Two-Dimensional Hydraulic Analyses of Joachim Creek, De Soto, Missouri

Scientific Investigations Report 2021–5058

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

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By Kyle D. Hix, Paul H. Rydlund, and David C. Heimann

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile ([ft^3/s]/mi^2)	0.01093	cubic meter per second per square kilometer ([m^3/s]/km^2)
Hydraulic gradient		
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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 vertical datum.

Abbreviations

AEP annual exceedance probability

DEM digital elevation model

FIS flood-insurance study

HEC–RAS Hydrologic Engineering Center River Analysis System

lidar light detection and ranging

n Manning's roughness coefficient

SMS Surface-water Modeling System

SRH–2D Sedimentation and River Hydraulics—Two-Dimensions model

USACE U.S. Army Corps of Engineers

USGS U.S. Geological Survey

1D one-dimensional

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Abstract

A two-dimensional hydraulic model; water-surface profiles; and digital maps of water-surface elevation, velocities, and water depths were developed for a 6.7-mile reach of Joachim Creek within and near the city of De Soto, Missouri. Water-surface profiles were generated for the 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probability (10-, 25-, 50-, 100-, and 500-year recurrence interval) flows. Digital maps of water-surface elevation, water depth, and velocity were generated for the 1- and 0.2-percent annual exceedance probability flows. Water-surface elevations and inundation extents of generated profiles and maps were substantially lower than similar products produced for the 2019 flood-insurance study that included the study reach. The differences in water-surface elevations can be attributed to differences in input streamflows and hydraulic simulation techniques.

The water-surface elevations generated for the 1- and 0.2-percent annual exceedance probability flows were used to assess the vulnerability and inundation depths of 231 selected structures within the city of De Soto. Results indicate that 157 to 177 of the 231 structures were affected at the 1-percent annual exceedance probability flow, depending on the adjacent grade elevation used for reference. Between 185 and 198 structures were affected at the 0.2-percent annual exceedance probability flow, depending on grade elevation. Inundation depths at the affected structures were 0.02 to 9.28 feet (ft), depending on the flow and adjacent grade reference.

Flood elevations were computed for Joachim Creek using a two-dimensional, finite-volume numerical modeling application for river hydraulics. The hydraulic model was calibrated using high-water marks from the April 18, 2013, flood and the maximum measured streamflow at the U.S. Geological Survey streamgage Joachim Creek at De Soto, Mo. (station 07019500), on September 8, 2018. The calibrated model was then used to compute the hydraulic conditions associated with the 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probability flows. The simulated water-surface elevations and digital elevation model (derived from light detection and ranging data having a 0.60-ft vertical accuracy and a 1.97-ft

horizontal resolution) were used to generate products including water-surface profiles and maps of inundated area, water depth, and velocities using model postprocessing software.

Introduction

The city of De Soto (fig. 1), Missouri, has experienced substantial flooding from Joachim Creek and joining tributaries throughout the corporate limits in recent years. Flooding in April 2013, May 2013, August 2016, and April 2017 has affected the community, leading to one fatality and elevating risk to first responders from a local rural firehouse (located in the floodway). Recent developments such as a local flood warning and mapping system (Heimann and others, 2019), an effective flood-insurance study (FIS) with accompanying flood-insurance rate maps (Federal Emergency Management Agency, 2019b), and a proposed floodplain management plan (U.S. Army Corps of Engineers, 2019) have helped mitigate risk within the city of De Soto.

Development of community ordinances in compliance with the National Flood Insurance Program requires an understanding of floodplain management and a high degree of certainty in flood analysis to support and implement the ordinances. More specifically, verification and certainty in the effects of flooding to local businesses and residents are vital to the sustainability and future growth of the community. Therefore, the U.S. Geological Survey (USGS), in cooperation with the City of De Soto developed a detailed hydrologic and hydraulic analyses of Joachim Creek to have a better understanding and verification of the existing regulatory floodplain. Analyses included the use of existing USGS streamgage Joachim Creek at De Soto, Mo. (station 07019500); development and analyses of flood-frequency streamflows; and hydraulic simulations of the 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probability (AEP) regulatory floods corresponding to 10-, 25-, 50-, 100-, and 500-year recurrence interval floods, respectively. The results for each hydraulic simulation included water-surface elevation computations, although the 1- and 0.2-percent AEP flood analyses also included water velocities and depths. The information from these analyses can be used by managers, engineers, and planners to make informed floodplain management decisions regarding risk and mitigation.
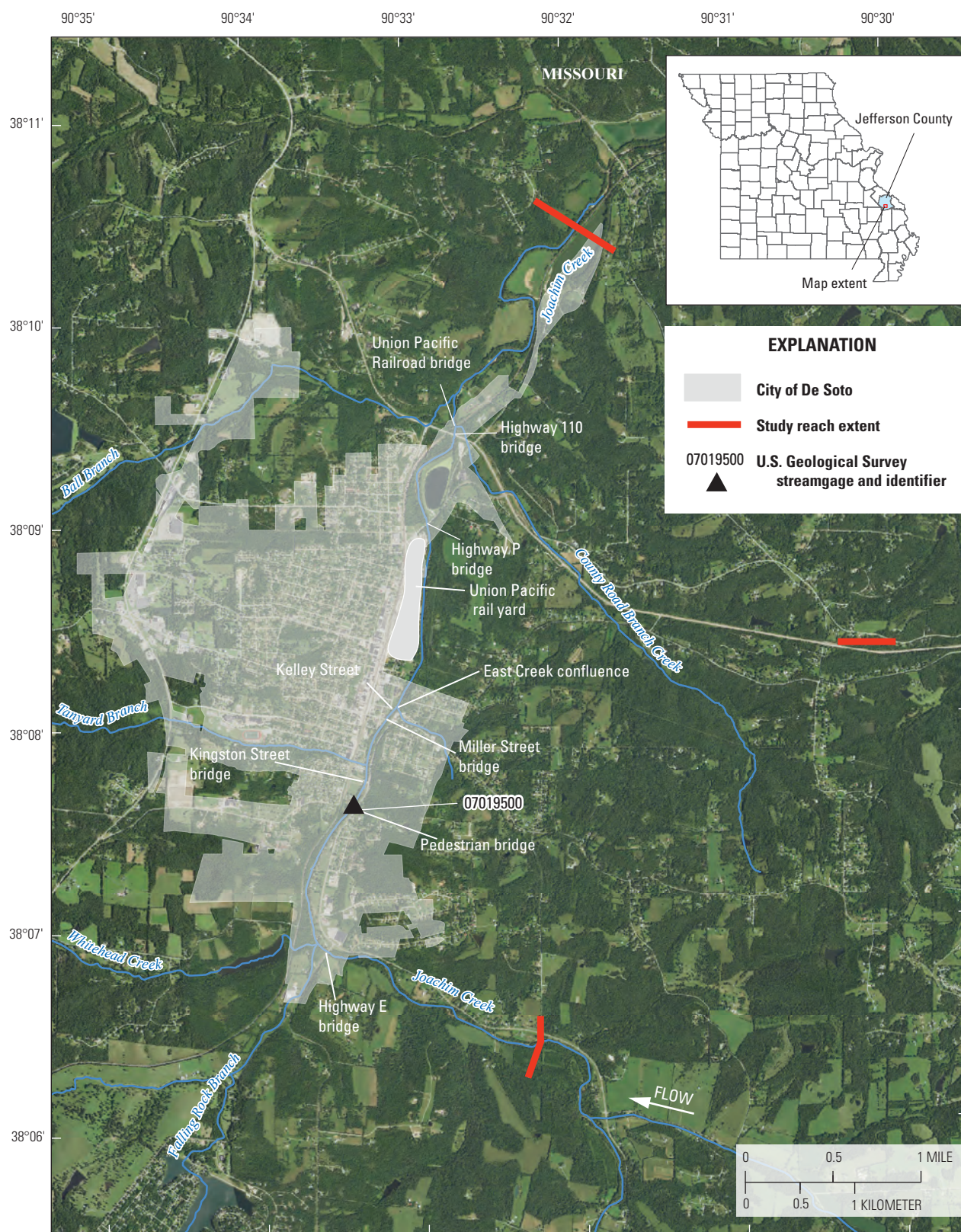
Figure 1.   Location of the study reach, flow-change locations used in the two-dimensional hydraulic model, and location of the cooperative U.S. Geological Survey streamgage Joachim Creek at De Soto, Missouri (station 07019500).

Purpose and Scope

The purpose of this report is to describe the development of a series of flood water-surface profiles, and maps of hydraulic characteristics, for selected regulatory flows for a reach of Joachim Creek in De Soto. Results from the simulation of the 1- and 0.2-percent AEP flows are used to assess the effects of flooding on selected structures within the city of De Soto. The techniques and hydrologic input data used in this study, and the corresponding results, were generated as an alternative and independent interpretation to the probabilistic streamflows and simulated consequences of these flows from results provided by the most recently published FIS (Federal Emergency Management Agency, 2019b). The profiles and maps were produced for flows corresponding to the 10-, 4-, 2-, 1-, and 0.2-percent AEPs and corresponding water levels referenced to the stage recorded at the USGS streamgage Joachim Creek at De Soto (station 07019500; table 1); the streamgage is about 2.4 mi downstream from the upstream extent of the study reach (fig. 1). The products from this study cover a range in stage from 10.57 to 17.53 feet (ft), referenced to the streamgage datum, and correspond to a range from about the National Weather Service flood stage of 10 ft to 4.53 ft greater than the major flood stage of 13 ft.

Study Area Description

The Joachim Creek study reach is in Jefferson County in east-central Missouri and is mostly within the city limits of De Soto (fig. 1). The 6.7-mi study reach extends from 1.3 mi upstream from the De Soto, Mo., city boundary downstream to the approximate downstream boundary of De Soto (fig. 1). The drainage area upstream from the USGS streamgage at De Soto is 42.4 square miles (mi^2), and the drainage area at the downstream extent of the study reach is 60.8 mi^2. The Joachim Creek Basin is in the Ozark Plateau physiographic region (Fenneman, 1938). Land slopes in the basin are generally 3 to 10 percent with local relief of 300 to 400 ft (Collier, 1955). The primary land cover of the study basin is forest (69.8 percent), followed by pasture and grasslands (17.3 percent) and open/barren land (7.3 percent), based on the 2016 National Land Cover Database (Jin and others, 2019). Less than 5 percent of the basin is classified as low- to high-intensity development. The study reach has an average top-of-bank width of 90.0 ft and an average slope of 11.4 feet per mile based on channel cross-section data obtained from a hydraulic model of Joachim Creek (Alicia Williams, Wood Environment and Infrastructure Solutions, written commun., 2018). Minor tributaries within the reach include (from upstream to downstream) Falling Rock Branch, Whitehead Creek, Tanyard Branch, East Creek, County Road Branch, and Ball Branch (fig. 1). Most of the land contiguous to the reach within the city limits is residential or commercial. Outside of the city limits, the land use primarily is forest and pasture. There are 7 bridge crossings in the main-stem reach, which include 1 railroad, 3 State highways, and 3 county/city road crossings.

Previous Studies

The most recently published FIS for the study area, including De Soto (Federal Emergency Management Agency, 2019b), presents estimates of the peak streamflows and associated AEPs and their associated water-surface elevations at several locations along Joachim Creek. A nonregulatory study also was previously completed to represent 1-ft incremental flood-inundation maps for the 6.7-mi study reach of Joachim Creek (Heimann and others, 2019) for stages at the USGS streamgage of 8.0 to 17.0 ft. The 8.0-ft stage corresponds to the National Weather Service "action stage" or near-bankfull stage, and the 17.0-ft stage approximates the stage corresponding to the 0.2-percent AEP flow. Flood profiles were computed for the river reach by means of a one-dimensional (1D) step-backwater model.

Table 1.   U.S. Geological Survey streamgage information for Joachim Creek at De Soto, Missouri.

[Station location is shown in figure 1. USGS, U.S. Geological Survey; mi^2, square mile; ft, foot; NAVD 88, North American Vertical Datum of 1988; ft³/s, cubic foot per second; °, degree; ′, minute; ″, second]

Station name	USGS station number	Drainage area (mi^2)	Latitude	Longitude	Period of peak-flow record (water years[1])	Maximum recorded stage (ft), streamgage datum and elevation (ft above NAVD 88), and date	Maximum streamflow (ft³/s) and date
Joachim Creek at De Soto, Missouri	07019500	42.4	38°07′36″	90°33′23″	2018–19	[2]14.3 (506.2) April 18, 2013	[3]15,000 April 18, 2013

[1]A water year is the 12-month period from October 1 of one year through September 30 of the following year and is designated by the calendar year in which it ends.

[2]Stage interpolated from observed high-water marks.

[3]Streamflow estimated using hydraulic model and observed high-water marks.

The hydrologic and hydraulic analyses for the previous FIS for Jefferson County, Mo. (Federal Emergency Management Agency, 2006), included a hydraulic analysis for Joachim Creek in De Soto, which was completed by the U.S. Army Corps of Engineers (USACE), St. Louis District, in August 2002 (Federal Emergency Management Agency, 2002). An additional FIS for De Soto was completed in 1981 by Booker Associates, Inc. (Federal Emergency Management Agency, 1981), and revised by the Federal Emergency Management Agency in 1998 (Federal Emergency Management Agency, 2006).

Development of Hydraulic Model

Tasks specific to the development of the two-dimensional hydraulic model, flood profiles, map products, and structure analyses for a reach of Joachim Creek near De Soto were as follows:

1. compilation of flow data from USGS streamgage Joachim Creek at De Soto (station 07019500);

2. collection and compilation of topographic and bathymetric data and geometric data for structures and bridges along the study reach;

3. estimation of energy-loss factors (material properties or roughness coefficients) in the stream channel and floodplain;

4. computation of water-surface elevations by use of the Sedimentation and River Hydraulics—Two-Dimensions river flow model (SRH–2D; Bureau of Reclamation, 2008);

5. production of estimated water-surface profiles and maps of flood inundation, water depths, and velocities for selected regulatory flows; and

6. assessment of the effects of the 1- and 0.2-percent AEP flows on selected structures within the city of De Soto.

Computation of Water-Surface Elevations

The water-surface elevations used to produce the flood products in this study were simulated using SRH–2D, version 3.2.3 (Bureau of Reclamation, 2008). SRH–2D is a two-dimensional, finite-volume numerical model for simulating flow hydraulics. It features a seamless wetting-drying algorithm that provides stability, has flexibility in mesh design and shape, and can simulate steady or unsteady flows in subcritical and critical flow regimes. The graphical user interface

Surface-water Modeling System (SMS), version 13.0.14 (Aquaveo, 2020), was used to develop model components, select model inputs, and evaluate the model results.

Hydrologic Data

The study reach includes one active USGS streamgage (Joachim Creek at De Soto, station 07019500; fig. 1, table 1), which began operation on July 17, 2018. Stage at the streamgage is measured every 5 minutes, transmitted every 15 minutes by a satellite radio in the streamgage, and made available on the internet through the USGS National Water Information System database (U.S. Geological Survey, 2020c). Stage data from this streamgage are referenced to a local datum but can be converted to water-surface elevations referenced to the North American Vertical Datum of 1988 by adding 491.90 ft. Continuous records of streamflow at the Joachim Creek streamgage are computed from a stage-streamflow relation (Turnipseed and Sauer, 2010), which has been developed for the streamgage, and are available through the USGS National Water Information System database (U.S. Geological Survey, 2020b).

The available annual peak-flow record at this station is less than the 10-year minimum record period required for the development of site-specific flood-frequency analysis (England and others, 2018). The peak flows used in this study, therefore, were determined using the USGS StreamStats application (U.S. Geological Survey, 2020a; table 2). The peak-flow component of StreamStats for Missouri was developed using regression analysis techniques, data from 278 streamgages (fig. 2), and annual peak-flow record through 2012 (Southard and Veilleux, 2014). Joachim Creek lies within the specified Ozark Plateau hydrologic region of Missouri, and flood-frequency regression equations for this region were developed using record from 135 streamgages. For the Ozark Plateau (region 2 in Southard and Veilleux [2014]), the basin characteristics determined to be statistically significant determinants of peak flows were drainage area and basin shape (squared distance of longest flow path divided by drainage area). The range of drainage areas used in the region 2 regression equations was from 0.17 to 4,008 mi², and the range of basin shape values was from 2.04 to 26.89. The range of these conditions for the Joachim Creek reach (drainage area of 41.1 to 58.8 mi²; basin shape of 3.24 to 4.17 [table 2]) was within the range of basin characteristics used in generating the regression equations for this region. The resulting streamflow estimates computed with the regression equations have a quantifiable uncertainty determined by the standard error of prediction and expressed by the 90-percent prediction interval (see example in table 3). The model flow-change locations developed for this study (table 2) are consistent with those used in the FIS (Federal Emergency Management Agency, 2019b).

Table 2. Model flow-change locations and corresponding input streamflows for 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probabilities for the Joachim Creek study reach, De Soto, Missouri, as determined using the U.S. Geological Survey StreamStats application. Note: flow locations correspond to those used in the Federal Emergency Management Agency (2019b) flood-insurance study.

[mi^2, square mile; ft^3/s, cubic foot per second; RR, Railroad]

Location (fig. 1)	Drainage area (mi^2)	Basin shape	Annual exceedance probability streamflow (ft^3/s)				
			10 percent	4 percent	2 percent	1 percent	0.2 percent
Highway E (used as flow for upstream model boundary)	41.1	3.24	8,110	11,300	13,700	16,100	21,900
Kelley Street	45.5	3.73	8,370	11,600	14,100	16,500	22,400
Union Pacific RR bridge	52.5	4.17	8,950	12,400	15,000	17,600	23,800
Downstream from Ball Branch confluence	58.8	3.83	9,880	13,700	16,600	19,500	26,400

Table 3. Example of lower and upper 90-percent prediction limits of uncertainty in streamflow estimates determined for the Joachim Creek study reach, De Soto, Missouri, using rural-regression equations developed by Southard and Veilleux (2014).

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

Location (fig. 1)	Annual exceedance probability streamflow (ft^3/s)				
	10 percent	4 percent	2 percent	1 percent	0.2 percent
Kelley Street	8,370	11,600	14,100	16,500	22,400
Kelley Street (lower prediction interval)	5,290	7,840	9,500	11,100	14,400
Kelley Street (upper prediction interval)	13,200	17,200	20,900	24,600	34,800

Because no current or historical streamgages within the Joachim Creek Basin were used in the development of the flood-frequency regression equations, an analysis of at-site derived flood-frequency flows from selected streamgages in the region (Heimann and Hix, 2021) was used to verify the application of the regression equations to this basin. A comparison of station-derived and regression equation-derived estimates of the 1-percent AEP flow for region 2 indicated strong agreement (fig. 3) and included selected basins near (within a two-county radius) Jefferson County and De Soto (fig. 2).

One means of normalizing estimates of peak streamflows for comparisons is by determining basin yields, computed as flow in cubic feet per second divided by drainage area in square miles. Unregulated basins of the same drainage area and within the same hydrologic response region should, in general, have similar yields. The peak-flow basin yield, in cubic feet per second per square mile, was determined for the 1-percent AEP streamflows generated from StreamStats for selected locations in the study reach (table 4). An initial assessment of at-site estimates of peak-flow yields for 1-percent AEP flows at stations within region 2 with similar drainage areas indicates a sizable range in yields (table 5), but Joachim Creek estimated yields (table 4) generally were within the determined range.

Basin yields also were determined from 1-percent AEP flows using at-site analyses (Southard and Veilleux, 2014) for selected stations in region 2 that were near the Joachim Creek Basin (fig. 2, table 6). A relation between drainage area and peak-flow basin yield using data from these 29 nearby stations was developed to compare yields developed using StreamStats with yields developed from at-site flood-frequency analyses (fig. 4). Stations selected for this analysis included a range of drainage areas (0.22 to 3,788 mi^2) such that the relation derived from the yields of the peak-flow estimates could be compared to the range of drainage areas corresponding to the selected locations in the Joachim Creek Basin. The relation between drainage area and peak-flow yield was used to estimate yields for the range of drainage areas within the Joachim Creek study reach (41.1 to 58.8 mi^2; table 7). The peak-streamflow yields from the StreamStats estimates for five locations in the Joachim Creek Basin were 391.7 to 331.6 cubic feet per second per square mile ([ft^3/s]/mi^2) corresponding to drainage areas of 41.1 to 58.8 mi^2 (table 4). Basin yields for drainage areas corresponding to the selected study reach locations and computed using the 2012 station-based relations were 272.8 to 310.0 (ft^3/s)/mi^2; a −15.2- to −20.8-percent difference from the StreamStats estimates.
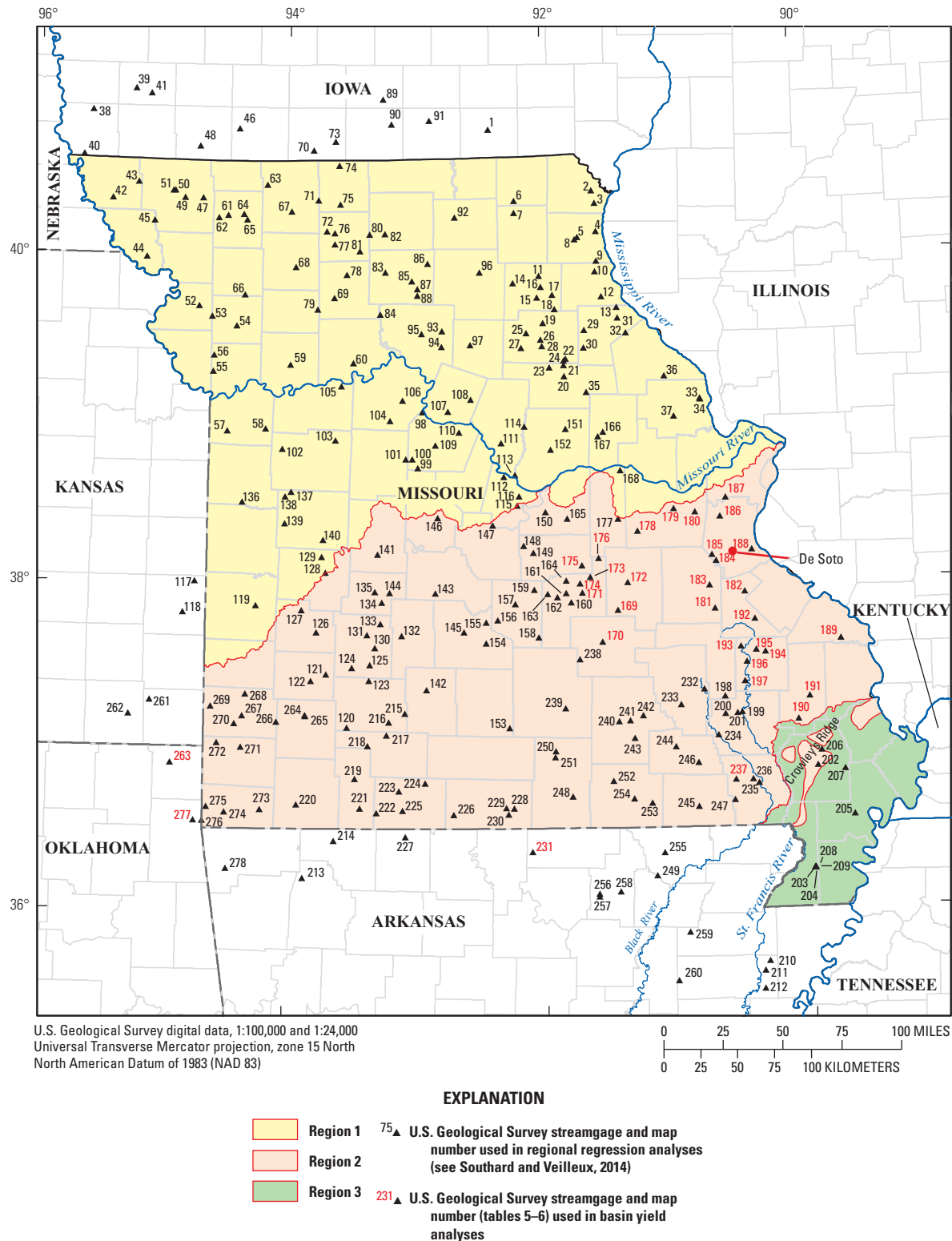
Figure 2. Location of streamgages used in the development of rural-regression equations including selected streamgages near De Soto, Missouri, and hydrologic region boundaries in Missouri and neighboring States of Missouri (modified from Southard and Veilleux, 2014).
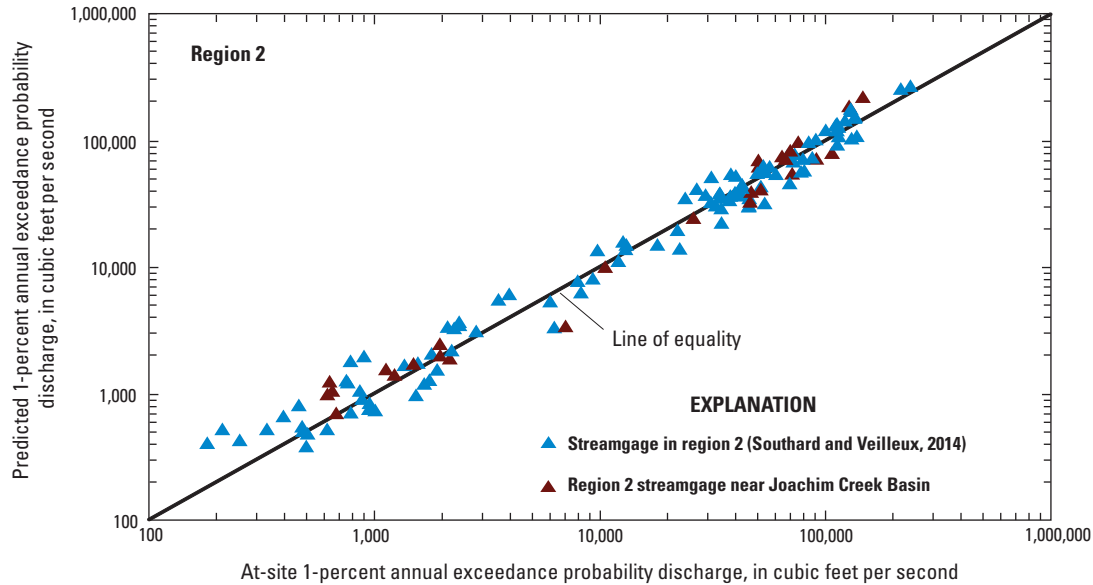
Figure 3. Relation between 1-percent annual exceedance probability streamflows computed from at-site streamflow analyses and those predicted from generalized-least squares regression equations for hydrologic region 2 (Ozark Plateau) in Missouri, including basins near Joachim Creek.

Table 4. Basin yields for 1-percent annual exceedance probability peak streamflows calculated from U.S. Geological Survey StreamStats peak-flow estimates at selected locations along Joachim Creek, De Soto, Missouri.

[mi^2, square mile; ft^3/s, cubic foot per second; (ft^3/s)/mi^2, cubic foot per second per square mile; RR, Railroad]

Location	Drainage area (mi^2)	StreamStats peak-flow estimate (ft^3/s)	StreamStats estimate yield ([ft^3/s]/mi^2)	StreamStats lower prediction interval yield ([ft^3/s]/mi^2)	StreamStats upper prediction interval yield ([ft^3/s]/mi^2)
Highway E	41.1	16,100	391.7	262.7	583.9
Pedestrian bridge	42.4	16,100	379.7	254.7	563.7
Kelley Street	45.5	16,500	362.6	244.0	540.6
Union Pacific RR bridge	52.5	17,600	335.2	226.7	497.1
Ball Branch confluence	58.8	19,500	331.6	222.8	493.2

Table 5. Basin yields for 1-percent annual exceedance probability peak streamflows for stations within hydrologic response region 2 (Southard and Veilleux, 2014) with drainage areas comparable to those in the Joachim Creek study reach, De Soto, Missouri.

[ID, identifier; USGS, U.S. Geological Survey; mi^2, square mile; AEP, annual exceedance probability; ft^3/s, cubic foot per second; (ft^3/s)/mi^2, cubic foot per second per square mile]

Map ID	USGS station number	Station name	Drainage area (mi^2)	At-site 1-percent AEP peak-flow estimate (ft^3/s)	Peak-flow yield ([ft^3/s]/mi^2)
192	07033000	Wolf Creek near Farmington, Missouri	40.3	12,700	315.1
231	07059450	Big Creek near Elizabeth, Arkansas	51.9	9,800	188.8
237	07063470	Tenmile Creek near Poplar Bluff, Missouri	59.0	22,600	383.0
263	07185095	Tar Creek at 22nd Street Bridge at Miami, Oklahoma	44.7	13,100	293.1
277	07189542	Honey Creek near South West City, Missouri	48.2	18,000	373.4

Table 6.   Station (expected moments algorithm) and rural-regression 1-percent annual exceedance probability flows for selected stations near the Joachim Creek Basin, De Soto, Missouri.

[mi², square mile; EMA/MGB, expected moments algorithm with multiple Grubb-Beck low outlier test estimates; RRE, rural-regression equation estimates; ft³/s, cubic foot per second; (ft³/s)/mi², cubic foot per second per square mile; --, no data or not applicable]

Map ID (fig. 2)	Drainage area (mi²)	Station	1-percent annual exceedance probability discharge, in cubic feet per second				RRE flow (ft³/s)
			[1]Through 2012		Through 2019		
			EMA/MGB flow (ft³/s)	Yield, ([ft³/s]/mi²)	EMA/MGB flow (ft³/s)	Yield ([ft³/s]/mi²)	
169	199	07010350	42,400	213	47,200	237	36,800
170	0.89	07011200	633	711	--	--	1,240
171	1.05	07012000	1,670	1,590	--	--	1,190
172	781	07013000	69,200	88.6	72,200	92.5	75,200
173	21.3	07015000	12,100	568	--	--	11,200
174	0.22	07015500	212	964	--	--	521
175	24.1	07015700	10,600	440	--	--	10,000
176	135	07015720	46,200	342	47,700	353	35,100
177	0.64	07015800	652	1,020	--	--	1,050
178	608	07016000	50,600	83.2	--	--	69,900
179	808	07016500	50,800	62.9	55,000	68.1	62,300
180	2,673	07017000	131,000	49.0	--	--	171,000
181	175	07017200	52,000	297	54,100	309	43,500
182	3.35	07017500	1,960	585	--	--	2,460
183	2.16	07017700	1,960	907	--	--	2,000
184	718	07018000	73,500	102	--	--	78,000
185	735	07018100	68,200	92.8	[2]74,700	102	76,800
186	917	07018500	64,500	70.3	--	--	75,200
187	3,788	07019000	147,000	38.8	159,000	42.0	221,000
188	0.44	07019820	678	1,540	--	--	698
189	1.66	07020700	2,160	1,300	--	--	1,890
190	423	07021000	71,500	169	[2]78,700	186	54,800
191	0.52	07021200	619	1,190	--	--	983
192	40.3	07033000	12,700	315	--	--	15,900
193	234	07034000	47,100	201	--	--	39,300
194	90.5	07033500	26,100	288	--	--	24,500
195	4.03	07035500	7,070	1,750	--	--	3,410
196	505	07035800	91,700	182	[2]93,400	185	71,800
197	664	07036100	108,000	163	[2]115,000	173	79,900

[1]Data from Southard and Veilleux (2014).

[2]Estimated using peak streamflow data through 2017.

Stations used in Southard and Veilleux (2014) had at least 10 years of record, and stations used in this analysis had an average of 38 years of record through 2012. Record flooding has occurred in east-central Missouri since 2012 and within the hydrologic region of interest, record flooding has occurred in 2015 (Holmes and others, 2016) and 2017 (Heimann and others, 2018). The annual peak streamflows from these flood years could substantially affect the flood-frequency estimates and, therefore, calculated peak-flow yields. To maximize the accuracy of the station flood-frequency estimates for this study, and to determine the potential effect of recent floods on flood-frequency estimates, the flood-frequency flows for the 29 stations used in figure 4A were updated using available record through 2019 (table 6). The station-determined flood-frequency and basin yield estimates were computed using USGS PeakFQ software,

Table 7.   Basin yields for 1-percent annual exceedance probability peak streamflows at selected locations along Joachim Creek, De Soto, Missouri, calculated from flood-frequency analyses from nearest stations (with peak record greater than 10 years) using record through 2012 and 2019.

[mi^2, square mile; (ft^3/s)/mi^2, cubic foot per second per square mile; ft, foot; RR, Railroad]

Location	Drainage area (mi^2)	Estimated yield using peak-flow record through 2012 ([ft^3/s]/mi^2)	Estimated yield using peak-flow record through 2019 ([ft^3/s]/mi^2)
Highway E (500 ft downstream)	41.1	310.0	316.8
Pedestrian bridge	42.4	306.6	313.4
Kelley Street	45.5	299.0	305.7
Union Pacific RR bridge	52.5	284.1	290.7
Downstream from Ball Branch confluence	58.8	272.8	279.4

version 7.3 (Flynn and others, 2006), with a regional skew estimate of −0.30 for Missouri (Southard and Veilleux, 2014). If no peak-flow record existed past 2012 at a station, the 2012 estimate was again included in the 2019 analysis. The updated peak-flow estimates were used to develop a second relation between drainage area and basin yield and to determine updated yield estimates for drainages corresponding to the selected locations within the Joachim Creek Basin (fig. 4B, table 7). Basin yields for drainage areas corresponding to the selected study reach locations computed using station record through 2019 were 279.4 to 316.8 (ft^3/s)/mi^2; a −13.2- to −19.1-percent difference from the StreamStats estimates. The overall results indicate that the StreamStats utility using regional regression analyses through 2012 (and updated through 2019 at selected locations) provides a conservatively high estimate of peak streamflows and basin yields compared to nearby station-derived flood-frequency estimates using long-term (average of 66 years) peak-flow record. The differences between yield estimates using nearby at-site station analyses and those determined from StreamStats were well within the prediction interval ranges of the StreamStats yields (table 4). The StreamStats-derived peak-flow values were used in the hydraulic model, as discussed in the following sections.

Topographic and Bathymetric Data

Cross-section elevation data were obtained from a digital elevation model (DEM) that was derived from light detection and ranging (lidar) data that were collected during December 2010 by Surdex Corporation, Chesterfield, Mo., through a contract with the USACE, St. Louis Division. The data were postprocessed by Surdex Corporation on April 6, 2011 (Missouri Spatial Data Information Service, 2019a). The bare-earth lidar data were processed using USGS Base Lidar Specifications, version 1.3 (Heidemann, 2018), that met or exceeded the National Map Accuracy Standards for vertical and horizontal accuracy guidelines for 2-ft contours (American Society for Photogrammetry and Remote Sensing,

1990, 2004). The lidar data have a horizontal accuracy of a 1.97-ft (60-centimeter) root mean squared error and a vertical accuracy of a 0.607-ft (18.5-centimeter) root mean squared error.

The final DEM, which was resampled to a 3.28-ft grid-cell size to decrease the geographic information system processing time, has a vertical accuracy of plus or minus 1 ft. Any development or landscape modifications within the Joachim Creek floodplain that took place after the lidar was flown (December 2010) and that could result in substantial topographic and hydraulic changes to the floodplain were considered for inclusion in the DEM. For example, modifications within the Union Pacific rail yard in De Soto (fig. 1) and at locations of selected nonstructural assets were surveyed and incorporated into the DEM and interpolated onto the model mesh. The lidar-derived DEM was supplemented with field data from the rail yard and structures. The field data were collected by a modified Level II Global Navigation Satellite Systems survey (Rydlund and Densmore, 2012) along the profile of a berm on the south end of the Union Pacific rail yard and at 231 structures within De Soto. The highest adjacent grade and lowest adjacent grade (highest and lowest elevation of ground adjacent to structure) were collected for each structure. The grade values of the 231 structures and surveyed points from the rail yard berm were merged into the final DEM.

Lidar data typically cannot provide ground elevations below the water surface of a stream; therefore, channel bottom elevations also were incorporated into the DEM from channel surveys. Channel surveys of Joachim Creek, corresponding to cross-section locations in the USACE Hydrologic Engineering Center River Analysis System (HEC–RAS) model used in a previous flood-inundation mapping study (Heimann and others, 2019), were surveyed by Wood Environment and Infrastructure Solutions during 2015 (Alicia Williams, Wood Environment and Infrastructure Solutions, written commun., 2018) and spot verified by USGS field crews during 2018. The channel elevations were measured by wading at selected HEC–RAS model transect locations. A differential global
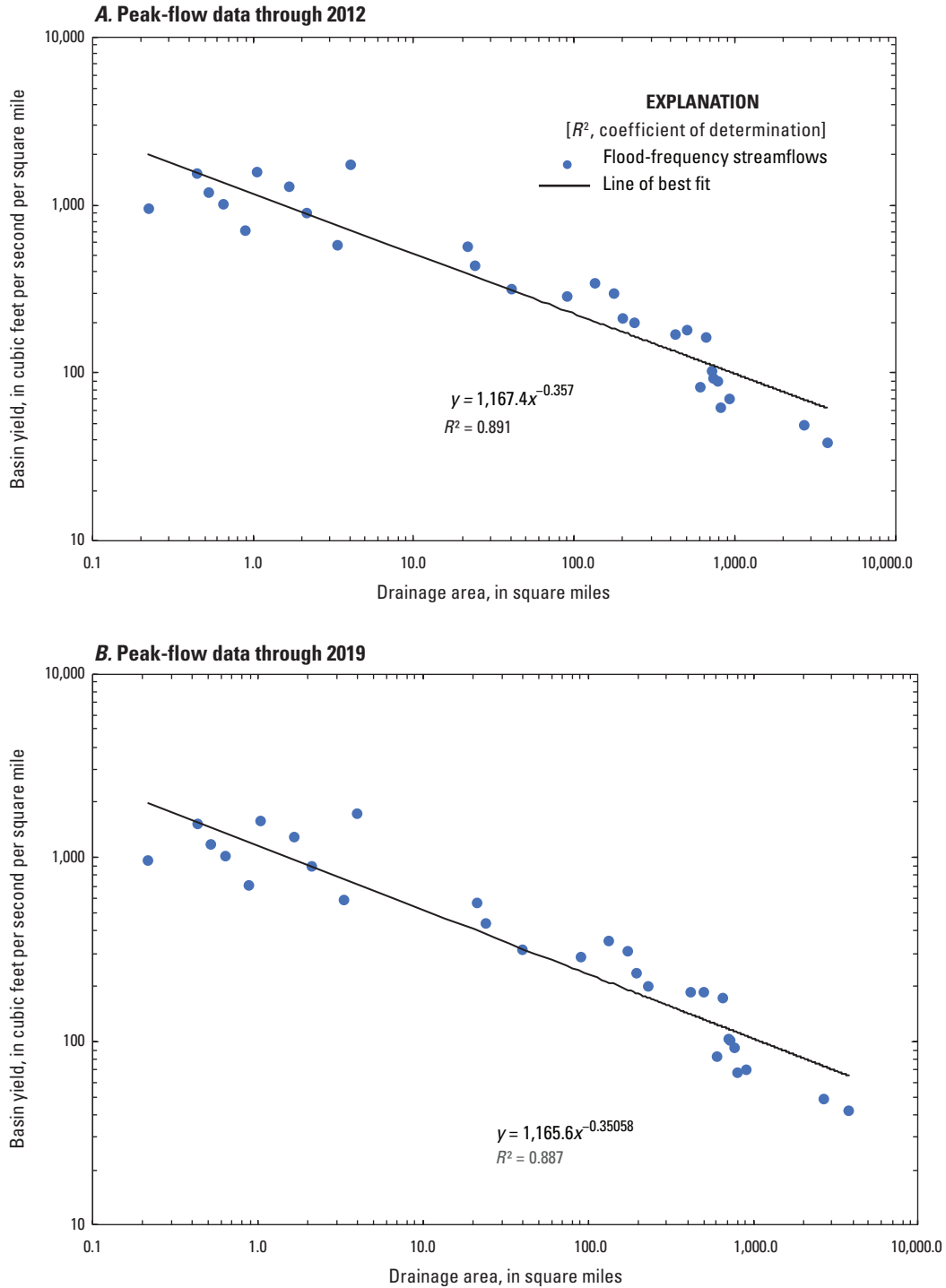
Figure 4.   Relation between drainage area and basin yield determined using 1-percent annual exceedance probability streamflows computed from at-site flood-frequency analyses at stations nearest the Joachim Creek Basin, De Soto, Missouri. *A*, for peak-flow record through 2012; *B*, for peak-flow record through 2019.

positioning system with real-time kinematic technology was used to derive horizontal locations and the elevation of the water surface and channel bottom at surveyed points.

Hydraulic Structures

A total of 7 structures, consisting of 6 road crossings (3 county road bridges and 3 State highway bridges) and 1 railroad bridge, have the potential to affect water-surface elevations during floods along the stream. Bridge-geometry data were obtained from a HEC–RAS model developed by Wood Environment and Infrastructure Solutions (Alicia Williams, Wood Environment and Infrastructure Solutions, written commun., 2018) and from as-built bridge plans. The bridge-geometry data were verified by field surveys in 2018 and 2020 by personnel from the USGS Central Midwest Water Science Center. Bridge piers were modeled as flow obstructions in SRH–2D; that is, as a hole in the mesh corresponding to the location, dimensions, and orientation of the pier. The culverts throughout the study area were modeled as bridge structures with pressure flow boundaries using the geometry data from the HEC–RAS model developed by Wood Environment and Infrastructure Solutions (Alicia Williams, Wood Environment and Infrastructure Solutions, written commun., 2018). The DEM resolution generated from lidar data was high enough to accurately capture the roadway embankments and levee elevations, and the computational mesh was created to align with the top of these features.

Energy-Loss Factors

Hydraulic analyses require the estimation of energy losses that result from frictional resistance exerted by a channel on flow. These energy losses are quantified by the Manning's roughness coefficient (n-value). Initial (precalibration) n-values were selected using field observations, high-resolution aerial photographs (Missouri Spatial Data Information Service, 2019b), and tabulated estimates of n-values (Chow, 1959; Arcement and Schneider, 1989). As part of the general calibration process, the initial n-values were adjusted until the differences between simulated and observed water-surface elevations at the streamgage and elsewhere along the study reach were minimized. The final n-values ranged from 0.015 to 0.045 for the main channel and from 0.05 to 0.12 for the overbank areas modeled in this analysis. The lowest channel coefficients were placed in straight bedrock-lined reaches, and the highest were placed in low-gradient, fine-material substrate reaches with vegetated banks. The lowest floodplain coefficients were placed in open fields and the highest in densely forested areas. An n-value of 0.05 was selected for grassland areas, and an n-value of 0.09 was selected for forests and agricultural areas. The developed areas ranged from open space to high-intensity development and n-values from 0.08 to 0.12 were selected, respectively.

The calibration process involved adjusting initial n-values such that the difference between the computed water-surface elevation and the observed water-surface elevation was minimized. A stage-streamflow relation is still in development for the De Soto streamgage, and the in-channel values were calibrated to the highest flow measurement at the streamgage. A flow of 5,400 cubic feet per second (ft^3/s) was measured at USGS streamgage Joachim Creek at De Soto (station 07019500) on September 8, 2018, and is the highest flow measurement made with flows contained within the channel. A constant flow was used in the calibration given the lack of a rating and the midreach location of the measurement. The n-values were adjusted such that the water surface at the streamgage site matched the observed water surface for the streamflow. The calibration of the overbank material properties followed a similar process. The overbank n-values were calibrated to the April 18, 2013, flood event. The overbank condition calibration was completed using an estimated constant streamflow of 15,000 ft^3/s, consistent with the 1D model calibration in Heimann and others (2018), and high-water marks collected along the length of the study reach. The estimated constant flow of 15,000 ft^3/s was determined from "splitting" the high-water marks during the 1D calibration. The modification of n-values during the calibration process for the in-channel and overbank components was repeated until all the simulated and observed values at the marks were within 0.5 ft.

Hydraulic Model

Hydraulic analyses were completed using the two-dimensional model SRH–2D, version 3.2.3 (Bureau of Reclamation, 2008), in steady-state flow conditions (constant streamflows). The computational mesh consisted of 45,364 nodes (points) that were connected to form 75,758 elements (cells). Elements in the channel and on man-made structures primarily were quadrilateral in shape and aligned such that the structures were well represented. Elements in the floodplain and remaining upland areas were triangular. The downstream boundary condition for each simulation was the normal-depth water surface determined within the preprocessing and model development software SMS, version 13.0.14. The upstream boundary condition was the constant peak streamflows for the given event. The flows used for each event and flow-change locations were discussed in the "Hydrologic Data" section and provided in table 2.

The SRH–2D model was calibrated to the highest stage-streamflow measurements made at the USGS streamgage Joachim Creek at De Soto (station 07019500) and to high-water marks from the April 18, 2013, flood. The computed water surface for the in-channel flow calibration, corresponding to the highest stage-streamflow measurement at the streamgage, was within 0.36 ft of the observed water surface (table 8). For the April 18, 2013, flood, the average difference between the computed water surface and observed water

Table 8.   Calibration of model to target in-channel water-surface elevation at the U.S. Geological Survey streamgage Joachim Creek at De Soto, Missouri (station 07019500), and to selected locations along Joachim Creek for the flood of April 18, 2013.

[ft, foot; ft³/s, cubic foot per second; USGS, U.S. Geological Survey; HWM, high-water mark]

Location (distance from upstream boundary, ft)	Latitude (decimal degrees)	Longitude (decimal degrees)	Observed water-surface elevation (ft)	Simulated water-surface elevation (ft)	Difference between observed and simulated water surfaces (ft)
In-channel calibration to maximum measured streamflow of 5,400 ft³/s on September 8, 2018					
USGS streamgage	38.12688	−90.5566	499.90	500.26	0.36
April 18, 2013, flood peak of 15,000 ft³/s					
HWM 1 (5,059)	38.11236	−90.5526	527.56	527.71	0.15
HWM 2 (12,618)	38.12681	−90.5572	507.77	507.43	−0.34
HWM 3 (15,035)	38.13274	−90.5555	501.96	501.48	−0.48
HWM 4 (15,546)	38.13378	−90.5540	501.03	501.29	0.26
HWM 5 (16,861)	38.13705	−90.5527	496.85	496.90	0.05
HWM 6 (23,970)	38.15473	−90.5501	481.76	481.99	0.23

surface at the high-water marks was −0.02 ft and ranged from −0.48 to 0.26 ft. The calibration results indicate that the model accurately computes water-surface elevations for a wide range of flows.

Development of Water-Surface Elevations

The calibrated hydraulic model was used to generate water-surface profiles for the 10-, 4-, 2-, 1-, and 0.2-percent AEP flows (table 2) corresponding to stages from 10.57 to 17.53 ft as referenced to the local datum of the Joachim Creek at De Soto streamgage. These stages correspond to elevations of 502.47 ft and 509.43 ft above the North American Vertical Datum of 1988, respectively. The regulatory flows were obtained using the USGS StreamStats application, as discussed in the "Hydrologic Data" section. Each regulatory flow included flow-change locations, which are provided in table 2. The streamflows at each location were considered constant for the steady-state model.

Model Sensitivity Analysis

The primary model parameter manipulated during calibration was material properties (*n*-value). To determine the sensitivity of the model to changes and uncertainties in material properties, the 1-percent AEP model with material properties set 10 percent higher and 10 percent lower than *n*-values used in the final calibration were run to quantify differences. The results from the 10-percent increase in material property *n*-values resulted in an average water-surface elevation change of −0.407 and a standard deviation of 0.135. A 10-percent decrease in material property values resulted in changes in water-surface elevations of 0.431 and a standard deviation of 0.169. The intent of the calibration process was to ensure that the material properties depicted in the model

correspond to the target water-surface elevations. Although the roughness coefficients of the current (2020) model simulations match the target water elevations, the results of the sensitivity analysis indicate that small changes in material properties into the future, including land-cover or structure changes, can result in substantial changes in localized water-surface elevations.

Development of Water-Surface Profiles and Map Products

Water-surface profiles and map products were created for a reach of Joachim Creek within, and near, the city of De Soto. The water-surface profiles for the 10-, 4-, 2-, 1-, and 0.2-percent AEP flows generated by SRH–2D were postprocessed and exported from SMS (figs. 5–9). Maps of flood water-surface elevations, velocity, and water depth also were generated for the 1- and 0.2-percent AEP flows using output from the SRH–2D model that was processed and exported through SMS (figs. 10–15). The presented water-surface elevation maps of the 1- (fig. 10) and 0.2-percent (fig. 13) AEP flows also include the corresponding spatial extents of mainstem inundation from the Federal Emergency Management Agency (2019a) study for comparison. The results indicate the water-surface elevation profiles and inundation extents from products of this study are substantially lower than those of the published FIS (Federal Emergency Management Agency, 2019b). The differences can be attributed to the magnitude of estimated input flows and the hydraulic modeling technique. The Federal Emergency Management Agency (2019b) simulations were completed using input hydrographs and peak streamflows generated from a USACE Hydrologic Engineering Center Hydrologic Modeling System rainfall-runoff model and simulated in HEC–RAS (1D) using an unsteady flow method to account for overbank storage. The
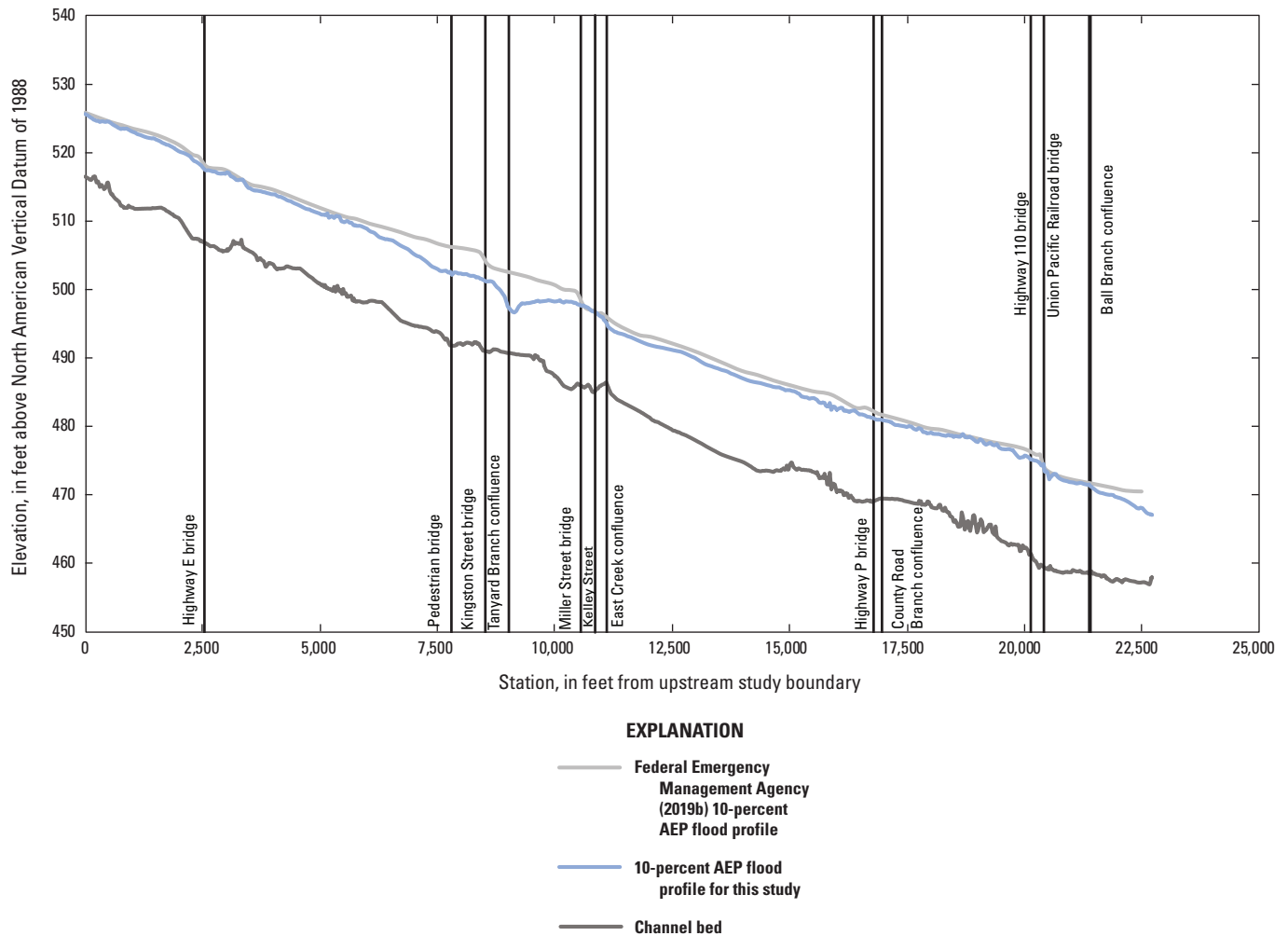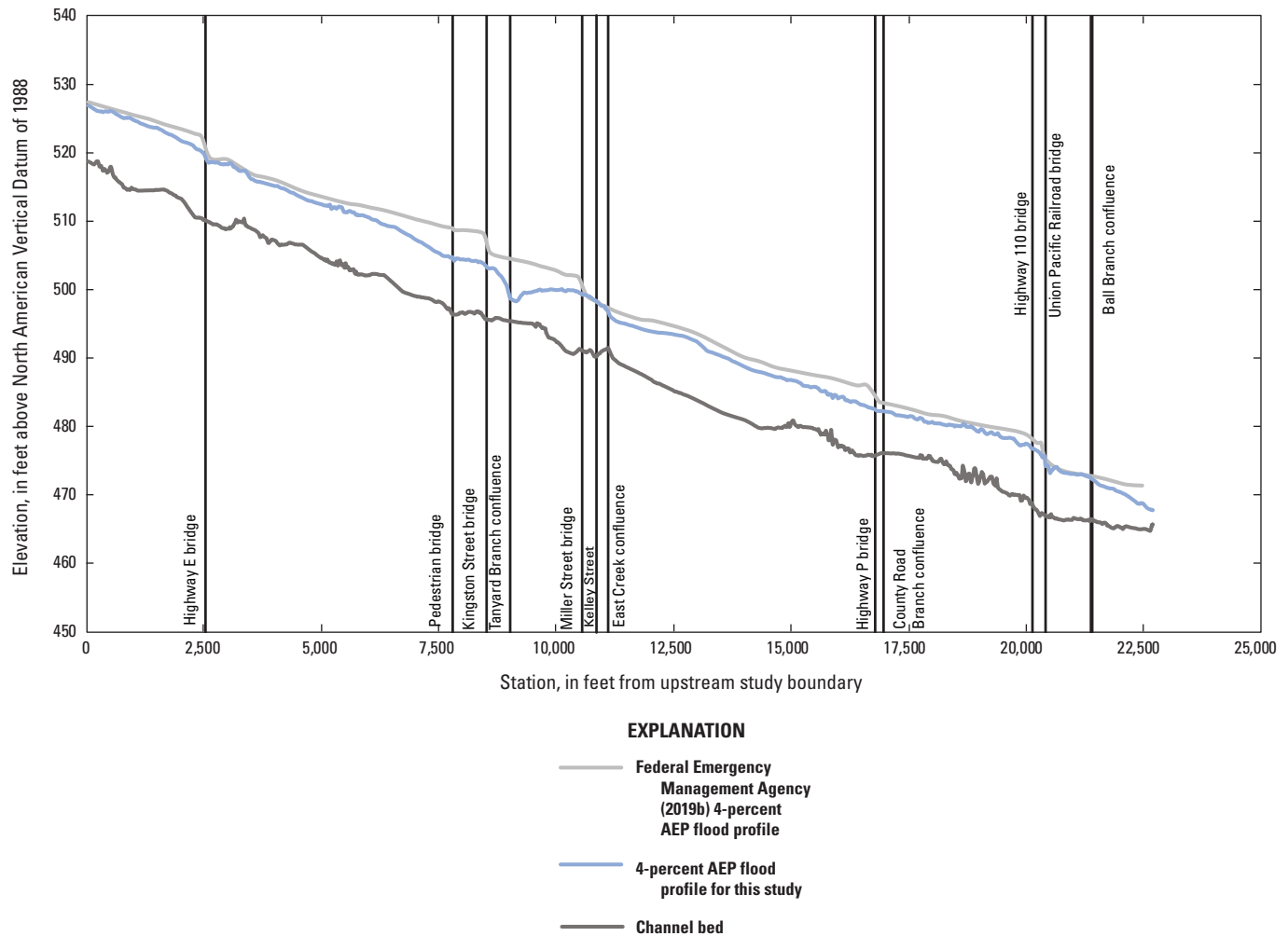
Figure 5. The 10-percent annual exceedance probability flood profile for the Joachim Creek study reach, De Soto, Missouri, from the Federal Emergency Management Agency (2019b) flood-insurance study and this study.

model input flows in this study (table 2) were generated from the USGS StreamStats utility and simulated with a steady-state two-dimensional model.

The DEM data used in developing the profiles and maps for this study were derived from the same lidar data described previously in the "Topographic and Bathymetric Data" section and, therefore, have an estimated vertical accuracy of 1 ft. Therefore, the resulting inundation maps have a vertical accuracy of about plus or minus 1.0 ft. Any inundated areas that were detached from the main channel were examined to identify subsurface connections with the main river, such as through culverts under roadways. Where such connections existed, the mapped inundated areas were retained in their respective flood maps; otherwise, the detached areas were erroneously delineated parts of the flood extent and were

deleted. Bridges and structures are shown as inundated in the maps regardless of the relative level of the water surface to the structure. The flood-inundation areas were overlaid on high-resolution, georeferenced aerial photographs of the study area.

The generated profiles and map products from this study are subject to some uncertainty as a result of the modeling process. The probabilistic flows used to compute flood extents were estimated using regional regression equations within the USGS StreamStats application. These equations are based on historical observed data and are subject to uncertainty because additional peak-flow record, climate trends, and changes in land-cover conditions can affect results. A quantitative description of the uncertainty in StreamStats flow estimates is provided in the prediction intervals (table 4). Although simulated
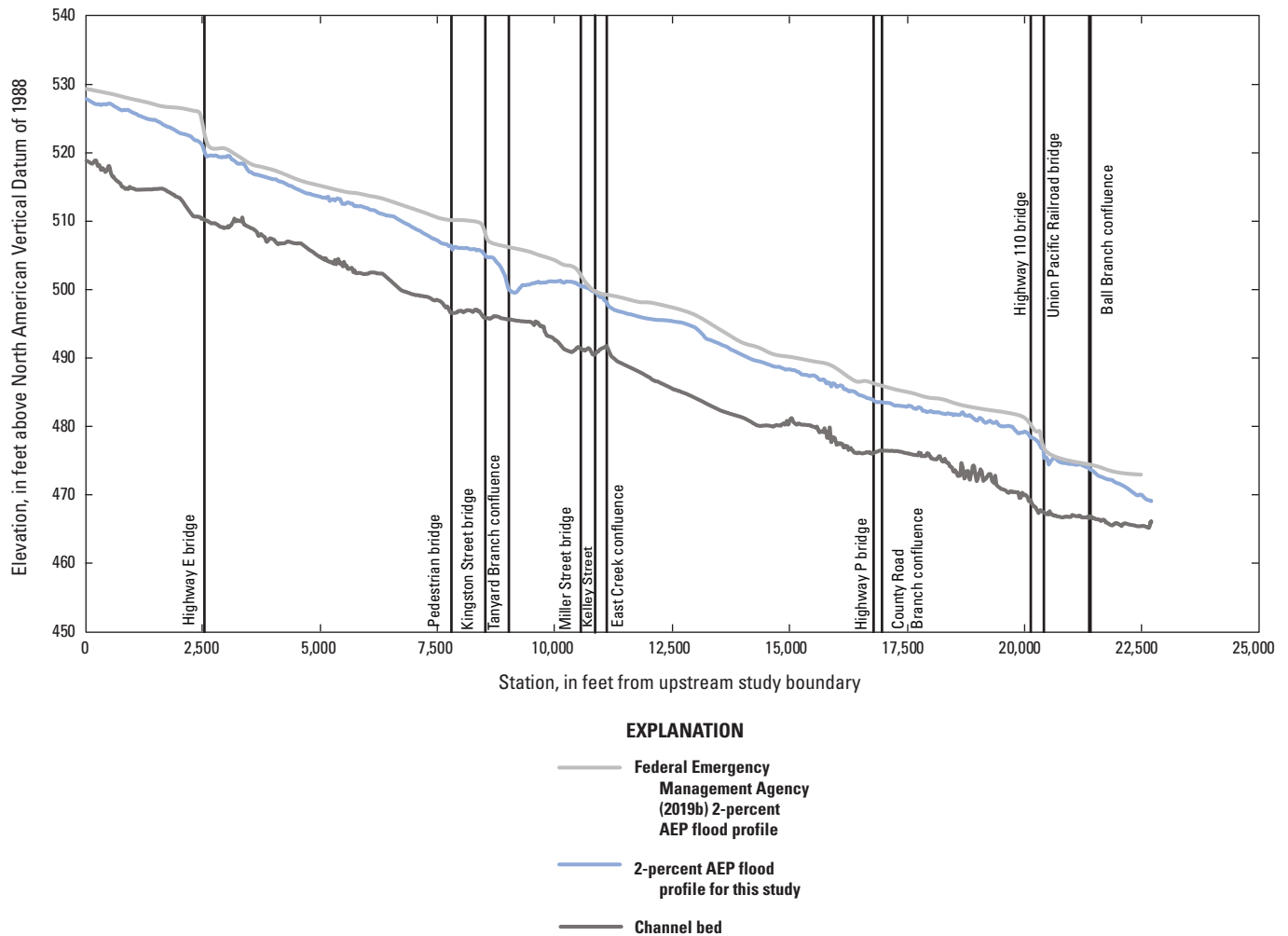
Figure 6.   The 4-percent annual exceedance probability flood profile for the Joachim Creek study reach, De Soto, Missouri, from the Federal Emergency Management Agency (2019b) flood-insurance study and this study.

and observed water-surface elevations were within 0.5 ft, there is some uncertainty in the calibration from the lack of a fully developed stage-streamflow rating at the De Soto streamgage and the estimated overbank flow obtained from the previous 1D analysis (Heimann and others, 2019). Additionally, the input flows were modeled using steady-state hydraulic modeling that assumes steady, uniform, unobstructed flow. The land-cover characteristics and material properties in the model reflect land use as of 2016 (2016 National Land Cover Database; Jin and others, 2019) and hydraulic structures in the study area as of December 2020. Additional areas may be flooded as a result of unanticipated changes to streambed elevations or roughness, backwater into tributaries along the reach, or backwater from localized debris or ice jams. The

accuracy of the floodwater extent portrayed on these maps also will vary with the accuracy of the DEM used to simulate the land surface.

The 1- and 0.2-percent AEP flows were modeled in a "no ceiling" condition to determine if pressure flow occurred at any bridge. The "no ceiling" condition simulated the water-surface elevation without the bridge deck/ceiling, and the simulated water-surface elevation is compared to the elevation of the lowest point in the bridge ceiling, or "low chord." If the modeled water-surface location is greater than the lowest ceiling elevation, then the bridge is modeled with pressure flow. Information from the 1- and 0.2-percent AEP profiles through the bridges in the study reach indicates that the 1-percent AEP flow did not result in pressure flow through any
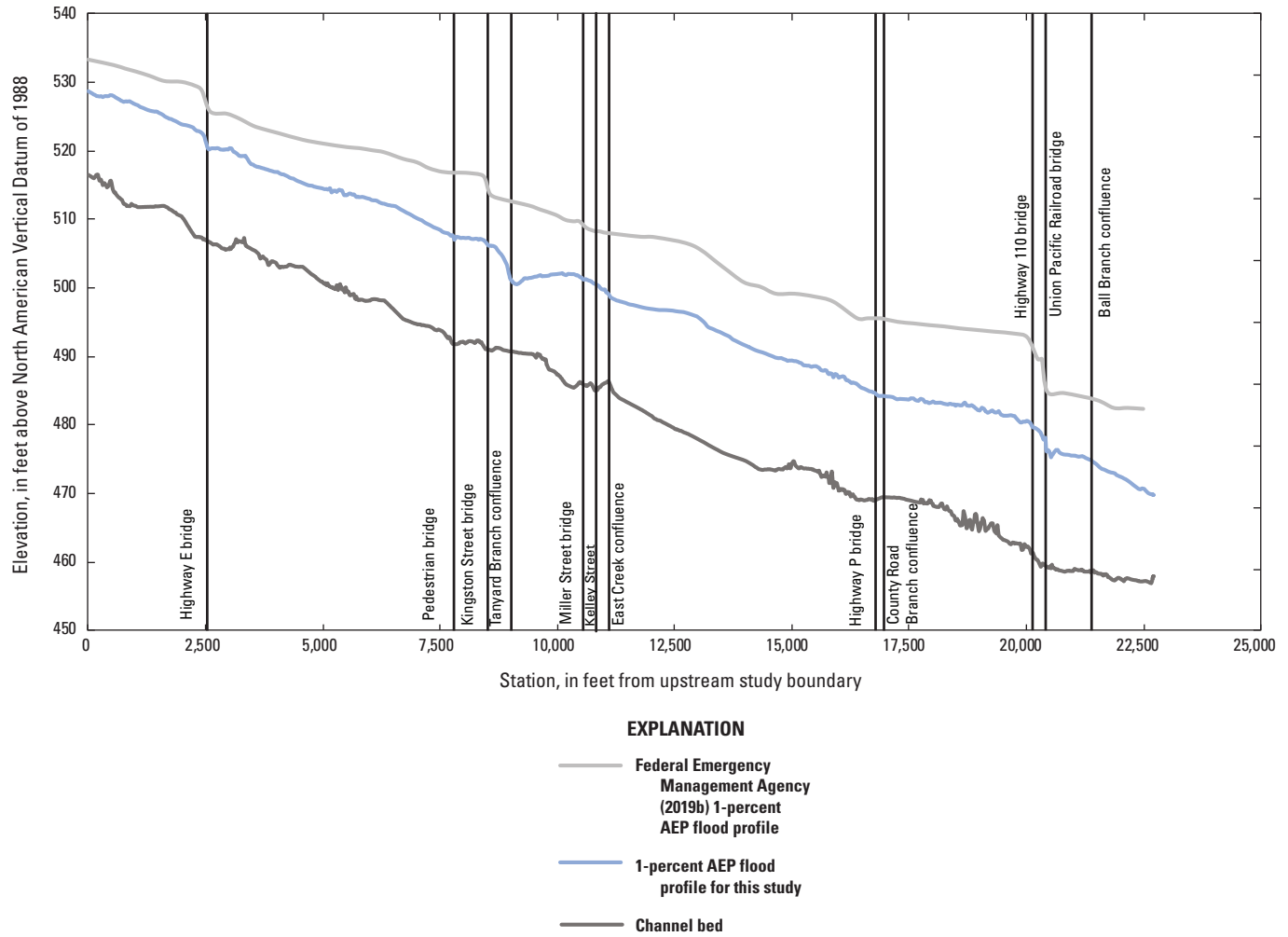
Figure 7. The 2-percent annual exceedance probability flood profile for the Joachim Creek study reach, De Soto, Missouri, from the Federal Emergency Management Agency (2019b) flood-insurance study and this study.

bridge. The 0.2-percent AEP flows resulted in pressure flow at five bridges (table 9): Pedestrian bridge, Kingston Street, Miller Street, Highway P, and Union Pacific Railroad bridges. The simulations of the water-surface elevation profiles of the 1- and 0.2-percent AEP floods indicate the elevation of the bridge crest was not exceeded at any bridge although the road approaches on either end of a bridge may be inundated (figs. 10, 13).

Analysis of Water Depths at Selected Structures

Water-surface elevations were determined at 231 selected structures within the city of De Soto that are within the Federal Emergency Management Agency (2019b) 1-percent floodplain area. The water-surface elevations for 1- and 0.2-percent AEP flows generated for this study and the associated water depths at these structures were quantified by comparing to adjacent grade elevations. Results indicate that for the 1-pecent AEP flow, 157 to 177 of the 231 structures were inundated, depending on whether the highest adjacent grade or lowest adjacent grade elevation was used for reference. Corresponding inundated depths at those affected structures were 0.02 to 7.11 ft (appendix 1, table 1.1; table 10 in Hix and Heimann [2021; located in the "model_output" folder within the "Joachim_Creek_model.zip" file]). Using generated water-surface elevations from the 0.2-percent AEP flow simulation, 185 to 198 of the 231 structures were affected, depending on the selected grade elevation, and associated water depths were 0.12 to 9.28 ft.

Figure 8.   The 1-percent annual exceedance probability flood profile for the Joachim Creek study reach, De Soto, Missouri, from the Federal Emergency Management Agency (2019b) flood-insurance study and this study.
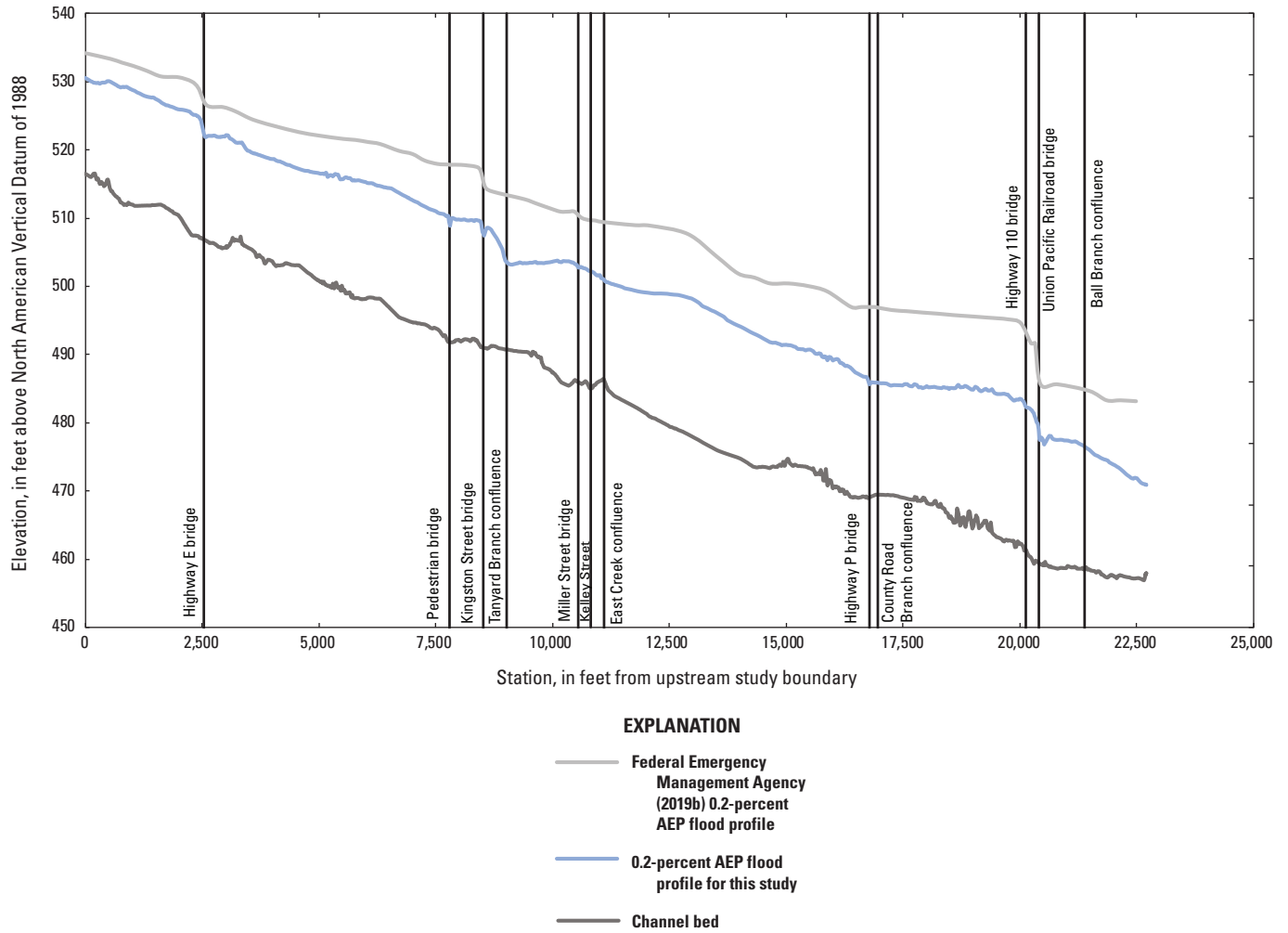
Figure 9.   The 0.2-percent annual exceedance probability flood profile for the Joachim Creek study reach, De Soto, Missouri, from the Federal Emergency Management Agency (2019b) flood-insurance study and this study.

Figure 10.   Modeled water-surface elevations for the 1-percent annual exceedance flow in the Joachim Creek study reach, De Soto, Missouri.

Figure 11.   Modeled water velocities for the 1-percent annual exceedance flow in the Joachim Creek study reach, De Soto, Missouri.
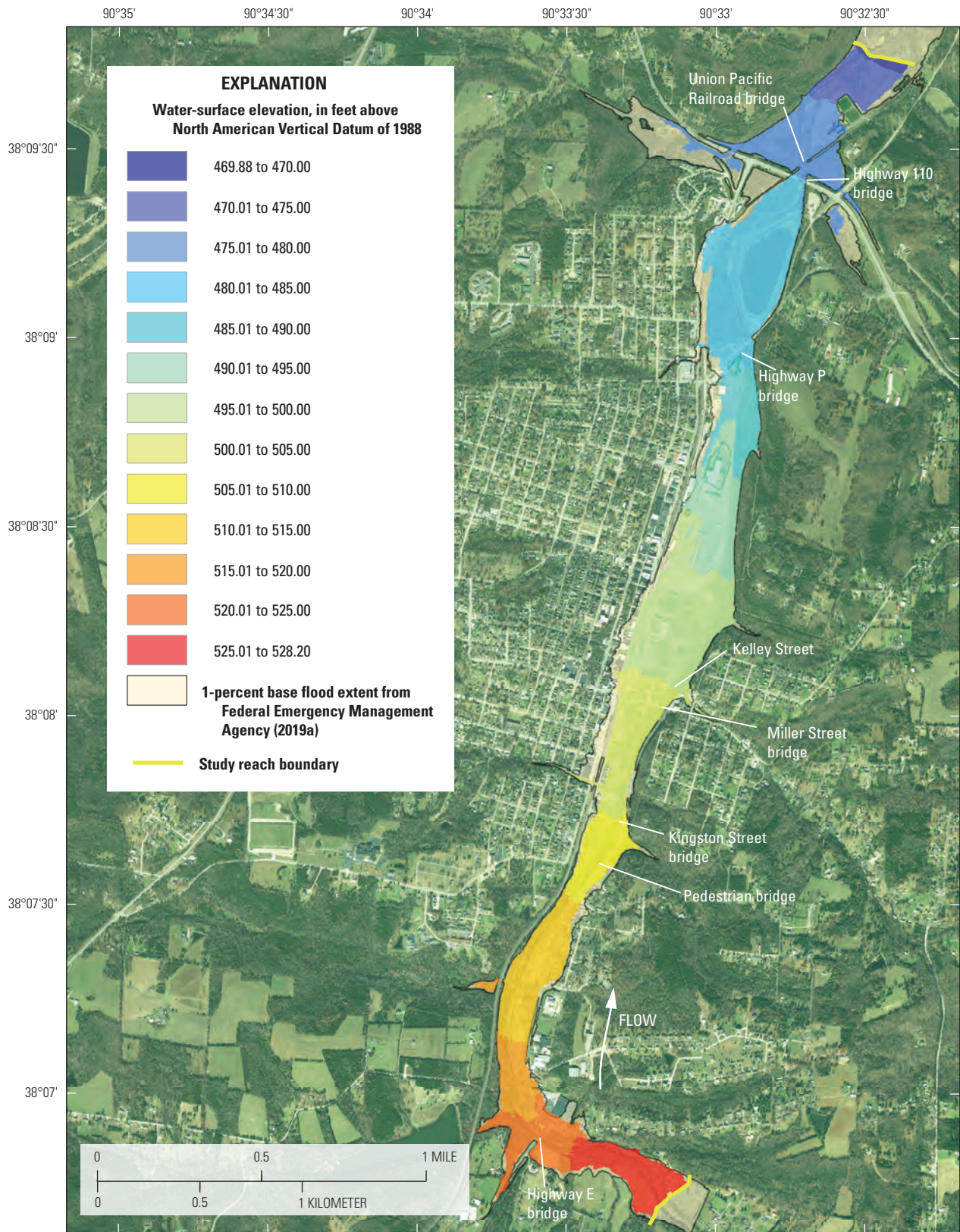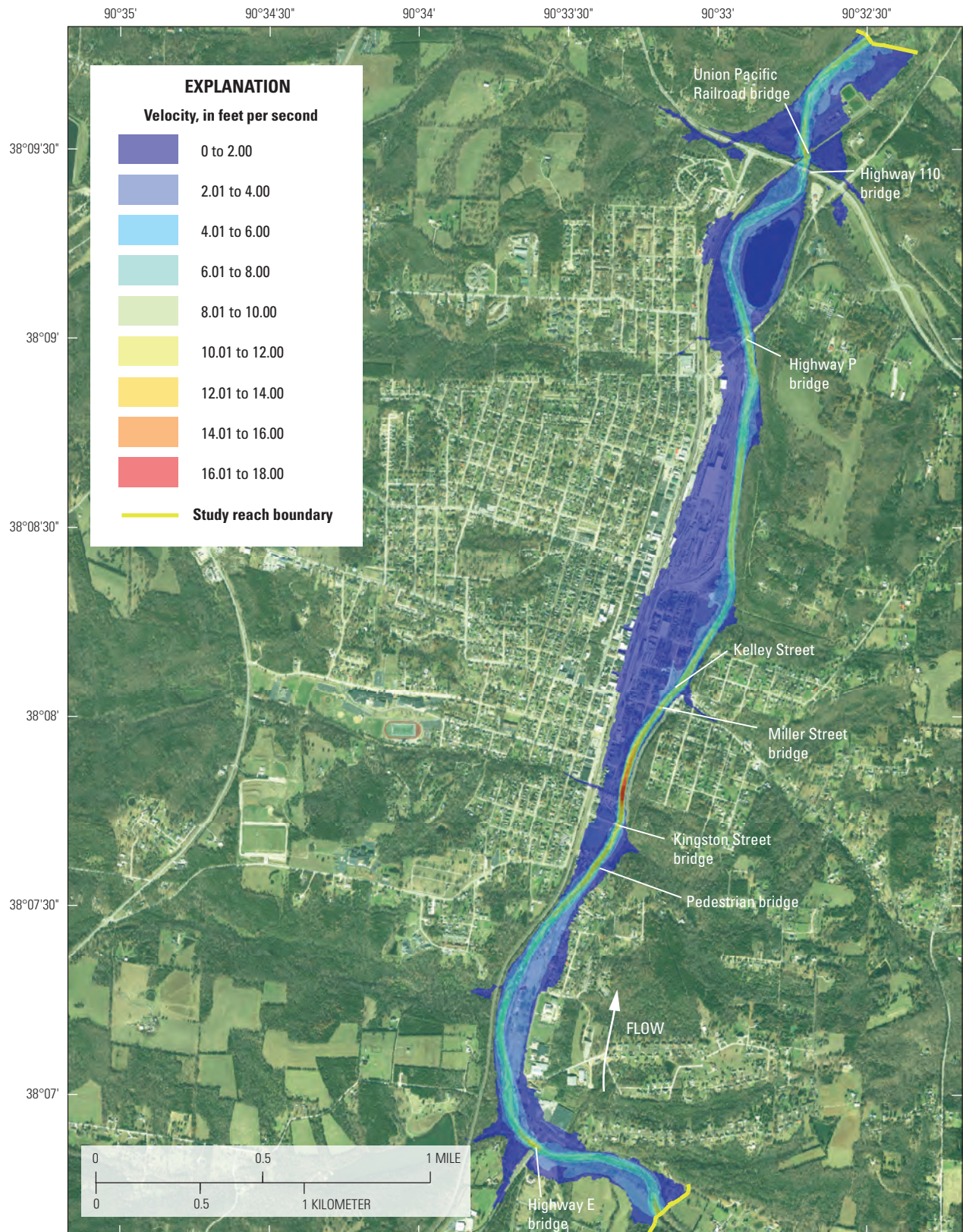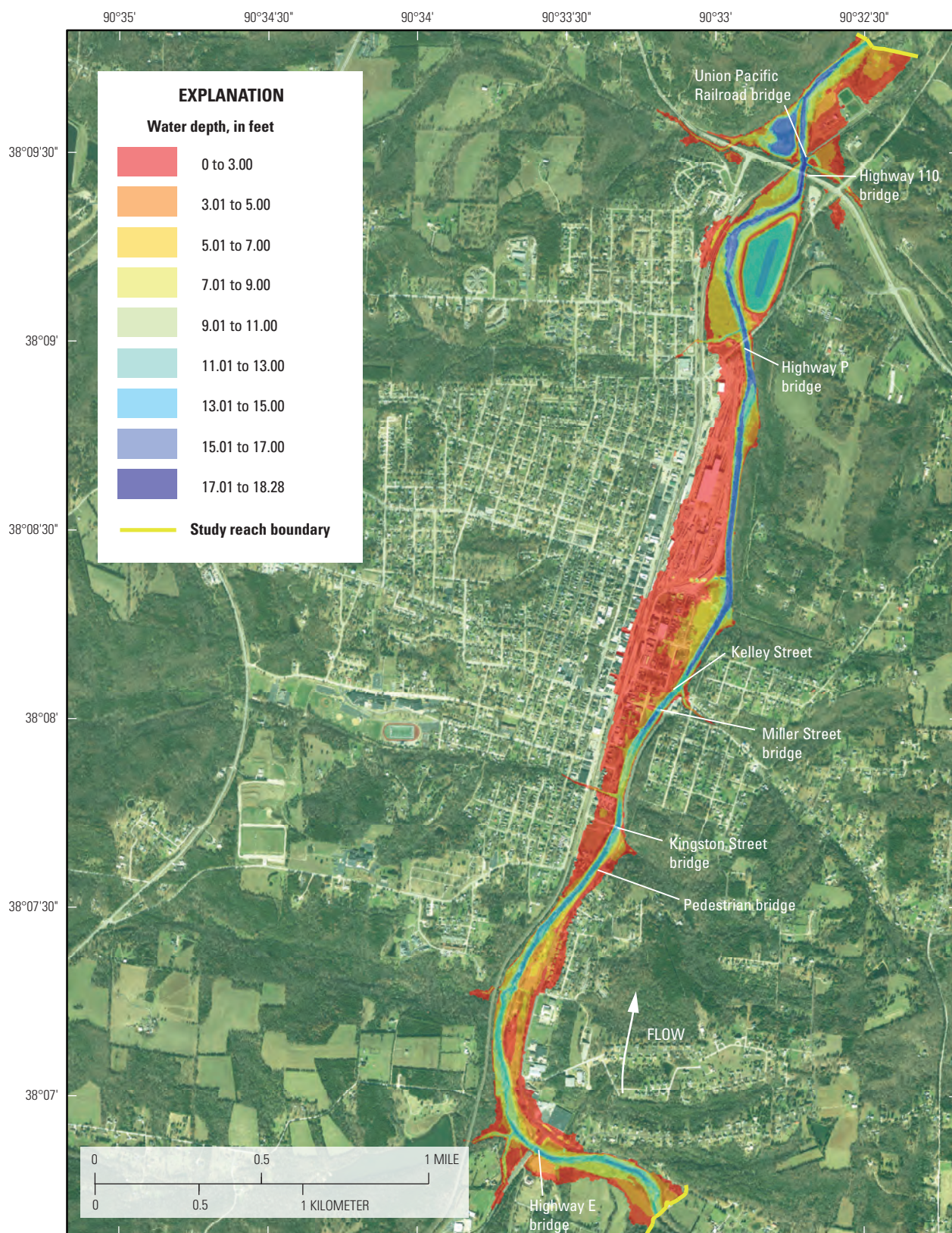
Base from Farm Service Agency, National Agricultural Imagery Program, 2018
Universal Transverse Mercator projection, zone 15 North
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)
Vertical elevations referenced to the North American Vertical Datum of 1988 (NAVD 88)

Figure 12.   Modeled water depths for the 1-percent annual exceedance flow in the Joachim Creek study reach, De Soto, Missouri.

Figure 13. Modeled water-surface elevations for the 0.2-percent annual exceedance flow in the Joachim Creek study reach, De Soto, Missouri.

Figure 14.   Modeled water velocities for the 0.2-percent annual exceedance flow in the Joachim Creek study reach, De Soto, Missouri.
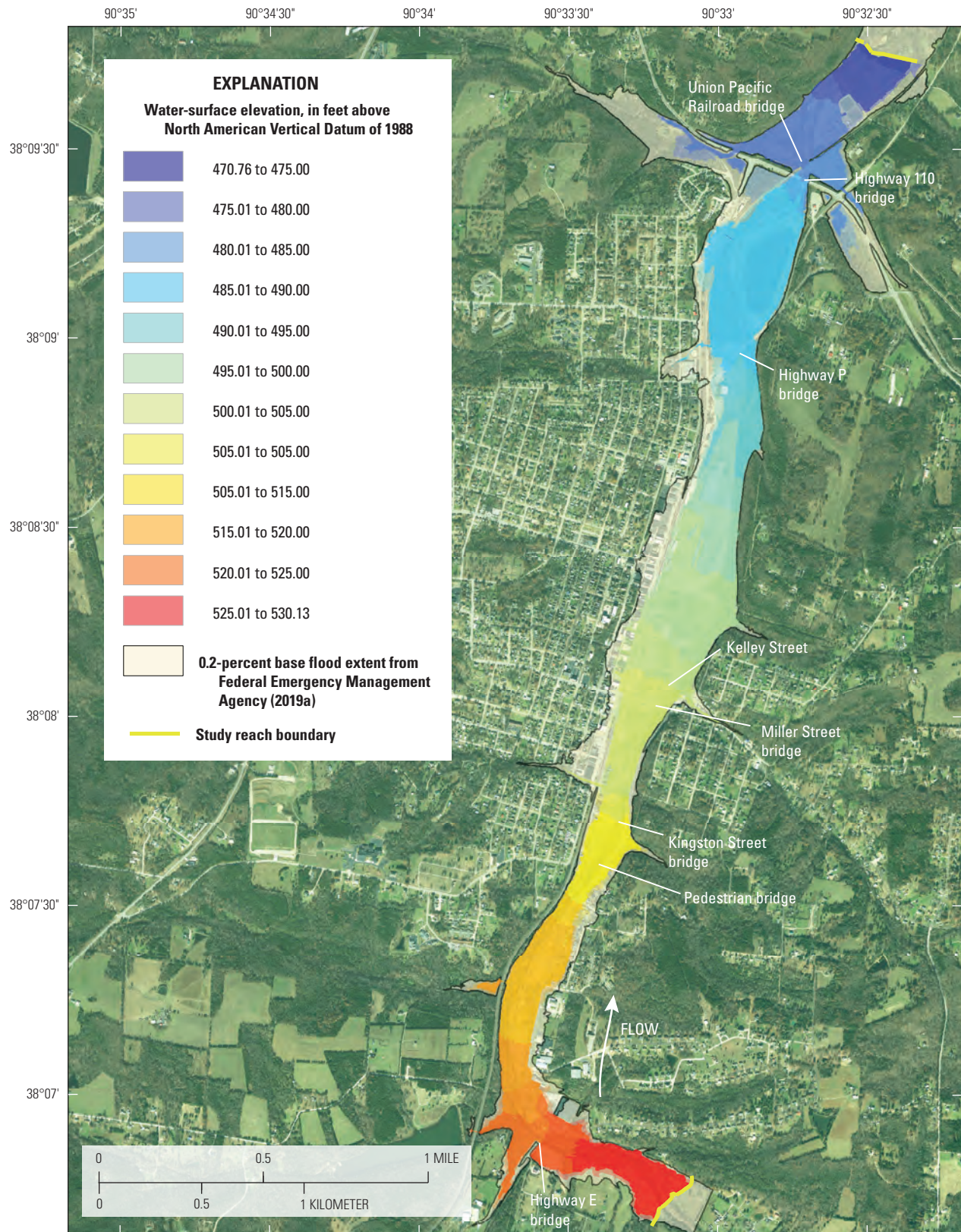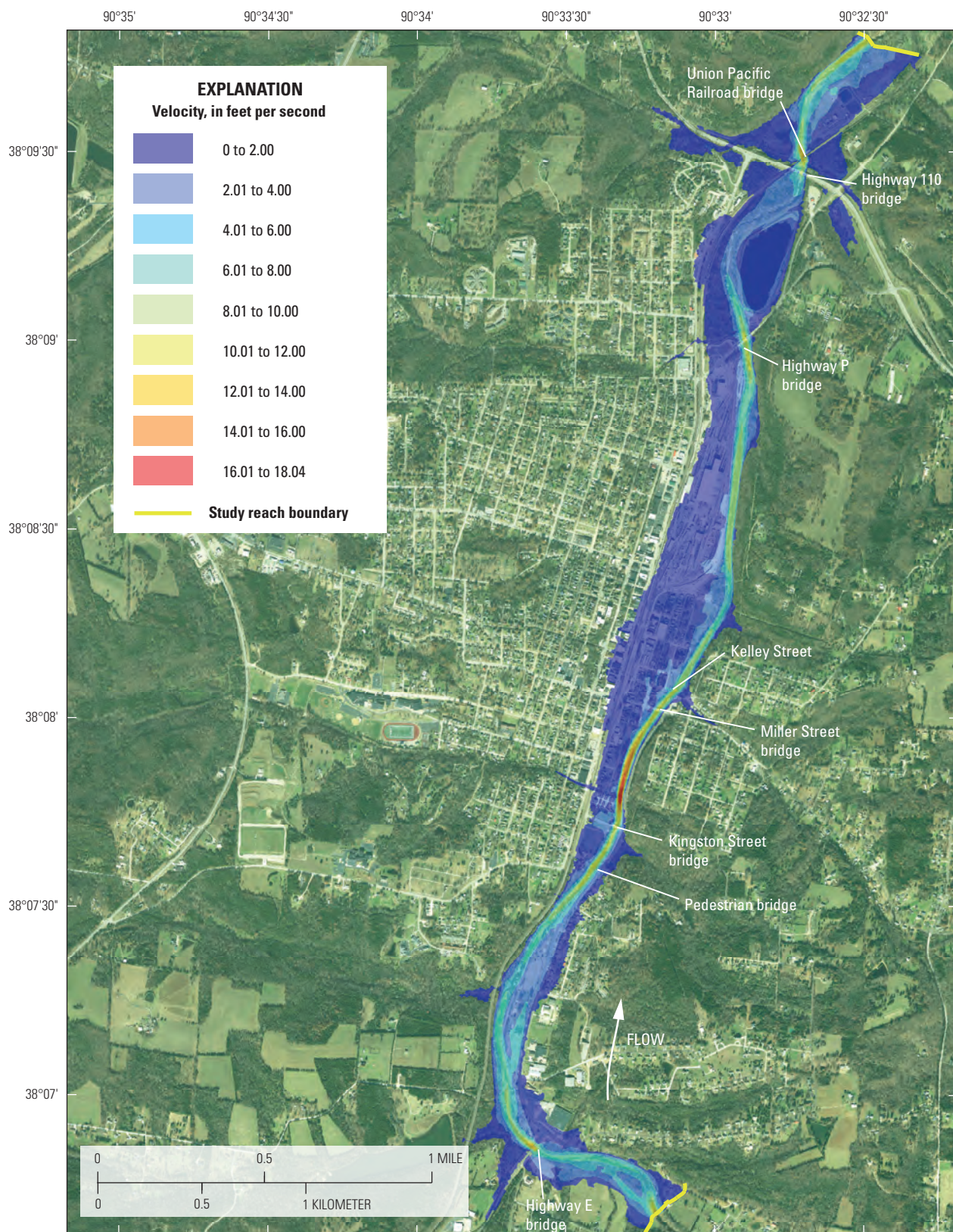
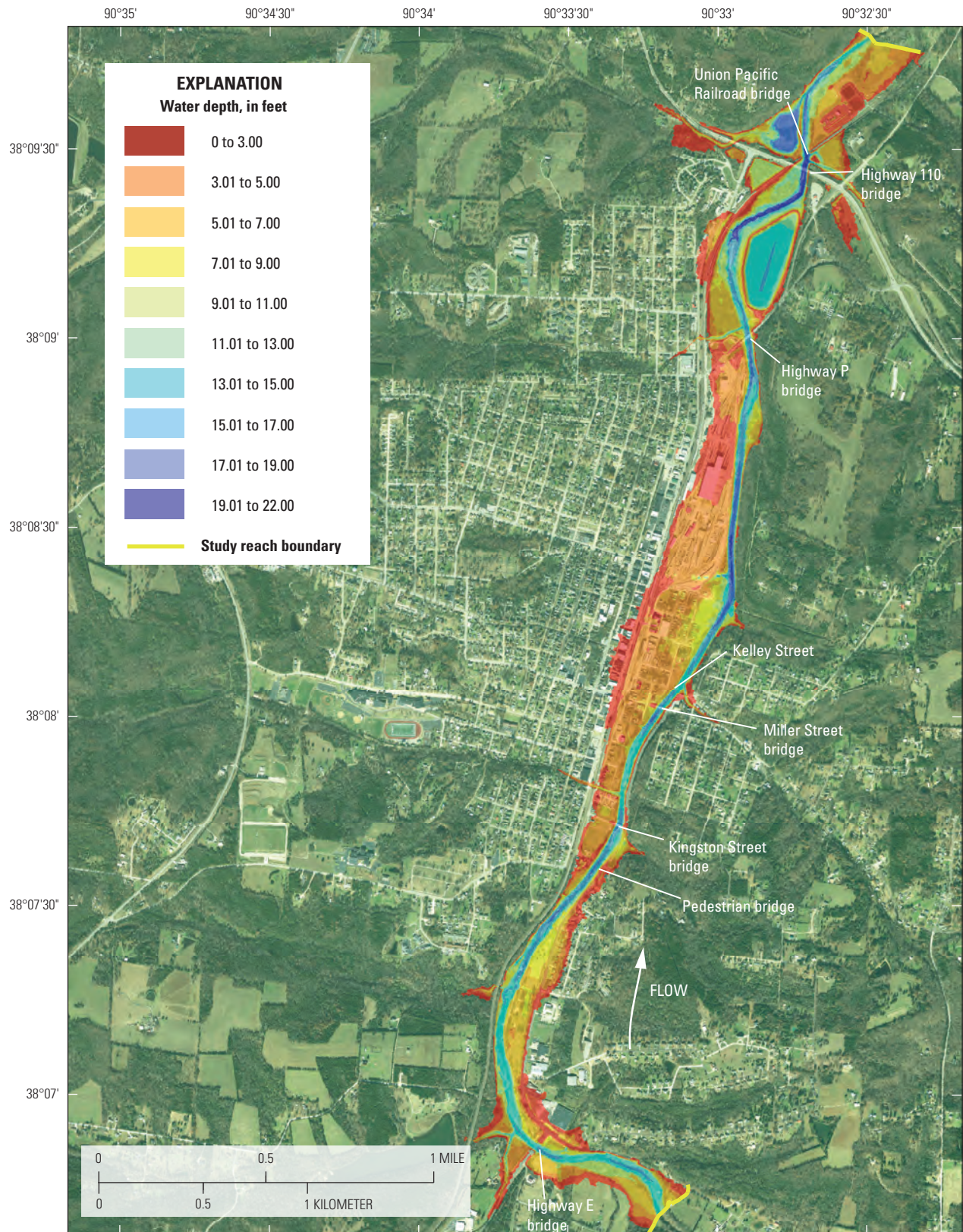**Figure 15.** Modeled water depths for the 0.2-percent annual exceedance flow in the Joachim Creek study reach, De Soto, Missouri.

Table 9. Summary of simulated water-surface elevations, relative to bridge structure thresholds, for bridges within the Joachim Creek study reach, De Soto, Missouri.

[NAVD 88, North American Vertical Datum of 1988]

Bridge (fig. 1)	Water-surface elevation (feet above NAVD 88)				Pressure flow? (water-surface elevation exceeded bridge ceiling/ low chord?)		Water-surface elevation exceeded bridge crest?	
	At upstream bridge face		Structure elevation at lowest point in bridge ceiling or low chord	Structure elevation at bridge crest (highest point of bridge deck)	Annual exceedance probability			
	Annual exceedance probability							
	0.2 percent	1 percent			0.2 percent	1 percent	0.2 percent	1 percent
Highway E	523.05	521.10	523.75	529.90	NO	NO	NO	NO
Pedestrian	509.40	507.51	508.40	510.40	YES	NO	NO	NO
Kingston Street	508.06	506.46	506.78	511.58	YES	NO	NO	NO
Miller Street	503.00	501.40	502.90	509.20	YES	NO	NO	NO
Highway P	486.64	484.76	485.60	493.30	YES	NO	NO	NO
Highway 110	482.75	480.01	505.65	515.40	NO	NO	NO	NO
Union Pacific Railroad	479.48	477.52	478.50	487.50	YES	NO	NO	NO

Summary

Water-surface profiles and map products were developed for selected regulatory flows for a 6.7-mile reach of Joachim Creek, De Soto, Missouri. The flood products were developed using a two-dimensional model and pre- and postprocessing software to compute water-surface elevation profiles and to generate maps of inundation area, depth, and velocities. The hydraulic model was calibrated using global positioning system measurements of water-surface elevations of high-water marks from the April 18, 2013, flood and the maximum measured streamflow measured on September 8, 2018, at the U.S. Geological Survey streamgage Joachim Creek at De Soto, Mo. (station 07019500).

The probabilistic peak streamflows used in this study for input in the hydraulic model were determined using the U.S. Geological Survey StreamStats application. The magnitude of the basin yield of input streamflows generated from StreamStats estimates within the study reach was verified with yields from at-site flood-frequency analyses at long-term stations within the same hydrologic region. Comparisons indicate that the StreamStats utility using regional regression analyses through 2012 (and updated through 2019 at selected locations) provides a conservatively high estimate of peak streamflows and basin yields compared to nearby station-derived flood-frequency estimates using long-term peak-flow record.

The calibrated model was used to compute water-surface profiles for the 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probability flows and maps of flood-inundation extent, velocities, and water depths for the 1- and 0.2-percent annual exceedance probability flows. The probabilistic flows correspond to a range of stages at the reference streamgage from 10.57 to 17.53 feet (ft). These stages correspond to elevations of 502.47 ft and 509.43 ft above the North American Vertical Datum of 1988, respectively. Water-surface elevations and inundation extents of generated profiles and maps were substantially lower than similar products produced for the 2019 flood-insurance study. Differences in water-surface elevations between profiles and maps in this study and a 2019 flood-insurance study can be attributed to differences in input streamflows and hydraulic simulation techniques.

Simulated water-surface elevations for the 1- and 0.2-percent annual exceedance probability floods were compared to adjacent grade elevations at 231 structures within the city of De Soto. From 157 to 177 structures were affected at the 1-percent annual exceedance flow, depending on whether the lowest adjacent grade or highest adjacent grade was used for comparison, and 185 to 198 structures were affected at the 0.2-percent annual exceedance probability flow. Inundation depths at affected structures were 0.02 to 7.11 ft at the 1-percent annual exceedance probability flow and 0.12 to 9.28 ft at the 0.2-percent annual exceedance probability flow. The results of this study can provide additional information to managers, engineers, and planners to use in decision making regarding floodplain management, flood risk, and mitigation efforts from flooding along Joachim Creek.

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Appendix 1

Table 1.1.   Summary of water-surface elevations and depths at selected structures in city of De Soto, Missouri, for 1- and 0.2-percent annual exceedance probability streamflows. [Available for download at https://doi.org/10.3133/sir20215058]