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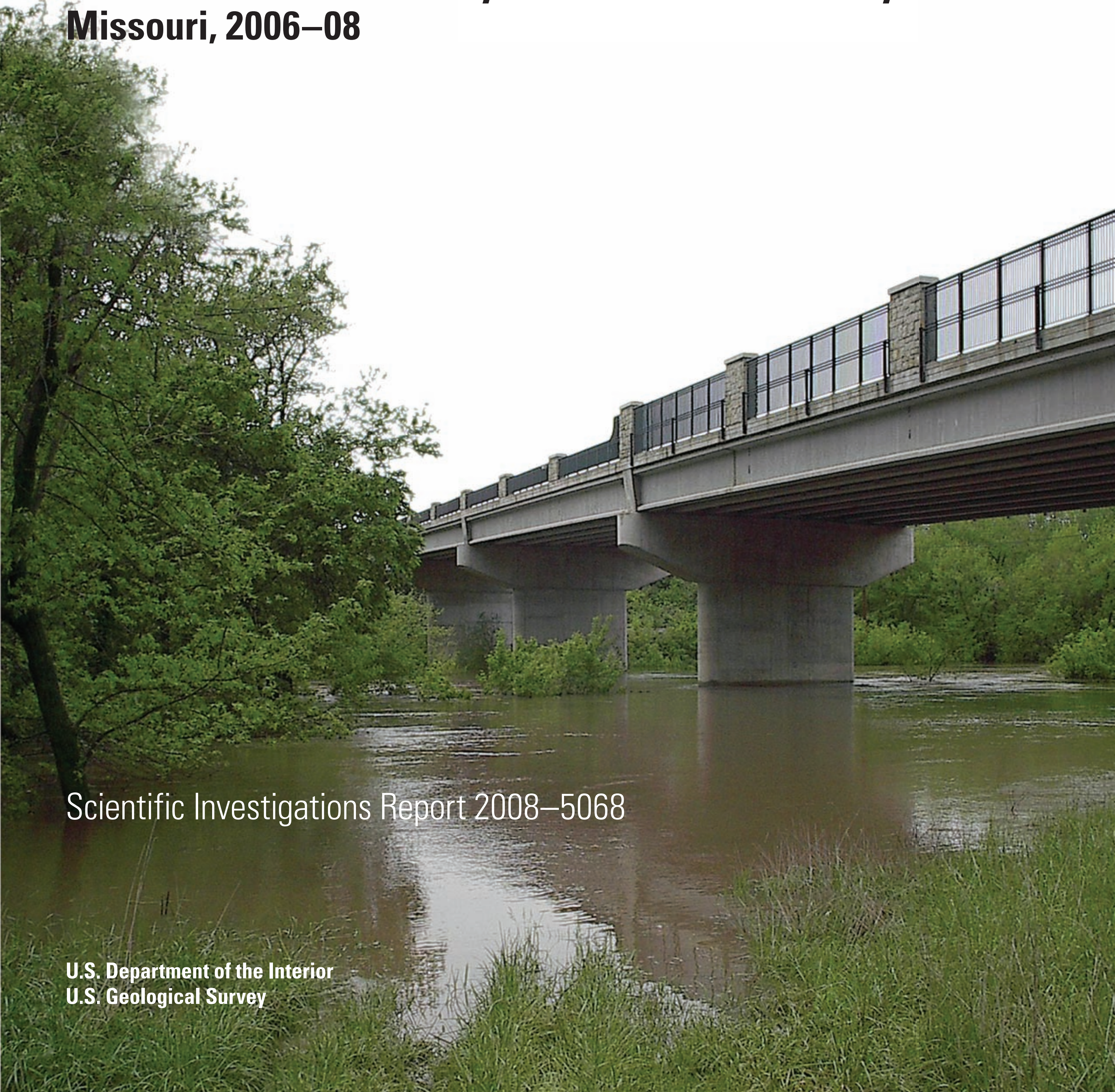
Estimated Flood-Inundation Mapping for the Upper Blue River, Indian Creek, and Dyke Branch in Kansas City, Missouri, 2006–08



Scientific Investigations Report 2008–5068

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

Cover Photograph. Blue River near 63rd Street, May 7, 2007. Photograph taken by Brian Kelly, U.S. Geological Survey.

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CONVERSION FACTORS AND DATUM

Multiply	By	To Obtain
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per foot (ft/ft)	1	meter per meter (m/m)
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)

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

$$°C = (°F - 32) / 1.8$$

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. Some elevations in this report refer to the distance above the North American Vertical Datum of 1988 (NAVD 88).

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

Estimated Flood-Inundation Mapping for the Upper Blue River, Indian Creek, and Dyke Branch in Kansas City, Missouri, 2006–08

By Brian P. Kelly and Richard J. Huizinga

Abstract

In the interest of improved public safety during flooding, the U.S. Geological Survey, in cooperation with the city of Kansas City, Missouri, completed a flood-inundation study of the Blue River in Kansas City, Missouri, from the U.S. Geological Survey streamflow gage at Kenneth Road to 63rd Street, of Indian Creek from the Kansas-Missouri border to its mouth, and of Dyke Branch from the Kansas-Missouri border to its mouth, to determine the estimated extent of flood inundation at selected flood stages on the Blue River, Indian Creek, and Dyke Branch. The results of this study spatially interpolate information provided by U.S. Geological Survey gages, Kansas City Automated Local Evaluation in Real Time gages, and the National Weather Service flood-peak prediction service that comprise the Blue River flood-alert system and are a valuable tool for public officials and residents to minimize flood deaths and damage in Kansas City.

To provide public access to the information presented in this report, a World Wide Web site (*http://mo.water.usgs.gov/indep/kelly/blueriver*) was created that displays the results of two-dimensional modeling between Hickman Mills Drive and 63rd Street, estimated flood-inundation maps for 13 flood stages, the latest gage heights, and National Weather Service stage forecasts for each forecast location within the study area. The results of a previous study of flood inundation on the Blue River from 63rd Street to the mouth also are available. In addition the full text of this report, all tables and maps are available for download (*http://pubs.usgs.gov/sir/2008/5068*).

Thirteen flood-inundation maps were produced at 2-foot intervals for water-surface elevations from 763.8 to 787.8 feet referenced to the Blue River at the 63rd Street Automated Local Evaluation in Real Time stream gage operated by the city of Kansas City, Missouri. Each map is associated with gages at Kenneth Road, Blue Ridge Boulevard, Kansas City (at Bannister Road), U.S. Highway 71, and 63rd Street on the Blue River, and at 103rd Street on Indian Creek. The National Weather Service issues peak stage forecasts for Blue Ridge Boulevard, Kansas City (at Bannister Road), U.S. Highway 71, and 63rd Street during floods.

A two-dimensional depth-averaged flow model simulated flooding within a hydraulically complex, 5.6-mile study reach of the Blue River between Hickman Mills Drive and 63rd Street. Hydraulic simulation of the study reach provided information for the estimated flood-inundation maps and water-velocity magnitude and direction maps.

Flood profiles of the upper Blue River between the U.S. Geological Survey streamflow gage at Kenneth Road and Hickman Mills Drive were developed from water-surface elevations calculated using Federal Emergency Management Agency flood-frequency discharges and 2006 stage-discharge ratings at U.S. Geological Survey streamflow gages. Flood profiles between Hickman Mills Drive and 63rd Street were developed from two-dimensional hydraulic modeling conducted for this study. Flood profiles of Indian Creek between the Kansas-Missouri border and the mouth were developed from water-surface elevations calculated using current stage-discharge ratings at the U.S. Geological Survey streamflow gage at 103rd Street, and water-surface slopes derived from Federal Emergency Management Agency flood-frequency stage-discharge relations. Mapped flood water-surface elevations at the mouth of Dyke Branch were set equal to the flood water-surface elevations of Indian Creek at the Dyke Branch mouth for all Indian Creek water-surface elevations; water-surface elevation slopes were derived from Federal Emergency Management Agency flood-frequency stage-discharge relations.

Introduction

The Blue River flows 37 miles (mi) from the Kansas-Missouri border 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. Indian Creek is the largest tributary to the Blue River in Kansas City, Missouri. 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

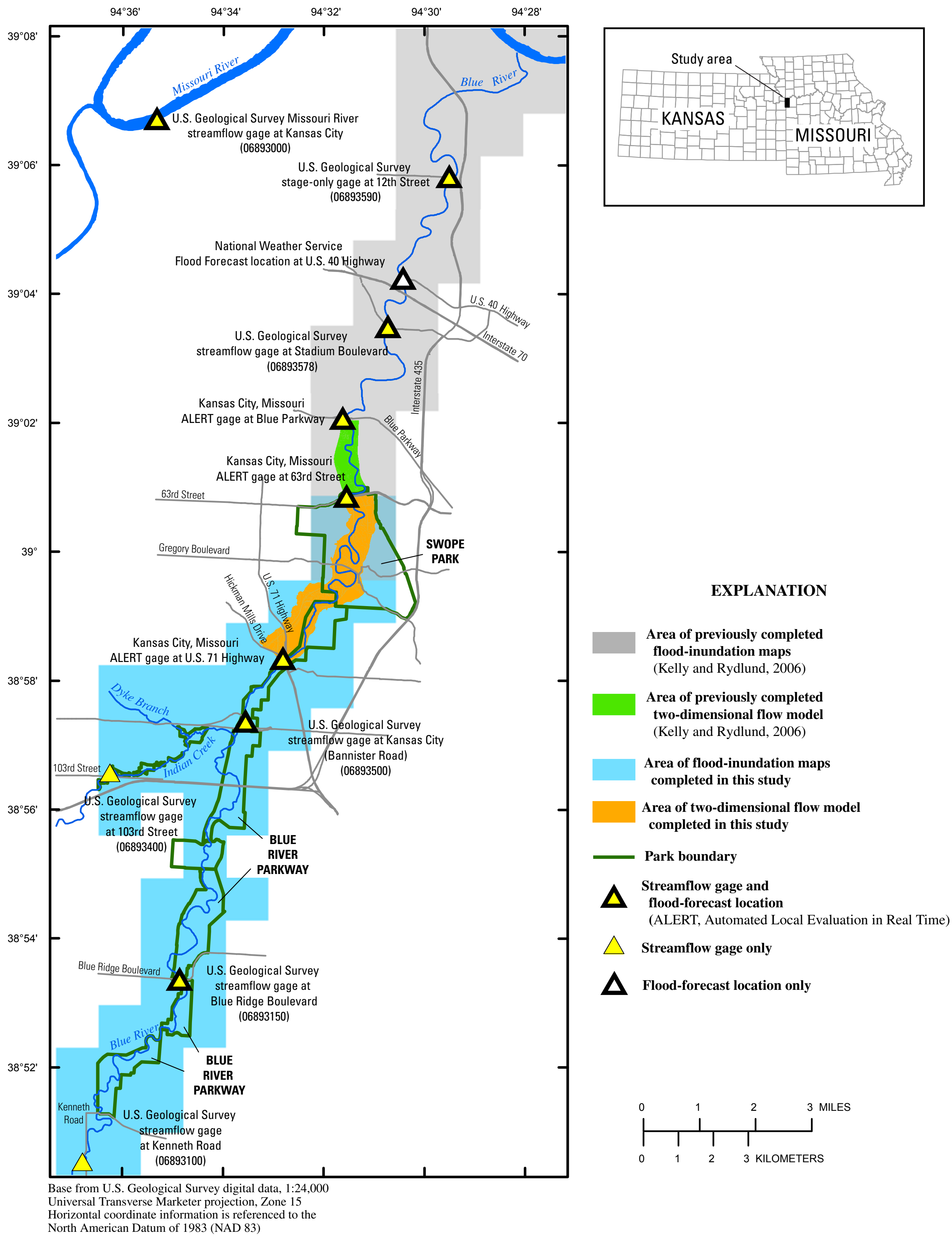


Figure 1. Study area, National Weather Service flood-forecast locations, and streamflow gage locations.

resulted in the deaths of more than 26 people in the last 30 years. Because of the large amount of people and industry, the National Weather Service (NWS) issues flood forecasts during high water at eight locations along the Blue River in Kansas City, Missouri, and at one location on the Missouri River at Kansas City (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 information does not provide the public with a visual picture of what the flood stage looks like through the entire river reach (Studley, 2003). Despite the known flooding hazards, emergency management agencies 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, Perry and others, 1997) and often is of marginal use to recovery efforts. However, in recent years the convergence of technological advances in real-time streamflow information, flood prediction, availability of 1- and 2-foot (ft)-contour-interval topographic maps, two-dimensional hydraulic modeling, and geographic information systems (GIS) technology now makes delivery of real-time stage information, flood-forecast prediction, and estimated flood-inundation maps on the World Wide Web possible.

In the interest of improved public safety during times of flooding, the U.S. Geological Survey (USGS), in cooperation with the city of Kansas City, Missouri, began a project in 2003 to determine the extent and character of inundation in the Blue River valley from flooding in the Blue River for selected water-surface elevations above flood stage. In the first phase of the project, a website was created that associates real-time flow data and flood-inundation maps from the mouth of the Blue River upstream to Gregory Boulevard. A two-dimensional model was applied to a hydraulically complex, 2-mi length of the Blue River centered on the reach between 63rd Street and the mouth of Brush Creek (fig. 1 in Kelly and Rydlund, 2006). Model results provided information about the performance of existing hydraulic structures, channel conditions, and areal distribution of water velocity on this reach of river for the estimated flood-inundation maps on the web. The second phase of the flood-inundation project, described in this report, began in 2006 and addresses the part of the Blue River from 63rd Street upstream to the USGS streamflow gage at Kenneth Road near the Kansas-Missouri border, as well as Indian Creek from its mouth to the state border and Dyke Branch, a tributary of Indian Creek. The second phase includes expansion of the website to include stage information and flood-inundation maps from the USGS gage at Kenneth Road to 63rd Street. Also, a detailed two-dimensional hydraulic simulation of the reach between Hickman Mills Drive and 63rd Street provides flood-inundation maps, flood-plain water velocities and depths for existing flood-plain developments, and maps representing the areal distribution of water velocity magnitude and direction for a range of stages. Results from the second phase two-dimensional hydraulic model updates flood information from 63rd Street to Gregory Boulevard presented in the first phase of the project. The results of these studies spatially interpolate information provided by USGS streamflow 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 are a valuable tool for public officials and residents to minimize flood deaths and damage in Kansas City. In this report stage is a generic term for water level above an arbitrary datum established for each streamflow gage, and water-surface elevation is the elevation of the river surface above the National Geodetic Vertical Datum of 1929 (NGVD 29).

Purpose and Scope

The purpose of this report is to describe estimated flood-inundation mapping in Kansas City, Missouri, for the upper Blue River between the USGS streamflow gage at Kenneth Road and 63rd Street, Indian Creek between the Kansas-Missouri border and the mouth, and Dyke Branch, a tributary of Indian Creek. Methods used to construct, calibrate, and verify the two-dimensional hydraulic modeling of the Blue River between Hickman Mills Drive and 63rd Street, to prepare estimated flood-inundation maps, and to present estimated flood-inundation maps on the World Wide Web are described. Thirteen velocity-magnitude and direction maps are presented at 2-ft intervals above Blue River flood stage for the model reach. Thirteen flood-inundation maps are presented at 2-ft intervals above flood stage for the upper Blue River and Indian Creek flood plains from the USGS gage at Kenneth Road downstream to 63rd Street.

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, Kansas City District, for providing channel bathymetry, and construction data; and the National Weather Service Forecast Office—Kansas City/Pleasant Hill for providing peak flood stages at flood-forecast locations and historical peak-stage information.

Description of Study Area

The study area includes the Blue River flood plain from about 1,500 ft upstream from the USGS streamflow gage on the Blue River at Kenneth Road near the Kansas-Missouri border north to 63rd Street, and the Indian Creek flood plain from the state border east to its confluence with the Blue River (fig. 1). Within Kansas City, the Blue River flood plain is about 18 mi long; and the length of the Blue River is about 37 mi. The water-surface elevation of the Blue River at normal stage descends about 115 ft from the USGS streamflow gage on the

Blue River at Kenneth Road to 63rd Street, and the water-surface elevation of Indian Creek at normal stage descends about 34 ft from the Kansas–Missouri border to the mouth. Total relief of the flood plain within the study area is approximately 135 ft, and land-surface elevation ranges from more than 890 ft along the valley walls at the south end of the study area to about 755 ft at 63rd Street (fig. 2). 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) and almost 68 percent of 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 basin likely has increased peak discharges and, thus, the areal extent of flood inundation for the Blue River. The small drainage areas of the Blue River [275 square miles (mi^2)] and Indian Creek (50 mi^2) indicate that flash floods are likely and there is minimal time for flood forecasting and response. The Blue River and Indian Creek basins also are the location of large parks and recreational development. Swope Park (fig. 1) is home to the city zoo and two large golf courses. Blue River Parkway, administered by Jackson County, covers most of the Blue River riparian corridor for 9 mi upstream from Swope Park. Bicycle, pedestrian, and equestrian trails exist or are planned for the entire length of both streams.

Because of the large number of people, businesses, and parks along the upper Blue River in Kansas City, the NWS issues flood forecasts for four gage locations in the study area (fig. 1) during high water. Current river stages and peak-stage forecasts are presented on the NWS Advanced Hydrologic Prediction Service internet site at *http://www.weather.gov/ahps/*. Additional stage and streamflow data are provided by USGS streamflow gages (available at *http://waterdata.usgs.gov/mo/nwis/current/?type=flow*), and Kansas City ALERT Gages. Gage locations in the study area on the Blue River (upstream to downstream order) are the USGS streamflow gage on the Blue River at Kenneth Road (station number 06893100), the USGS streamflow gage and NWS forecast location at Blue Ridge Boulevard (station number 06893150), the USGS streamflow gage and NWS forecast location at Kansas City at Bannister Road (station number 06893500), the Kansas City ALERT stage-only gage and NWS forecast location at U.S. 71 Highway, and the Kansas City ALERT stage-only gage and NWS forecast location at 63rd Street. The gage location on Indian Creek is the USGS streamflow gage on Indian Creek at 103rd Street in Kansas City (station number 06893400). Gage or forecast-location names, elevation of gage datum, flood gage heights, and local impacts for selected flood gage heights are listed in table 1.

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; Froelich, 2002] was chosen to simulate steady-state flood flows within a hydraulically complex reach of the Blue River. Two-dimensional models simulate 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 maps of flood-inundation extent, water velocity and flow direction, and depth within the flood plain. These model outputs also can be useful in designing potential channel and flood-plain improvements throughout the simulated reach.

Description of Model Reach

The modeled reach of the Blue River between Hickman Mills Drive and 63rd Street (fig. 3) is approximately 5.6 river miles long and consists of a deeply incised channel, sharp meander bends, small tributary junctions, and frequent riffles exhibiting substantial gradient change. The model reach is bordered on the east and west by flood-plain valley walls. The flood plain of the model reach mostly is timber and brush, kept grasses (mowed park land and golf courses), and thick grasses with small sprouts. A thick riparian corridor exists along the Blue River. Several small unnamed tributaries exist in the model reach. The tributaries have drainage areas between 1 and 2 mi^2 and were not considered to contribute to flood discharges because of limited contributions of flow at the time of main-stem flooding.

Model Development

Two-dimensional modeling provides more hydraulic detail than conventional one-dimensional analysis. The FESWMS Flo2DH model simulates flow in two dimensions in the horizontal plane. It uses a finite-element mesh and the Galerkin finite-element method of solving three partial-differential equations representing conservation of mass and momentum (Froehlich, 2002). This two-dimensional model simulates longitudinal and lateral variations in water-surface elevations and velocities and can accommodate geometric features, such as highway embankments, bridge structures, channel bends, berms, buildings, and other flow obstructions. A graphical user interface called the Surface-Water Modeling System (SMS; Environmental Modeling Research Laboratory, 1999) was used to construct the two-dimensional finite-element mesh, facilitate assignment of roughness coefficients and other hydraulic and material parameters to the mesh elements, execute the model, and evaluate the model output.

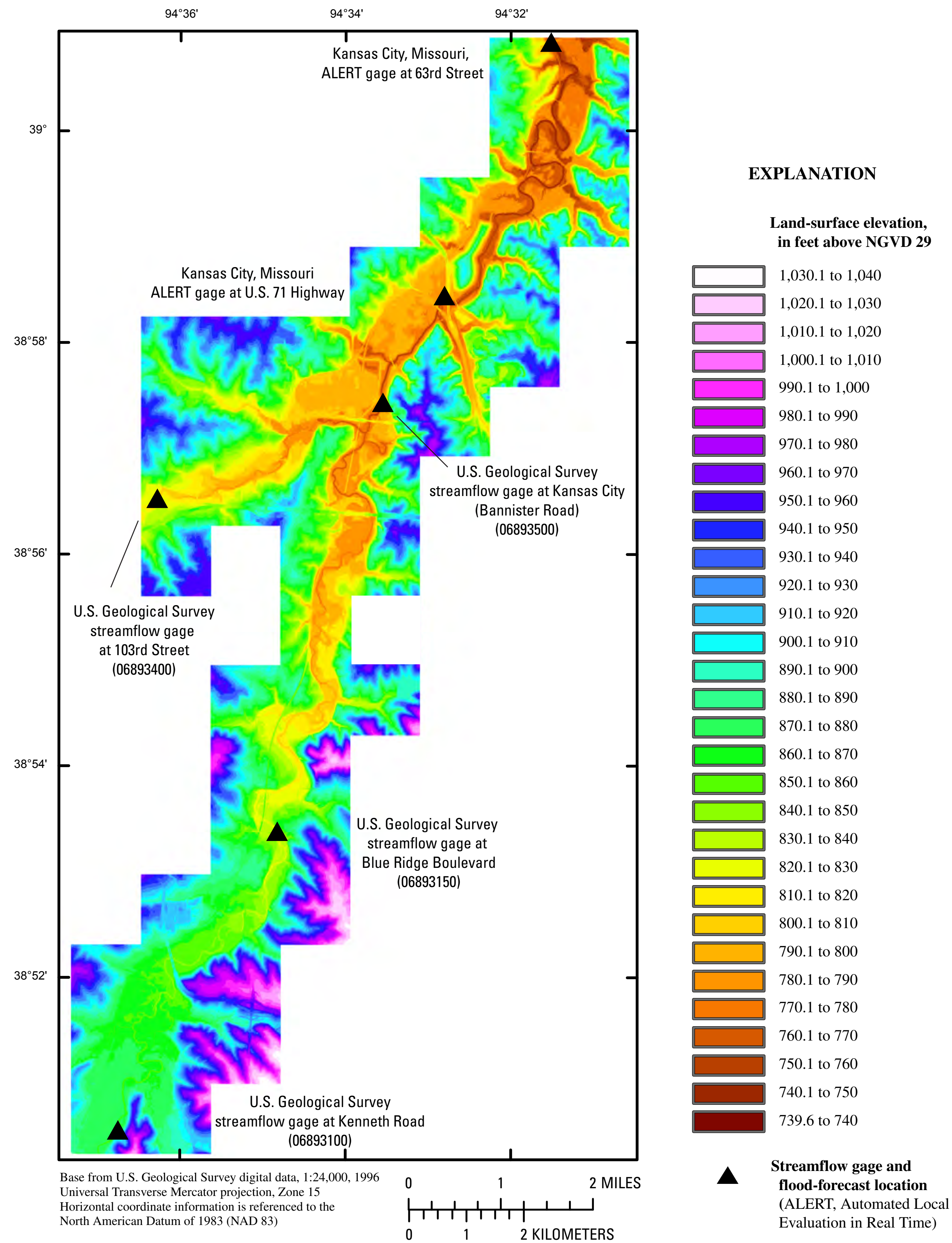


Figure 2. Land-surface elevation in the study area.

Table 1. Location, elevation of gage datum, flood gage height, and local flood impacts of reference stream gages and flood forecast sites used for flood-inundation maps.

[NWS, National Weather Service; ft, feet; USGS, U.S. Geological Survey; NAVD 88, North American Vertical Datum of 1988; NA, not applicable; NGVD 29, National Geodetic Vertical Datum of 1929]

Stream gage and station number or NWS forecast location name	Elevation of gage datum (ft)	Flood stage[a, b] (ft)	Local flood impacts[a]
Blue River			
USGS Streamflow gage (06893100)—Blue River at Kenneth Road in Overland Park, Kansas	858.36 (NAVD 88)	NA	NA
USGS Streamflow gage (06893150)—Blue River at Blue Ridge Boulevard in Kansas City, Missouri (NWS Forecast Location)	800.00 (NAVD 88)	51.6	Water overtops the Blue Ridge Boulevard Bridge.
		50.3	Water begins to flood the Blue Ridge Boulevard about 100 yards east of the Bridge.
		47.8	Water begins to flood the first floor of homes.
		47.2	Water reaches the bottom of Blue Ridge Boulevard Bridge.
		46.0	Basement flooding of homes begins near the Blue Ridge Boulevard Extension.
		38.6	Blue Ridge Boulevard on the west side of the bridge begins to flood.
		36.5	Red Bridge road begins to flood.
		36.0	Low-lying apartments on Holmes Road begin to flood.
		35.3	Recreation area on the northwest side of the bridge begins to flood.
USGS Streamflow gage (06893500)—Blue River at Kansas City (at Bannister Road), Missouri (NWS Forecast Location)	753.73 (NGVD 29)	41.0	Water approaches the Federal Complex at Bannister Road.
		34.0	Woodlands along the river are flooded. Water may approach flood stage at U.S. 71 Highway and other downstream locations.
Kansas City ALERT stage-only gage at U.S. 71 Highway (NWS Forecast Location)	722.90 (NGVD 29)	66.0	Floodwater approaches a major business complex near this site. The parking lot of the business may be flooded and water may reach the building.
		61.0	Low-lying areas in the vicinity of Hickman Mills Drive, 85th Street, and U.S. 71 Highway begin to flood.
Kansas City ALERT stage-only gage at 63rd Street (NWS Forecast Location)	721.78 (NGVD 29)	55.6	Water approaches the railroad tracks on the west side of the river.
		52.3	Water enters a manufacturing plant on Colorado Street.
		49.0	Water approaches 59th Street.
		48.0	Low-lying areas in the vicinity of 63rd Street begin to flood.
Indian Creek			
USGS Streamflow gage (06893400)—Indian Creek at 103rd Street in Kansas City, Missouri	722.57 (NAVD 88)	NA	NA

[a]National Weather Service, 2007.

[b]Add zero gage datum to gage height to convert gage height to water-surface elevation.

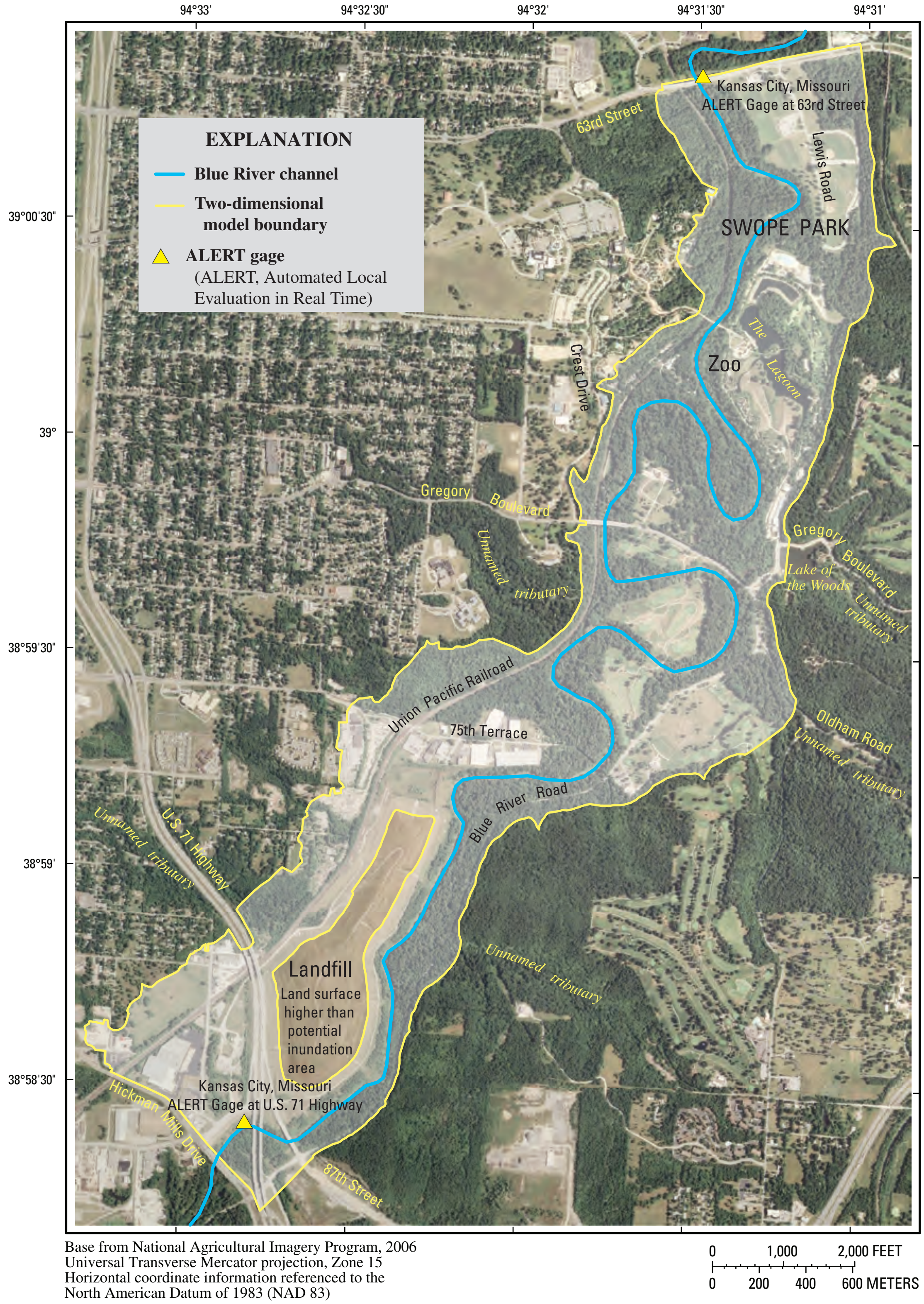


Figure 3. Simulated model reach of the Blue River between Hickman Mills Drive and 63rd Street.

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 (City of Kansas City, Missouri, written commun., 2004) and supplemental onsite 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. 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 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 were set to improve relative consistency among elements. Smooth contours, smooth 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 boundary 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 are actually dry (Froehlich, 2002). The deeply incised channel within the study reach has steep banks that required smaller thin elements along the banks and additional element refinement near the top of the banks (fig. 4).

Once a finite-element mesh was created and the quality maintained, the elements of the mesh were characterized by assigning material (fig. 5) and hydraulic properties to the elements, such as Manning's roughness coefficient (Chow, 1959; Barnes, 1967; Arcement and Schneider, 1989), and additional turbulence parameters such as base kinematic eddy viscosity (V_o) and element storativity depth. A depth-dependent Manning's roughness coefficient (*n*-value) method was used, wherein the "lower depth" *n*-value is applied when the water depth over the nodes around an element is less than the lower depth, and the "upper depth" *n*-value is applied when the water depth is greater than the upper depth; when the water depth is between the lower and upper depths, the *n*-value is interpolated linearly from the upper and lower *n*-values (Froehlich, 2002). Depth-dependent *n*-values were used to account for changes in the roughness with increased depth of flow; generally, the roughness decreases with increased depth because the effect of the physical features causing the roughness decreases as the depth of flow increases (for example, grass and brush that lie over in high flows). Roughness coefficients and depths consistent with previous two-dimensional models completed immediately downstream (Kelly and Rydlund, 2006; Huizinga, 2007) were established throughout the flood plain and within the channel. Final coefficients for the calibrated model are listed in table 2.

Base 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 bridges in the model reach were incorporated into the mesh in two ways. First, large piers and piers with solid webs were hard-coded into the model mesh, and the elements within each pier location were disabled to force flow around such piers. All the piers for the 63rd Street and Gregory Boulevard bridges were incorporated into the mesh in this way, as were the piers near the main channel for the 87th Street and U.S. 71 Highway bridges. The remaining piers for the 87th Street and U.S. 71 Highway bridges, as well as the piers for the U.S. 71 Highway bridges over the Union Pacific Railroad, were incorporated into the model using the pier module in FESWMS. These additional piers generally were circular columns ranging from 3 to 5 ft in diameter that would not substantially affect flow in the model, but would have resulted in inordinate mesh refinement to incorporate directly into the model mesh. Position, orientation, and dimensions of each pier were obtained from bridge plans (City of Kansas City, Department of Public Works, 1917; Missouri Department of Transportation, 1988a, 1988b, 1988c, 1988d) to accurately position and size the piers (fig. 6).

Model Calibration

The amount of flow into the mesh and a water-surface elevation where flow leaves the mesh are required model inputs. The two-dimensional model from the first phase of the project was calibrated to a flood that occurred May 19, 2004, that produced bank-full and partial overbank flow conditions (Kelly and Rydlund, 2006) at a discharge of 12,300 cubic feet per second (ft^3/s). Peak-flow measurements and high-water marks were acquired during this event. A study by Huizinga (2007) that used a version of the two-dimensional model from the first phase was calibrated to the May 19, 2004, flood, but also was calibrated to a flood that occurred May 15, 1990, which had a discharge of approximately 31,800 ft^3/s, and for which flow occurred on the flood plain on both sides of the channel.

A particular flow scenario cannot be simulated directly because the model cannot be started with boundary conditions that exactly represent the true conditions (Huizinga and Rydlund, 2001; Kelly and Rydlund, 2006, Huizinga, 2007). The conditions that are to be simulated are reached in a process called spindown. In a subcritical flow regime, spindown involves starting the model with the desired discharge as the upstream boundary condition and a downstream water-surface elevation that is higher than the highest land-surface elevation in the mesh. This condition must be met so that all nodes and elements in the model are "wet" (having a positive depth of flow). The model is run with these conditions for

Table 2. Manning's roughness coefficients (*n*-values) for the calibrated model of the Blue River between Hickman Mills Drive and 63rd Street.

[ft, feet]

Land-use coverage	Lower depth		Upper depth	
	Manning's *n*	Depth (ft)	Manning's *n*	Depth (ft)
Channel and bank				
Sand and gravel channel	0.040	3.0	0.025	4.0
Riprap-lined channel[a]	.045	1.5	.030	8.0
Timber and brush[b]	.110	2.5	.080	5.0
Thick timber corridor with thick sprouts[c]	.125	3.0	.110	6.0
Thick grasses with scattered sprouts	.055	1.7	.045	3.2
Flood plain				
Kept grasses[d]	0.050	1.0	0.033	2.7
Kept grasses with interspersed trees[e]	.055	1.5	.040	2.5
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
Commercial area with junkyard, cars, and machinery	.150	5.0	.080	7.0

[a]Not used in Kelly and Rydlund (2006).

[b]"Thick brush and timber banks" in Kelly and Rydlund (2006).

[c]Kelly and Rydlund (2006).

[d]"Industrial area with kept grasses" in Kelly and Rydlund (2006).

[e]"Residential area with kept grasses and interspersed trees" in Kelly and Rydlund (2006).

a sufficient number of iterations to cause the water-surface elevation changes between iterations to be minimized within a preset limit. Once the limit is reached, the model is said to have "converged." The downstream water-surface elevation is then decreased by some finite amount, the model is restarted using the results of the previous run—called a hotstart—as the starting point for the new run, and the model is run until convergence occurs. This process is repeated until the desired downstream water-surface elevation is reached, as dictated by high-water marks, flood profiles, or other known site parameters. During the spindown process, if the simulated water-surface elevation at a particular node is less than the land-surface elevation assigned to the node, then the node is said to "go dry." If one or more of the nodes for a particular element go dry, then the element goes dry, and the element is not included in the computations during that iteration. As the simulation proceeds through iterations, an element can oscillate between wet and dry, which can lead to solution instability and a loss of convergence. To limit this instability, the user sets a tolerance on the depth of flow over a node; however, if an element goes dry and stays dry for several iterations, it can and should be manually disabled to prevent model instability.

The peak stage of May 19, 2004, occurred at 6:30 p.m. at 63rd Street. A discharge measurement was made in a boat using hydroacoustic technology at a location immediately upstream from the 63rd Street bridge. The narrow and sinuous channel, timbered corridor, considerable velocities, standing waves, and turbulence prevented adequate hydroacoustic measurements anywhere else in the study reach. In the first phase of the project, Kelly and Rydlund (2006) used an average flow of 12,300 ft^3/s for this flood, and this value was considered the upstream total flow boundary condition for a steady-state condition of the current (2008) two-dimensional model because there are no major inflow tributaries between U.S. 71 Highway and Blue Parkway.

Six high-water marks indicating peak stage were identified along the study reach for the flood of May 19, 2004, and were considered "fair" to "poor" in quality. Because the ALERT gage at U.S. 71 Highway was not functioning during the flood, a peak stage at the gage was estimated from the existing flood-forecast stage from the NWS, based on the peak stage at 63rd Street (Steve Predmore, NWS, written commun., 2007). The cross-sectional area and average velocity from the discharge measurement made upstream from the 63rd Street bridge were used as calibration values near the downstream boundary. Measured and simulated water-surface elevations are described in table 3, and the water-surface elevation, cross-sectional area, and velocity from the measurement upstream

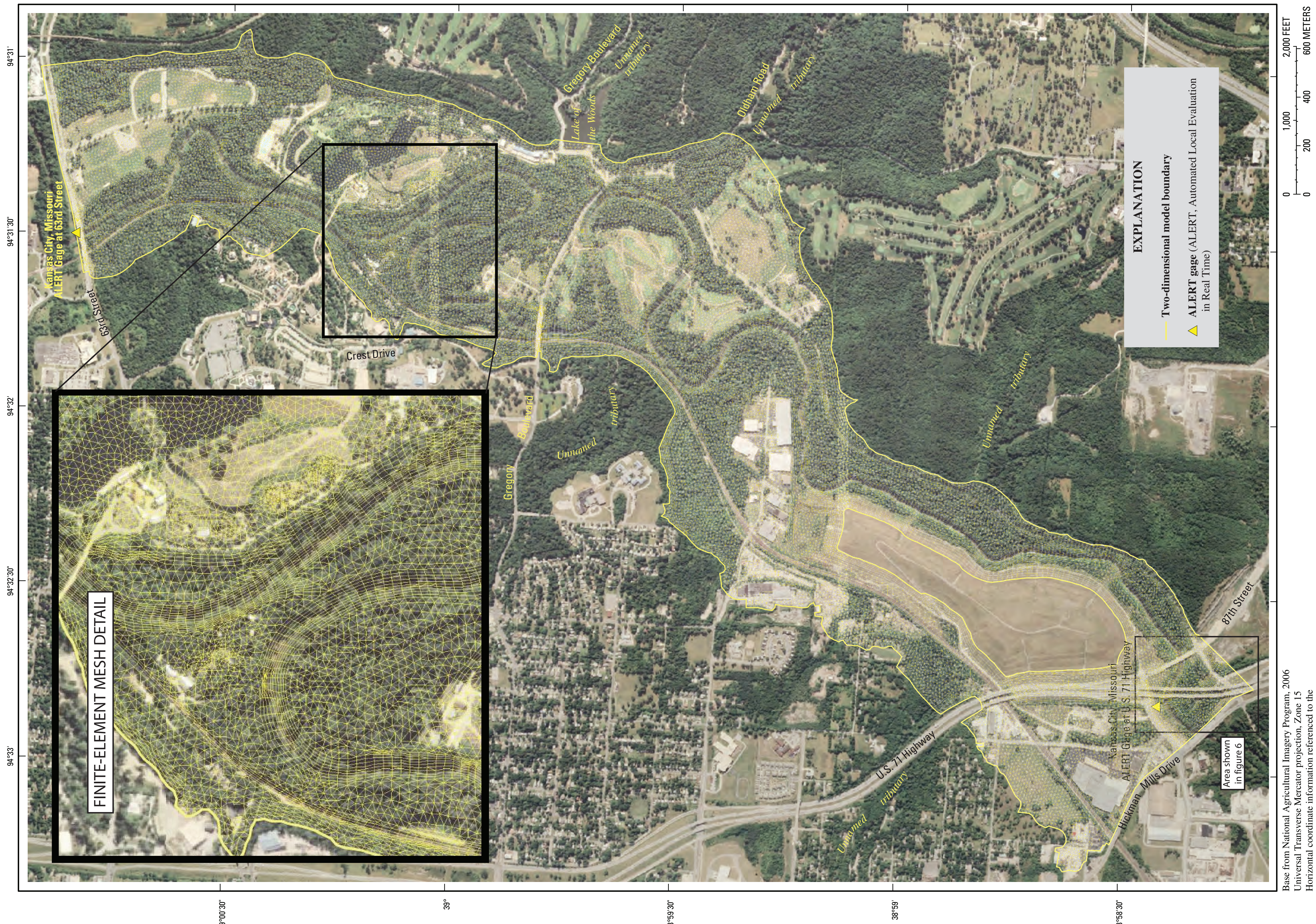


Figure 4. Finite-element mesh of the Blue River between Hickman Mills Drive and 63rd Street.

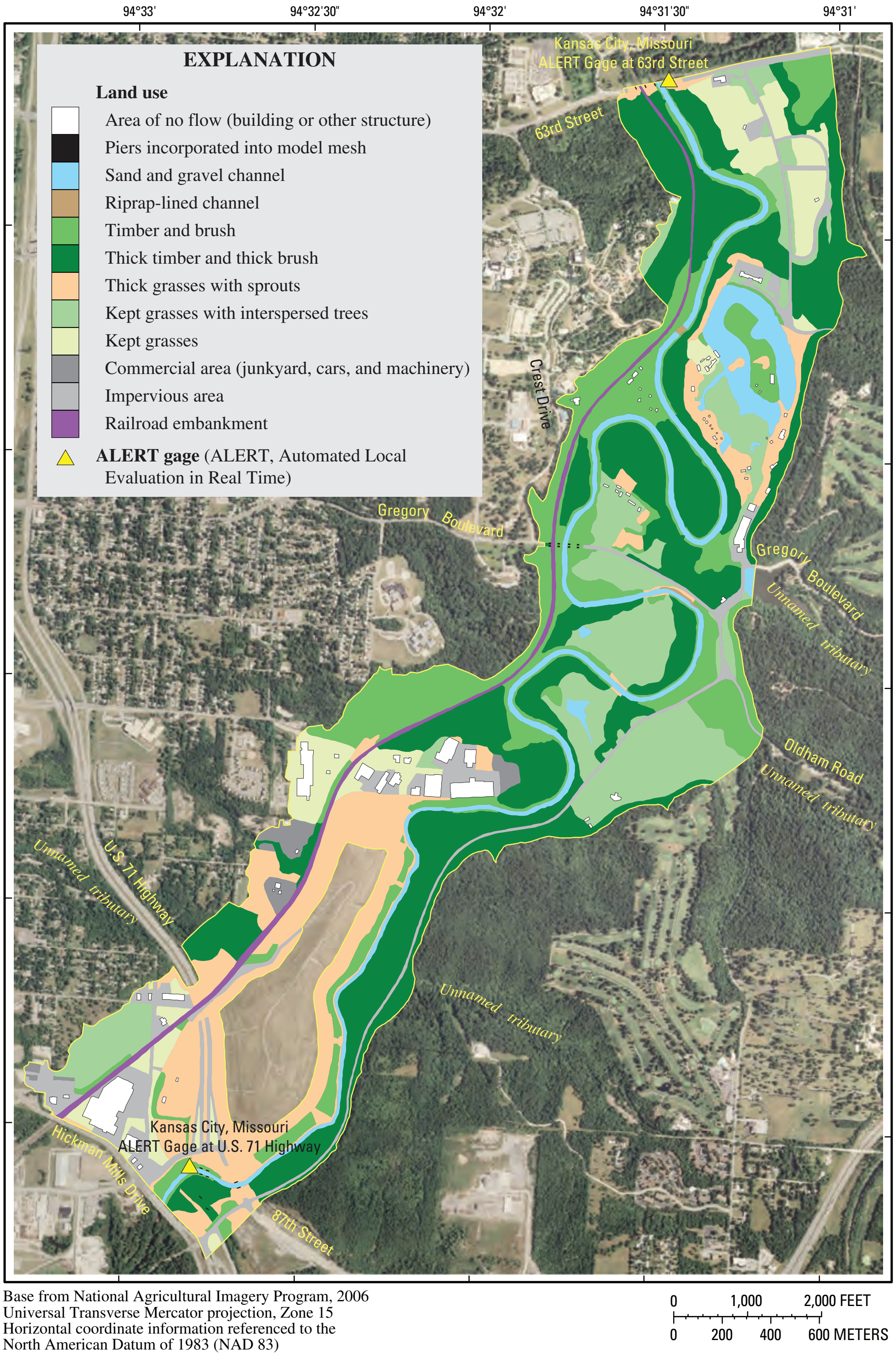


Figure 5. Land-use coverage used in the model of the Blue River between Hickman Mills Drive and 63rd Street.

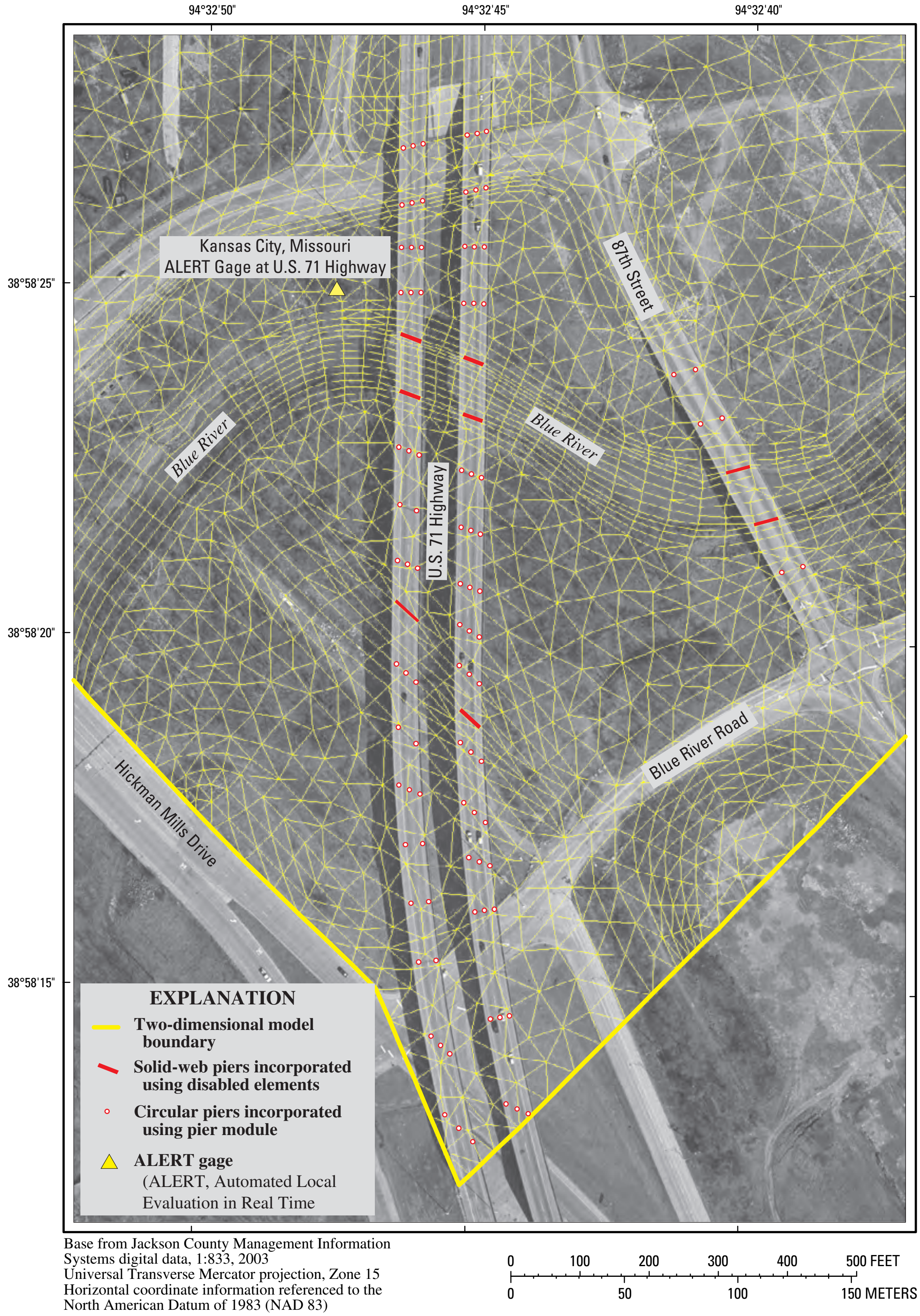


Figure 6. Finite-element mesh in the vicinity of U.S. 71 Highway showing piers incorporated into the mesh using disabled elements and the pier module.

from the 63rd Street bridge are shown with the simulated results in table 4. Generally, the simulated water-surface elevations were within 0.2 ft of the measured water-surface elevations for the May 19, 2004, flood, with the exception of the southwest mark near Lewis Road and the estimated water-surface elevation at the ALERT gage at U.S. 71 Highway (fig. 7). Two similar floods on March 5, 2004, and June 4, 2005, which had water-surface elevations that bracketed water-surface elevations for the May 19, 2004, flood at the gage at 63rd Street (759.0 ft and 763.3 ft, —a difference of 4.3 ft), had nearly identical peak-stage readings at the gage at U.S. 71 Highway (782.9 ft and 782.8 ft). These stages were both about 4 ft higher than the forecast stage; therefore, the water-surface elevation at the gage at U.S. 71 Highway was not considered crucial to the calibration to the flood of May 19, 2004.

Two historical high-water marks indicating peak stage were identified along the study reach for the flood of May 15, 1990 (Helena Mosser, U.S. Army Corps of Engineers, written commun., 2006), and an historical peak stage was recorded for the ALERT gage at U.S. 71 Highway (National Weather Service, 2007). Although the conditions of the Blue River channel and flood plain between 75th Terrace and 63rd Street (fig. 3) currently (2008) are essentially the same as existed in 1990, substantial changes have occurred in land use and channel conditions in the vicinity of U.S. 71 Highway and downstream. Therefore, the historical peak stage at the ALERT gage at U.S. 71 Highway (788.0 ft) was not used, and a value again was estimated from the existing flood forecast rating from the NWS, based on the peak stage at 63rd Street (Steve Predmore, written commun., 2007). Measured and simulated

Table 3. Measured and simulated water-surface elevations for the calibration floods of May 15, 1990, and May 19, 2004.

[ft^3/s, cubic feet per second; ft, feet; --, not determined/not applicable]

Location	May 19, 2004, flood (12,300 ft^3/s)			May 15, 1990, flood (31,800 ft^3/s)		
	Measured water-surface elevation (ft)	Simulated water-surface elevation (ft)	Simulated minus measured (ft)	Measured water-surface elevation (ft)	Simulated water-surface elevation (ft)	Simulated minus measured (ft)
Lewis Road, northeast[a]	763.8	764.0	0.2	--	--	--
Lewis Road, southwest[a]	763.7	764.0	-.3	--	--	--
Gregory Boulevard	[b]769.3	769.5	.2	781.6	781.6	0
Blue River Road	771.4	771.4	0	--	--	--
Stage-only gage at U.S. 71 Highway	[c]778.9	778.3	-.6	[c]788.9	788.8	-0.1

[a]These three measurements were all in the same area of Swope Park, except that the northeast mark was in an area of backwater away from the main channel. Therefore, the "average" water-surface elevation created by these three marks (763.9 ft) was used as the comparison value for the calibration.

[b]The measured water-surface elevation for the flood of May 19, 2004, was obtained from a paint mark on the downstream side of one of the Gregory Boulevard bridge piers and was considered a "poor" mark. The difference between the simulated and measured values likely is the result of drawdown effects from the pier.

[c]The estimated water-surface elevation was obtained from the forecast stage from the National Weather Service (Steve Predmore, written commun., 2007) based on the water-surface elevation at the 63rd Street gage for 2007 conditions.

Table 4. Measured and simulated water-surface elevation, cross-sectional area, and area-weighted average velocity at the discharge measurement location upstream from the 63rd Street Bridge for the calibration flood of May 19, 2004.

[ft, feet; ft^2, square feet; ft/s, feet per second]

Parameter	Measured	Simulated	Absolute value of percentage difference of simulated relative to measured
Water-surface elevation (ft)	762.4	762.3	0.01
Cross-sectional area (ft^2)	4,230	4,072	3.74
Average velocity (ft/s)	2.88	3.02	4.86

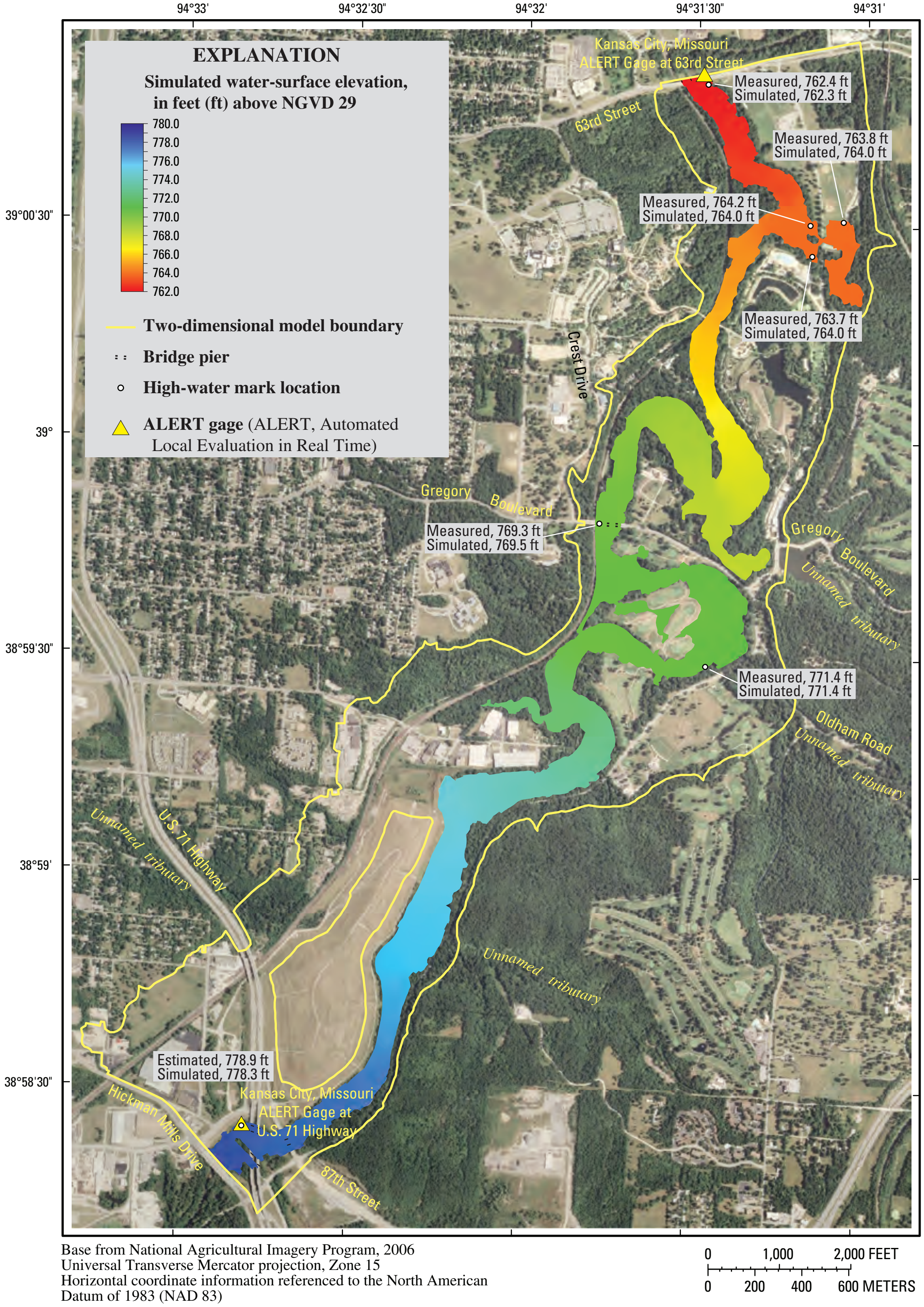


Figure 7. Simulated water-surface elevation and high-water marks for the flood of May 19, 2004.

water-surface elevations are listed in table 3. The simulated water-surface elevations (fig. 8) were within 0.1 ft of the measured or estimated water-surface elevations, and the quality of the high-water marks indicating water-surface elevation was considered “fair.”

The May 19, 2004 flood primarily was contained within the channel and adjacent overbanks (fig. 7). Depth-averaged velocities as high as 6.5 feet per second (ft/s) were simulated in the channel in the vicinity of U.S. Highway 71, and velocities as high as 6.0 ft/s were simulated under the Gregory Boulevard Bridge and at several locations between Gregory Boulevard and 63rd Street (fig. 9). Velocities in the channel between U.S. 71 Highway and Gregory Boulevard generally were lower than in the downstream channel, where velocities as high as 5.3 ft/s occurred at a few locations of local flow constriction (fig. 9). The general water-surface elevation slope throughout the reach for the May 19, 2004, flood was approximately 0.00059 feet per foot (ft/ft) or about 3.1 feet per mile (ft/mi). Water depths of 23 to 28 ft were simulated in the deeply incised channel, with a few local scour holes as deep as 33 ft (fig. 10). On the flood plain, water depths ranging from 10 to 15 ft were simulated in the overbank areas immediately adjacent to the channel. Localized terraces with simulated water depths of 5 ft or less exist on the inside of several of the meander bends (fig. 10).

The May 15, 1990 flood was not contained to the channel or adjacent overbanks, but was more widespread throughout the flood plain (fig. 8) than the May 19, 2004 flood. Depth-averaged velocities as high as 7.5 ft/s were simulated in the channel upstream from U.S. Highway 71, and velocities as high as 6.5 ft/s were simulated under the Gregory Boulevard Bridge and between Gregory Boulevard and 63rd Street in an area of local flow constriction (fig. 11). As with the 2004 flood, velocities in the channel between U.S. 71 Highway and Gregory Boulevard generally were lower than in the downstream channel; however, velocities as high as 6.3 ft/s were simulated at a few locations of local flow constriction (fig. 11). Unlike the 2004 flood, however, velocities in the meander bends upstream and downstream from Gregory Boulevard were substantially lower as flow increased across the narrow flood plain between the upstream and downstream sides of each bend. The general water-surface elevation slope throughout the reach for the May 15, 1990, flood was approximately 0.00047 ft/ft, or about 2.5 ft/mi. The water-surface elevation had the greatest changes where substantial water-velocity gradients occurred (fig. 8). Water depths of 36 to 46 ft were simulated in the deeply incised channel (fig. 12). On the flood plain, water depths ranging from 15 to 25 ft were simulated in much of the overbank areas immediately adjacent to the channel (fig. 12). Localized terraces with simulated water depths of 10 ft or less existed on the inside of several of the meander bends in the model reach (fig. 12).

Simulated Velocity Magnitude and Direction

Discharge values associated with water-surface elevation at the 63rd Street Bridge at 2-ft intervals from 763.8 through 787.8 ft were selected and input into the two-dimensional model (table 5). Each discharge and water-surface elevation pair was simulated in the two-dimensional model, using the “spindown” process described in the “Model Calibration” section of this report. The process was initiated with the first boundary conditions of a discharge of 92,000 ft3/s and water-surface elevation at 787.8 ft. Acceptable convergence with the given boundary conditions was achieved when the maximum change in water-surface elevation was less than 0.005 ft. Once the model attained acceptable convergence, the next water-surface elevation and discharge were simulated. Thirteen water-surface elevations (2-ft intervals from 763.8 to 787.8 ft above NGVD 29) are depicted with flow-trace animations for the model reach in appendix 1 (at the back of this report).

Estimated Flood-Inundation Mapping

Water-surface elevations between Hickman Mills Drive and 63rd Street were determined using the two-dimensional flow-modeling results. Upstream from Hickman Mills Drive, water-surface elevations at each gage or forecast location were extrapolated across the flood plain along cross-section lines oriented perpendicular to the downstream direction of the Blue River flood plain. Cross-section line locations were selected to provide water-surface information at gage locations, where changes in orientation of the flood plain occurred, at bridges, and at large bends in the river. The locations of these cross sections and the model reach, which required no horizontal extrapolation, are shown on figure 13.

Flood profiles of the unmodeled reach of the upper Blue River between the USGS gage at Kenneth Road and Hickman Mills Drive were developed from flood discharges published by the Federal Emergency Management Agency (FEMA; Federal Emergency Management Agency, 1990, 2002) and 2006 stage-discharge ratings at USGS streamflow gages (H.F. Hauck, written commun., 2006). To ensure the consistency of Blue River water-surface elevations between the modeled reach and the unmodeled reach above Hickman Mills Drive, the two-dimensional model-derived discharge at Hickman Mills Drive was used to assign an equivalent discharge from the FEMA discharge data to each upstream gage for each flood-inundation map. Water-surface elevations calculated using FEMA discharge data and 2006 USGS stage-discharge ratings at each gage were then assigned to cross sections coinciding with the gage location. Water-surface elevations were assigned to cross sections between gages by linear interpolation between cross sections at gage locations.

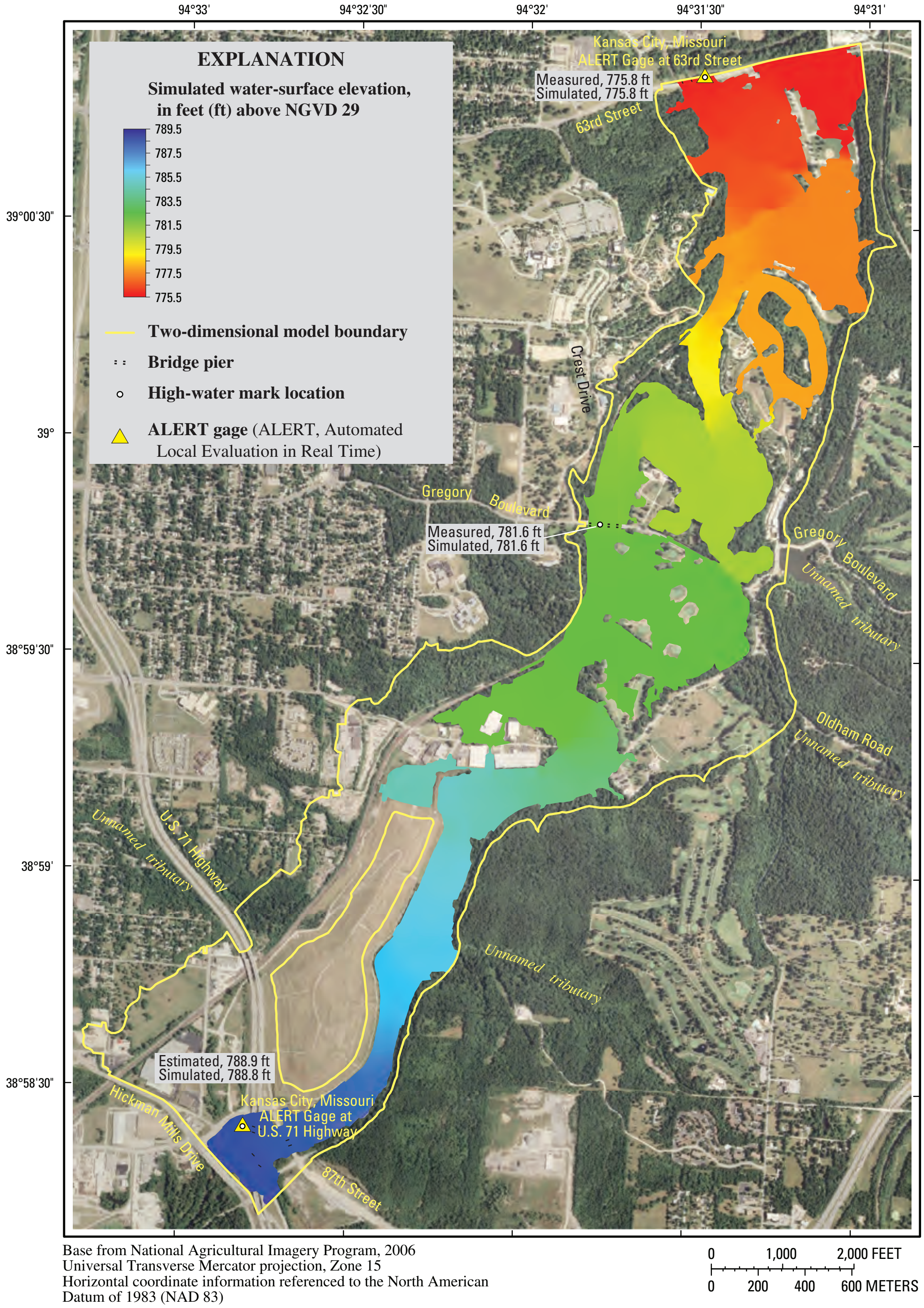


Figure 8. Simulated water-surface elevation and high-water marks for the flood of May 15, 1990.

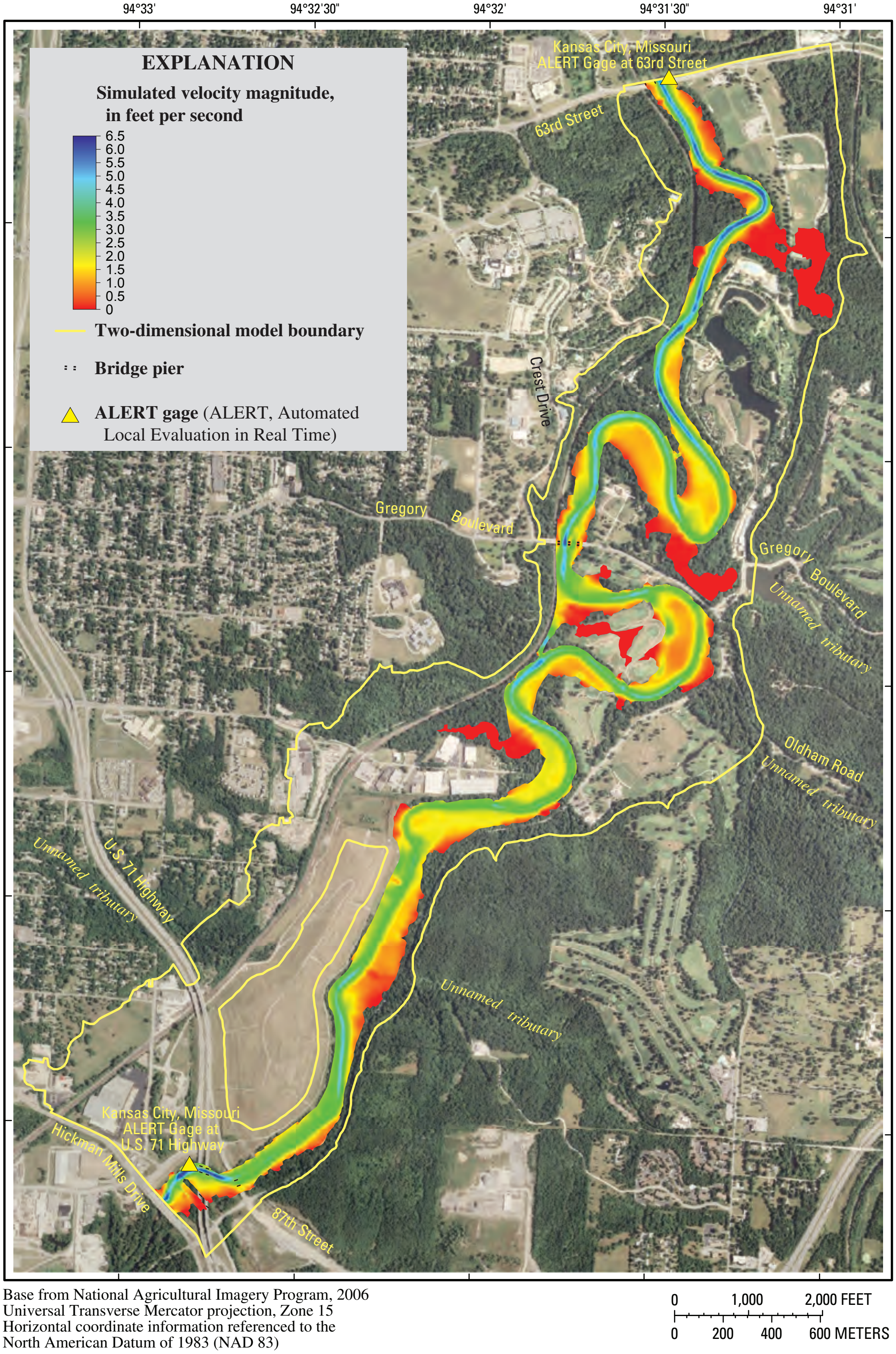


Figure 9. Simulated velocity magnitude for the flood of May 19, 2004.

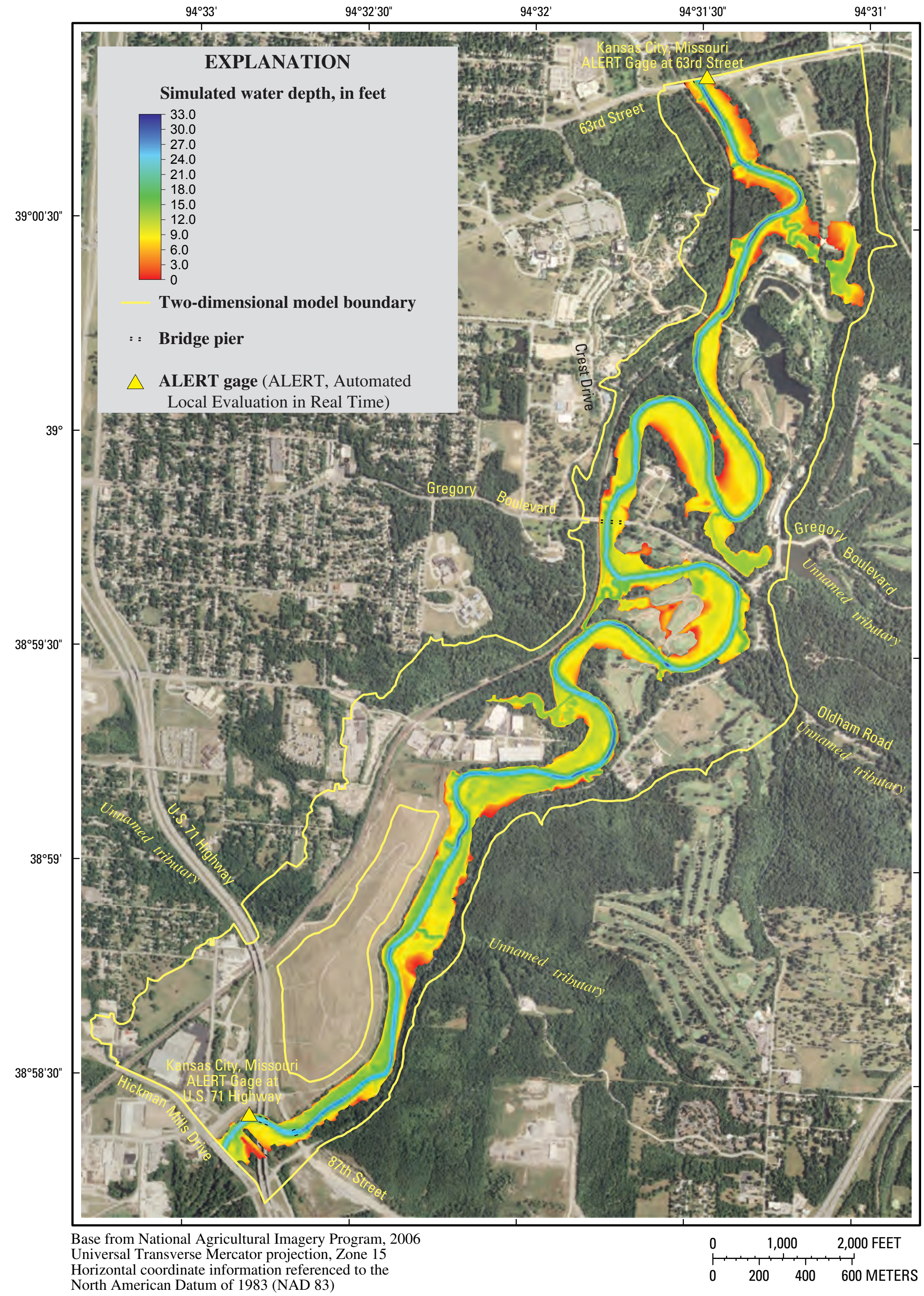
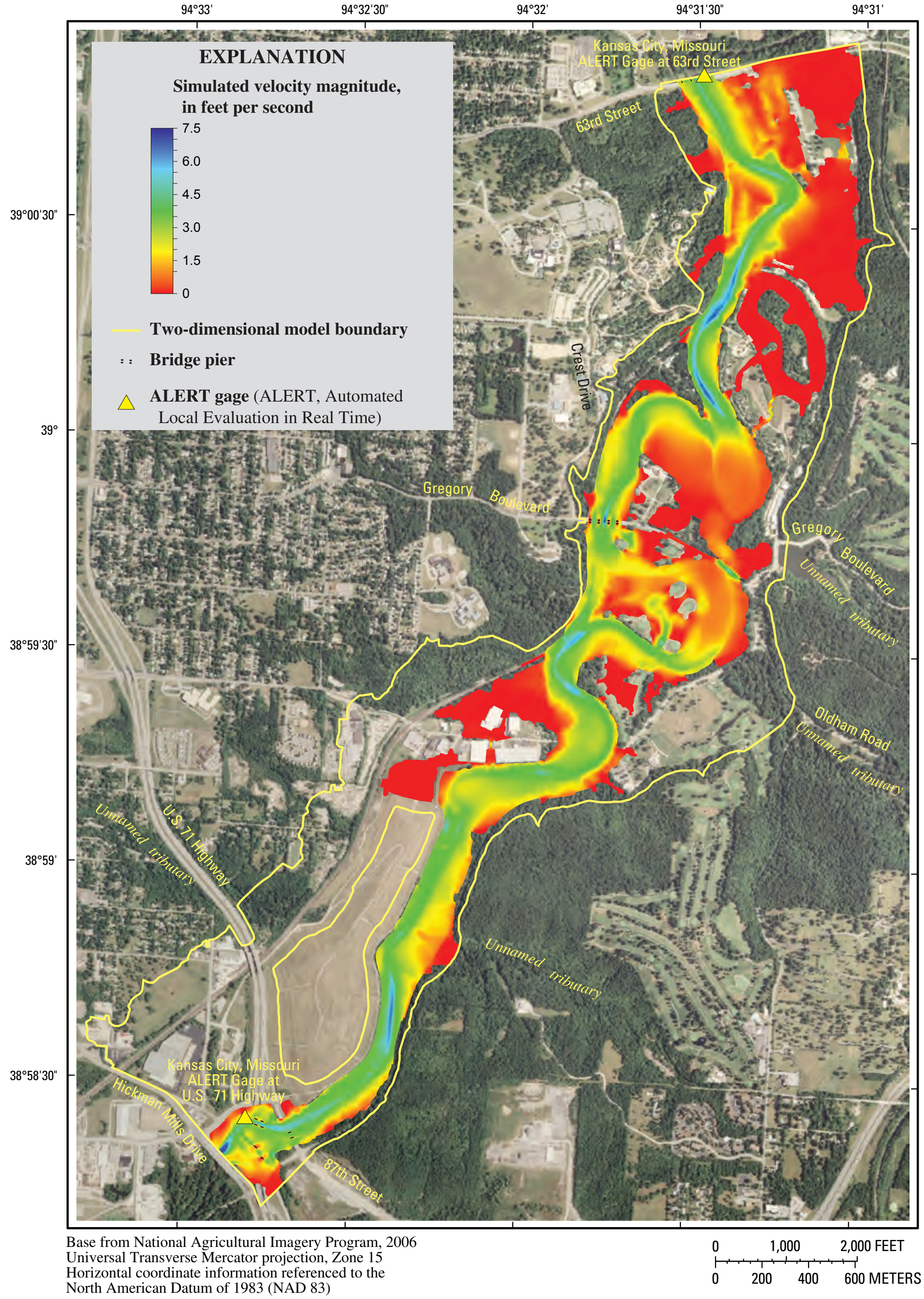


Figure 10. Simulated water depth for the flood of May 19, 2004.



Base from National Agricultural Imagery Program, 2006
Universal Transverse Mercator projection, Zone 15
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 11. Simulated velocity magnitude for the flood of May 15, 1990.

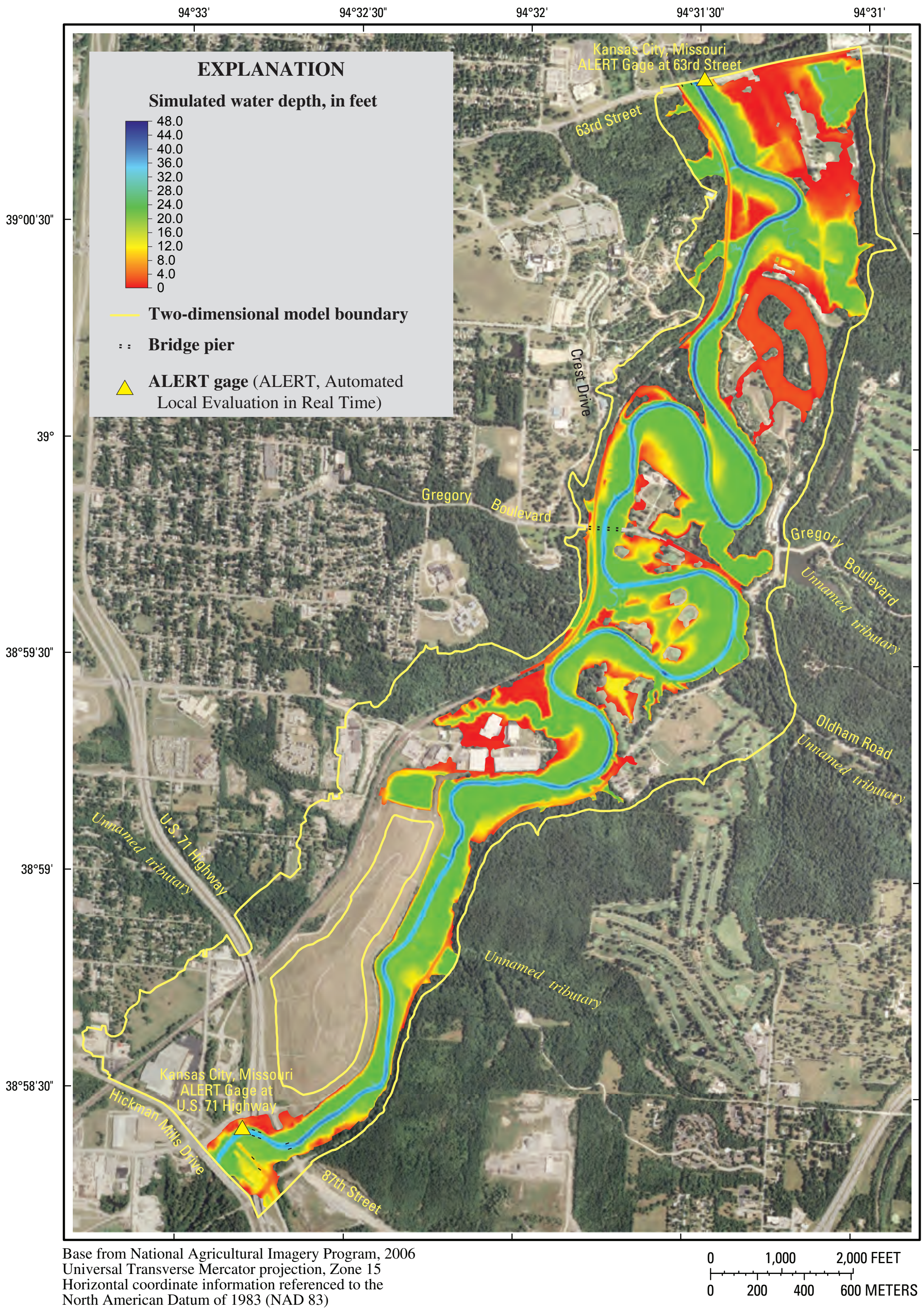


Figure 12. Simulated water depth for the flood of May 15, 1990.

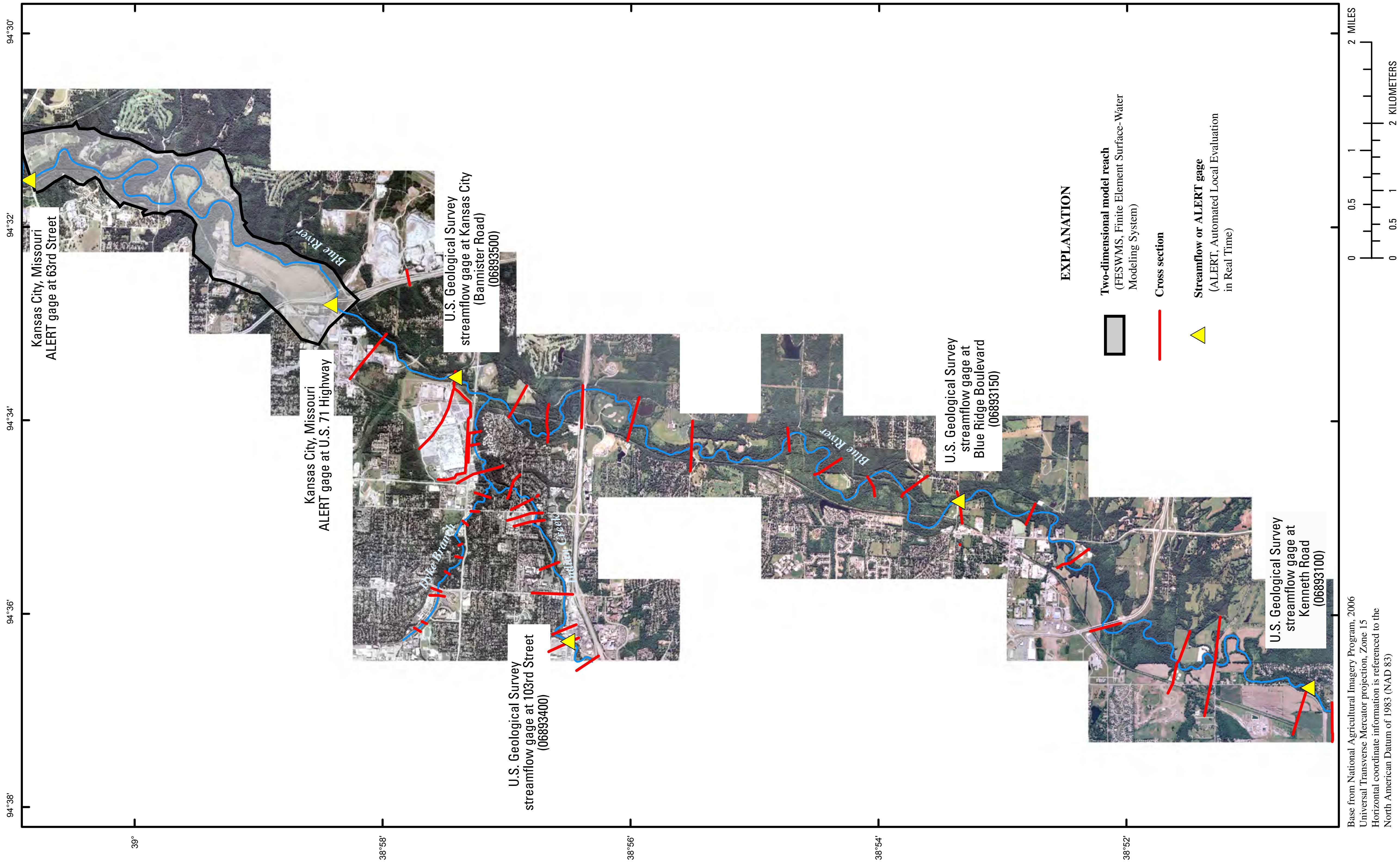


Figure 13. Location of cross sections used for flood-inundation area interpolation and the area of the FESWMS model used to create flood-inundation surfaces.

Table 5. Simulated rating depicting water-surface elevation at the 63rd Street Bridge and discharge as boundary conditions for developed flood inundation results in the two-dimensional model reach.

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

Simulated rating	
Water-surface elevation (ft)	**Discharge (ft^3/s)**
763.8	14,000
765.8	17,000
767.8	20,300
769.8	23,000
771.8	26,320
773.8	29,000
775.8	33,700
777.8	37,630
779.8	41,920
781.8	48,100
783.8	56,670
785.8	71,600
787.8	92,000

Flood profiles of Indian Creek between the Kansas-Missouri border and the mouth were developed from FEMA flood-frequency stage-discharge relations (Federal Emergency Management Agency, 1990) and stage-discharge ratings at the USGS streamflow gage at 103rd Street. To ensure the consistency of Blue River and Indian Creek water-surface elevation, the two-dimensional model-derived discharge at Hickman Mills Drive was used to assign an equivalent discharge from the FEMA discharge data to the gage at 103rd Street for each flood-inundation map. Water-surface elevations were assigned to cross sections between the 103rd Street gage and the Indian Creek mouth by linear interpolation.

Flood-profile slopes of Dyke Branch between the Kansas-Missouri border and its mouth were developed from water-surface elevations calculated using water-surface elevation slopes derived from FEMA flood-frequency stage-discharge relations (Federal Emergency Management Agency, 1990). To ensure consistency of Dyke Branch and Indian Creek water-surface elevation, the water-surface elevation of Indian Creek at the Dyke Branch mouth was used as a starting point. Mapped flood water-surface elevations of other small tributaries to the Blue River in the study area were set equal to the flood water-surface elevations of the Blue River at their mouths for all Blue River water-surface elevations.

The calculated water-surface elevation profiles and source of slope data for the Blue River from the USGS gage at Kenneth Road to 63rd Street, Indian Creek from the Kansas-Missouri border to the mouth, and Dyke Branch from the Kansas-Missouri border to the mouth for all flood-inundation maps are shown on figure 14 and listed in table 6.

For the lower Blue River flood-inundation maps (Kelly and Rydlund, 2006), a Blue River NWS water-surface elevation of 750 ft (NGVD 29) at Blue Parkway was used as the base elevation for generation of all flood-inundation maps. To ensure flood-inundation maps previously developed for the lower Blue River are consistent with flood-inundation maps developed for the upper Blue River, the water-surface elevation at 63rd Street, where the flood-inundation maps intersect, are the same for both sets of maps. Thirteen maps were produced at 2-ft water-surface elevation intervals from 763.8 to 787.8 ft at 63rd Street to approximate the range of river stages from the 2- to 500-year flood frequencies (table 7). Water-surface elevations and gage heights for historical crests are listed in table 8 (National Weather Service, 2007). Water-surface elevations and gage heights for mapped floods at gage and forecast locations within the study area are listed in table 9.

Two-dimensional model results, boundaries of the study area and model reach, and cross sections of equal water-surface elevation were input into a geographic information system (GIS) software program used to interpolate water-surface elevations between cross sections for each flood profile to produce 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.

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 Indian Creek and major roadways on the flood plains of the Blue River and Indian Creek were incorporated into the land-surface elevation data. Flood-inundation maps were created by subtracting the land-surface elevation from the water-surface elevation for each flood surface. The positive values in the resulting raster data set indicate the extent of flood inundation and the depth of water. The 5-ft horizontal resolution of each flood-inundation raster data set is the same as the flood-inundation surface and the land surface.

Some areas 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 water-surface elevation is below the top of the levee or flood wall. An onsite field survey was conducted to determine if these areas were open to flooding from the Blue River at water-surface elevations below the tops of the levee, flood wall, or embankment protecting the area. Areas were inspected for culverts, pipes, or other openings that would allow water to enter the protected area. Protected areas are indicated on the flood-inundation maps as areas that are lower than the selected water-surface elevation, but are inside a levee or flood wall that is higher than the water-surface elevation for the selected flood. Unprotected areas are indi-

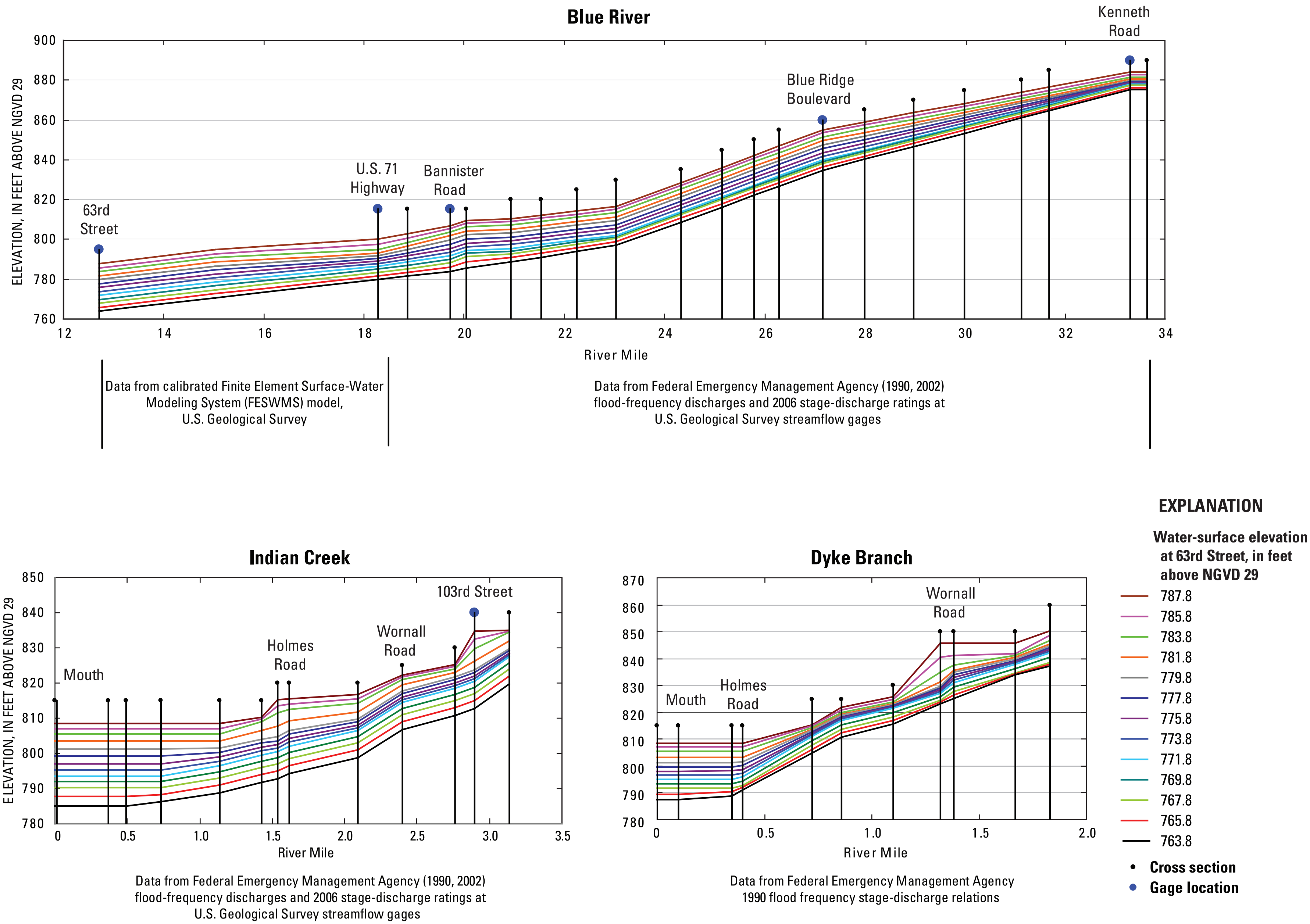


Figure 14. Calculated Blue River slopes, water-surface elevations, cross sections, and sources of data for flood-inundation maps.

Table 6. River mile and calculated Blue River, Indian Creek, and Dyke Branch water-surface elevation data for flood-inundation maps.-

[NGVD 29, National Geodetic Vertical Datum of 1929; Blvd, Boulevard; Hwy, Highway]

Gage or major bridge	River mile	Water-surface elevation, in feet (NGVD 29)												
		Plate 2.1	Plate 2.2	Plate 2.3	Plate 2.4	Plate 2.5	Plate 2.6	Plate 2.7	Plate 2.8	Plate 2.9	Plate 2.10	Plate 2.11	Plate 2.12	Plate 2.13
Blue River														
63rd Street	12.71	763.80	765.80	767.80	769.80	771.80	773.80	775.80	777.80	779.80	781.80	783.80	785.80	787.80
	13.30	765.54	767.54	769.53	771.56	773.55	775.57	777.55	779.56	781.56	783.54	785.55	787.56	789.55
Gregory Blvd	15.02	770.68	772.66	774.64	776.68	778.69	780.72	782.70	784.71	786.71	788.69	790.70	792.71	794.70
	16.08	773.69	775.59	777.49	779.40	781.25	783.05	784.80	786.56	788.30	790.11	792.06	794.26	796.52
	17.17	776.79	778.61	780.43	782.19	783.89	785.44	786.96	788.46	789.94	791.57	793.46	795.85	798.39
U.S. 71 Hwy	18.28	779.94	781.68	783.42	785.03	786.57	787.88	789.16	790.40	791.62	793.06	794.88	797.47	800.30
	18.87	781.60	783.49	785.37	787.08	788.72	790.23	791.70	793.28	794.86	796.62	798.55	800.72	803.03
Kansas City	19.72	784.00	786.09	788.19	790.03	791.81	793.61	795.36	797.42	799.54	801.76	803.83	805.41	806.97
(Bannister Road)	20.04	785.59	788.58	791.57	793.15	794.62	796.42	798.17	800.19	802.26	804.38	806.43	808.06	809.60
	20.94	788.78	790.77	792.77	794.17	795.53	797.33	799.09	801.10	803.14	805.24	807.28	808.93	810.46
	21.54	791.13	793.08	795.03	796.20	797.36	799.16	800.92	802.91	804.92	806.94	808.98	810.66	812.18
	22.26	793.95	795.84	797.73	798.64	799.55	801.36	803.13	805.07	807.05	809.00	811.01	812.74	814.24
	23.04	797.00	798.83	800.67	801.29	801.92	803.74	805.51	807.42	809.35	811.22	813.22	814.99	816.47
	24.33	808.76	810.57	812.39	813.07	813.75	815.60	817.41	819.35	821.31	823.19	825.20	827.00	828.50
	25.15	816.23	818.04	819.85	820.55	821.27	823.14	824.97	826.93	828.91	830.80	832.82	834.64	836.14
	25.80	822.15	823.95	825.76	826.49	827.23	829.12	830.97	832.94	834.93	836.83	838.86	840.69	842.21
	26.30	826.71	828.50	830.30	831.05	831.82	833.72	835.58	837.57	839.57	841.47	843.51	845.34	846.87
Blue Ridge Blvd	27.17	834.63	836.42	838.21	838.99	839.80	841.72	843.61	845.61	847.63	849.54	851.59	853.44	854.98
	28.01	840.21	841.89	843.56	844.27	845.00	846.73	848.42	850.23	852.04	853.78	855.67	857.45	858.98
	28.98	846.65	848.20	849.74	850.37	851.00	852.51	853.98	855.55	857.14	858.67	860.37	862.08	863.60
	29.99	853.35	854.77	856.18	856.72	857.26	858.53	859.76	861.10	862.44	863.76	865.27	866.90	868.41
	31.13	860.92	862.18	863.44	863.89	864.32	865.32	866.30	867.36	868.43	869.51	870.79	872.34	873.84
	31.68	864.57	865.76	866.95	867.34	867.72	868.59	869.45	870.38	871.32	872.28	873.46	874.96	876.46
Kenneth Road	33.30	875.33	876.30	877.27	877.53	877.75	878.25	878.73	879.27	879.83	880.45	881.32	882.69	884.17
	33.64	875.33	876.30	877.27	877.53	877.75	878.25	878.73	879.27	879.83	880.45	881.32	882.69	884.17

Table 6. River mile and calculated Blue River, Indian Creek, and Dyke Branch water-surface elevation data for flood-inundation maps.—Continued

[NGVD 29, National Geodetic Vertical Datum of 1929; Blvd, Boulevard; Hwy, Highway]

Gage or major bridge	River mile	Water-surface elevation, in feet (NGVD 29)												
		Plate 2.1	Plate 2.2	Plate 2.3	Plate 2.4	Plate 2.5	Plate 2.6	Plate 2.7	Plate 2.8	Plate 2.9	Plate 2.10	Plate 2.11	Plate 2.12	Plate 2.13
Indian Creek														
	0.00	784.99	787.64	790.29	791.96	793.55	795.35	797.11	799.14	801.22	803.39	805.44	807.05	808.60
	.37	784.99	787.64	790.29	791.96	793.55	795.35	797.11	799.14	801.22	803.39	805.44	807.05	808.60
	.49	784.99	787.64	790.29	791.96	793.55	795.35	797.11	799.14	801.22	803.39	805.44	807.05	808.60
	.73	786.15	788.24	790.33	791.96	793.55	795.35	797.11	799.14	801.22	803.39	805.44	807.05	808.60
	1.14	788.84	790.93	793.01	794.81	796.50	797.76	798.99	800.27	801.56	803.39	805.44	807.05	808.60
	1.43	791.84	793.93	796.01	797.81	799.49	800.64	801.76	802.93	804.11	806.59	809.08	809.73	810.35
Holmes Road	1.54	792.84	794.93	797.01	798.81	800.48	801.52	802.53	803.59	804.66	807.80	811.57	813.50	815.35
	1.62	794.34	796.43	798.51	800.31	801.99	803.14	804.26	805.43	806.61	809.33	812.45	814.06	815.60
	2.09	798.84	800.93	803.01	804.81	806.46	807.28	808.08	808.91	809.75	811.86	814.32	815.61	816.85
Wornall Road	2.40	806.84	808.93	811.01	812.81	814.46	815.28	816.08	816.91	817.75	819.39	821.08	821.73	822.35
	2.76	810.84	812.93	815.01	816.81	818.46	819.28	820.08	820.91	821.75	822.92	824.08	824.73	825.35
103rd Street	2.90	812.84	814.93	817.01	818.81	820.46	821.28	822.08	822.91	823.75	826.33	829.81	832.38	834.85
	3.14	819.84	821.93	824.01	825.81	827.44	828.04	828.62	829.23	829.85	832.09	834.46	834.79	835.10
Dyke Branch														
	0.00	787.50	789.58	791.67	793.39	795.03	796.55	798.05	799.71	801.39	803.39	805.44	807.05	808.60
	.10	787.50	789.58	791.67	793.39	795.03	796.55	798.05	799.71	801.39	803.39	805.44	807.05	808.60
Holmes Road	.35	788.92	790.32	791.72	793.39	795.03	796.62	798.17	799.79	801.42	803.39	805.45	807.06	808.60
	.40	791.17	791.95	792.72	794.42	796.12	797.46	798.78	800.15	801.52	803.39	805.45	807.06	808.60
	.72	804.90	806.29	807.68	809.42	811.05	811.60	812.14	812.70	813.26	813.74	814.25	814.89	815.50
	.86	810.90	812.29	813.68	815.42	817.04	817.48	817.91	818.36	818.81	819.24	819.87	820.83	821.75
	1.10	815.61	816.90	818.19	819.92	821.53	821.86	822.18	822.52	822.86	823.24	823.87	824.83	825.75
Wornall Road	1.32	823.13	823.89	824.64	825.87	827.06	827.72	828.37	829.04	829.72	831.41	835.08	840.52	845.75
	1.38	825.32	826.51	827.69	829.42	831.09	832.08	833.05	834.06	835.07	835.74	837.47	841.31	845.75
	1.67	834.02	834.39	834.75	836.42	838.04	838.48	838.91	839.36	839.81	840.47	841.25	841.89	845.75
	1.83	837.17	837.95	838.72	840.42	842.06	842.72	843.37	844.04	844.72	845.47	846.74	848.66	850.50

Table 7. Flood frequency, discharge, and water-surface elevations at 63rd Street.

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

Flood frequency	Discharge (ft^3/s)	Water-surface elevation (ft)
2 year	13,200	763.05
5 year	20,300	767.93
10 year	26,320	771.60
20 year	34,000	776.20
50 year	44,500	780.64
100 year	53,690	783.06
200 year	62,000	784.55
500 year	74,720	786.17

cated as inundated. Thirteen Blue River flood-inundation maps are shown on maps 2.1 through 2.13 in appendix 2 (at the back of this report).

The Blue River flood-inundation surfaces used for maps in this report correspond to hypothetical surfaces that represent the peak stage of a selected flood for all locations in the study reach. Consequently, these maps do not depict water-surface 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 water-surface elevation and not on changes of discharge. Therefore, one map will not likely represent flood inundation for the entire study area caused by a single flood. Rather, flood inundation for a single flood event is represented using inundation maps that cover areas near individual gages or forecast locations.

The study area was divided into nine regions that correspond to the six forecast or stream-gage locations on the Blue River (fig. 15). 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 maps in appendix 2. Three regions are associated with two stream gage locations because the extent of flood inundation for those regions is equally valid for data from either stream gage location.

Table 8. Water-surface elevations and gage heights of historical crests for National Weather Service forecast locations for flood inundation on the Blue River.

[ft, feet; NWS, National Weather Service; datum National Geodetic Vertical Datum of 1929; *, indirectly measured or estimated]

Forecast or streamflow gage location	Date	Water-surface elevation (ft)	Gage height (ft above gage datum)
Blue River at 63rd Street	*5/15/1990	775.9	54.12
Data collection began June 1998	*9/13/1961	774.7	52.92
NWS Datum = 721.78 ft	*11/17/1928	772.9	51.12
	*7/10/1993	771.7	49.92
	*5/16/1995	771.6	49.82
Blue River at U.S. 71 Highway	*9/13/1961	788.7	65.75
Data collection began April 1998	*5/15/1990	788.1	65.15
NWS Datum = 722.9 ft	*6/9/1984	786.1	63.15
Blue River at Kansas City (Bannister Road)	9/13/1961	798.2	44.46
Data collection began November 1928	5/15/1990	794.3	40.64
NWS Datum = 753.7 ft	11/17/1928	792.7	39.00
	7/11/1951	792.0	38.30
	7/31/1958	791.5	37.80
	6/9/1984	791.0	37.30
	4/23/1944	789.6	35.88
	9/13/1977	788.4	34.74
Blue River at Blue Ridge Boulevard	*9/13/1961	844.5	44.50
Data collection began December 2002	*1/1/1958	839.5	39.50
NWS Datum = 800.0 ft	5/19/2004	839.0	39.03
	3/5/2003	838.6	38.55

Table 9. Equivalent water-surface elevations and gage heights for stream gages and National Weather Service forecast locations for flood-inundation maps on the Blue River and Indian Creek.

[ft, feet; NWS, National Weather Service; datum National Geodetic Vertical Datum of 1929; bold water-surface elevation indicates gage height is above National Weather Service flood stage]

Gage or flood-forecast location											
Blue River										Indian Creek	
63rd Street NWS forecast location (stage-only gage)		U.S. 71 Highway NWS forecast location (stage-only gage)		Kansas City at Bannister Road NWS forecast location (streamflow gage)		Blue Ridge Boulevard NWS forecast location (streamflow gage)		Kenneth Road (streamflow gage)		103rd Street (streamflow gage)	
Water-surface elevation (ft)	Gage height (ft above NWS gage datum of 721.78)	Water-surface elevation (ft)	Gage height (ft above NWS gage datum of 722.9)	Water-surface elevation (ft)	Gage height (ft above NWS gage datum of 753.7)	Water-surface elevation (ft)	Gage height (ft above NWS gage datum of 800.0)	Water-surface elevation (ft)	Gage height (ft above NWS gage datum of 858.36)	Water-surface elevation (ft)	Gage height (ft above NWS gage datum of 722.57)
763.8	42.0	779.9	57.0	784.0	30.3	834.6	34.6	875.3	17.0	812.8	90.3
765.8	44.0	781.7	58.8	786.1	32.4	**836.4**	**36.4**	876.3	17.9	814.9	92.4
767.8	46.0	783.4	60.5	**788.2**	**34.5**	**838.2**	**38.2**	877.3	18.9	817.0	94.4
769.8	**48.0**	**785.0**	**62.1**	**790.0**	**36.3**	**839.0**	**39.0**	877.5	19.2	818.8	96.2
771.8	**50.0**	**786.6**	**63.7**	**791.8**	**38.1**	**839.8**	**39.8**	877.8	19.4	820.5	97.9
773.8	**52.0**	**787.9**	**65.0**	**793.6**	**39.9**	**841.7**	**41.7**	878.2	19.9	821.3	98.7
775.8	**54.0**	**789.2**	**66.3**	**795.4**	**41.7**	**843.6**	**43.6**	878.7	20.4	822.1	99.5
777.8	**56.0**	**790.4**	**67.5**	**797.4**	**43.7**	**845.6**	**45.6**	879.3	20.9	822.9	100.3
779.8	**58.0**	**791.6**	**68.7**	**799.5**	**45.8**	**847.6**	**47.6**	879.8	21.5	823.8	101.2
781.8	**60.0**	**793.1**	**70.2**	**801.8**	**48.1**	**849.5**	**49.5**	880.4	22.1	826.3	103.8
783.8	**62.0**	**794.9**	**72.0**	**803.8**	**50.1**	**851.6**	**51.6**	881.3	23.0	829.8	107.2
785.8	**64.0**	**797.5**	**74.6**	**805.4**	**51.7**	**853.4**	**53.4**	882.7	24.3	832.4	109.8
787.8	**66.0**	**800.3**	**77.4**	**807.0**	**53.3**	**855.0**	**55.0**	884.2	25.8	834.9	112.3

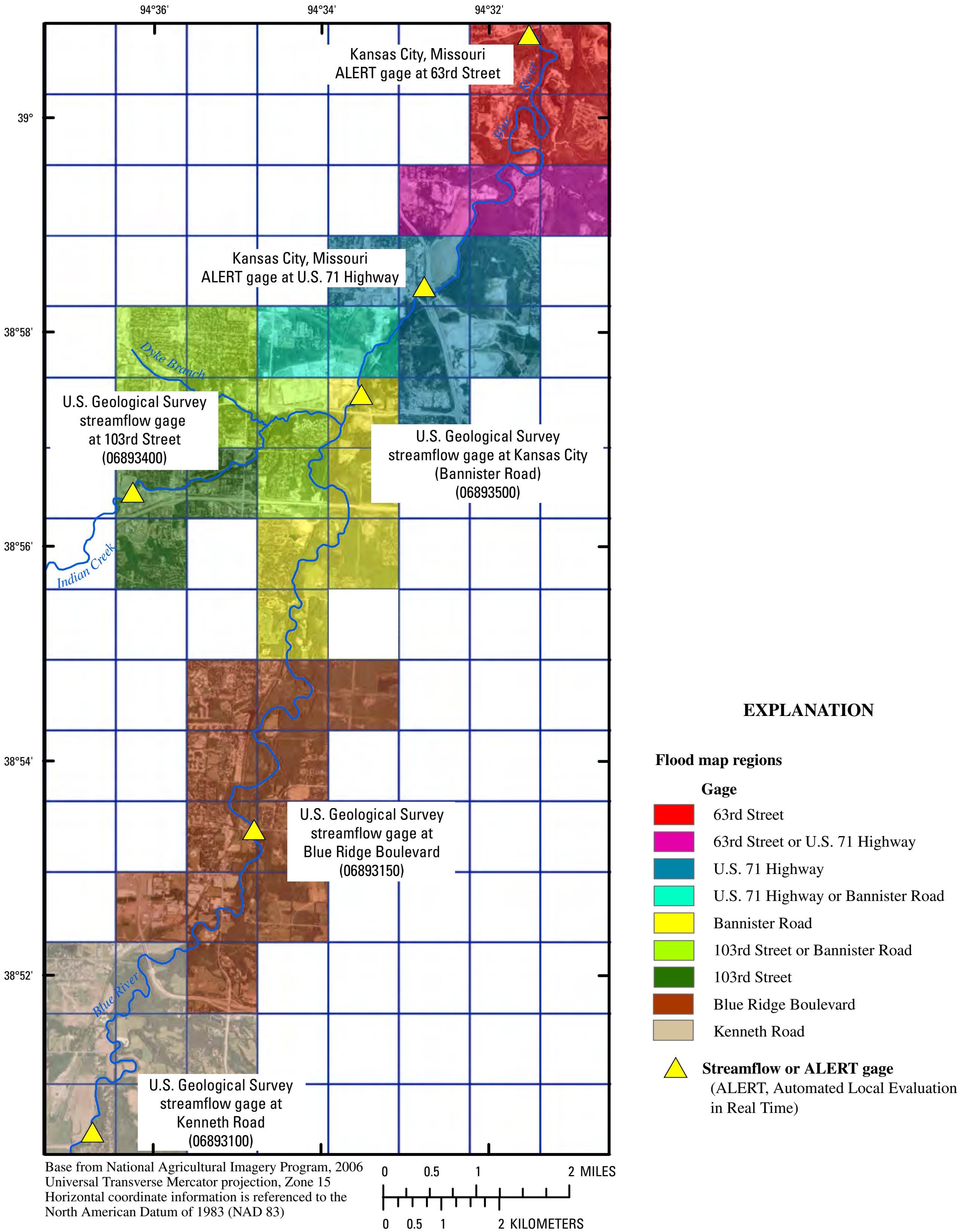


Figure 15. Regions and sections of Blue River flood-inundation maps associated with each forecast or gage location.

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 minimize flood deaths and damage in the flood plain of the lower Blue River in Kansas City, and 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 permits users to view near real-time stage information and select inundation maps for current flood conditions, forecasted peak stage, or other selected river stages. 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 access to a computer or the World Wide Web. Local emergency management personnel can use inundation maps that correspond to a forecast peak to determine threatened areas, identify road closures, and take appropriate actions to warn residents and property owners. The maps will help the public, business owners, and the media to 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 information related to location and water depth of inundated areas, the two-dimensional modeling results provide velocity magnitude and direction throughout the model reach along the Blue River between Hickman Mills Drive and 63rd Street. Such hydraulic details can be used to assess potential channel improvements or flooding effects on landforms and structures in the flood plain.

Although there are substantial benefits to 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, two-dimensional hydraulic model results, measured high-water marks, and interpolated water-surface elevations. Small tributary flooding and 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 flood inundation along and from these tributaries could be higher than the estimated flood inundation from the Blue River. 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. 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 flood peaks on the Blue River arrive. Flood-inundation maps in this report represent only flooding caused by the Blue River and Indian Creek.

Topographic data provided by the city of Kansas City is vertically 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 water-surface elevation for each flood inundation map. For areas that are flat or have a small 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 water-surface elevations typically deviate from reality. Good measurements of discharge are within 5 percent of the actual discharge, and hydraulic model results calibrated to measured discharge are subject to the limitations of those measurements. As stated in the model calibration section, the two-dimensional model results were within about 0.2 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 floodwater 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.

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 over small areas 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 water-surface elevations may differ from interpolated water-surface elevations on inundation maps over small areas near the constriction. Upstream from these structures, the actual water-surface elevation may be higher than the interpolated surface; downstream the water-surface elevation may be lower. The amount of error is variable and depends on water velocity and the size of the constriction.

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 that are both greater than 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 Hickman Mills Drive and 63rd Street, flood-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 maps are available for download. The Web site URL is *http://pubs.usgs.gov/sir/2008/5068.*

The main page of the Blue River Flood Inundation Website 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 or gage locations from the table to access the web page specific to that location. Each forecast or gage 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 water-surface elevation of interest. Once the water-surface 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 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 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 United States Geological Survey (USGS), in cooperation with the city of Kansas City, Missouri, completed a study in 2007 to determine the extent and character of inundation in the Blue River valley from flooding in the Blue River. A website was created that associates real-time flow data and flood-inundation maps on the lower Blue River from the mouth upstream to Gregory Boulevard. A two-dimensional model was applied to a hydraulically complex, 2-mile length of the Blue River centered on the reach between 63rd Street and the mouth of Brush Creek to provide information about the performance of existing hydraulic structures, channel conditions, and areal distribution of water velocity for the estimated flood-inundation maps on the Web. The second phase of the project, described in this report, began in 2006 and addresses the part of the Blue River from 63rd Street upstream to the USGS gage at Kenneth Road, Indian Creek from its mouth to the Kansas-Missouri border, and Dyke Branch, a tributary of Indian Creek. The second phase expands the Website to include stage information and flood-inundation maps from the USGS gage at Kenneth Road to 63rd Street and a detailed two-dimensional hydraulic simulation of the reach between Hickman Mills Drive and 63rd Street that provides maps of flood-inundation extent, flood-plain water velocity, flow direction, and depths for existing flood-plain developments for a range of stages. These products spatially integrate information provided by USGS gages, Kansas City Automated Local Evaluation in Real Time (ALERT) gages, and the National Weather Service (NWS) flood-peak prediction service that comprise the Blue River flood-alert system, and are a valuable tool for public officials and residents to minimize flood deaths and damage in Kansas City.

Much of the lower Blue River flood plain is covered by industrial development. The Blue River and Indian Creek basins also are the location of large parks and recreational development. Bicycle, pedestrian, and equestrian trails exist or are planned for the entire length of both streams. Rapid development in the upper end of the basin has likely increased the volume of runoff, and thus the discharge of flood events for the Blue River. The NWS issues peak-stage forecasts at four gage locations in the study area during high water. The small drainage areas of the Blue River and Indian Creek basins cause rapid flooding and allow minimal time for flood forecasting and response.

Water-surface elevations between Hickman Mills Drive and 63rd Street were determined using the two-dimensional flow modeling. A depth-averaged flow model Finite Element Surface-Water Modeling System (FESWMS) Flo2DH was used to simulate steady-state flood flows within this 5.6-mile hydraulically complex reach of the Blue River. The two-dimensional model was used to prepare maps of water velocity, flow direction, depth, and inundation extent in the model reach. These model outputs also can be useful in designing potential channel and flood-plain improvements throughout the simulated reach.

Upstream from Hickman Mills Drive, water-surface elevations at each gage or forecast location were extrapolated across the flood plain along cross-section lines oriented perpendicular to the downstream direction of the Blue River flood plain. Flood-profiles were developed from water-surface elevations using Federal Emergency Management Agency (FEMA) flood frequency discharges and 2006 stage-discharge ratings at USGS streamflow gages. Flood-profile slopes of Indian Creek between the Kansas-Missouri border and the mouth were developed from water-surface elevations calculated using current stage-discharge ratings at the USGS streamflow gage at 103rd Street and water-surface elevations derived from FEMA flood-frequency stage-discharge relations. Flood-profile slopes of Dyke Branch between the Kansas-Missouri border and the mouth were developed from water-surface elevations calculated using water-surface elevation slopes derived from FEMA flood-frequency stage-discharge relations. Mapped flood water-surface elevations of other small tributaries to the Blue River in the study area were set equal to the flood water-surface elevations of the Blue River at their mouths for all Blue River water-surface elevations. Thirteen maps were produced at 2-ft water-surface elevation intervals from 763.8 to 787.8 ft at 63rd Street to approximate the range of river stages from the 2- to 500-year flood frequencies.

The flood-inundation maps created during this study are an important tool for public officials and residents to minimize flood deaths and damage in the flood plain of the upper Blue River and Indian Creek in Kansas City and supplement information collected by the metropolitan Kansas City flood-alert system. Data used to construct the flood-inundation maps include topographic data, two-dimensional hydraulic model results, stage-discharge ratings at streamflow gages, measured high-water marks, and interpolated water-surface 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 Hickman Mills Drive and 63rd Street, flood-inundation maps, real-time gage heights, and NWS stage forecast for each forecast location within the study area. In addition, the full text of this report, tables, and maps are available for download at URL *http://pubs.usgs.gov/sir/2008/5068.*

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