hermann, Missouri (Parrett and others, 1993; fig. 1).

During the flood of 1993, most highway and railroad bridges across the Missouri River from Kansas City to St. Louis, Missouri, were closed. In most cases, the bridges were not overtopped, but the road embankments leading to the bridges were inundated. One of the road closures was U.S. Highways 54 and 63, a major transportation route through central Missouri that crosses the Missouri River floodplain at Jefferson City (fig. 1). In this report, this highway will be referred to only as U.S. Highway 54.

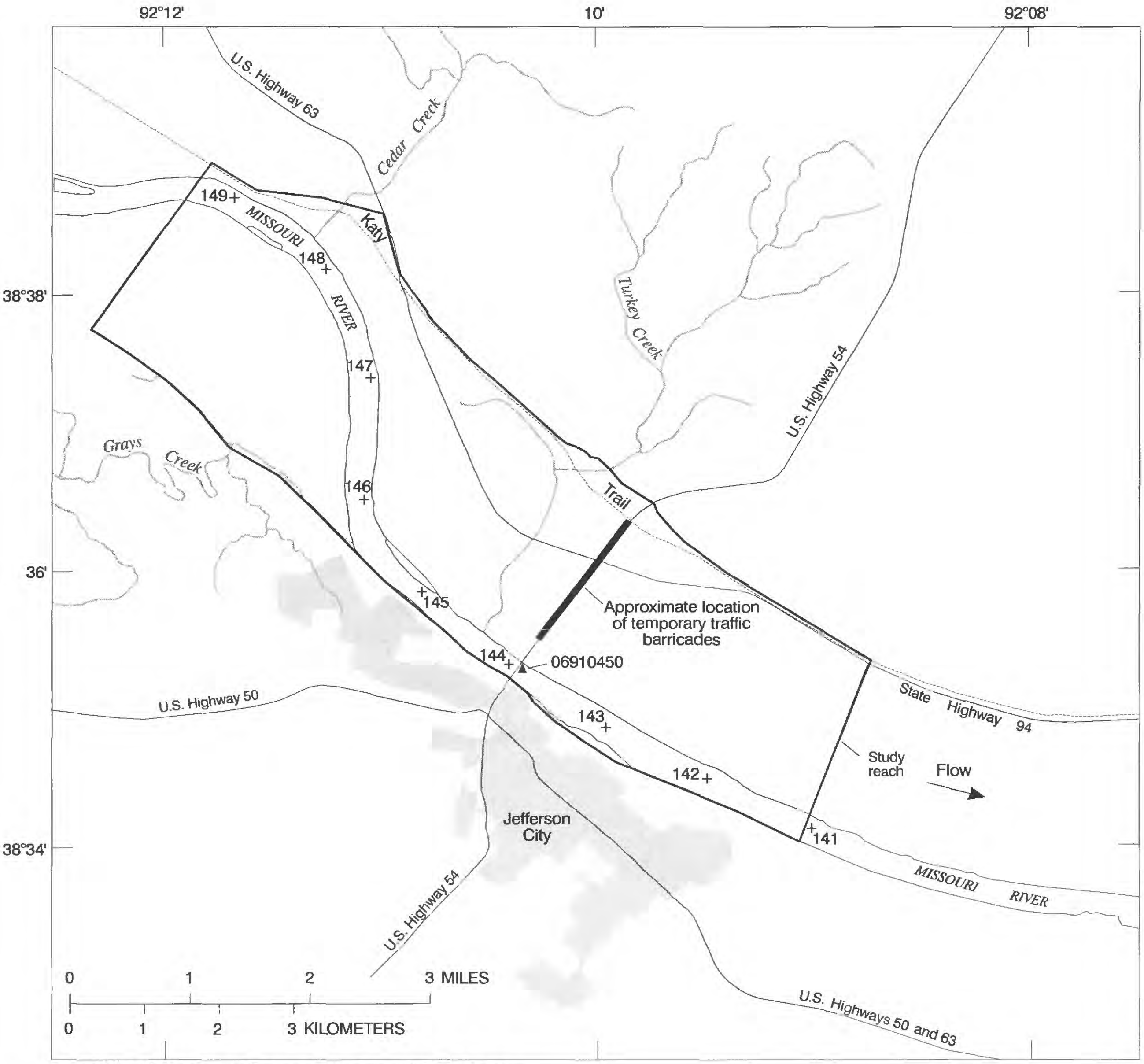
At the USGS stage-gaging station on U.S. Highway 54 at Jefferson City, the Missouri River had a flood-peak elevation of 559.30 ft (feet) above sea level, which exceeded the previous maximum elevation in July 1951 by more than 4 ft. During the 1993 flood peak, temporary traffic barricades were placed along U.S. Highway 54 (fig. 1) to impede floodwaters from overtopping the road embankment. Consequently, the USGS, in cooperation with the Missouri Department of Transportation, began a study in 1996 to analyze possible backwater effects of the traffic barricades. Data contained in this report will assist State and local governments in evaluating the effectiveness of the temporary traffic barricades and the magnitude of backwater caused by using this type of barricade.

Purpose and Scope

This report gives the results of a study in which the two-dimensional, Finite-Element Surface-Water Modeling System (FESWMS) model was used to determine the depth and areal extent of the 1993 Missouri River backwater caused by the placement of temporary traffic barricades along U.S. Highway 54 at Jefferson City. The report also documents the flow distribution and velocities of floodwaters along the U.S. Highway 54 embankment, both with (existing conditions) and without (alternative conditions) the traffic barricades in place.

Description of Study Reach

The study reach begins near river mile 141 and ends near river mile 149 on the Missouri River at Jefferson City (fig. 1). The width of the floodplain throughout this reach generally is 1.6 to 1.7 mi (miles). The U.S. Highway 54 bridges are approximately 0.6 mi long and raised substantially above normal water-surface elevations for barge traffic on the Missouri River. The U.S. Highway 54 embankment is about 1.3 mi long from the U.S. Highway 54 bridges to the north bank of the Missouri River floodplain. Two roadway interchanges exist within the floodplain—one primarily is for local transportation in the floodplain and the other is used to divert traffic onto U.S. Highway 63 to the west and State Highway 94 to the east. In the study reach, U.S. Highway 63 extends northwest for about 3 mi, and State Highway 94 extends east along the bluff on the north side of the floodplain. Also, along the north edge of the floodplain is the Katy Trail, a refurbished railroad line used for bicycling and hiking. The Katy Trail goes under U.S. Highway 54 at the north edge of the floodplain (fig. 1).



Base from U.S. Geological Survey digital data 1:100,000, 1986
Transverse Mercator Projection
Central Meridian 92°30', Origin 35°50'

EXPLANATION

142 + RIVER-MILE MARKER Number is distance upstream from mouth, in miles

06910450 ▲ U.S. GEOLOGICAL SURVEY STAGE-GAGING STATION AND NUMBER

Figure 1. Location of the study reach at Jefferson City, Missouri.

DESCRIPTION OF THE 1993 FLOOD

Because there is only a USGS stage-gaging station on the Missouri River at Jefferson City, no current stage-discharge relation exists for the river at U.S. Highway 54; however, an estimate of the peak discharge was obtained based on the peak discharges at the USGS streamflow-gaging stations at Boonville (06909000) and Hermann (06934500), Missouri. The USGS streamflow-gaging station at Boonville, 52.7 river mi upstream from Jefferson City (fig. 1), established a record peak elevation of 602.52 ft above sea level and a peak discharge of 755,000 ft^3/s (cubic feet per second) on July 29, 1993. The previous record maximum elevation and discharge at Boonville were 598.1 ft above sea level and 710,000 ft^3/s in June 1844. The USGS streamflow-gaging station at Hermann, approximately 46 river mi downstream from Jefferson City (fig. 1), had a peak elevation on July 31, 1993, of 518.53 ft above sea level and a peak discharge of 750,000 ft^3/s. The 1993 peak elevation at Hermann surpassed the 1844 flood peak of 517.1 ft above sea level. However, the 1844 peak discharge was 892,000 ft^3/s, substantially larger than the peak discharge for the 1993 flood. Since there was no substantial difference in peak discharge between Boonville and Hermann, the flood-peak discharge was estimated to be 750,000 ft^3/s throughout the Missouri River near Jefferson City study reach.

The discharge-frequency curves for the Boonville and Hermann streamflow-gaging stations were used with the 750,000 ft^3/s peak discharge at Jefferson City to evaluate the 1993 flood recurrence interval at the U.S. Highway 54 crossing at Jefferson City (fig. 2). From figure 2, the recurrence interval for the 1993 peak discharge at the USGS gaging station at Hermann (06934500) was 300 years and at the station at Boonville (06909000) was at least 500 years.

A discharge of 700,000 ft^3/s was used by the Federal Emergency Management Agency (U.S. Department of Housing and Urban Development, 1981) to outline the inundation boundaries for the 500-year flood in the Jefferson City area. To assist in the evaluation of the Missouri River flooding along U.S. Highway 54 near Jefferson City, the Federal Emergency Management Agency 500-year flood profile is provided in figure 3.

A flood-peak elevation of 559.30 ft above sea level was recorded at the USGS stage-gaging station on the Missouri River at Jefferson City (06910450) on July 30, 1993. Flood-peak elevations obtained along the study reach were used to describe the 1993 flood profiles for the north and the south banks of the floodplain (fig. 3). The skew of the Missouri River main channel with respect to its location in the floodplain (fig. 1) has resulted in a relatively smooth water-surface profile along the main channel (south bank); however, upstream from the U.S. Highway 54 embankment (north bank), flood-peak elevations were about 2.5 ft higher (fig. 3). Consequently, to define accurately the boundary conditions of the 1993 flood, a two-dimensional model was needed that would represent both the longitudinal and lateral variation in water-surface elevations.

SIMULATION OF EFFECT OF TRAFFIC BARRICADES

The FESWMS model simulates flows in two dimensions in the horizontal plane. It uses a finite-element grid and the Galerkin finite-element method of solving three partial-differential equations representing conservation of mass and momentum (Lee and Froehlich, 1989). This two-dimensional model can simulate lateral and longitudinal variations in velocities and water-surface elevations and can accommodate geometric features, such as highway embankments and channel bends.

Model Development

The model grid (fig. 4) was designed to closely represent the nonuniform characteristics of the study reach area inundated by the 1993 Missouri River flood near Jefferson City. The grid for the study reach was extended sufficiently upstream and downstream (at least one floodplain width) from the U.S. Highway 54 crossing to eliminate any errors in flow computations due to estimated boundary conditions. The reach begins about 2.7 mi downstream from the U.S. Highway 54 crossing of the Missouri River and continues to about 4.5 mi upstream from the crossing (fig. 4). The bluffs along the floodplain determined the lateral

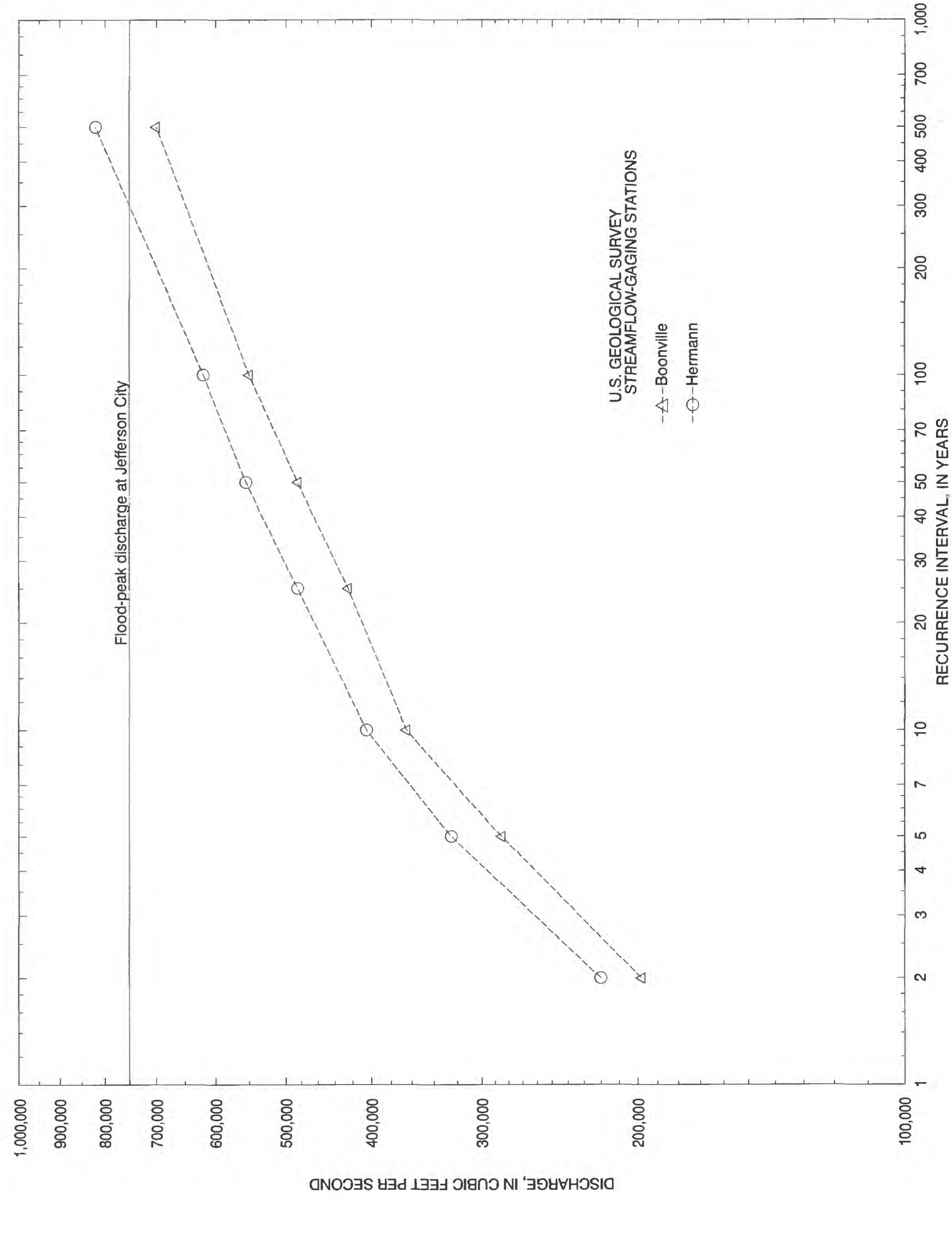


Figure 2. Discharge-frequency curves for the Missouri River at Boonville (06909000) and Hermann (06934500), Missouri, streamflow-gaging stations.

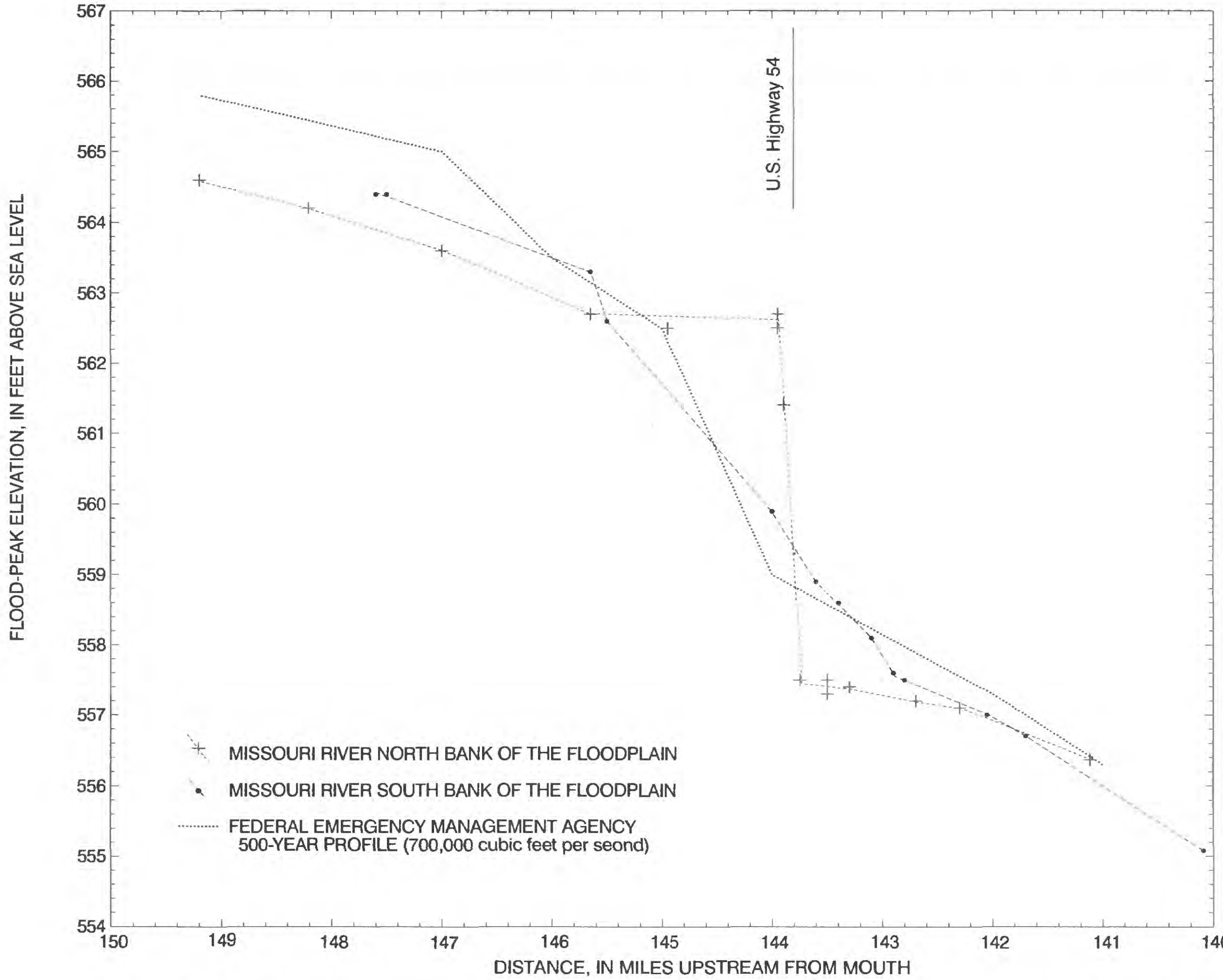


Figure 3. Missouri River 1993 flood-peak elevations and profiles and the Federal Emergency Management Agency 500-year profile (U.S. Department of Housing and Urban Development, 1981, panel 2) near U.S. Highway 54 at Jefferson City, Missouri.

Figure 4. Finite-element grid used in flow simulations at Jefferson City, Missouri.

extent of the grid. A total of 36 cross sections was used from onsite transit-stadia surveys to define the topography of the reach. While surveying the cross sections, roughness coefficients (Manning's n) were estimated for use in flow calculations in each element of the grid. Most water-surface elevations within the study reach were taken from high-water marks previously published by Alexander (1995); however, additional flood-peak elevations were surveyed in where available.

In areas where substantial changes in topography exist, the grid must be more refined for model consistency. In this study, examples of changes in topography that required more refinement were at levees, roadway embankments, and river banks. Also, in areas where velocity, depth, and water-surface elevation changes were expected to be large, such as near the U.S. Highway 54 bridge openings, grid details were increased to better facilitate simulation by the FESWMS flow model (fig. 4). The finite-element grid used in this study has 11,539 elements and 45,040 nodes.

Calibration of Model to Existing Conditions—With Traffic Barricades

Before the flood peak of July 30, 1993, temporary traffic barricades were placed on the upstream and downstream shoulders of U.S. Highway 54 to prevent overtopping of the roadway by floodwaters. Placement of the barricades allowed the roadway to remain open for some time, but the barricades were breached, and floodwaters scoured the roadbed and displaced the barricades north of the U.S. Highways 54 and 63 interchange. The barricades, 2.7 ft high and 10 ft long, are steel-reinforced concrete. The location and height of the barricades, accordingly, were included in the model representation.

A discharge of 750,000 ft^3/s and a starting elevation of 556.2 ft at the downstream end of the modeled reach were used as boundary conditions. During calibration of the model, Manning's n values (table 1) were adjusted within reasonable limits until simulated flood-peak elevations satisfactorily matched the surveyed flood-peak elevations. The FESWMS model simulation of existing conditions (with traffic barricades) indicates that the calibrated model results are within ± (plus or minus) 0.25 ft of the surveyed flood-peak elevations (fig. 5). The simulated model results indicate the discharge under the main channel bridges was 738,700 ft^3/s (98.5 percent of the total estimated discharge). Because the discharge over U.S. Highway 54 was unknown, flood-peak elevations available from an earlier report (Alexander, 1995) and additional elevations (high-water marks) surveyed during this study were used to verify that less than 1 percent (7,110 ft^3/s) of the total simulated flow went over U.S. Highway 54 (table 2). However, north of U.S. Highway 63, the flow over U.S. Highway 54 damaged a large section of concrete roadway, resulting in road closure for several days after the floodwaters receded.

Table 1. Manning's n values used in model calibrations

Land coverage	Manning's n
Floodplain—row crop	0.032
Woods	.050–.200
Levee	.030–.060
Highway	.045
Building	.100
Missouri River main channel	.024

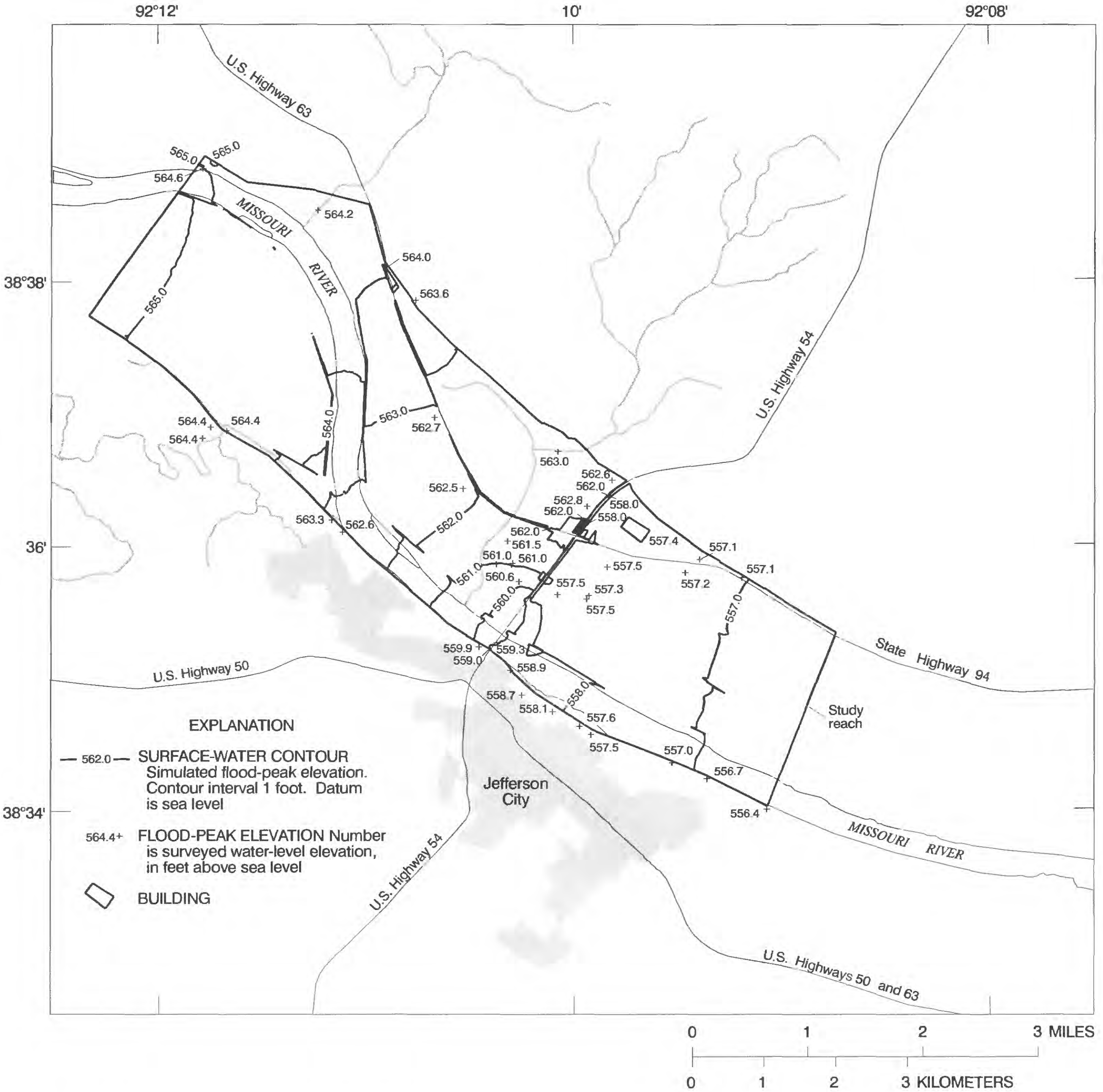


Figure 5. Simulated and surveyed 1993 flood-peak elevations for existing conditions with traffic barricades along U.S. Highway 54 at Jefferson City, Missouri.

Table 2. Distribution of the simulated 1993 flood discharge along U.S. Highway 54

[ft^3/s, cubic feet per second]

Location	Simulated discharge, existing conditions (ft^3/s)	Simulated discharge, alternative conditions (ft^3/s)
Missouri River main channel bridge	738,700	733,000
Over U.S. Highway 54	7,110	12,500
Through Katy Trail overpass	4,190	4,240
Total	750,000	[1]749,740

[1]Difference from 750,000 cubic feet per second is due to model rounding.

Other simulation results indicated that the maximum velocity and depth in the main channel were 12.5 ft/s (feet per second) and 51.2 ft. North of the U.S. Highway 63 interchange, the maximum velocity and depth over the road embankment were 5.8 ft/s and 2.6 ft, whereas the maximum velocity and depth in the Katy Trail overpass were 5.9 ft/s and 9.4 ft.

Simulation of Alternative Conditions—Without Traffic Barricades

Once the model was calibrated to the existing 1993 flood conditions, it was used to simulate alternative conditions (without traffic barricades). The alternative-condition model used existing U.S. Highway 54 embankment elevations, omitting representation of the barricades. That was the only difference in the construction of the two models.

Surface-water elevations of the model results for the alternative conditions are given in figure 6. These results indicate the discharge under the main channel bridges was 733,000 ft^3/s (table 2). By lowering the U.S. Highway 54 embankment elevations to represent conditions without traffic barricades, the model indicates more flow over the road (12,500 ft^3/s; table 2) than with the barricades. The discharge through the Katy Trail overpass was nearly the same for both conditions.

Other simulation results for the alternative conditions indicate that the maximum velocity and depth in the main channel were computed to be 12.4 ft/s and 51.2 ft. Maximum velocity and depth for flow over the roadway embankment were 5.0 ft/s and 3.7 ft, whereas the maximum velocity and depth through the Katy Trail overpass were 6.3 ft/s and 9.8 ft.

Comparison of Existing and Alternative Conditions

To compare the differences in flood-peak elevations between the existing and alternative conditions, a difference map was calculated and is shown in figure 7. Based on the model simulations, the traffic barricades resulted in about 0.2 ft of additional backwater immediately upstream from the U.S. Highway 54 road embankment (fig. 7). About 2,000 ft upstream from the road embankment, 0.1 ft of additional backwater occurs between U.S. Highway 63 and the main channel levee along the Missouri River. North of the U.S. Highway 63 interchange, 0.1 to 0.6 ft of additional backwater occurred along the traffic barricades, and in the immediate vicinity of the U.S. Highway 63 interchange. Backwater conditions were 0.1 to 0.2 ft higher at the upstream side of U.S. Highway 54 at the Katy Trail overpass. Because of model roundoff of computed surface-water elevations, the 0.0-ft-difference line is not shown upstream from U.S. Highway 54.

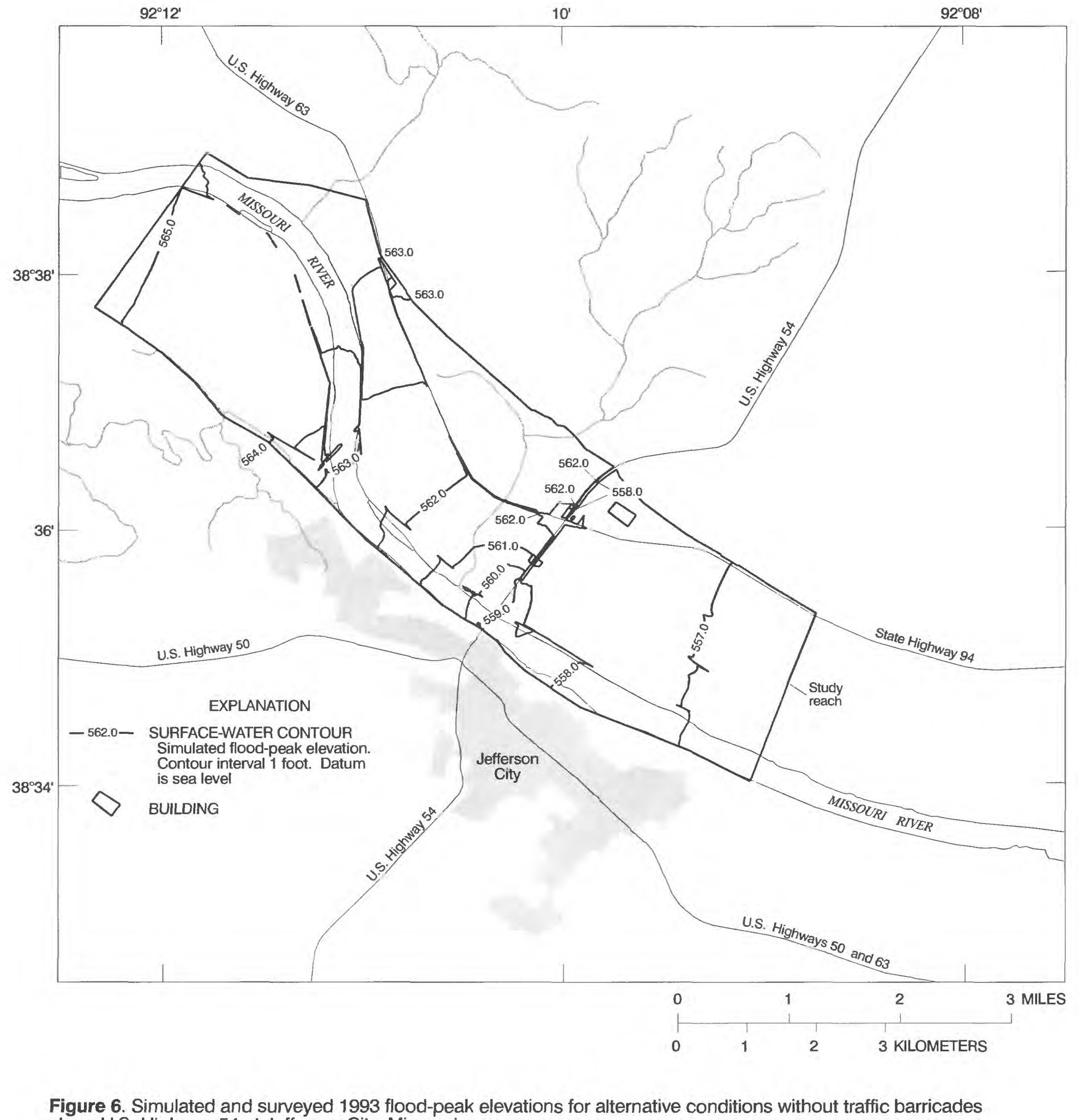


Figure 6. Simulated and surveyed 1993 flood-peak elevations for alternative conditions without traffic barricades along U.S. Highway 54 at Jefferson City, Missouri.

0 1 MILE

0 1 KILOMETER

EXPLANATION

— 0.1 — LINE OF EQUAL ADDITIONAL BACKWATER DEPTH
Difference in flood-peak elevations for existing conditions (with traffic barricades) and alternative conditions (without traffic barricades). The 0.3- to 0.6-foot area is in the vicinity of the traffic barricades

BUILDING

Figure 7. Differences in 1993 flood-peak elevations for existing and alternative conditions (with and without traffic barricades along U.S. Highway 54 at Jefferson City, Missouri).

SUMMARY

A two-dimensional Finite-Element Surface-Water Modeling System (FESWMS) was used to simulate the backwater from temporary traffic barricades along U.S. Highway 54 at Jefferson City, Missouri, during the flood of 1993. The study simulated flood-peak elevations for two conditions. One simulation was for existing conditions with traffic barricades during the 1993 flood and the other for alternative conditions without traffic barricades.

Using a peak discharge of 750,000 cubic feet per second and flood-peak elevations data (boundary conditions), the model was calibrated to the existing conditions. The flow distribution results indicated that 98.5 percent of the flow was under the main channel bridges and less than 1 percent was over the U.S. Highway 54 road embankment. The maximum velocity in the main channel was 12.5 feet per second and over the road was 5.8 feet per second. The maximum velocity of floodwaters through the Katy Trail overpass was 5.9 feet per second. Simulation of the alternative conditions indicated an increase of flow over U.S. Highway 54 from 7,110 to 12,500 cubic feet per second. The discharge through the Katy Trail overpass remained nearly the same for both simulations, whereas flow through the main channel bridge decreased by 5,700 cubic feet per second. The maximum velocity at the main channel bridges was 12.4 feet per second, and the maximum velocity over the U.S. Highway 54 road embankment was 5.0 feet per second.

The traffic barricades in the model decreased the flow over the road and resulted in about 0.1 foot more backwater between the main channel levee along the Missouri River and U.S. Highway 63 to a distance of about 2,000 feet upstream. North of the U.S. Highway 63 interchange, 0.1 to 0.6 foot more backwater occurred along the temporary traffic barricades and in the immediate vicinity of the U.S. Highway 63 interchange. Backwater was 0.1 to 0.2 foot higher at the upstream side of U.S. Highway 54 at the Katy Trail overpass.

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