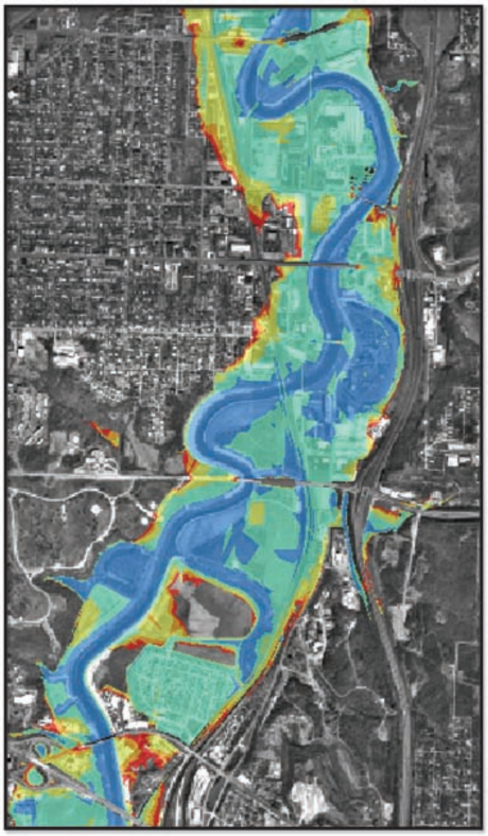
Prepared in cooperation with the City of Kansas City, Missouri

Estimated Flood-Inundation Mapping for the Lower Blue River in Kansas City, Missouri, 2003–05



Scientific Investigations Report 2006–5089

U.S. Department of the Interior
U.S. Geological Survey

Cover: Blue River at 63rd Street, Kansas City, Missouri, on May 19, 2004 (left). Photograph courtesy of Paul H. Rydlund, Jr., U.S. Geological Survey. Flood-inundation map example for the lower Blue River, Kansas City, Missouri, between I-70 and 12th Street (right).

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U.S. Department of the Interior
P. Lynn Scarlett, Acting Secretary

U.S. Geological Survey
P. Patrick Leahy, Acting Director

U.S. Geological Survey, Reston, Virginia: 2006
For sale by U.S. Geological Survey, Information Services
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Denver, CO 80225

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Suggested citation:
Kelly, B.P., and Rydlund, P.H., Jr., 2006. Estimated Flood-Inundation Mapping for the Lower Blue River in Kansas City, Missouri, 2003–05: U.S. Geologic al Survey Scientific Investigations Report 2006–5089, 27 p.

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Conversion Factors and Datum

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
Flow rate		
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
square foot per second (ft^2/s)	0.0929	square meter per second (m^2/s)
cubic foot per second (ft^3/s)	2446.6	cubic meter per day (m^3/d)
Hydraulic gradient		
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C = (°F - 32) / 1.8

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the National Geodetic Vertical Datum of 1929 (NGVD 29)—A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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By Brian P. Kelly and Paul H. Rydlund, Jr.

Abstract

The U.S. Geological Survey, in cooperation with the city of Kansas City, Missouri, began a study in 2003 of the lower Blue River in Kansas City, Missouri, from Gregory Boulevard to the mouth at the Missouri River to determine the estimated extent of flood inundation in the Blue River valley from flooding on the lower Blue River and from Missouri River backwater. Much of the lower Blue River flood plain is covered by industrial development. Rapid development in the upper end of the watershed has increased the volume of runoff, and thus the discharge of flood events for the Blue River. Modifications to the channel of the Blue River began in late 1983 in response to the need for flood control. By 2004, the channel had been widened and straightened from the mouth to immediately downstream from Blue Parkway to convey a 30-year flood.

A two-dimensional depth-averaged flow model was used to simulate flooding within a 2-mile study reach of the Blue River between 63rd Street and Blue Parkway. Hydraulic simulation of the study reach provided information for the design and performance of proposed hydraulic structures and channel improvements and for the production of estimated flood-inundation maps and maps representing an areal distribution of water velocity, both magnitude and direction.

Flood profiles of the Blue River were developed between Gregory Boulevard and 63rd Street from stage elevations calculated from high water marks from the flood of May 19, 2004; between 63rd Street and Blue Parkway from two-dimensional hydraulic modeling conducted for this study; and between Blue Parkway and the mouth from an existing one-dimensional hydraulic model by the U.S. Army Corps of Engineers. Twelve inundation maps were produced at 2-foot intervals for Blue Parkway stage elevations from 750 to 772 feet. Each map is associated with National Weather Service flood-peak forecast locations at 63rd Street, Blue Parkway, Stadium Drive, U.S. Highway 40, 12th Street, and the Missouri River at the Hannibal railroad bridge in Kansas City. The National Weather Service issues peak-stage forecasts for these locations during times of flooding. Missouri River backwater inundation profiles were developed using interpolated Missouri River stage elevations at the mouth of the Blue River. Twelve backwater-inundation maps were produced at 2-foot intervals for the mouth of the Blue River from 730.9 to 752.9.

To provide public access to the information presented in this report, a World Wide Web site (http://mo.water.usgs.gov/indep/kelly/blueriver/index.htm) was created that displays the results of two-dimensional modeling between 63rd Street and Blue Parkway, estimated flood-inundation maps, estimated backwater-inundation maps, and the latest gage heights and National Weather Service stage forecast for each forecast location within the study area. In addition, the full text of this report, all tables, and all plates are available for download at http://pubs.water.usgs.gov/sir2006-5089.

Introduction

The Blue River flows through the middle of Kansas City to its mouth at the Missouri River (fig. 1) and has been a source of flood damage in Kansas City for many years. Flooding in the Blue River Basin has caused millions of dollars of damage (U.S. Geological Survey, 1952; National Oceanic and Atmospheric Administration, 1977; Hauth and Carswell, 1978; Becker and Alexander, 1983) and has resulted in the deaths of more than 26 people in the last 25 years. The National Weather Service (NWS) in Kansas City provides a flood peak prediction service at the Missouri River and five forecast locations in the study area (fig. 1). Although this information is useful for residents within the vicinity of a NWS station, it is of limited use to residents upstream and downstream because the stage elevation is not flat (Studley, 2003). In this report, stage is a generic term for river level, or river level in terms of gage height, and stage elevation is the elevation of the river surface above the National Geodetic Vertical Datum of 1929 (NGVD 29). Despite the known hazards of flooding, Federal Emergency Management Agency (FEMA), city of Kansas City, and State emergency management mitigation teams typically lack information related to the location, depth, and velocities of water in inundated areas during and after floods. Flood-inundation mapping frequently is done long after major floods (U.S. Geological Survey, 1952; Perry, 1994) and often is of marginal use to recovery efforts. However, in recent years the convergence of major technological advances in real-time streamflow information, flood prediction, availability of 1- and 2-ft (foot)-contour-interval topographic maps, two-dimensional hydraulic modeling, and geographic information systems (GIS) technology now makes World Wide Web based delivery of real-time stage infor-

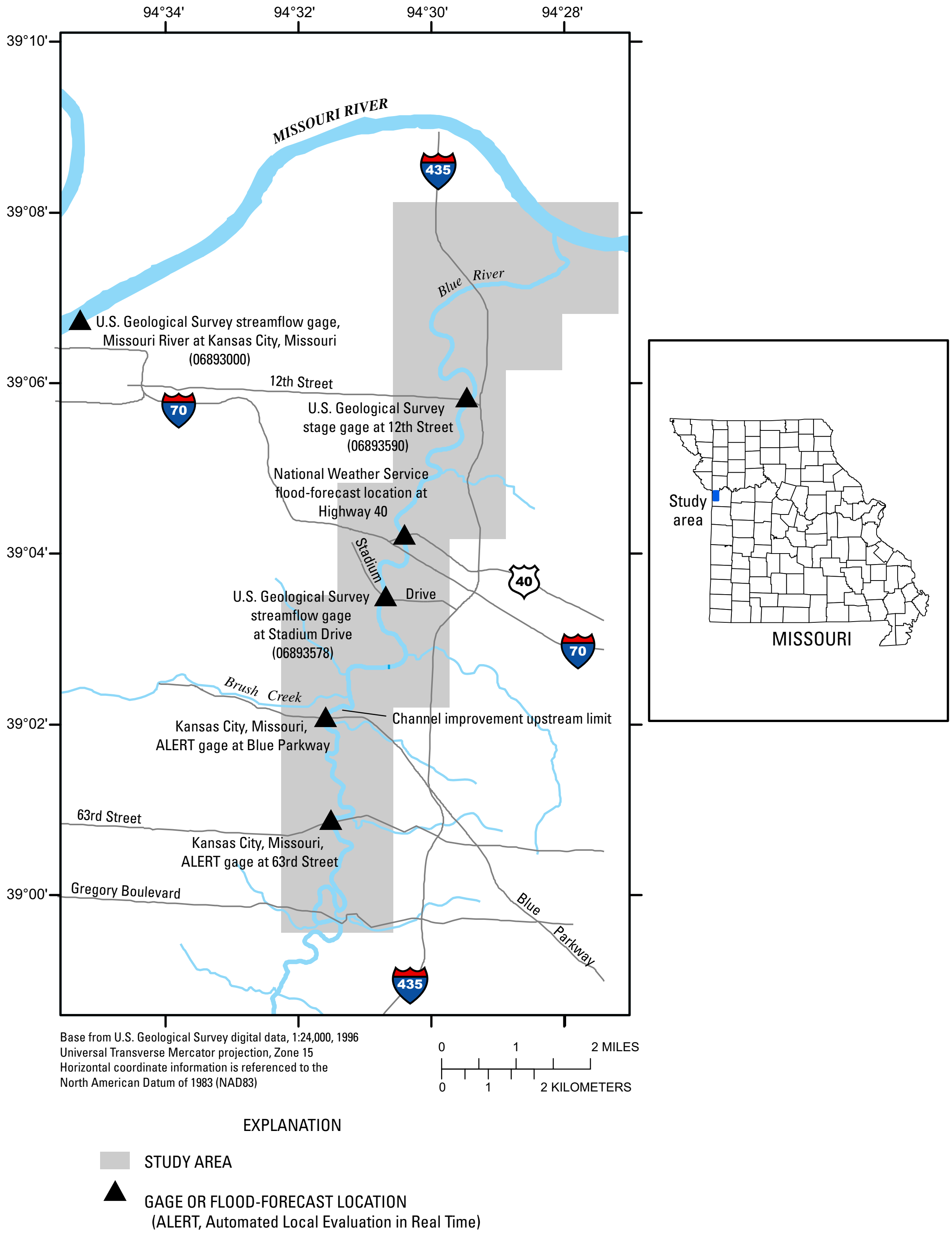


Figure 1. Study area, National Weather Service flood-forecast locations, and channel improvement limit.

mation, flood forecast prediction, and estimated flood-inundation maps possible.

The Kansas City U.S. Army Corps of Engineers (USACE) was authorized by Congress in 1970 to modify the Blue River channel from the mouth at the Missouri River southward (upstream) to 63rd Street. The primary emphasis of the project was to increase hydraulic capacity, thereby providing flood damage reduction in the Blue River valley. The upstream limit of channel improvement is currently (2005) located approximately 1,240 ft upstream from Brush Creek (approximately 1,250 ft downstream from the study reach) (fig. 1). Contingent upon funding, the remaining reach of Blue River upstream to 63rd Street also may be channelized (http://www.nwk.usace.army.mil/projects/blueriver/status.htm). A detailed two-dimensional hydraulic simulation was needed in the study reach between 63rd Street and Blue Parkway to provide flood-plain water velocities and depths for the design and performance of proposed hydraulic structures and existing flood-plain developments, along with the production of flood-inundation maps and maps representing an areal distribution of water velocity, both magnitude and direction.

To address these needs, the USGS, in cooperation with the city of Kansas City, Missouri, began a study in 2003 of the Blue River from Gregory Boulevard to the mouth to determine the extent and character of inundation in the Blue River valley from flooding in the lower Blue River and backwater from the Missouri River for selected stage elevations above flood stage. The results of this study supplement information provided by USGS gages, Kansas City ALERT (Automated Local Evaluation in Real Time) gages, and the NWS flood peak prediction service that comprise the Blue River flood-alert system and represent a valuable tool for public officials and residents to minimize flood deaths and damage in Kansas City.

Purpose and Scope

The purpose of this report is to describe estimated flood-inundation mapping for the Lower Blue River. Methods used to construct, calibrate, and verify the two-dimensional hydraulic modeling of the Blue River between 63rd Street and Blue Parkway, to prepare estimated flood-inundation maps for the Blue River from Gregory Boulevard downstream to the mouth at the Missouri River, and to present estimated flood-inundation maps on the World Wide Web are described. Twelve velocity magnitude and direction maps are presented at 2-ft intervals above Blue River flood stage for the modeled area. Twelve Blue River flood-inundation maps and 12 Missouri River backwater-inundation maps are presented at 2-ft intervals above flood stage for the Blue River flood plain from Gregory Boulevard downstream to the mouth.

Acknowledgments

The following are acknowledged for their support of this study: the city of Kansas City—Parks and Recreation for providing access to the Blue River for flood measurement; the Kansas City U.S. Army Corps of Engineers for providing channel bathymetry, construction data, and one-dimensional model results of the improved Blue River channel; and the NWS Forecast Office—Kansas City/Pleasant Hill for providing peak flood stages at flood-forecast locations and historical peak stage information.

Study Area Description

The study area includes the Blue River flood plain from Gregory Boulevard north to the mouth of the Blue River at the Missouri River (fig. 1). Within the study area, the length of the Blue River flood plain is about 10.6 mi (miles), and the actual length of the Blue River is about 15.5 mi. The stage elevation of the Blue River at normal stage decreases about 47 ft from Gregory Boulevard to the mouth.

The local climate is characterized by large variations and sudden changes in temperature and precipitation. The average temperature in January, the coldest month, is 26.9 °F (degrees Fahrenheit) and the average temperature in July, the hottest month, is 78.5 °F. Average annual precipitation is 38 in. (inches); almost 68 percent of the precipitation occurs between April and September (National Oceanic and Atmospheric Administration, 2003). An estimate of the 90 percent rainfall event for the Kansas City area (the 90th percentile daily rainfall accumulation, excluding accumulations less than 0.1 in.) is 1.37 in. (Young and McEnroe, 2002).

Much of the lower Blue River flood plain is covered by industrial development. Rapid development in the upper end of the watershed has increased the volume of runoff, and thus the discharge of flood events for the Blue River. The small size of the basin [275 mi^2 (square miles)] causes flash floods and allows minimal time for flood forecasting and response. Modifications to the channel of the Blue River began in late 1983 in response to the need for flood control. By 2004, the channel had been widened and straightened from the mouth at the Missouri River to immediately downstream from Blue Parkway (fig. 1). Channel modifications were designed to convey a 30-year flood.

Because of the large number of people and businesses along the Blue River, the NWS issues peak-stage forecasts for five gage locations in the study area and for the Missouri River at Kansas City (fig. 1) during high water. Current river stage and peak-stage forecasts are presented on the NWS Advanced Hydrologic Prediction Service internet site at http://www.weather.gov/ahps/. The NWS forecast locations in the study area on the Blue River, in order from upstream to downstream are the Kansas City ALERT gage on the Blue River at 63rd Street, the Kansas City ALERT gage on the Blue River at

Blue Parkway, the USGS streamflow gage on the Blue River at Stadium Drive (station number 06893578), the NWS forecast location on the Blue River at U.S. Highway 40, and the USGS stage-only gage on the Blue River at 12th Street (station number 06893590). The forecast location for the Missouri River is the USGS streamflow gage on the Missouri River at Kansas City (station number 06893000). Forecast location name, zero gage datum, flood gage height, and local impacts for selected flood gage heights are listed in table 1.

Table 1. Forecast location, zero datum, flood-gage height, and local flood impacts.

[ft, feet; NGVD 29, National Geodetic Vertical Datum of 1929; USGS, U.S. Geological Survey; NA, not applicable]

Forecast location name	Zero gage datum (ft) (NGVD 29)	Flood gage height (ft)[1,2]	Local flood impacts[1]
Kansas City ALERT Gage at 63rd Street	721.78	48.0	Low-lying areas in the vicinity of 63rd Street begin to flood.
		49.0	Water approaches 59th Street.
		52.3	Water enters a manufacturing plant on Colorado Street.
		55.6	Water approaches the railroad tracks on the west side of the river.
Kansas City ALERT Gage at Blue Parkway	722.47	33.4	The lower Blue Parkway floods on the west side of the river.
		38.1	The lower Blue Parkway floods east of the lower bridge.
		38.2	Brighton Avenue near Blue Parkway floods.
		39.0	Hardesty Street at 51st Street floods.
		40.7	The lower Blue Parkway Bridge is flooded.
		44.0	Flood waters approach the first floors of the businesses near the Blue River.
USGS Streamflow Gage—Blue River at Stadium Drive in Kansas City, Missouri	718.29	32.0	A low-lying area on the east side of the river near Stadium Drive begins to flood.
		35.2	Water reaches the bottom of the Stadium Drive Bridge.
		36.4	Stadium Drive and Leeds Trafficway intersection is flooded.
		39.9	Water overtops the Stadium Drive Bridge.
National Weather Service Forecast Location at U.S Highway 40	721.65	30.0	Low-lying areas near U.S. Highway 40 are flooded.
		33.0	Water begins to flood a mobile home park on U.S. Highway 40.
USGS Stage Gage—Blue River at 12th Street in Kansas City, Missouri	714.41	30.0	Low-lying areas near 12th Street flood. If the Missouri River is high, Blue River flood waters may approach the top of the flood wall on the west bank of the Blue River near the Wilson Avenue Bridge.
		36.1	12th Street floods 300 yards west of the bridge.
		36.8	Water overtops railroad tracks on the west side of the river.
		39.0	Water reaches the bottom of the 12th Street Bridge.
		51.0	Flood waters overtop the 12th Street Bridge.

Table 1. Forecast location, zero datum, flood-gage height, and local flood impacts.—Continued

[ft, feet; NGVD 29, National Geodetic Vertical Datum of 1929; USGS, U.S. Geological Survey; NA, not applicable]

Forecast location name	Zero gage datum (ft) (NGVD 29)	Flood gage height (ft)[1,2]	Local flood impacts[1]
USGS Streamflow Gage—Missouri River at Kansas City	706.40	32.0	Minor flooding outside of levees occurs.
		35.0	Farm levees are overtopped. Cropland, homesteads, and secondary roads behind the levees floods.
		39.0	Gaps in levees and floodwalls in the Central Industrial District must be closed.
		40.0	Gaps in the levees and floodwalls at North Kansas City must be closed.
		43.7	Gaps in the levees and floodwalls of the East Bottoms area must be closed.
		48.5	The levee in the Birmingham Unit is overtopped.
		49.6	Major levees in the Kansas City, Missouri, area begin to overtop.

[1]National Weather Service, 2005.

[2]Add zero gage datum to gage height to convert gage height to stage elevation.

Total relief of the flood plain within the study area is approximately 110 ft, and land-surface elevation ranges from more than 820 ft along the valley walls at the south end of the study area to about 710 ft at the mouth of the Blue River (fig. 2).

Two-Dimensional Model Application

A depth-averaged flow model, Flo2DH, [part of the Federal Highway Administrations's Finite Element Surface-Water Modeling System (FESWMS) designed for hydraulic structures and flood plains], was chosen to simulate steady-state flood flows within a hydraulically complex part of the Blue River reach. Two-dimensional modeling is beneficial in simulating flow around bends, piers, buildings, and encroaching hydraulic structures; flow within expanding and contracting reaches; and backwater effects on inflowing tributaries. The two-dimensional model was used to construct flood-inundation maps in the simulated reach. In addition, the model computes water velocity, flow direction, depth, and inundation extent within the flood plain. These model outputs can be useful in designing potential channel and flood-plain improvements throughout the simulated reach.

Study Reach Description

The hydraulically complex part of the Blue River between 63rd Street and Blue Parkway (hereinafter referred to as the "study reach") is approximately 2 river miles long and consists of a deeply incised channel, sharp meander bends, small tributary junctions, and frequent riffles exhibiting substantial gradient change (fig. 3). The study reach is bordered on the west by the Union Pacific Railroad and on the east by Hardesty Avenue. The west and east limits of the study reach were pre-determined using hydraulic engineering judgement according to limits of substantial flow and velocity. The flood plain is representative of industrial land use mixed with small residential homes (fig. 4). Aside from the thick riparian corridor along the Blue River, the western part of the flood plain is predominantly impervious; the eastern part of the flood plain consists of residential dwellings. Four small unnamed tributaries exist along the Blue River at the lower, middle, and upper end of the study reach (fig. 3). The tributaries have drainage areas between 1 and 2 mi^2 and were not considered in the analysis because of limited contributions of flow at the time of main stem flooding. A 60-ft triple barrel concrete box culvert providing hydraulic connectivity to both sides of Brighton Avenue is present within the middle tributary that dissects the western part of the flood plain of the study reach (fig. 3). The channel of the middle tributary west of Brighton Avenue is inundated for high flow events because of backwater from the Blue River flooding. With time, the culvert essentially has become ineffective because of the infilling of silt and build up of debris within the barrels of the culvert. Byram's Ford, a historic site from the Civil War, is located approximately 2,800 ft downstream from the 63rd Street Bridge.

Model Development

Two-dimensional modeling provides more hydraulic detail as compared to conventional one-dimensional analysis. The FESWMS Flo2DH model uses the Galerkin finite-element method as a numerical procedure for solving differential equations representing conservation of mass and momentum (Froehlich, 2002). A graphical interface known as Surface Water Modeling System (SMS, Environmental Modeling Systems

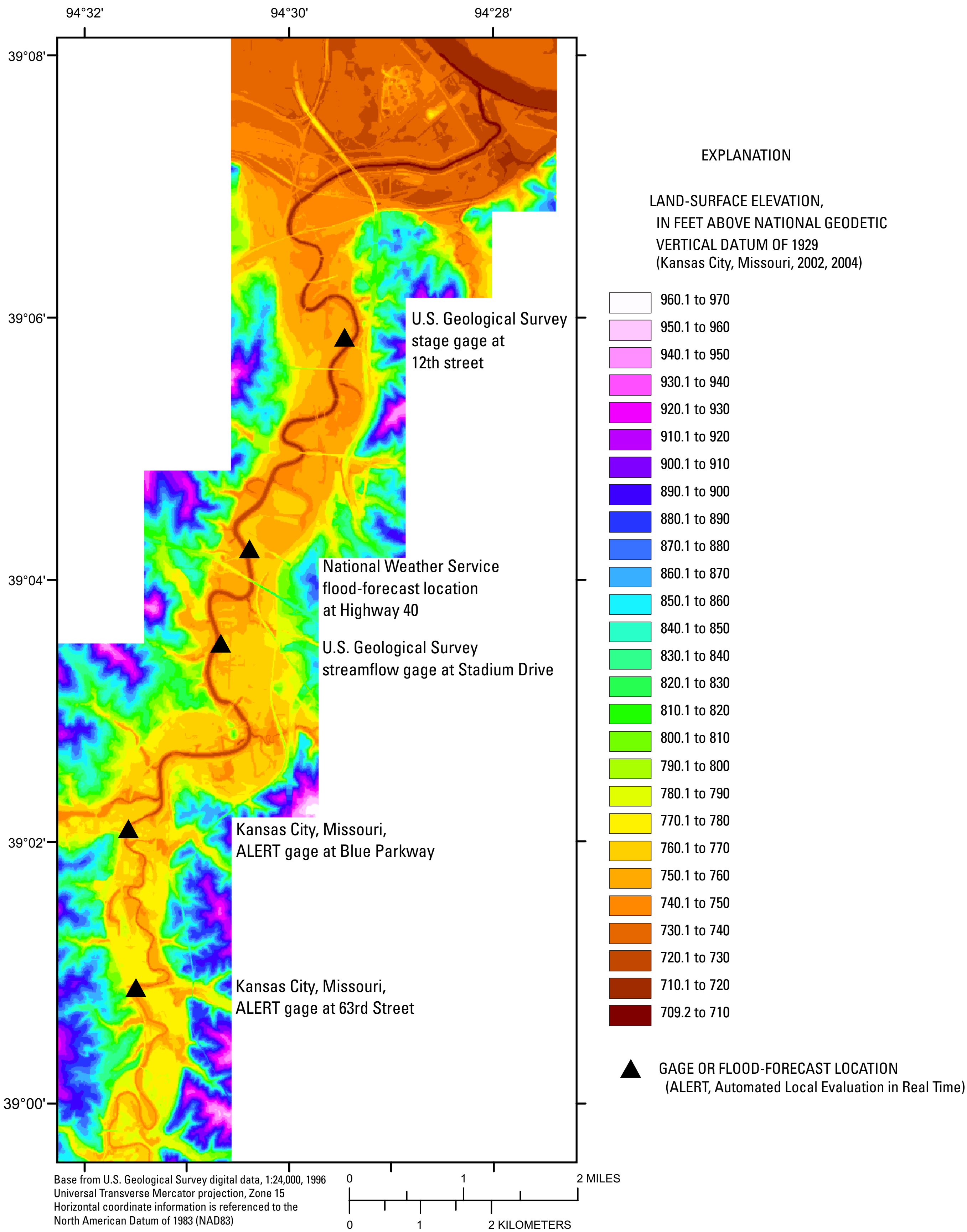


Figure 2. Land-surface elevation of the study area.

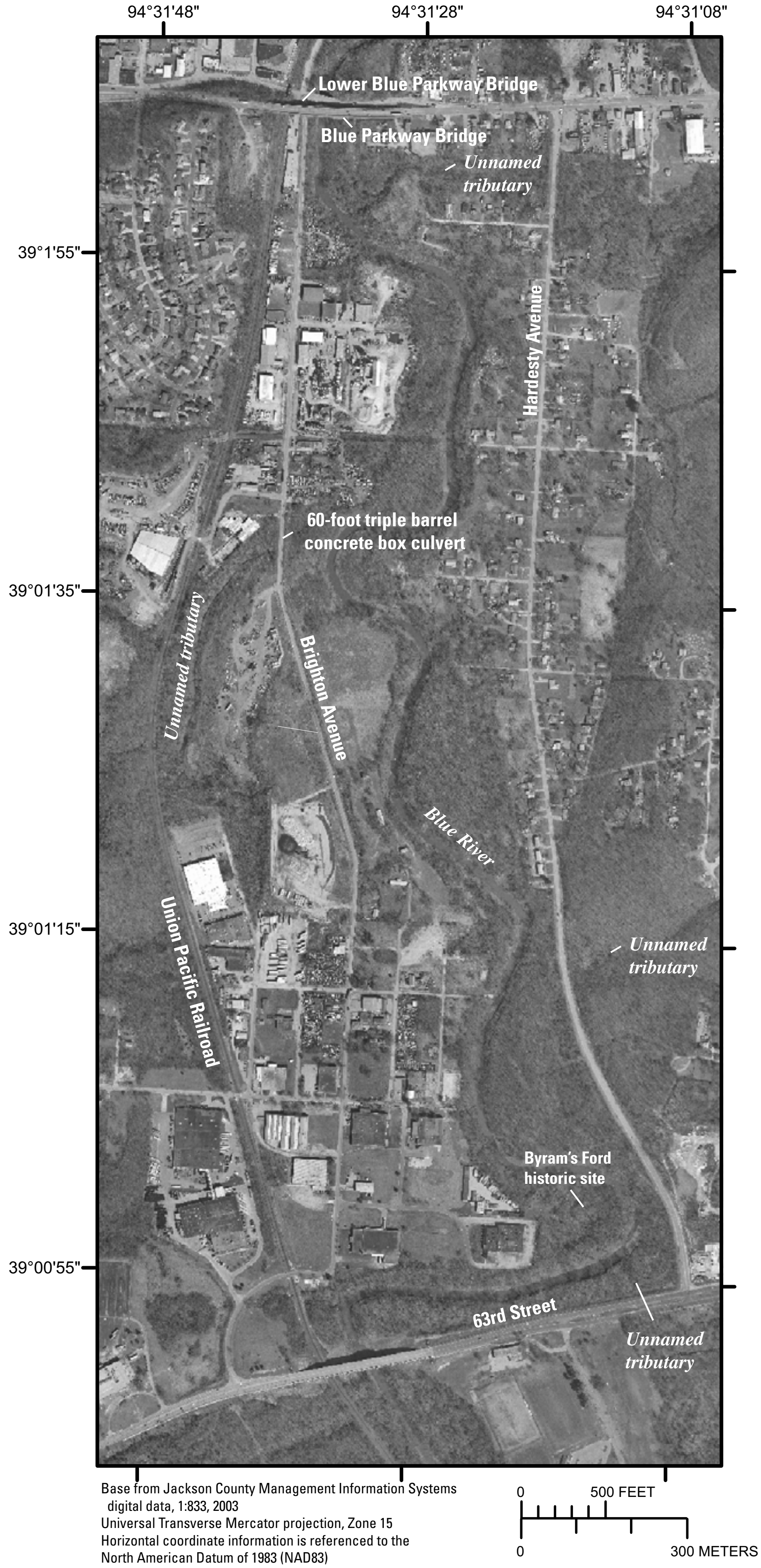


Figure 3. Simulated study reach of the Blue River between 63rd Street and Blue Parkway.

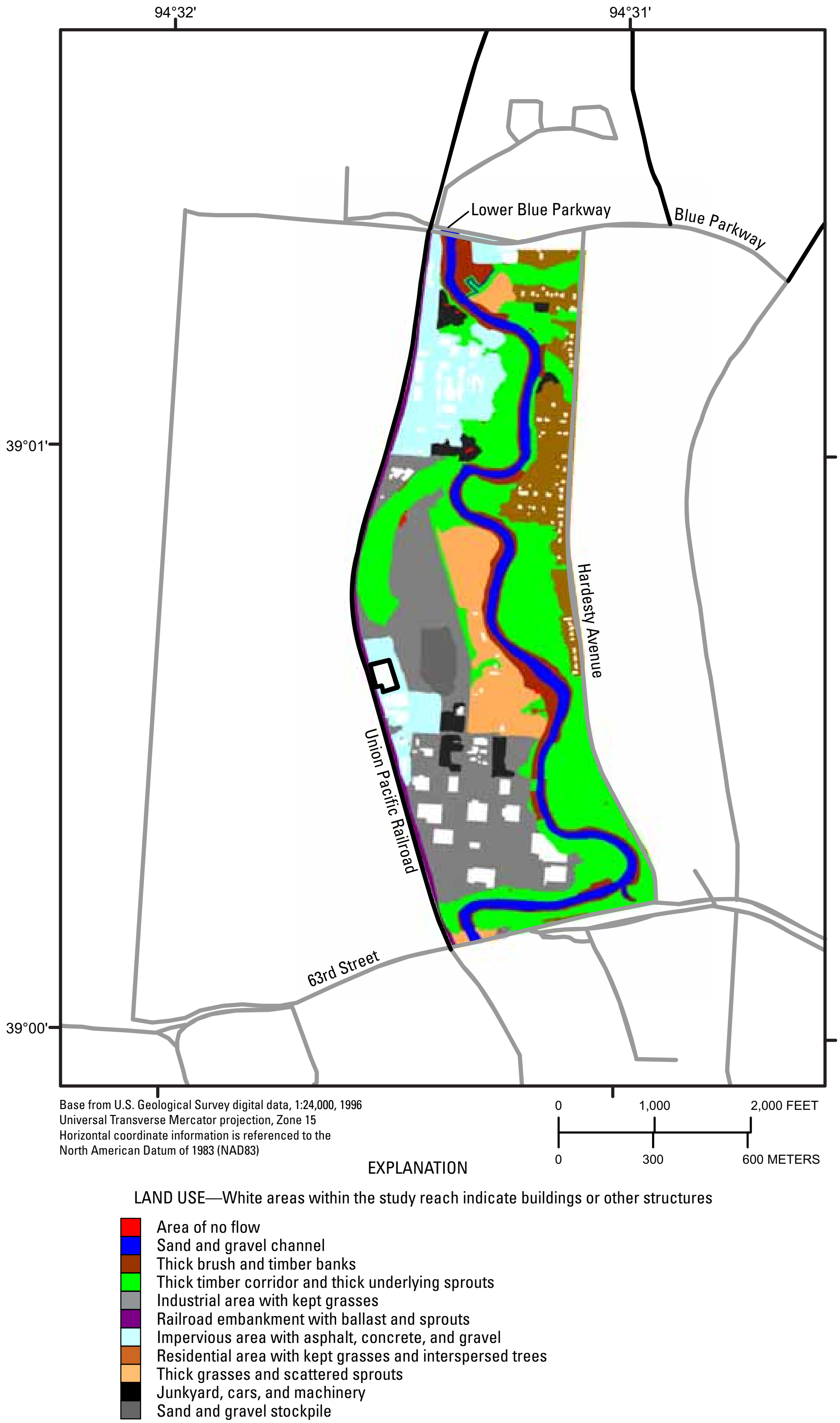


Figure 4. Land-use coverage used in flow simulations in the study reach.

Incorporated, 1999[1]) was used to construct and execute the two-dimensional model. The SMS allows interactive editing and display of finite element networks in addition to tools specifically designed for FESWMS.

Two-dimensional model geometry is characterized by elements and nodes in the form of a finite element network or mesh. The SMS software was used to convert existing 2-ft topographic contour data and supplemental field-survey data into a scatter data set that was optimally configured into a finite-element network, or mesh, consisting of triangular and quadrilateral elements. Field surveys were conducted using Global Positioning Systems (GPS) technology and conventional surveying techniques. First-floor elevations of commercial and residential structures and the Blue River channel bathymetry were surveyed. The finite-element mesh provides the geometric foundation for two-dimensional flow characteristics as opposed to individual cross-sections employed by one-dimensional models.

The quality of the mesh was checked using a mesh-quality utility within SMS. Mesh quality refers to individual element shape and the consistency in which elements relate to one another; well-constructed elements will ensure better numerical stability in the finite element network. Elements should adhere to guidelines concerning interior angles, aspect ratios, element size, curved sides, and the location of midside nodes within the element. In addition to the shape of individual elements, guidelines are set to improve relative consistency among elements. Smooth contours and boundaries, adequate size transition among elements, density of elements, and the necessity of constructing smaller elements at the wet/dry boundary interface often were employed. The wet/dry interface is one of the more common causes of solution divergence, especially if the elements in transition are comparatively large, and only small parts of those elements actually are dry (Froehlich, 2002). The deeply incised channel within the study reach has steep banks that required smaller, thinner elements along the banks and additional element refinement near the top of the banks.

Once a finite-element mesh has been created and the quality has been maintained, the elements of the mesh are characterized by assigning material (fig. 4) and hydraulic properties to the elements, such as Manning's *n* roughness coefficients (Chow, 1959; Barnes, 1967; Arcement and Schneider, 1989), and additional turbulence parameters such as base kinematic eddy viscosities and element storativity depth. Manning's *n* roughness coefficients were established throughout the overbanks and within the channel banks. Roughness coefficients were water depth dependent and defined as the "lower depth" n-value over an element existing less than the lower depth, and the "upper depth" n-value over an element existing greater than the upper depth; the n-value is interpolated linearly from the upper and lower n-values (Froehlich, 1989). Mannings *n*-roughness coefficients for the calibrated model run are listed in table 2.

Table 2. Manning's *n* roughness coefficients for the calibrated model run.

[ft, feet]

Land-use coverage	Lower depth		Upper depth	
	Manning's *n*	Depth (ft)	Manning's *n*	Depth (ft)
Channel and bank				
Blue River main channel (sand and gravel)	0.040	3.0	0.025	4.0
Thick brush and timber banks	.110	2.5	.080	5.0
Thick timber corridor with thick sprouts	.125	3.0	.092	6.0
Thick grasses and scattered sprouts	.055	1.7	.040	3.2
Flood plain				
Industrial area with kept grasses	0.050	1.0	0.033	2.7
Railroad embankment with ballast and sprouts	.038	1.0	.032	2.0
Impervious area with asphalt, concrete, and gravel	.027	1.0	.025	2.0
Residential area with kept grasses and interspersed trees	.038	1.5	.032	2.5
Commercial area with junkyard, cars, and machinery	.150	5.0	.040	7.0
Sand and gravel stockpile	.032	1.0	.030	2.5

[1]Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Kinematic eddy viscosities (V_o) represent turbulent conditions throughout the finite-element mesh and are necessary to provide numerical damping for model stability. Element storativity is another turbulence parameter that allows partially dry elements to be retained in calculations when solving governing equations (Froehlich, 2002).

Piers for the existing Blue Parkway Bridge and the downstream adjacent lower Blue Parkway Bridge were incorporated into the mesh (fig. 5). A separate model was used to simulate proposed deck widening of the Blue Parkway Bridge and removal of the lower Blue Parkway Bridge. Piers for the proposed Blue Parkway Bridge also were incorporated into the mesh (fig. 6). The elements within each pier location were disabled to force flow around the piers. Dimensions of all piers were taken from bridge plans to accurately construct disabled elements. (Department of Public Works, City of Kansas City, 2004).

Model Calibration

The amount of flow into the mesh and a stage elevation where flow leaves the mesh are required model inputs. A flood occurred May 19, 2004, that produced both bank-full and overbank flow conditions. Peak-flow measurements and high-water marks were acquired during this event. The total flow along the study reach and stage elevation at the downstream face of the lower Blue Parkway Bridge were used as boundary conditions. Two bridges are present at the downstream end of the reach. The Blue Parkway Bridge over the Blue River, and the Union Pacific Railroad is approximately 50 ft upstream from the lower Blue Parkway Bridge (fig. 3). The downstream lower Blue Parkway Bridge consists of three, 54-ft concrete slab spans supported by two concrete main channel piers with solid web walls and vertical abutments. The main channel columns for the Blue Parkway Bridge were incorporated into the mesh along with the main channel piers for the lower Blue Parkway Bridge (fig. 5). The calibrated downstream stage elevation and the low-chord elevation (ceiling elevation) of both downstream bridges did not induce pressure flow. As a result, the low chord of both bridge decks was not acknowledged in the calibration model run. Elements representing vertical abutments at the downstream lower Blue Parkway Bridge were disabled to force encroachment of flow.

Simulations cannot begin directly with boundary conditions that represent measured conditions. For sub-critical flow regimes, flow simulations often begin with the measured discharge and a flat stage-elevation slope. An iterative process known as “spindown” is required to gently lower the stage elevation at the downstream boundary condition. Subsequent iterative model runs are used as “hotstarts,” which provide the initial condition for the next model run. This process is repeated until the desired downstream stage elevation is achieved. Throughout the process of a “spindown,” elements often are manually disabled to prevent solution instability that comes from wetting and drying. Throughout the iterative process of a given simulation, nodes within elements may become dry if the stage elevation for that particular iteration is less than the land-surface elevation assigned to that node. Conversely, the element becomes wet if the stage elevation is greater than the assigned land-surface elevation for several element nodes. As the simulation proceeds through the assigned number of iterations, an element can oscillate between wet and dry (Huizinga and Rydlund, 2001), which can lead to solution instability but may sometimes be overcome by setting a storativity depth tolerance that defines the depth of flow over a node. However, if an element becomes dry and stays dry for several iterations, it should be disabled to allow model convergence (Huizinga and Rydlund, 2001).

The peak stage of May 19, 2004, occurred at 6:30 p.m. at 63rd Street. The main stem peak stage at the lower Blue Parkway Bridge, which was consistent with the peak stage at 63rd Street, occurred at 7:00 p.m. Discharge measurements were made in a boat using hydroacoustic technology at a location immediately upstream from the 63rd Street Bridge and at a location approximately 540 ft upstream from the mouth of Brush Creek (fig. 1). Both measurements were made at the time of the peak stage. The narrow and sinuous channel, timbered corridor, considerable velocities, standing waves, and turbulence prevented adequate hydroacoustic measurements to be made anywhere else in the study reach to obtain flow and velocity measurements. For the upstream and downstream locations, mean flows of 12,200 and 12,400 ft^3/s (cubic feet per second) were computed. Both flows were averaged as 12,300 ft^3/s, which was considered the upstream total flow boundary condition for a steady-state condition. As a quality assurance measure, a current-meter measurement was made at the upstream face of the lower Blue Parkway Bridge concurrent with the hydroacoustic measurement at the location above the mouth of Brush Creek. The measured flow from the current-meter measurement was 12,900 ft^3/s.

Four distinct high-water marks indicating peak stage were identified along the study reach for the flood on May 19, 2004. One mark, in a tributary approximately 1,700 ft upstream from the downstream face of lower Blue Parkway Bridge, was unusually high and was thought to represent a local peak before the Blue River peak of May 19, 2004, and was not included in the calibration process. The measured area and velocity of the current-meter measurement were used as calibration values at the downstream boundary condition. Although the hydroacoustic measurement was made immediately upstream from the downstream face of the 63rd Street Bridge (upstream boundary location), a comparison of simulated and measured velocity and cross-sectional area also

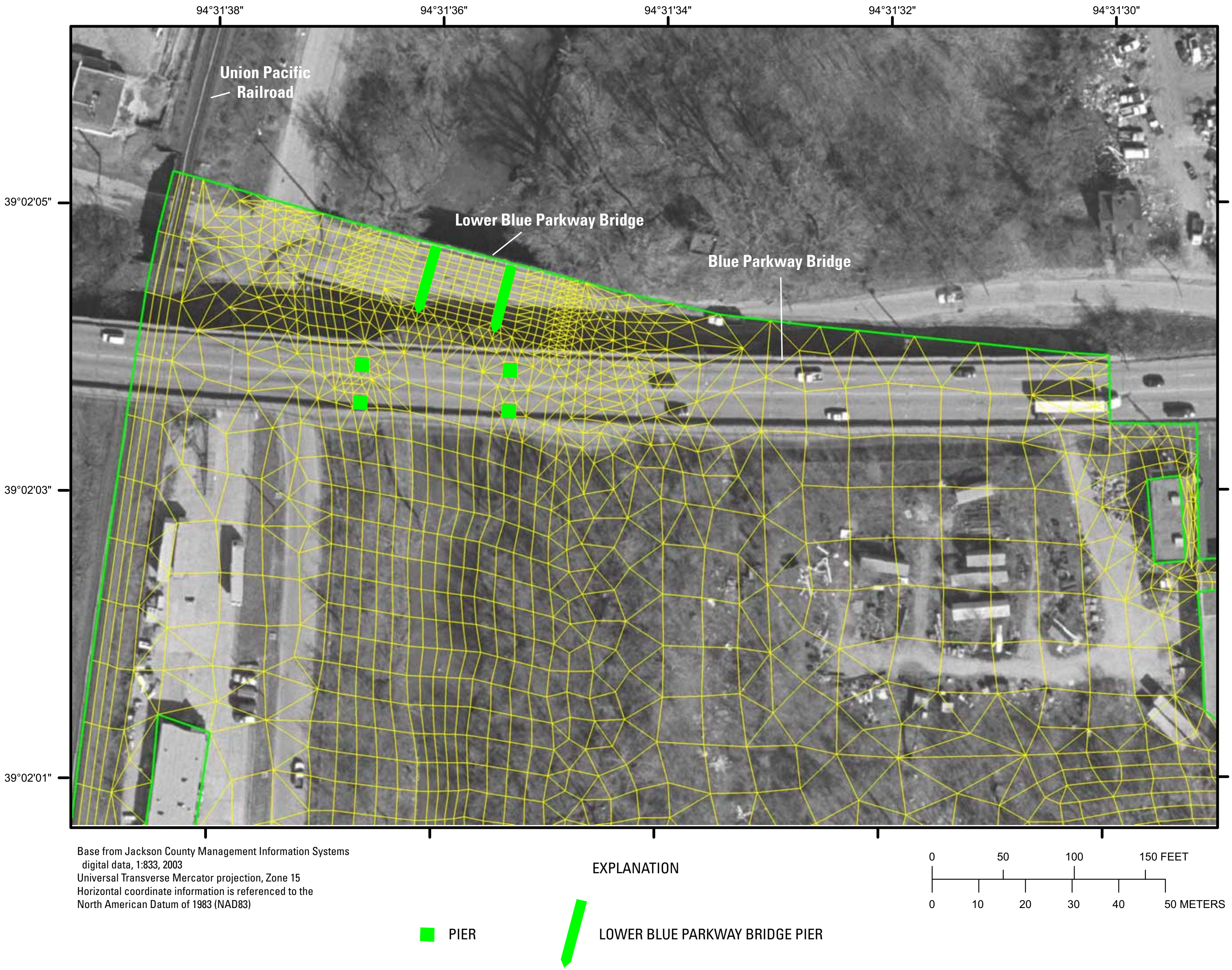


Figure 5. Finite-element mesh incorporating pier configuration for the current (2005) Blue Parkway Bridge and downstream lower Blue Parkway Bridge for model calibration flood of May 19, 2004.

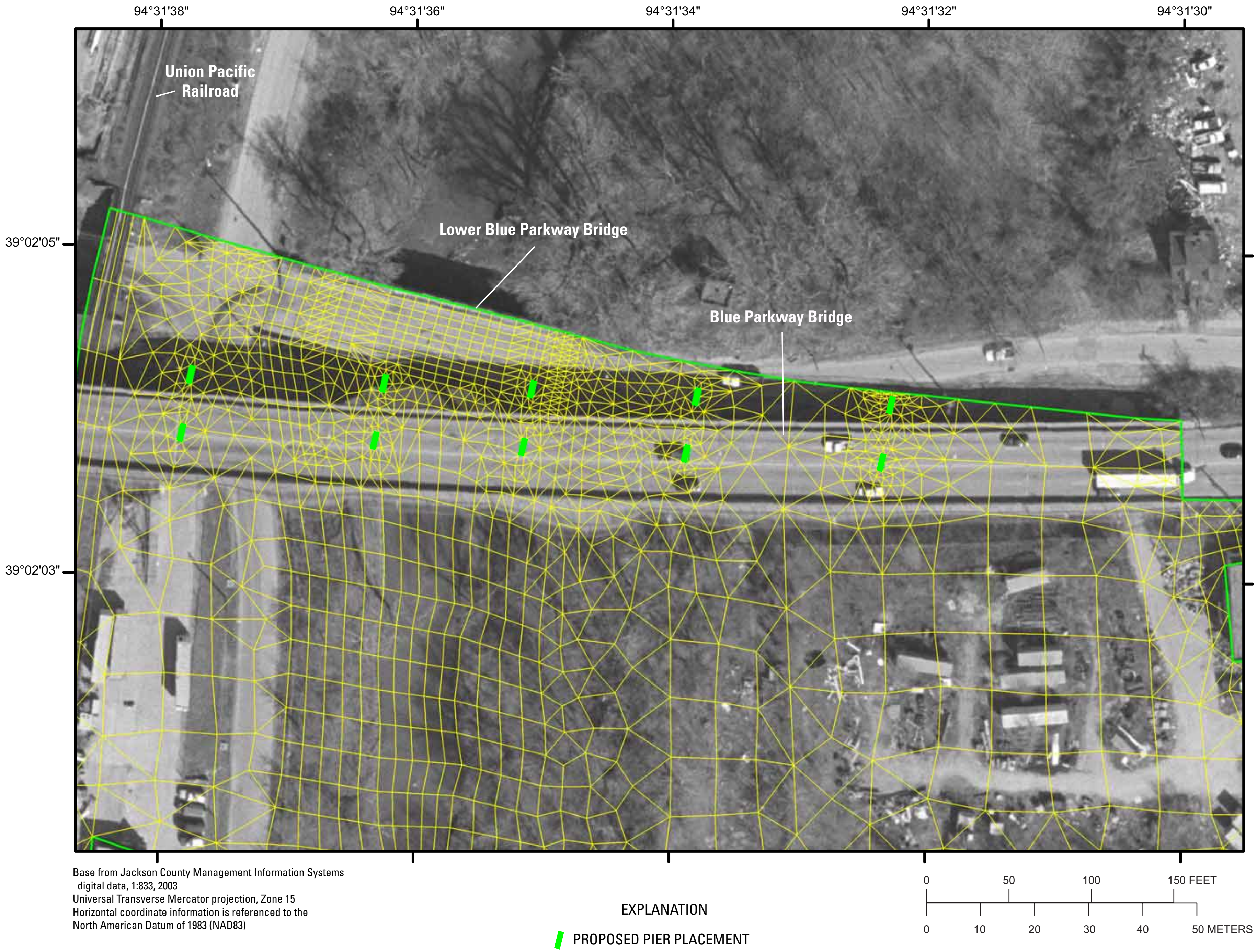


Figure 6. Modified finite-element mesh based on pier configuration of the proposed Blue Parkway structure.

was made at the upstream model boundary. Measured and simulated stage elevation, cross-sectional area, and velocity are described in table 3. Generally, the measured stage elevations were within 0.2 to 0.53 ft of the simulated stage elevations. The quality of the high-water marks indicating measured stage elevation was considered poor.

Table 3. Measured and simulated stage elevation, cross-sectional area, and velocity.

[ft, feet; ft^2, square feet; ft/s, feet per second; --, not determined/not applicable]

Location	Measured stage elevation (ft)	Simulated stage elevation (ft)	Measured cross-sectional area (ft^2)	Simulated cross-sectional area (ft^2)	Measured velocity (ft/s)	Simulated velocity (ft/s)
Lower Blue Parkway Bridge	748.59[1]	748.59[1]	1,883	1,797	6.85	6.87
Brighton Ave. toe of embankment	756.56	756.78	--	--	--	--
Byram's Ford	760.32	760.85	--	--	--	--
63rd Street Bridge	762.39	762.80	4,230[2]	4,841[2]	2.88[2]	2.54[2]

[1]Starting stage elevation boundary condition.

[2]Measurement made immediately upstream from 63rd Street Bridge. Simulated results obtained from downstream face of bridge.

Except for a flood-plain area in the middle of the study reach, the flood of May 19, 2004, primarily was contained within the channel and overbanks. Velocities as high as 12 ft/s (feet per second) were simulated at the downstream end of the study reach because of increased slope, a narrow confined section of channel, and converging flow from the lower Blue Parkway Bridge (figs. 3, 7). The increased slope likely is caused by the channelization immediately downstream, which has lowered the stage elevation at the downstream end of the unchannelized reach and thus increased the water-surface slope. The general stage-elevation slope throughout the reach for the calibrated flood was approximately 0.0013 ft/ft (foot per foot) or about 7 ft/mi (feet per mile). Water depths of 25 to 30 ft were simulated in the deeply incised channel (fig. 8). The stage elevation depicted the greatest changes where substantial water velocity gradients occurred (fig. 9).

Development of Simulated Rating Using One-Dimensional Hydraulic Analysis

To produce flood-inundation layers for the study reach, a range of boundary conditions was developed for high flows. This was accomplished using existing one-dimensional Hydraulic Engineering Centers River Analysis System (HEC-RAS) model results from the USACE on the lower Blue River main stem (hereinafter referred to as the "lower Blue River HEC-RAS model"). Results were available from this model for a range of discharges on the improved channel from the mouth of the Blue River to a cross section immediately upstream from the mouth of Brush Creek (fig. 1). A new HEC-RAS model (hereinafter referred to as the "constructed HEC-RAS model") was constructed to extend the results from the lower Blue River HEC-RAS model from immediately upstream from the mouth of Brush Creek to the upstream face of the lower Blue Parkway Bridge. Cross sections were derived from the available 2-ft contour data and cross-section data acquired from discharge measurements. Five cross sections were used in the constructed HEC-RAS model (fig. 10). Input into the constructed HEC-RAS model consisted of stage elevation and discharge measurements made at the upstream side of the lower Blue Parkway Bridge (cross-section 4) and at the limit of channel improvement immediately upstream from the mouth of Brush Creek (cross-section 1) for the May 19, 2004, flood. The constructed HEC-RAS model was calibrated to the discharge measurements (table 4).

Table 4. Measured and simulated conditions for the constructed HEC-RAS model.

[ft, feet; ft2, square feet; ft/s, feet per second

Hydraulic parameter	Cross-section 1		Cross-section 4	
	Measured	Simulated	Measured	Simulated
Stage Elevation (ft)	747.4	747.4	749.16	749.16
Flow area (ft^2)	2,901.8	2,909.5	1,883.00	1,888.40
Top width (ft)	238.2	238.4	146.00	145.30
Velocity (ft/s)	4.3	4.34	6.85	6.60

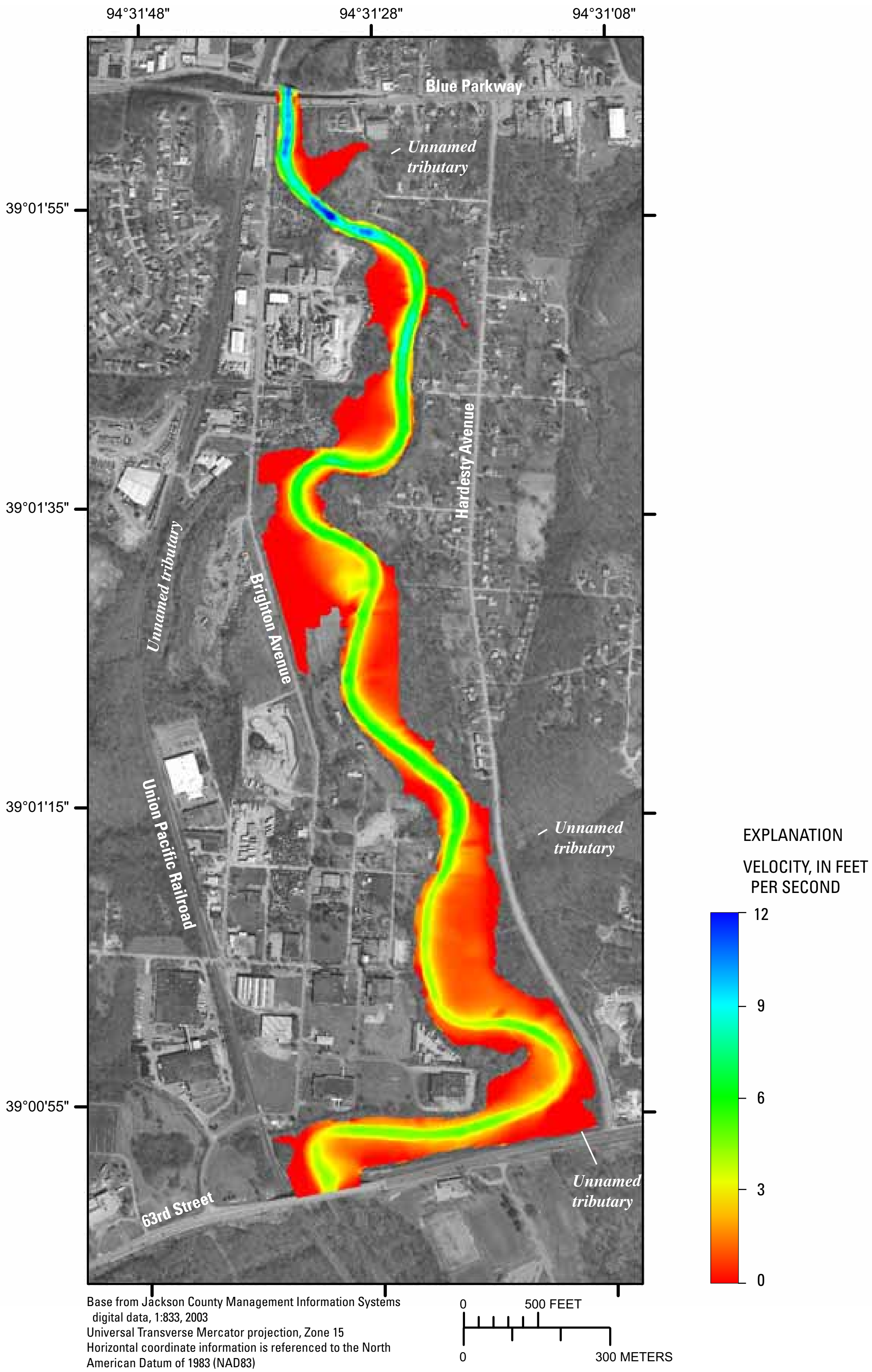


Figure 7. Simulated velocity magnitude for the May 19, 2004, flood.

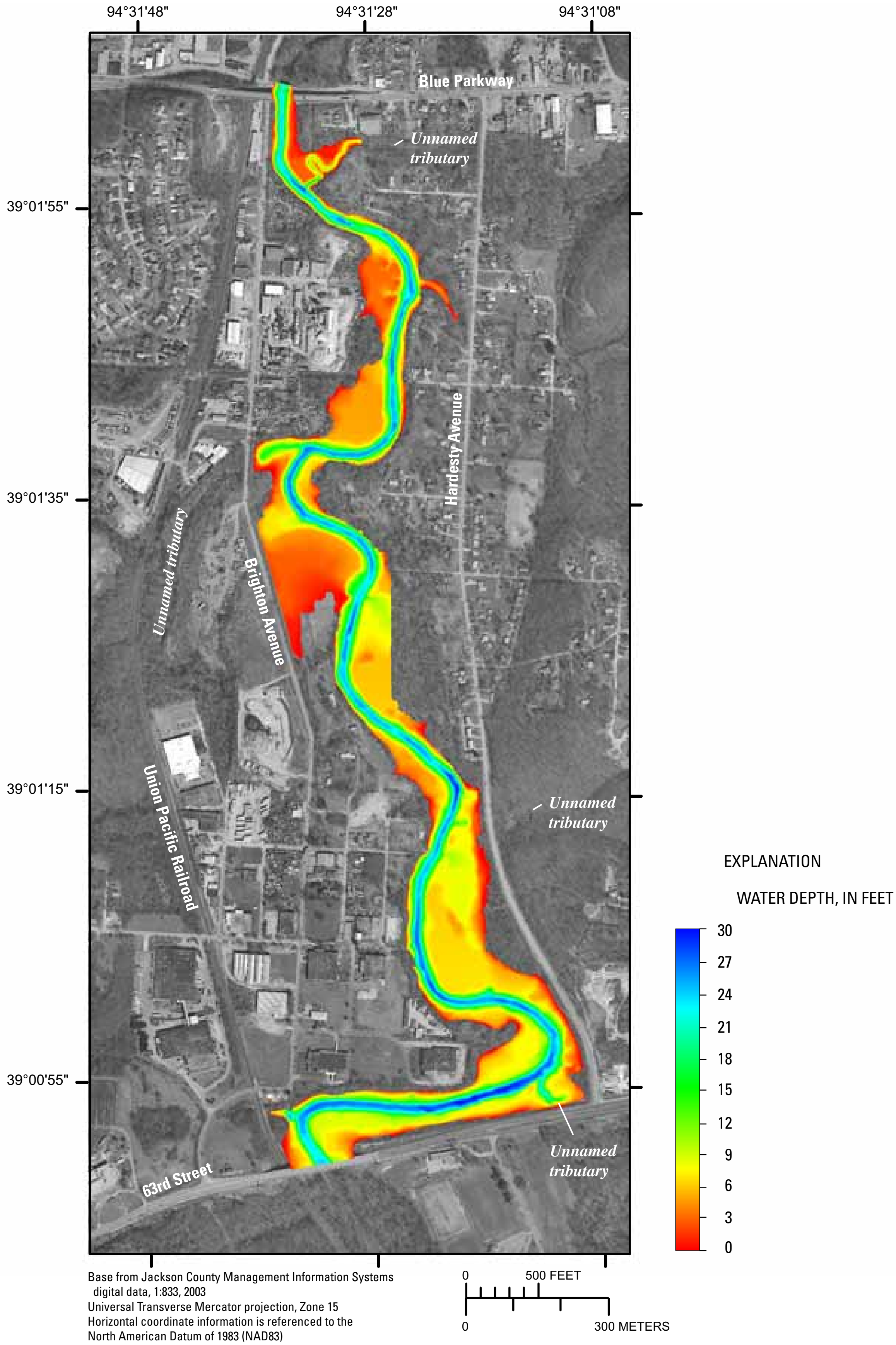


Figure 8. Simulated water depth for the May 19, 2004, flood.

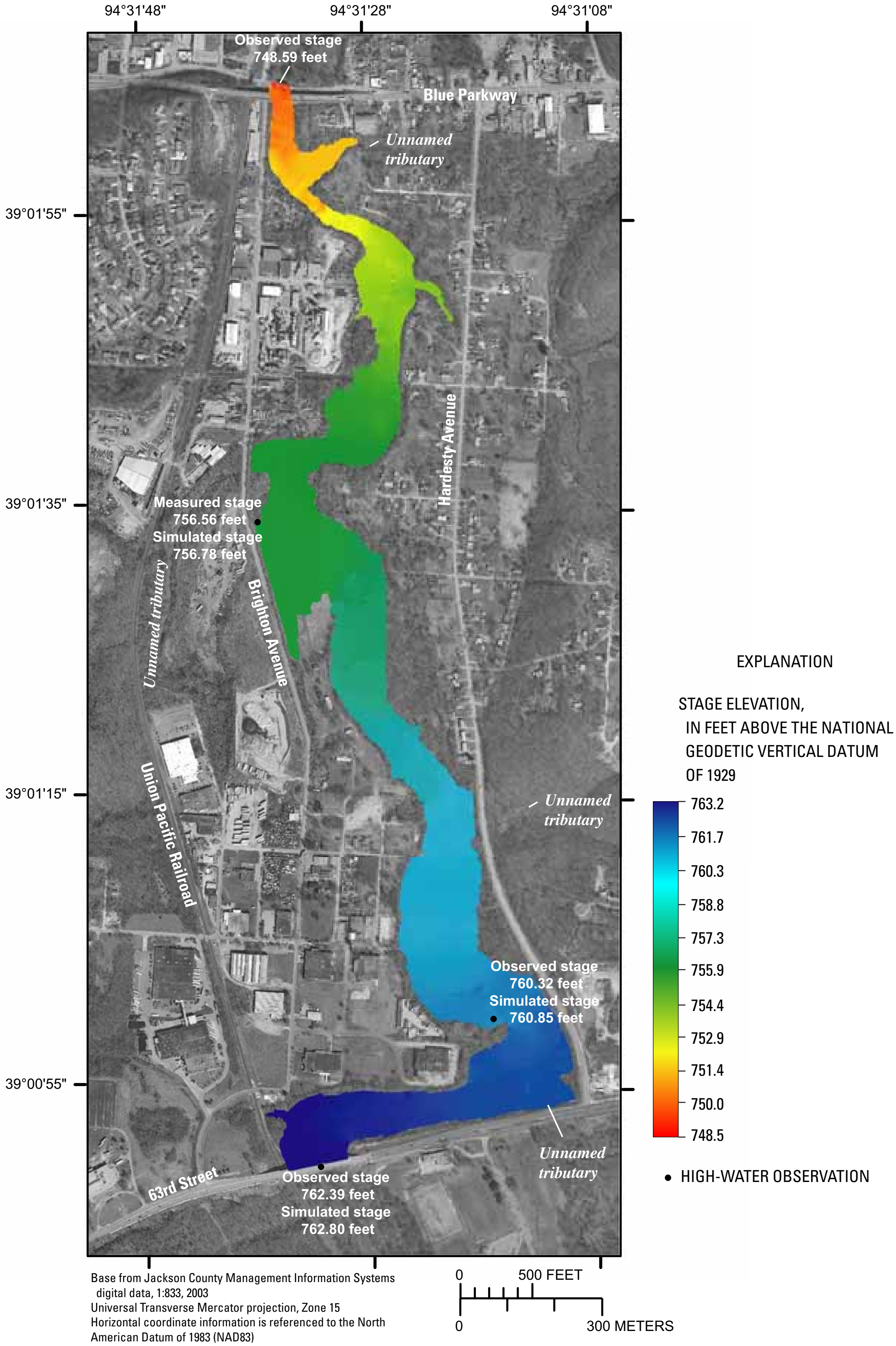


Figure 9. Simulated stage elevation and high-water observations for the May 19, 2004, flood.

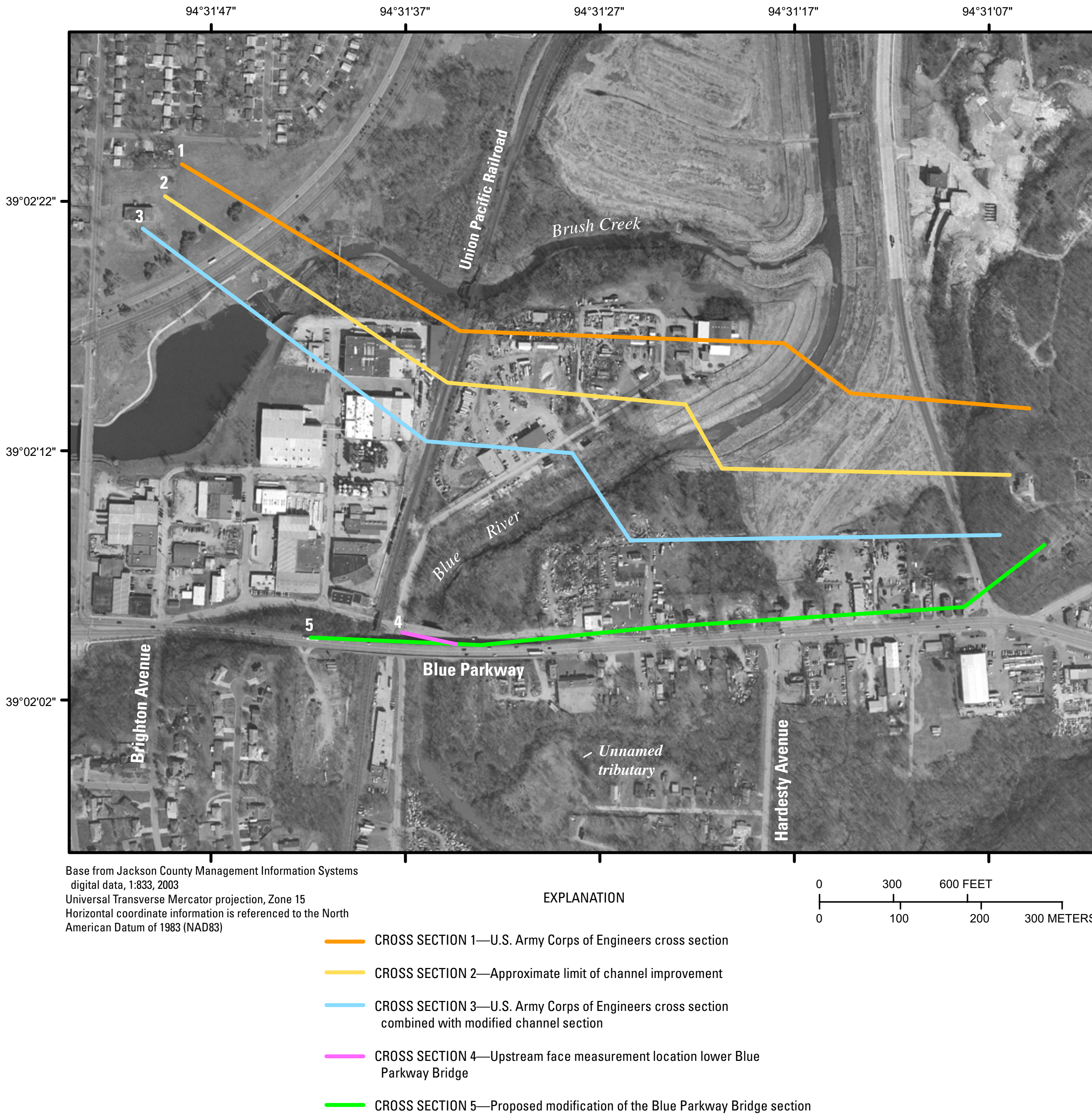


Figure 10. Cross sections used in the constructed Hydraulic Engineering Centers River Analysis System (HEC-RAS) model.

Differences as much as 0.5 ft in stage elevation were observed between the lower Blue River HEC-RAS model and the constructed HEC-RAS model when calibrated for the discharge from the May 19 measurement data. Stage elevation differences likely were a result of scour and fill process that may have occurred as a result of lower main stem channel improvements. Because the Blue River is in a sub-critical flow regime where one-dimensional standard step computations are appropriate, the two HEC-RAS models would represent parallel slope or energy-grade line (EGL) characteristics at the upstream end of the lower Blue River HEC-RAS model and downstream end of the constructed HEC-RAS model. The difference in the EGL for the two models was 0.00003 ft/ft. This difference in EGL was maintained for the 2- to 500-year discharges provided by the lower Blue River HEC-RAS model, and are listed in table 5.

Table 5. Energy-grade line (EGL) slope for the Kansas City U.S. Army Corps of Engineers HEC-RAS model of the lower Blue River and HEC-RAS model constructed between the lower Blue River model and the study reach for selected flood-frequency values.

[ft^3/s, cubic feet per second; EGL, energy-grade line; ft/ft, foot per foot]

Flood frequency (years)	Discharge (ft^3)	EGL slope at cross-section 1 of the lower Blue River HCE-RAS model (ft/ft)	EGL slope at cross-section 1 of the constructed HCE-RAS model (ft/ft)
2	13,200	0.000574	0.000544
5	20,300	.000512	.000482
10	26,320	.000454	.000424
20	34,000	.000382	.000352
50	44,500	.000338	.000308
100	53,690	.000344	.000314
200	62,000	.000336	.000306
500	74,720	.000366	.000336

Eight flood-frequency discharge values acquired from the Kansas City USACE were modeled from cross-section 1 upstream using the EGL from table 5 to the face of the lower Blue Parkway Bridge where the study reach begins (USACE, written commun., 2004). The simulated stage elevation for each of the flood-frequency discharge values was used to develop a stage-discharge rating at the face of the lower Blue Parkway Bridge. The resulting rating provided the boundary condition information needed to use the two-dimensional simulation to create flood-inundation maps from the lower Blue Parkway Bridge to 63rd Street. Discharge values associated with stage elevation at the lower Blue Parkway Bridge at 2-ft increments from 750 through 772 ft were selected from the rating curve and input into the two-dimensional model (table 6).

Simulated Velocity Magnitude and Direction Flood-Inundation Maps

The hydraulic flood-inundation model for the study reach incorporates design plans for the proposed Blue Parkway structure over the Blue River and Union Pacific Railroad. New pier alignment and pier dimensions were coded into the finite element mesh (fig. 6) and another "spindown" process was initiated beginning with the first boundary conditions at a discharge of 71,690 ft^3/s and stage elevation at 772 ft. Once the model attained acceptable convergence parameters, the next flood-stage elevation was simulated. Convergence parameters, including an average change in unit flow rates in the x and y direction and an average change in stage elevation, were examined for each simulated flood-stage elevation. Acceptable convergence was achieved with an average change in unit flow rates of less than 0.1 ft^2/s (square foot per second) and an average change in stage elevation less than 0.1 ft. Geographic information system (GIS) technology was used to create velocity magnitude and direction profiles for the study reach. Twelve flood-stage elevations (2-ft increments for 750 to 772 ft above NGVD29) are depicted for the downstream vicinity of 63rd Street, the middle of the study reach, and the upstream vicinity of the lower Blue Parkway Bridge in Appendixes 1, 2, and 3 (at the back of this report).

Estimated Flood-Inundation Mapping

Flood-profile slopes of the Blue River between Gregory Boulevard and 63rd Street were developed from stage elevations calculated from high-water marks from the flood of May 19, 2004. Locations of visible changes in flood-stage elevation slopes were identified and different stage-elevation slopes were used between each break in slope. To ensure the consistency of

Blue River flood-stage elevation in this reach, the stage elevation at each change in slope was determined from downstream to upstream with the two-dimensional model-derived stage elevations at 63rd Street as the starting point.

Table 6. Simulated rating depicting stage elevation at the lower Blue Parkway Bridge and discharge as boundary conditions for developed flood-inundation maps in the study reach.

[ft, feet; ft3/s, cubic feet per second

Stage elevation (ft)	Discharge (ft^3/s)
750	13,930
752	16,740
754	20,110
756	23,210
758	26,650
760	29,970
762	33,700
764	37,630
766	41,920
768	48,100
770	56,670
772	71,690

Stage elevation between 63rd Street and Blue Parkway was determined using the two-dimensional flow-modeling results previously described. The stage discharge relation developed between the two-dimensional model and the Lower Blue River HEC-RAS model for the constructed HEC-RAS model was used to calculate stage and stage-elevation slopes for the reach of unimproved channel between Blue Parkway and the upstream limit of the improved channel (fig.1). Stage-elevation slopes and stage elevations between the upstream limit of the improved channel and the mouth of the Blue River were obtained from the lower Blue River HEC-RAS model results (fig. 11). The lower Blue River HEC-RAS model is based on theoretical flow in the improved Blue River channel and was not calibrated to actual flow events; however, because stage-discharge measurements during floods on the lower Blue River were unavailable for improved channel conditions, the model results represent the best available data for that reach. Locations of visible changes in flood-stage elevation slope in this reach were identified, and different stage-elevation slopes were used between each break in slope. To ensure the consistency of the entire Blue River flood-stage elevation, the stage-elevation slopes were used between each break in slope. The relation between stage at Blue Parkway and the upstream limit of the improved channel developed for the constructed HEC-RAS model was used to ensure consistency between the two-dimensional model results and the Lower Blue River HEC-RAS model results. The lower Blue River HEC-RAS model provided river profiles and stage elevations for the 2-, 5-, 10-, 20-, 50-, 100-, 200-, and 500-year floods at each change in slope. The range of stage elevations of the model encompass the range of stage elevations selected for flood-inundation mapping, but do not correspond exactly. To select the appropriate flood-stage slope from the model results, the stage elevation for the flood-inundation surface was compared to the stage elevation determined by the model. The appropriate flood-stage slope chosen was from the profile with the stage elevation closest to the desired flood inundation stage elevation.

Missouri River backwater inundation profiles from flood stage to the highest stage recorded in July 1993 were developed by interpolating the Missouri River stage elevation recorded at the gage at Kansas City to the mouth of the Blue River using slopes derived from Kelly (1996) and Perry and others (1997). The calculated stage elevation profiles and source of slope data (lower Blue River HEC-RAS model, calibrated two-dimensional model, or high-water marks) from Gregory Boulevard to the mouth of the Blue River for all Blue River flood-inundation maps are shown on figure 11.

The Kansas City Missouri ALERT Gage at Blue Parkway was chosen as the reference gage for the Blue River flood-inundation mapping to provide a consistent naming convention between flood maps and two-dimensional model results. A Blue River NWS flood-stage elevation of 750 ft (NGVD 29) at Blue Parkway was used as the base elevation to generate all of the flood-inundation maps. Twelve maps were produced at 2-ft intervals from stage elevations from 750 to 772 ft at Blue Parkway to approximate the range of river stages from the 2- to 500-year flood frequencies (tables 5 and 6). Stage elevations and gage heights for floods at forecast locations within the study area for flooding on the Blue River are listed in table 7.

Upstream from 63rd Street and downstream from Blue Parkway, stage elevations at each forecast location and breaks in slope were extrapolated across the flood plain along cross section lines oriented perpendicular to the downstream direction of the Blue River flood plain. The locations of these cross sections and the study reach, which required no horizontal extrapolation, are shown on figure 12.

Two-dimensional model results, boundaries of the study area and study reach, cross sections of equal flood-stage elevation at gages, and changes in flood profile slopes were input into the GIS software program ARC/INFO. ARC/INFO software was used to interpolate flood-stage elevations between cross sections for each flood profile to produce sloped flood-inundation surfaces. The resulting surface was converted to a raster data set representing the flood-inundation surface using square cells, 5 ft on a side.

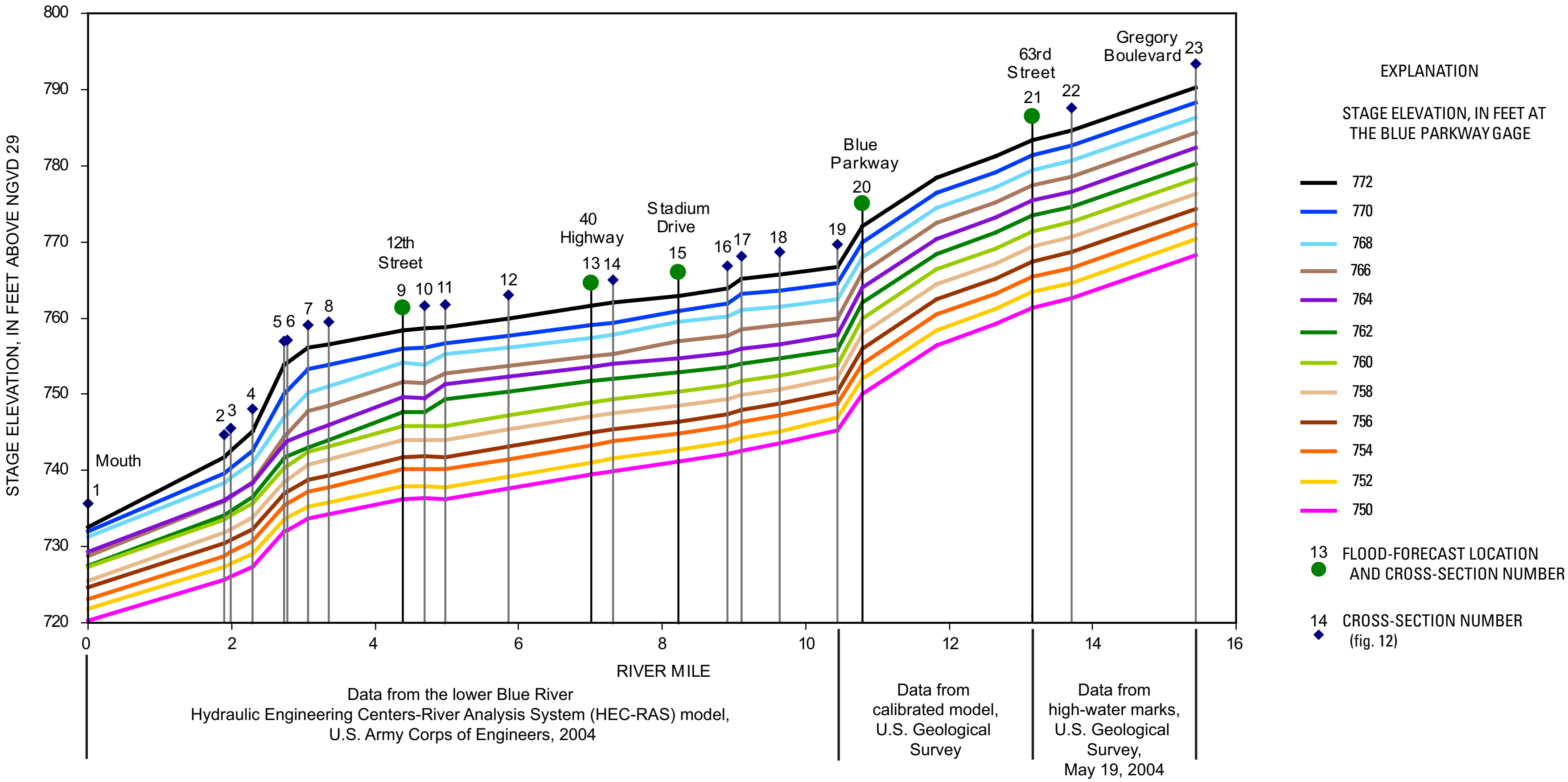


Figure 11. Calculated Blue River slopes, stage elevations, cross sections, and sources of data for all flood-inundation maps from Gregory Boulevard to the mouth of the Blue River.

Base from Jackson County Management Information Systems digital data, 1:833, 2003
Universal Transverse Mercator projection, Zone 15
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD83)

Figure 12. Location of cross sections used for flood-inundation area interpolation and the area of the constructed FESWMS used to create flood-inundation surfaces.

Table 7. Equivalent peak flood-stage elevations and gage heights for forecast locations for flood inundation on the Blue River.

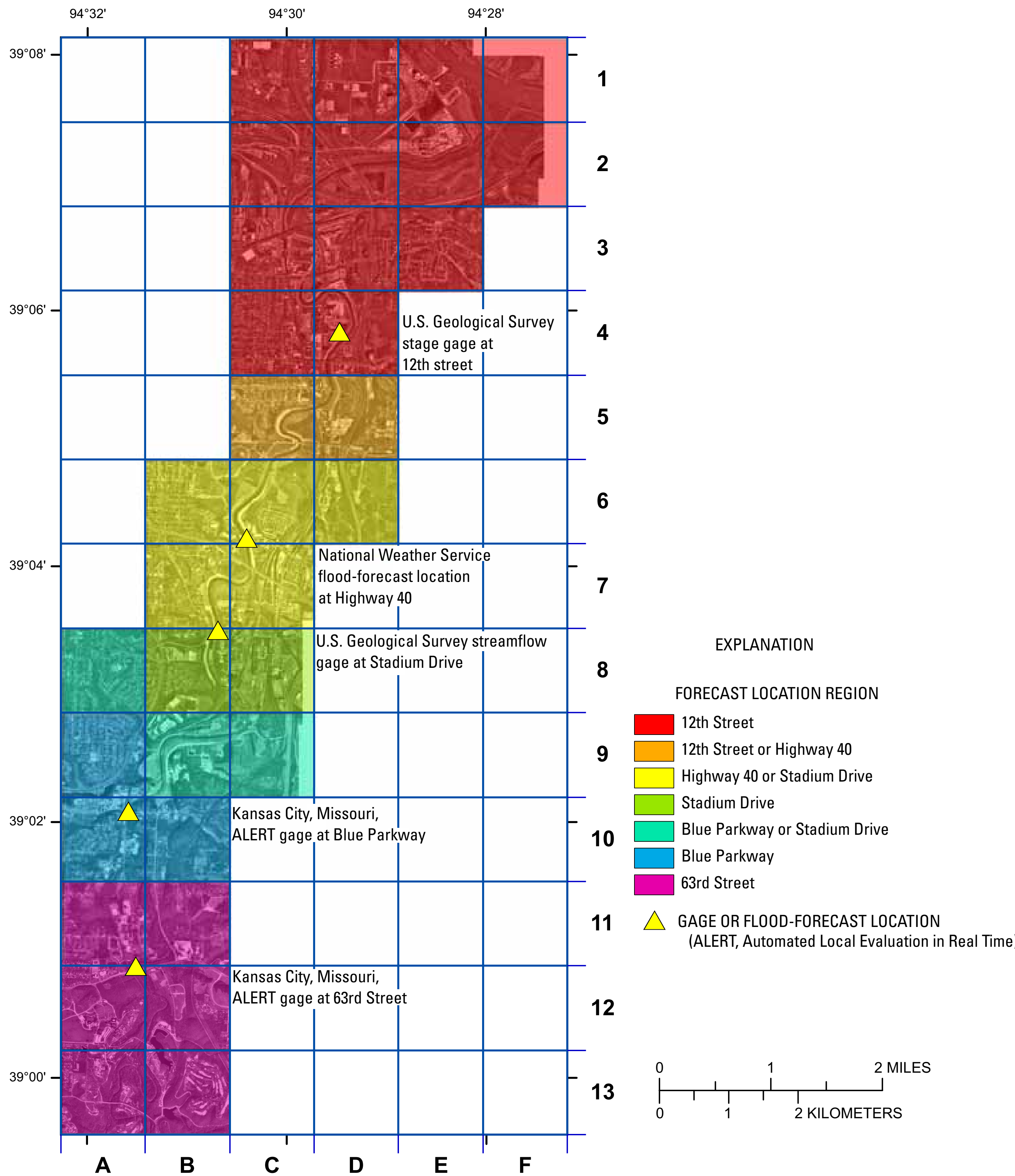
[ft, feet; datum NGVD29; bold stage elevation indicates gage height is above flood stage]

Forecast location									
12th Street		U.S. Highway 40		Stadium Drive		Blue Parkway		63rd Street	
Stage elevation (ft)	Gage height (ft above gage datum of 714.41)	Stage elevation (ft)	Gage height (ft above gage datum of 721.65)	Stage elevation (ft)	Gage height (ft above gage datum of 718.30)	Stage elevation (ft)	Gage height (ft above gage datum of 722.47)	Stage elevation (ft)	Gage height (ft above gage datum of 721.78)
736.3	21.9	739.5	17.8	741.1	22.8	750.0	27.5	763.8	42.0
737.9	23.5	741.1	19.4	742.7	24.4	752.0	29.5	765.8	44.0
740.1	25.7	743.3	21.7	744.8	26.5	754.0	31.5	767.8	46.0
741.7	27.3	744.9	23.3	746.4	28.1	**756.0**	**33.5**	**769.8**	**48.0**
744.0	29.5	747.1	25.5	748.5	30.2	**758.0**	**35.5**	**771.8**	**50.0**
745.8	**31.3**	748.9	27.3	750.3	32.0	**760.0**	**37.5**	**773.8**	**52.0**
747.7	**33.3**	**751.7**	**30.1**	**752.8**	**34.5**	**762.0**	**39.5**	**775.8**	**54.0**
749.6	**35.2**	**753.6**	**32.0**	**754.7**	**36.4**	**764.0**	**41.5**	**777.8**	**56.0**
751.6	**37.2**	**754.9**	**33.3**	**757.0**	**38.7**	**766.0**	**43.5**	**779.8**	**58.0**
754.1	**39.7**	**757.4**	**35.8**	**759.5**	**41.2**	**768.0**	**45.5**	**781.8**	**60.0**
756.0	**41.6**	**759.0**	**37.4**	**761.0**	**42.7**	**770.0**	**47.5**	**783.8**	**62.0**
758.3	**43.9**	**761.6**	**39.9**	**762.9**	**44.6**	**772.0**	**49.5**	**785.8**	**64.0**

Land-surface elevations from 2001 with updates from 2004, provided by the city of Kansas City, Missouri, included the latest modifications to the Blue River channel and were converted to a raster data set representing land surface using square cells, 5 ft on a side. Elevations of all bridges that span the Blue River and major roadways on the flood plain of the Blue River were incorporated into the land-surface elevation data. The data generally are accurate to 1 ft (one-half of the 2-ft contour interval). Flood-inundation maps were created by subtracting the land-surface elevation from the flood-stage elevation for each flood-inundation surface. The positive values in the resulting raster data set indicate the extent of flood inundation and the water depth. The resolution of each flood inundation raster data set is the same as the flood-inundation surface and the land surface.

Some locations within the study area are protected by levees, flood walls, or embankments. The techniques used to generate the flood-inundation maps identified these protected areas as being inundated although they are protected from flooding as long as Blue River stage elevation is below the top of the levee or flood wall. A field survey was conducted to determine if these locations were open to flooding from the Blue River at stage elevations below the tops of the levee, flood wall, or embankment protecting the site. Sites were inspected for culverts, pipes, or other openings that would allow water to enter the protected area. Protected sites are indicated on the flood-inundation maps as areas that lie lower than the selected flood-stage elevation of the inundation map. Unprotected sites are indicated as inundated. Twelve Blue River flood-inundation maps are shown on plates 4.1 through 4.12 in Appendix 4 (at the back of this report).

The Blue River flood-inundation surfaces used for maps in this report (appendix 4) correspond to hypothetical surfaces demarked by the maximum inundation of the flood plain. Consequently, these maps do not depict stage elevations that occur at a point in time, but a surface of inundation caused by a flood peak that occurs at different locations at different times. Also, the flood-inundation maps are based on uniform increments of river stage elevation above flood-stage elevation and not on discharge changes. Therefore, it is unlikely that one map will correctly represent flood inundation for the entire study area caused by a single flood. Rather, flood inundation will be represented for different forecast locations using inundation maps that match the peak river stage elevation for each forecast location.



Base from Jackson County Management Information Systems digital data, 1:833, 2003
Universal Transverse Mercator projection, Zone 15
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD83)

Figure 13. Regions and sections of the Blue River flood-inundation maps associated with each forecast location.

The study area was divided into five regions that correspond to the five forecast locations on the Blue River (fig. 13). Each region is divided into equal-sized square sections (4,000 ft on a side) that correspond to the square sections shown on flood-inundation plates in appendix 4. Several sections are associated with two forecast location regions because the extent of flood inundation for those sections is equally valid for data from either forecast location. Sections are named by their respective row (1-13) and column (A-F) designations. For example, section 1-C is at the top center of each plate and section 13-A is at the bottom left of each plate.

The USGS streamflow gage on the Missouri River at Kansas City, Missouri, was chosen as the reference gage for maps of Blue River inundation caused by backwater from floods on the Missouri River. Backwater-inundation maps of the Blue River were developed using techniques similar to those used to create the Blue River flood-inundation maps. River-stage elevation data for the flood of 1993, the 500-year flood, the 100-year flood, and lower flood data were used to determine the change in stage elevation between the USGS streamflow gage and the mouth of the Blue River (Kelly, 1996, Perry and others, 1997). At stage elevations above flood-stage elevation on the Missouri River, the decrease in river-stage elevation between the USGS streamflow gage on the Missouri River at Kansas City and the mouth of the Blue River becomes greater as river stage rises. This occurs because levees and flood walls between the USGS gage and the mouth of the Blue River are nearer to the channel of the Missouri River than upstream and downstream from this reach, and flow is constricted in the Missouri River during floods. At the mouth of the Blue River, a Missouri River stage elevation of 730.9 ft was used as the lowest elevation for generation of backwater-inundation maps. This stage elevation corresponds to an elevation of 738.4 ft and a NWS flood stage of 32 ft at the USGS streamflow gage on the Missouri River at Kansas City. Twelve maps were produced at 2-ft intervals from 730.9 to 752.9 ft (Missouri River stage at the USGS streamflow gage from 32 to 59.3 ft) to include the historic range of Missouri River stage elevations above flood-stage elevation for the Kansas City area. Equivalent stage elevations and gage heights for forecast locations within the study area for Missouri River backwater inundation of the Blue River are listed in table 8.

Table 8. Equivalent flood-stage elevations and gage heights for forecast locations for Missouri River backwater inundation of the Blue River.

[ft, feet; datum NGVD29; bold stage elevation indicates gage height is above flood stage; na, not applicable]

Forecast location							
Missouri River at Kansas City		Blue River at the mouth		12th Street		U.S. Highway 40	
Stage elevation (ft)	Gage height (ft above gage datum of 706.4)	Stage elevation (ft)	Gage height	Stage elevation (ft)	Gage height (ft above gage datum of 714.41)	Stage elevation (ft)	Gage height (ft above gage datum of 721.65)
738.4	32.0	730.9	--	730.9	16.5	730.9	9.3
740.9	34.5	732.9	--	732.9	18.5	732.9	11.3
743.8	37.4	734.9	--	734.9	20.5	734.9	13.3
745.8	39.4	736.9	--	736.9	22.5	736.9	15.3
749.0	42.6	738.9	--	738.9	24.5	738.9	17.3
752.5	46.1	740.9	--	740.9	26.5	740.9	19.3
755.3	48.9	742.9	--	742.9	28.5	742.9	21.3
757.7	51.3	744.9	--	744.9	30.5	744.9	23.3
759.7	53.3	746.9	--	746.9	32.5	746.9	25.3
761.7	55.3	748.9	--	748.9	34.5	748.9	27.3
763.7	57.3	750.9	--	750.9	36.5	750.9	29.3
765.7	59.3	752.9	--	752.9	38.5	752.9	31.3

Table 8. Equivalent flood-stage elevations and gage heights for forecast locations for Missouri River backwater inundation of the Blue River.—Continued

[ft, feet; datum NGVD29; bold stage elevation indicates gage height is above flood stage; na, not applicable]

Forecast location					
Stadium Drive		Blue Parkway		63rd Street	
Stage elevation (ft)	Gage height (ft above gage datum of 718.30)	Stage elevation (ft)	Gage height (ft above gage datum of 722.47)	Stage elevation (ft)	Gage height (ft above gage datum of 721.78)
730.9	12.6	730.9	8.4	730.9	9.1
732.9	14.6	732.9	10.4	732.9	11.1
734.9	16.6	734.9	12.4	734.9	13.1
736.9	18.6	736.9	14.4	736.9	15.1
738.9	20.6	738.9	16.4	738.9	17.1
740.9	22.6	740.9	18.4	740.9	19.1
742.9	24.6	742.9	20.4	742.9	21.1
744.9	26.6	744.9	22.4	744.9	23.1
746.9	28.6	746.9	24.4	746.9	25.1
748.9	30.6	748.9	26.4	748.9	27.1
750.9	32.6	750.9	28.4	750.9	29.1
752.9	34.6	752.9	30.4	752.9	31.1

The elevation of the backwater inundation surface as calculated is constant and equal to the stage elevation at the mouth of the Blue River. Therefore, backwater-inundation-surface profiles are flat. Backwater-inundation-stage elevations were created in ARC/INFO by assigning the stage elevation at the mouth of the Blue River to all cells in each raster data set. Backwater-inundation maps were created by subtracting the land-surface elevation data from the backwater-inundation-stage elevation data. The positive values in the resulting raster data set indicate the extent of backwater inundation and the water depth. The resolution of each backwater-inundation raster data set (5-ft squares) is the same as the backwater-inundation surface and the land-surface elevation. Areas protected by levees were identified as previously discussed, and are indicated as areas that lie lower than the selected flood stage elevation of the inundation map. Twelve Blue River backwater-inundation maps are shown in appendix 5 (plates 5.1 through 5.12, at the back of this report). Backwater-inundation maps are divided into the same sections as the flood-inundation maps. However, stage elevation data from the USGS streamflow gage on the Missouri River at Kansas City are associated with all sections because it was the only gage used to create the backwater-inundation maps.

Estimated Flood-Inundation Mapping Benefits and Limitations

The estimated flood-inundation maps created during this study are an important tool for public officials and residents to use to minimize flood deaths and damage in the flood plain of the lower Blue River in Kansas City, and to supplement information collected by the metropolitan Kansas City flood-alert system. Availability on the World Wide Web of estimated flood-inundation maps and near real-time river-stage data permit users to view near real-time stage information and select inundation maps for current flood conditions, forecasted peak stage, or other selected crests. Forecast inundation maps permit people in flood-affected areas to know where unsafe driving conditions are or might be, and to warn neighbors who do not have computer access or the World Wide Web. Local emergency management personnel can use forecast peak inundation maps to determine threatened areas, identify road closures, and take appropriate actions to warn property owners. The maps will help the public, business owners, and the media give warnings of property and roads threatened by floodwater, help in rescue operations during a flood, and may help save lives. Federal, State, and local emergency management teams can more efficiently conduct damage assessments and provide public information concerning flood insurance, acquisition of property, and applications for hazard mitigation grants (Studley, 2003).

In addition to providing information related to the location and the water depth of inundated areas, the two-dimensional modeling results also provide velocity magnitude and direction throughout the study reach along the Blue River between 63rd Street and Blue Parkway. Such hydraulic details can be used for proposed channel improvements and assessing flooding effects on structures in the flood plain.

Although there are substantial benefits to the flood-inundation maps, correct map interpretation depends on understanding the limitations and the error associated with the data used to construct the maps. Data used to construct the flood-inundation maps include topographic data, one- and two-dimensional hydraulic model results, measured high-water marks, and interpolated stage elevations. In addition, small tributary flooding and ponding of local runoff can cause inundation not depicted on the maps.

Flood-inundation maps show inundation for the downstream reaches of some minor tributaries of the Blue River. Flood inundation indicated for these tributaries is from flooding on the Blue River. When flooding occurs on these tributaries, as well as on the Blue River, the actual flood inundation along these tributaries could be higher than the estimated flood inundation. Inundation maps in this report also assume open channels with no blockages from log jams or other debris. Flood inundation can be greater upstream from the obstructions.

Topographic data provided by the city of Kansas City is accurate to plus or minus 1 ft (one-half the contour interval of 2 ft). Depth of flood inundation was calculated by subtracting land-surface elevation from stage elevation for each flood-inundation map. For areas that are flat or have a low slope, a 1-ft increase or decrease in flood depth may result in a large increase or decrease in inundated area.

Hydraulic models are approximations of actual streamflow and simulated discharge and stage typically deviate from reality. Measurements of discharge typically are within plus or minus 5 percent of the actual discharge, and hydraulic model results calibrated to measured discharge are subject to the limitations of those measurements. Variations in the error range are caused by changes in the cross-sectional area of flow at different discharge values. As stated in the model calibration section, the two-dimensional model results were within about 0.5 ft of high water marks for the study reach. However, error also is associated with the use of high-water marks collected after a flood. These marks are indicated by the elevation of the line of sediment or mud-coated surfaces or the location of deposits of floating material that were left behind as flood water receded. They approximate the maximum elevation of the flood surface, but are not exact because of wave action, multiple peaks, or peaks from local tributaries; errors usually are less than 0.25 ft.

During flood conditions when water flows at a high velocity, ramping may occur as water flows over submerged structures. This can raise the flood surface above what an interpolated surface indicates over small areas near submerged structures. Ramping can occur where water flows over submerged road beds, bridge decks, or other large features. In areas where flow is constricted, such as bridges or other structures with small openings, actual stage elevations may differ from interpolated stage elevations over small areas near the constriction. Upstream from these structures, the actual stage elevation will be higher than the interpolated surface; downstream the stage elevation will be lower. The amount of error is variable and depends on water velocity and the size of the constriction.

Flooding usually is associated with large amounts of local rainfall. Inundation from direct rainfall of some small areas within the Blue River flood plain may occur from small tributaries before the flood-inundation maps indicate flooding caused by the Blue River.

Errors and variations in data rarely occur in only one direction. The chance that the flood-inundation data for any one point is based on the maximum possible error is small because the errors are unlikely to be all positive or all negative with respect to the actual value. A combination of errors of varying value and sign is more likely to occur. To account for errors, the user should inspect not only the maps that represent the gage location and stage of interest, but also maps for values of stage both greater and less than the stage of interest.

Blue River Estimated Flood-Inundation Maps on the World Wide Web

To provide public access to the information presented in this report, a World Wide Web site (http://mo.water.usgs.gov/indep/kelly/blueriver/index.htm) was created that displays the results of two-dimensional modeling between 63rd Street and Blue Parkway, flood-inundation maps, backwater-inundation maps, and the latest gage heights and NWS stage forecast for each forecast location within the study area. In addition, the full text of this report, tables, and plates are available for download. The Web site URL is http://pubs.water.usgs.gov/sir2006-5089/.

The main page of the Blue River Flood Inundation Web site contains a map of the forecast locations and a table that lists current stages for gages on the Blue River, the Missouri River gage at Kansas City, and NWS forecast peak stage, if available. The user can select one of the forecast locations from the table to access the web page specific to that location. Each forecast location web page has a graph depicting the most recent stage observations for that location, a locator map with the region highlighted for which the gage data are valid, and a drop-down menu used to select a particular flood-stage elevation of interest. Once the flood-stage elevation is selected, the flood-inundation map of the region for the flood-forecast location appears. The user can view flood-inundation maps of the region for other flood stages of interest by selecting a new stage from a drop-down menu. Each region is divided into sections to allow closer inspection of inundated areas. The user can click on a section to access a more detailed view of the flood-inundation map within that section. The current section appears and also is outlined on a small locator map. The user can navigate to adjacent sections within the region for which the gage data are valid at that stage by clicking on the desired section on the locator map. The user can view flood-inundation maps of the section for other flood stages of interest by selecting a new stage from a drop-down menu. To access flood-inundation maps for another region, the user can click on the main flood inundation page link at the bottom of the page and select another region.

Summary

The U.S. Geological Survey (USGS), in cooperation with the city of Kansas City, Missouri, began a study in 2003 of the Blue River from Gregory Boulevard to the mouth to determine the estimated extent of flood inundation in the Blue River valley from flooding on the Blue River and from backwater inundation from flooding in the Missouri River for selected stage elevations above flood-stage elevation. Specific objectives of this project were to hydraulically model a complex stretch of the Blue River between 63rd Street and Blue Parkway to provide water velocity magnitudes and direction, and stage elevations in two dimensions, and create and provide access to estimated flood-inundation/water-depth maps and the National Weather Service (NWS) forecast stage for each forecast location on the World Wide Web for the lower Blue River in Kansas City, Missouri.

Much of the lower Blue River flood plain is covered by industrial development. Rapid development in the upper end of the watershed has increased the volume of runoff, and thus the discharge of flood events for the Blue River. The small size of the basin causes flash floods and allows minimal time for flood forecasting and response. Modifications to the channel of the Blue River began in late 1983 in response to the need for flood control. By 2004, the channel had been widened and straightened from the mouth to just downstream from Blue Parkway. The NWS issues peak-stage forecasts for five locations on the lower Blue River and for the Missouri River at Kansas City during high water.

A two-dimensional depth-averaged flow model, FESWMS Flo2DH, was used to simulate flooding within a 2-mile hydraulically complex study reach of the Blue River between 63rd Street and Blue Parkway. Hydraulic simulations of the study reach provided design and performance information for proposed hydraulic structures and channel improvements, extent of inundation, and the areal distribution of water velocity and flow direction. To produce flood-inundation maps for the study reach, boundary conditions for high flows were calculated using an existing lower Blue River Hydraulic Engineering Centers River Analysis System (HEC-RAS) one-dimensional model. A secondary HEC-RAS model was constructed and calibrated to extend stage elevations from the upper end of the lower Blue River HEC-RAS model near the mouth of Brush Creek to the upstream face of the lower Blue Parkway Bridge. The constructed HEC-RAS model was calibrated to the discharge measurements. Discharge values associated with stage at the lower Blue Parkway Bridge were selected from the simulated rating curve and input into the two-dimensional model. Two-dimensional flood-inundation simulations incorporated design plans for the proposed Blue Parkway Bridge over the Blue River and Union Pacific Railroad. Twelve velocity magnitude and direction profiles were produced for the reach just downstream from 63rd Street, the middle of the study reach, and the reach just upstream from the lower Blue Parkway Bridge.

Flood profiles of the Blue River were developed from stage elevations and slopes calculated between Gregory Boulevard and 63rd Street from high-water marks from the flood of May 19, 2004, between 63rd Street and Blue Parkway from two-dimensional hydraulic modeling conducted for this study, and between Blue Parkway and the mouth from the lower Blue River HEC-RAS model. Twelve maps were produced at 2-ft (foot) intervals from 750 to 772 ft at the Kansas City, Missouri, ALERT gage at Blue Parkway to approximate the range of river-stage elevations from the 2- to 500-year flood frequencies. Missouri River backwater inundation profiles from flood-stage elevation to the highest historical stage elevation were developed using Missouri River stage elevations at the mouth of the Blue River. The USGS streamflow gage on the Missouri River at Kansas City, Missouri, is the reference gage for maps of Blue River backwater inundation caused by flooding on the Missouri River. At the mouth of the Blue River, a Missouri River stage elevation of 730.9 ft was used as the lowest flood elevation for generation of backwater-inundation maps. This river-surface elevation corresponds to an elevation of 738.4 ft at the USGS gage on the Missouri River at Kansas City, and a stage of 32 ft. Twelve backwater-inundation maps were produced at 2-ft intervals to include the historical range of Missouri River stages above flood stage for the Kansas City area.

The flood-inundation maps created during this study represent a substantial increase in the capability of public officials and residents to minimize flood deaths and damage in the flood plain of the lower Blue River in Kansas City, and supplement information collected by metropolitan Kansas City flood-alert system. Data used to construct the flood-inundation maps include topographic data, one- and two-dimensional hydraulic model results, measured high-water marks, and interpolated stage elevations.

To provide public access to the information presented in this report, a World Wide Web site (http://mo.water.usgs.gov/indep/kelly/blueriver/index.htm) was created that displays the results of two-dimensional modeling between 63rd Street and Blue Parkway, flood-inundation maps, backwater-inundation maps, and the latest gage heights and NWS stage forecast for each forecast location within the study area. In addition, the full text of the report, tables, and plates are available for download. The Web site URL is http://pubs.water.usgs.gov/sir2006-5089/.

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Appendixes 1–4

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