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Flood-Innudation Maps for the North Fork Kentucky River at Hazard, Kentucky

Scientific Investigations Report 2018–5122

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

Front cover. Flooding on the North Fork Kentucky River at Hazard, Kentucky, February 11, 2018. Photo by Bart Massey, USA Drone Port.

Back cover. The record flood of 1957 in Hazard, Kentucky. AP Wirephoto, National Weather Service.

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Figures

Tables

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)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

Datum

Vertical coordinate information is referenced to either (1) stage, the height above an arbitrary datum established at a streamgage; or (2) elevation, the height above the North American Vertical Datum of 1988 (NAVD 88).

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

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Abstract

Digital flood-inundation maps for a 7.1-mile reach of the North Fork Kentucky River at Hazard, Kentucky (Ky.), were created by the U.S. Geological Survey (USGS) in cooperation with the Kentucky Silver Jackets and the U.S. Army Corps of Engineers Louisville District. The flood-inundation maps, which can be accessed through the USGS Flood Inundation Mapping Science website at https://water.usgs.gov/osw/flood_inundation/, depict estimates of the areal extent and depth of flooding corresponding to selected water levels (stages) at the USGS streamgage on the North Fork Kentucky River at Hazard, Ky. (USGS station number 03277500). Near-real-time stages at this streamgage may be obtained on the internet from the USGS National Water Information System at https://waterdata.usgs.gov/ or the National Weather Service (NWS) Advanced Hydrologic Prediction Service (AHPS) at https://water.weather.gov/ahps/, which also forecasts flood hydrographs at this site (NWS AHPS site HAZK2). NWS AHPS forecast peak stage information may be used in conjunction with the maps developed in this study to show predicted areas of flood inundation.

Flood profiles were computed for the North Fork Kentucky River reach by means of a one-dimensional, step-backwater model developed by the U.S. Army Corps of Engineers. The hydraulic model was calibrated by using the current stage-discharge relation (USGS rating no. 24.0) at USGS streamgage 03277500, North Fork Kentucky River at Hazard, Ky. The calibrated hydraulic model was then used to compute 26 water-surface profiles for flood stages at 1-foot (ft) intervals referenced to the streamgage datum and ranging from approximately bankfull (14 ft) to the highest even-foot increment stage (39 ft) of the current stage-discharge rating curve. The simulated water-surface profiles were then combined with a geographic information system digital elevation model, derived from light detection and ranging data, to delineate the area flooded at each water level.

The availability of these maps, along with information on the internet regarding current stage from the USGS streamgage at North Fork Kentucky River at Hazard, Ky., and forecasted stream stages from the NWS AHPS, provides emergency management personnel and residents with information that is critical for flood-response activities such as evacuations and road closures, as well as for postflood recovery efforts.

Introduction

The city of Hazard, Kentucky (Ky.), is located in Perry County (fig. 1) and has an estimated population of 5,090 as of July 1, 2017 (U.S. Census Bureau, 2017). Hazard is subject to flooding from the North Fork Kentucky River. Due to the surrounding rugged terrain, much of the city has been built in the valley near the river (Federal Emergency Management Agency [FEMA], 2006a). Hazard and the surrounding area have experienced flooding (stage > 20 feet [ft]) numerous times, most recently in 2015, 2017, and 2018. The flood of record occurred in January 1957. The majority of flood damages in the Hazard area have occurred along the North Fork Kentucky River, which flows through the middle of the city. During flood events, there is significant flooding of residential areas and business districts, many local roads become impassable, and some evacuations are necessary.

Prior to this study, emergency responders in Hazard relied on several information sources to make decisions on how to best alert the public and mitigate flood damages. One source is the FEMA flood insurance study (FIS) for Perry County (FEMA, 2006a). A second source of information is U.S. Geological Survey (USGS) streamgage 03277500, North Fork Kentucky River at Hazard, Ky., from which current (USGS, 2018a) and historical (USGS, 2018b) water levels (stage) and discharges, including annual peak flows, can be obtained (https://waterdata.usgs.gov/nwis/inventory/?site_no=03277500&agency_cd=USGS). A third source of flood-related information is the National Weather Service (NWS) Advanced Hydrologic Prediction Service (AHPS), which displays the USGS stage data and also issues forecasts of stage for the North Fork Kentucky River at the USGS streamgage (NWS, 2018a). The NWS does not routinely issue forecasts for the North Fork Kentucky River at Hazard, Ky., but it does so as needed during times of high-stage flows.

Although the current stage at a USGS streamgage and the NWS AHPS flood forecast information are particularly useful for residents in the immediate vicinity of a streamgage,

it is generally of limited use to residents farther upstream or downstream because the water-surface elevation is not constant along the entire stream reach. Additionally, knowledge of a water level at a streamgage is difficult to translate into depth and areal extent of flooding at points distant from the streamgage. One way to address these informational gaps is to produce a library of flood-inundation maps that are referenced to the stages recorded at the USGS streamgage. By referring to the appropriate map, emergency responders can discern the severity of flooding (depth of water and areal extent), identify roads that are or will soon be flooded, and make plans for notification or evacuation of residents in harm's way for some distance upstream and downstream from the streamgage. In addition, the capability to visualize the potential extent of flooding has been shown to motivate residents to take precautions and heed warnings that they might have previously disregarded. The USGS, in cooperation with the Kentucky Silver Jackets and the U.S. Army Corps of Engineers (USACE) Louisville District, led a study to produce a library of flood-inundation maps for the North Fork Kentucky River at Hazard, Ky. For this joint project, the USACE did the modeling, and the USGS collected the bathymetry, prepared the flood-inundation maps, and published this report.

Purpose and Scope

This report describes the development of a series of estimated flood-inundation maps for the North Fork Kentucky River at Hazard, Ky., and identifies where on the internet the maps can be accessed and ancillary data (geographic information system [GIS] flood polygons and depth grids) can be downloaded. Internet users can select estimated inundation maps that correspond to (1) flood stages at USGS streamgage 03277500 and (2) the NWS forecasted peak stage at the NWS AHPS site HAZK2. The scope of the study was limited to the North Fork Kentucky River reach extending 3.7 miles (mi) upstream and 3.4 mi downstream from USGS streamgage 03277500 at the Kentucky Boulevard bridge (fig. 1).

The flood-inundation maps were produced for flood levels referenced to the stage recorded at the USGS streamgage on the North Fork Kentucky River at Hazard, Ky. (table 1). The streamgage is on the right bank, 30 ft upstream of the Kentucky Boulevard bridge at Hazard. The maps cover a range in stage from 14 to 39 ft, gage datum. The 16-ft stage is defined by the NWS (2018b) as the "action stage" or that stage which, when reached by a rising stream, requires the NWS or a partner to take some type of mitigation action in preparation for possible significant hydrologic activity. The 20-ft, 27-ft, and 33-ft stages are defined by the NWS (2018a) as flood stage, moderate flood stage, and major flood stage, respectively. The 39-ft stage is the highest even-foot increment stage of the current stage-discharge rating curve (USGS, 2018a) and exceeds the major flood stage as defined by the NWS (NWS, 2018b).

Study Area Description

The North Fork Kentucky River near the city of Hazard in Perry County is in southeast Kentucky in the Dissected Appalachian Plateau of the Central Appalachians ecoregion (U.S. Environmental Protection Agency, 2002). The drainage area is 459 square miles (mi^2) at the upstream end of the study reach; 466 mi^2 at USGS streamgage 03277500, North Fork Kentucky River at Hazard; and 471 mi^2 at the downstream end of the study reach (USGS, 2018b, 2018c). The headwaters originate in eastern Letcher County near Payne Gap, Ky. (not shown), and the stream flows generally westward before turning a more northerly direction at Hazard. Flow is partially regulated by an upstream reservoir—Carr Fork Lake (not shown)—which came online in January 1976 and affects the streamflow at Hazard. There are no significant tributaries to the North Fork Kentucky River as it flows through the study reach. Minor tributaries within the study reach include (from upstream to downstream) Buffalo Creek, Gregory Branch, Davidson Branch, Messer Branch, and Walker Branch (not shown). The basin terrain is generally steep-sided hills, and the dominant rock types are sandstone, siltstone, shale, and coal (Carey and Hounshell, 2008). Similarly, the FIS for Perry County, Kentucky (FEMA, 2006a), describes the topography

Table 1. U.S. Geological Survey streamgage information for the North Fork Kentucky River at Hazard, Kentucky (station number 03277500).

[mi^2, square miles; NAD 83, North American Datum of 1983; NAVD 88, North American Vertical Datum of 1988; ft^3/s, cubic feet per second; °, degree; ', minute; ", second; ft, feet]

Streamgage name	Streamgage number	Drainage area (mi^2)	Latitude (NAD 83)	Longitude (NAD 83)	Datum of gage (NAVD 88)	Period of record	Maximum recorded flood elevation (NAVD 88) and date	Maximum discharge (ft^3/s) and date
North Fork Kentucky River at Hazard, KY	03277500	466	37°14'47.7"	-83°10'58.0"	839.20	January 1940 to present (2018)	876.74 ft on January 29, 1957 (corresponds to a gage height of 37.54 ft)	47,800 on January 29, 1957

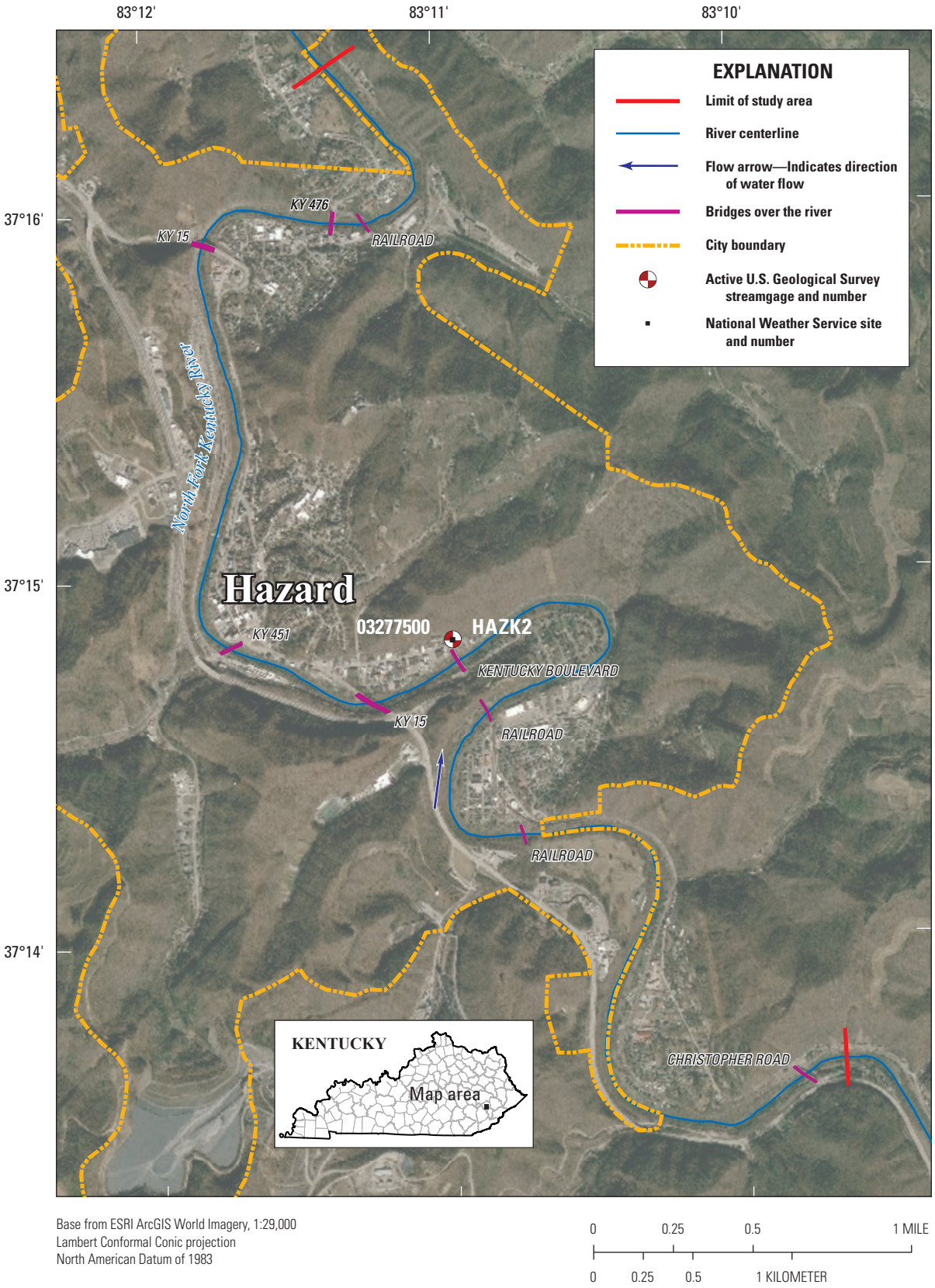

Figure 1. Location of study reach for the North Fork Kentucky River at Hazard, Kentucky; location of U.S. Geological Survey streamgage (03277500); and location of National Weather Service forecast site (HAZK2).

as being generally characterized by narrow valleys and high, rugged hills. The study reach is approximately 7.1 mi long and has an average top-of-bank channel width of about 160 ft and an average channel slope of 0.00074 (3.9 feet per mile). Most of the land contiguous to the study reach is developed (residential and commercial areas) or forested. The main channel and adjacent floodplain within the study reach has six major road crossings, three railroad crossings, and three low-head water control structures.

Previous Studies

The most recent FIS that provides information for the streamgage at the North Fork Kentucky River at Hazard is the FIS for Perry County, Kentucky (FEMA, 2006a). This version of the FIS, effective August 2, 2006, includes updated hydrologic and hydraulic analyses for a reach of the North Fork Kentucky River including the city of Hazard. The North Fork Kentucky River was studied by detailed methods using cross-section and structural-geometry data obtained from either the USACE or field surveys, peak flow information from analysis of the USGS gage at Hazard, and roughness factors from field observations and engineering judgment. The water-surface elevations were computed through the use of the Soil Conservation Service Water Surface Profile 2 computer program (U.S. Department of Agriculture, 1976), and flood profiles were prepared for the selected recurrence intervals. The FIS presents estimates of the peak discharges with 10-, 2-, 1-, and 0.2-percent annual exceedance probabilities for the North Fork Kentucky River at Hazard (FEMA, 2006a); however, peak flow statistics using more recent data are available from Hodgkins and Martin (2003) and are listed in table 2. FEMA has produced Digital Flood Insurance Rate Maps, which include the study area in Perry County (FEMA, 2006b). These maps outline the special flood-hazard areas around Hazard.

Creation of Flood-Inundation Map Library

The USGS has standardized the procedures for creating flood-inundation maps for flood-prone communities so that the process followed and products produced are similar regardless of which USGS office is responsible for the work (USGS, 2018d). Tasks specific to the development of the flood maps for Hazard, Ky., were: (1) compilation of flow data from USGS streamgage 03277500, (2) collection of topographic and bathymetric data for selected cross sections and geometric data for structures and bridges along the study reach, (3) estimation of energy-loss factors (roughness coefficients) in the stream channel and floodplain, (4) computation of water-surface profiles by use of the USACE's HEC–RAS computer program (USACE, 2016a), (5) production of estimated flood-inundation maps at various stream stages by use of the USACE's RAS Mapper computer program (USACE, 2016b) and a GIS computer program called ArcGIS (Esri, 2016), and (6) preparation of the maps, both as shapefile polygons that depict the areal extent of flood inundation and as depth grids that provide the depth of floodwaters, for display on a USGS flood-inundation mapping application. The USACE did the modeling for this project, and the USGS provided quality-control reviews of the hydraulic model and its related datasets and resulting flood-inundation maps. The methods used are generally cited from previously published reports (Bales and others, 2007; Whitehead and Ostheimer, 2009). If techniques varied significantly from previously documented methods in response to local hydrologic conditions or availability of data, they are described in detail in this report. Twenty-six maps were produced for water levels referenced to the stage at USGS streamgage 03277500, North Fork Kentucky River at Hazard, Ky., and range from approximately bankfull (14 ft) to the highest even-foot increment stage (39 ft) of the current stage-discharge rating curve.

Table 2. Peak discharges for selected annual exceedance probabilities for the North Fork Kentucky River at Hazard, Kentucky.

[mi^2, square miles; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey]

Location on North Fork Kentucky River	Drainage area (mi^2)	Peak discharges (ft^3/s) for indicated annual exceedance probabilities (in percent)[1]							
		50	20	10	4	2	1	0.5	0.2
At USGS streamgage number 03277500	466	17,800	27,300	33,300	40,500	45,700	50,700	55,700	62,400

[1]Data from Hodgkins and Martin (2003).

Computation of Water-Surface Profiles

The water-surface profiles used to produce the 26 flood-inundation maps in this study were simulated by using HEC–RAS, version 5.0.3 (USACE, 2016a). HEC–RAS is a one-dimensional, step-backwater model for simulation of water-surface profiles with gradually varied, steady-state or unsteady-state flow computation options. The HEC–RAS analysis for this study was done using the steady-state flow computation option. This work was completed by the USACE Louisville District.

Hydrologic Data

The study area's hydrologic network consists of one streamgage (fig. 1; table 1); USGS streamgage 03277500 has been in operation since January 10, 1940, and is collocated with the NWS AHPS site HAZK2. The NWS does not routinely issue forecasts for the North Fork Kentucky River at Hazard, Ky., but it does so as needed during times of high-stage flows. The USGS streamgage has been operating as a stage-discharge gage, except from October 1992 to October 2005 where it was stage only. This streamgage has a continuous record of measured water level (stage) and computed streamflow. Stage is measured every 15 minutes, transmitted hourly by a satellite radio in the streamgage, and made available on the internet through the USGS National Water Information System (USGS, 2018b). 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 (NAVD 88) by adding 839.20 ft. The datum of the streamgage is 839.76 ft National Geodetic Vertical Datum of 1929, but this study references all elevations to NAVD 88, so the gage datum was converted to NAVD 88 using a datum shift value of –0.56 ft obtained from VERTCON (National Geodetic Survey, 2018). Data from this streamgage are used for calibration of the model and comparison of model results.

The steady-flow data necessary for the hydraulic model consisted of flow regime, boundary conditions (normal depth), and input flow rates (estimated discharges or peak flows). The steady-flow data used in the model simulations (table 3) were obtained from the current stage-discharge relation (USGS rating no. 24.0, effective April 23, 2017, and current at the time of this investigation [2018]) for streamgage 03277500 and corresponded with the target stages. All computations used discharge values with known stages from actual streamflow measurements or the stage-discharge relation at the gage. No major tributaries join the North Fork Kentucky River within the 7.1-mi study reach (the drainage area increases 2.6 percent from the upstream end to the downstream end); therefore, the gage-derived discharges were not adjusted for tributary inflows but were held constant throughout the study reach for a given profile.

Topographic and Bathymetric Data

All topographic data used in this study are referenced vertically to NAVD 88 and horizontally to the North American Datum of 1983. Cross-section elevation data for the land surface were obtained from a digital elevation model (DEM) that was derived from light detection and ranging (lidar) data that were collected as part of a larger statewide mapping effort during 2012–17 by Photo Science, Inc. The lidar data for Perry County were collected in 2012. The DEM was obtained from the Kentucky GIS server (Kentucky Division of Geographic Information, 2017). The original lidar data were collected at a 1.0 meter or better horizontal point spacing and have a vertical

Table 3. Estimated discharges for corresponding stages and water-surface elevations at U.S. Geological Survey streamgage 03277500 used in the hydraulic model of the North Fork Kentucky River at Hazard, Kentucky.

[ft, feet; NAVD 88, North American Vertical Datum of 1988; USGS, U.S. Geological Survey; ft^3/s, cubic feet per second]

Stage (ft)	Water-surface elevation (ft, NAVD 88)	Estimated discharge at USGS streamgage number 03277500 (ft^3/s)
14.00	853.20	9,373
15.00	854.20	10,167
16.00	855.20	10,945
17.00	856.20	11,669
18.00	857.20	12,382
19.00	858.20	13,141
20.00	859.20	13,957
21.00	860.20	14,771
22.00	861.20	15,583
23.00	862.20	16,513
24.00	863.20	17,458
25.00	864.20	18,409
26.00	865.20	19,550
27.00	866.20	20,918
28.00	867.20	22,319
29.00	868.20	23,798
30.00	869.20	25,388
31.00	870.20	27,020
32.00	871.20	28,841
33.00	872.20	30,865
34.00	873.20	32,957
35.00	874.20	35,080
36.00	875.20	37,236
37.00	876.20	39,452
38.00	877.20	42,935
39.00	878.20	46,961

accuracy of 18.0 centimeters root mean squared error. By these criteria, the lidar data support production of 2-ft contours (Dewberry, 2012). The final DEM, which was kept at its original grid-cell size of 5 ft by 5 ft, has a vertical accuracy of plus or minus 1 ft.

Because lidar data cannot provide ground elevations below a stream's water surface, channel cross sections were surveyed by a USGS field crew in May 2016. A few additional cross sections at the downstream end of the reach were surveyed by a USGS field crew in December 2016. Cross-sectional depths were measured by using hydroacoustic instrumentation at a total of 31 cross sections along the study reach. A differential global positioning system with real-time kinematic technology was used to derive horizontal locations and the elevation of the water surface at each surveyed cross section.

In the ArcMap application of ArcGIS (Esri, 2016), these field data were used in conjunction with a bathymetry mesh tool, created by Merwade and others (2008), to interpolate below-water ground elevations through the study reach. The density of ground elevations in the mesh was determined by two variables: (1) the number of parallel longitudinal profiles that were evenly spaced across the channel and ran the length of the study reach and (2) the user-specified spacing between cross sections. Ground elevations were either extracted or interpolated from the field data at the intersections of the longitudinal profiles and cross sections. Instructions for the bathymetry mesh tool are presented by Merwade (2011).

The mesh elevations were then merged with ("burned" or "carved" into) the DEM data, resulting in a merged DEM that contains overbank and in-channel elevations. By using HEC–GeoRAS (USACE, 2011), which is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS, elevation data were extracted from the merged DEM for 153 cross sections at desired locations along the study reach. These data subsequently were input to the HEC–RAS model.

Hydraulic Structures

Various man-made structures (bridges, low-head dams, culverts, buildings, and roadway embankments) in and along the North Fork Kentucky River affect or have the potential to affect water-surface elevations during floods along the stream. To properly account for these features in the model, structural dimensions for the nine bridges were obtained from either an existing HEC–2 model or from design drawings provided by the Kentucky Transportation Cabinet. The bridges from the old HEC–2 model were the three Seaboard Systems Railroad bridges. Field inspection verified that these bridges have not been replaced or modified. The remaining six bridges that cross the river are road bridges, and the design drawings used to model the bridges accurately depicted the hydraulic characteristics. These bridges include highways KY 476, KY 15, KY 451, KY 15 (a second crossing), Kentucky Boulevard, and Christopher Road.

Culvert locations were confirmed in a field survey conducted by the USGS in May 2018; the confirmation of culvert locations was needed to aid in determining whether disconnected flood-inundation areas are actually connected to the river or just low areas in the topography. There are numerous cross-sections in the model that utilize block ineffective flow areas. The use of block ineffective flow areas was used to account for buildings in the overbank that are in the flooded area and would effectively block flow. In many areas, streets between buildings would be effective flow areas for flow conveyance, which necessitated the need to use a blocked approach. Ineffective areas were based on aerial imagery and field inspection and were adjusted during model refinement.

There are three water control structures within the study reach that were included in the hydraulic model as inline structures. The purpose of these structures is to maintain a pool during low flow conditions. No levees or flood management structures are known to exist in the study reach.

Energy-Loss Factors

Hydraulic analyses require the estimation of energy losses that result from frictional resistance exerted by a channel on the flow. Field observations, high-resolution aerial photographs, and the most recent FIS were used to select initial channel and floodplain friction coefficients. These friction coefficients, commonly called Manning's roughness coefficients (*n*-values), account for energy (friction) loss in the model (Arcement and Schneider, 1989). It was found that the flood profiles were especially sensitive to the *n*-values. Roughness-coefficient adjustment factors (flow roughness factors) are a feature in the model that allows the specified *n*-values to adjust with changes in flow. As part of the calibration process for mapping purposes, the initial *n*-values were varied by flow roughness factors (ranging from 0.74 to 1.36) in the model and adjusted until the differences between simulated and observed water-surface elevations at the streamgage were minimized. The final Manning's *n*-values ranged from 0.019 to 0.082 for the main channel and from 0.022 to 0.272 for the overbank areas modeled in this analysis. As elevations rise in the channel, the roughness is likely to increase with depth on the banks. Once flood waters spill from the channel, other factors could influence flood levels.

Hydraulic Model

The hydraulic analysis for this study was done using HEC–RAS with the steady-state flow computation option. Steady-state flow data consisted of flow regime, boundary conditions, and input flow rates that produced water-surface elevations at the streamgage cross section that closely matched target water-surface elevations. These target elevations coincided with even 1-ft increments of stage, referenced to the local gage datum. Subcritical (tranquil) flow regime was assumed for the simulations. Normal depth, based on an

estimated average water-surface slope of 0.0001507, was used as the reach's downstream boundary condition. This slope was calculated based on the channel-bed slope near the downstream end of the model. The upstream boundary condition was a series of input flow rates as discussed in the "Hydrologic Data" section.

The HEC–RAS model was calibrated to the current stage-discharge relation (USGS rating no. 24.0) at USGS streamgage 03277500, North Fork Kentucky River at Hazard, Ky. Model calibration was accomplished by adjusting Manning's *n*-values until the results of the hydraulic computations closely agreed with the observed water-surface elevations for given flows. Differences between target and simulated water-surface elevations for the 26 simulated flows at USGS streamgage 03277500 were all within +/- 0.09 ft (table 4). The results demonstrate that the model is capable of simulating reasonable water levels over a wide range of flows at the streamgage.

Table 4. Comparison of target water-surface elevations at U.S. Geological Survey streamgage 03277500, North Fork Kentucky River at Hazard, Kentucky, with water-surface elevations output from the hydraulic model.

[ft, feet; NAVD 88, North American Vertical Datum of 1988]

Stage (ft)	Target water-surface elevation (ft, NAVD 88)	Modeled water-surface elevation (ft, NAVD 88)	Elevation difference (ft)
14.00	853.20	853.22	0.02
15.00	854.20	854.22	0.02
16.00	855.20	855.24	0.04
17.00	856.20	856.25	0.05
18.00	857.20	857.26	0.06
19.00	858.20	858.18	–0.02
20.00	859.20	859.24	0.04
21.00	860.20	860.16	–0.04
22.00	861.20	861.18	–0.02
23.00	862.20	862.22	0.02
24.00	863.20	863.15	–0.05
25.00	864.20	864.18	–0.02
26.00	865.20	865.19	–0.01
27.00	866.20	866.19	–0.01
28.00	867.20	867.16	–0.04
29.00	868.20	868.23	0.03
30.00	869.20	869.25	0.05
31.00	870.20	870.21	0.01
32.00	871.20	871.18	–0.02
33.00	872.20	872.24	0.04
34.00	873.20	873.22	0.02
35.00	874.20	874.20	0.00
36.00	875.20	875.16	–0.04
37.00	876.20	876.18	–0.02
38.00	877.20	877.17	–0.03
39.00	878.20	878.29	0.09

Development of Water-Surface Profiles

The calibrated hydraulic model was used to generate water-surface profiles corresponding to flows for a total of 26 stages at 1-ft intervals ranging from 14 ft to 39 ft as referenced to USGS streamgage 03277500. These stages correspond to elevations from 853.20 ft to 878.20 ft, NAVD 88, respectively. Water-surface profiles for the lowest (14 ft) and the highest (39 ft) stages modeled are shown in figure 2. Discharges corresponding to the various stages were obtained from the current stage-discharge relation (USGS rating no. 24.0) at the North Fork Kentucky River streamgage. Discharges for all profiles (table 3) were selected with the assumption that there are no significant tributary inflows within the 7.1-mi modeled reach; the discharges were therefore estimated to be uniform and steady throughout the modeled reach.

Development of Flood-Inundation Maps

Flood-inundation maps were created for a reach of the North Fork Kentucky River at Hazard, Ky. The maps were created in a GIS by combining the 26 water-surface profiles and DEM data. The DEM data were derived from the same lidar data described previously in the "Topographic and Bathymetric Data" section; however, the channel terrain was recarved with the cross-section interpolation-surface feature in RAS Mapper (USACE, 2016b) to provide more accurate flood-inundation depths within the main channel. Estimated flood-inundation boundaries and depths for each simulated profile were developed with RAS Mapper, which has the capability to perform inundation mapping of water-surface profile results directly from HEC–RAS. Shapefile polygons and depth grids of the inundated areas for each profile were modified, as required, in the ArcMap application of ArcGIS to ensure a hydraulically reasonable transition of the flood boundaries between model cross sections (Whitehead and Ostheimer, 2009). The resulting inundation maps have a vertical accuracy of about plus or minus 1.0 ft. The datasets used in this study are available for download through a data release at https://doi.org/10.5066/P9CNAG9G (Boldt and others, 2018).

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. Culvert locations were confirmed in a field survey conducted by the USGS in May 2018. Where such connections existed, the mapped inundated areas were retained in their respective flood maps; otherwise, the erroneously delineated parts of

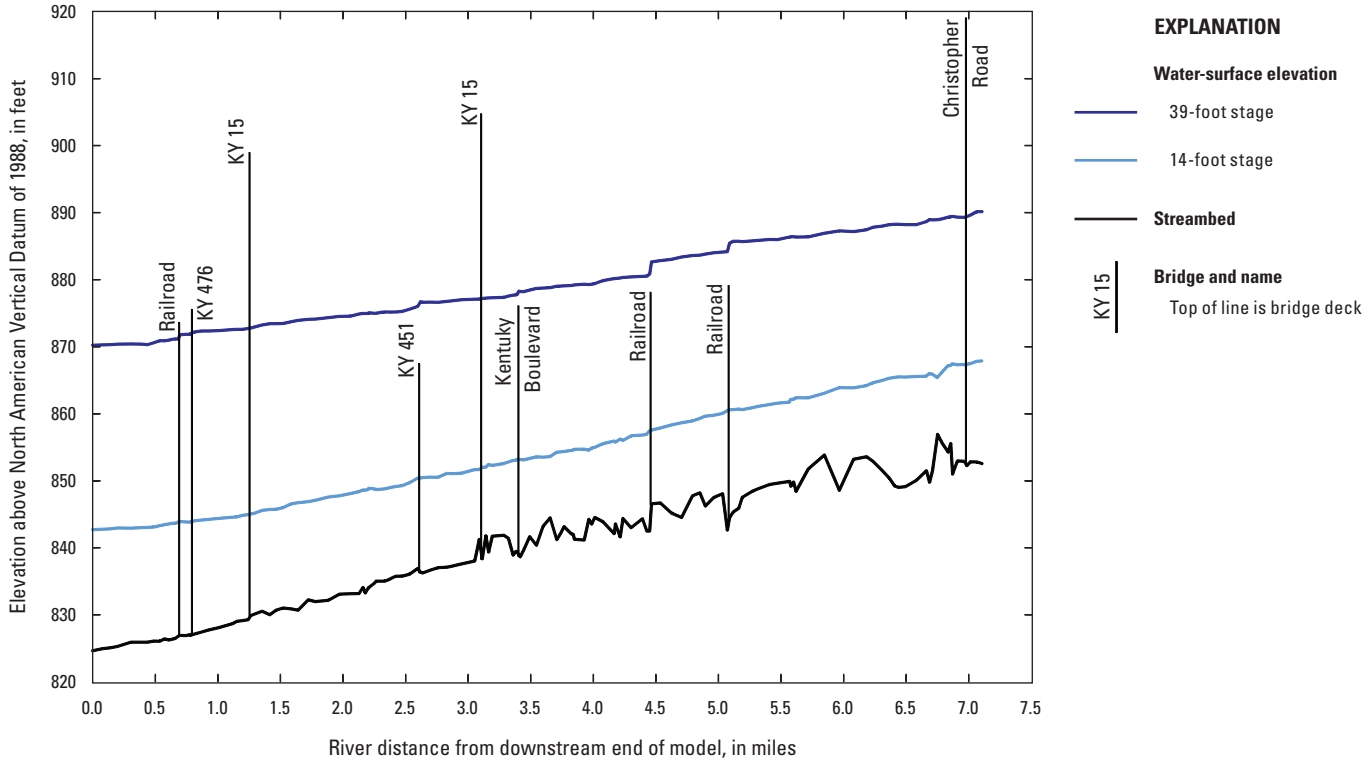

Figure 2. Water-surface profiles for the 7.1-mile study reach of the North Fork Kentucky River at Hazard, Kentucky, corresponding to a discharge at a stage of 14 feet and 39 feet at U.S. Geological Survey streamgage 03277500, which is on the upstream side of the Kentucky Boulevard bridge.

the flood extent were deleted. The flood-inundation areas are overlaid on high-resolution, georeferenced aerial photographs of the study area. Bridges were closely reviewed and are shown as shaded (inundated and likely impassable) or not shaded (dry and passable) to facilitate emergency planning and use. Bridge surfaces are shown as noninundated up to the lowest flood stage that either intersects the lowest structural chord of the bridge or completely inundates one or both approaches to the bridge. In these latter circumstances, the bridge surface is depicted as being inundated.

Estimates of water depth can be obtained from the depth-grid data that are included with the presentation of the flood maps on an interactive USGS mapping application described in the following section, "Flood-Inundation Map Delivery." The flood-inundation map corresponding to the highest simulated water-surface profile, a stage of 39 ft, is presented in figure 3.

Flood-Inundation Map Delivery

The flood-inundation maps from this study depict estimates of the areal extent and depth of flooding corresponding to selected water levels (stages) at USGS streamgage 03277500, North Fork Kentucky River at Hazard, Ky. The current study documentation is available online at the USGS Publications Warehouse (https://pubs.er.usgs.gov/publication/sir20185122). Also, a Flood Inundation Mapping Science website (USGS, 2018d) has been established to make USGS flood-inundation study information available to the public; that site links to a mapping application (https://wimcloud.usgs.gov/apps/FIM/FloodInundationMapper.html) that presents map libraries and provides detailed information on flood extent and depths for selected sites. The mapping application enables the production of customized flood-inundation maps from the map library for the North Fork Kentucky River at Hazard, Ky. A link on the map library website connects to the USGS National Water Information System (USGS, 2018a), which presents the current stage and streamflow at USGS streamgage 03277500 to which the flood-inundation maps are referenced. A second link connects to the NWS AHPS site (NWS, 2018a) so that the user can obtain applicable information on forecasted peak stage. The estimated flood-inundation maps are displayed in sufficient detail so that preparations for flooding and decisions for emergency response can be performed efficiently. Depending

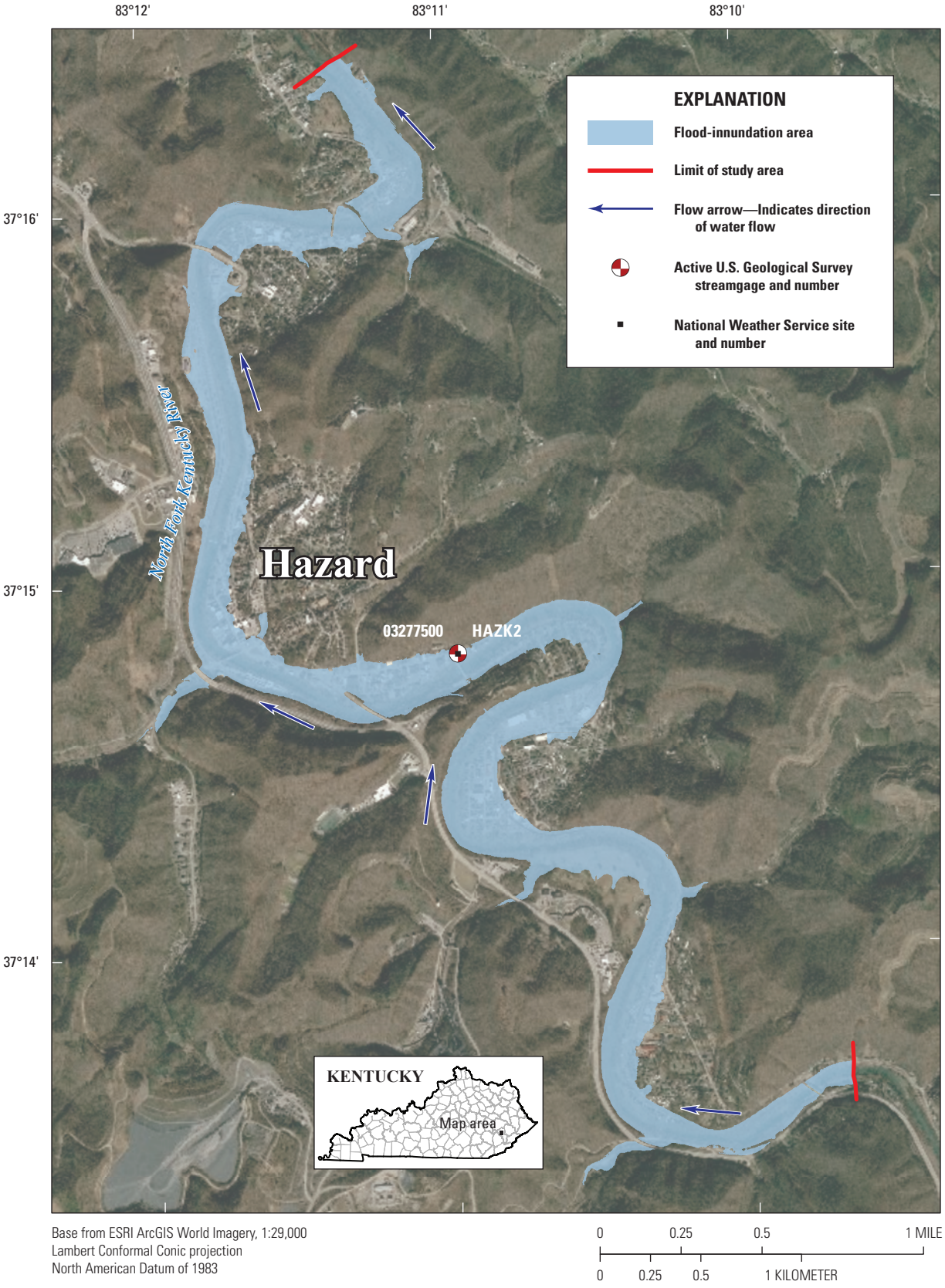

Figure 3. Flood-inundation map for the North Fork Kentucky River at Hazard, Kentucky, corresponding to a stage of 39 feet at the U.S. Geological Survey streamgage (station number 03277500).

on the flood magnitude, roadways and bridges are shown as shaded (inundated and likely impassable) or not shaded (dry and passable) to facilitate emergency planning and use. A shaded building should not be interpreted to mean that the structure is completely submerged, but rather that bare earth surfaces in the vicinity of the building are inundated. In these instances, the water depth (as indicated in the mapping application by clicking the cursor over an inundated area) near the building would be an estimate of the water level inside the structure, unless flood-proofing measures had been implemented.

Disclaimer for Flood-Inundation Maps

The flood-inundation maps should not be used for navigation, regulatory, permitting, or other legal purposes. The USGS provides these maps "as-is" for a quick reference, emergency planning tool but assumes no legal liability or responsibility resulting from the use of this information.

Uncertainties and Limitations Regarding Use of Flood-Inundation Maps

Although the flood-inundation maps represent the boundaries of inundated areas with a distinct line, some uncertainty is associated with these maps (Bales and Wagner, 2009). The flood boundaries shown were estimated on the basis of water stages and streamflows at a single USGS streamgage. Water-surface elevations along the stream reach were estimated by steady-state hydraulic modeling, assuming unobstructed flow, and using streamflows and hydrologic conditions anticipated at the USGS streamgage. The hydraulic model reflects the land-cover characteristics and any bridge, dam, levee, or other hydraulic structures existing as of May 2016. Unique meteorological factors (timing and distribution of precipitation) may cause actual streamflows along the modeled reach to vary from those assumed during a flood, which may lead to deviations in the water-surface elevations and inundation boundaries shown. Additional areas may be flooded because of unanticipated conditions such as changes in the streambed elevation or roughness, backwater into major tributaries along a main-stem river, or backwater from localized debris or ice jams. The accuracy of the floodwater extent portrayed on these maps will vary with the accuracy of the DEM used to simulate the land surface.

If this series of flood-inundation maps will be used in conjunction with NWS river forecasts, the user should be aware of additional uncertainties that may be inherent or factored into NWS forecast procedures. The NWS uses forecast models to estimate the quantity and timing of water flowing through selected stream reaches in the United States. These forecast models (1) estimate the amount of runoff generated by precipitation and snowmelt, (2) simulate the movement of floodwater as it proceeds downstream, and (3) predict the flow and stage (and water-surface elevation) for the stream at a given location (AHPS forecast point) throughout the forecast period (every 6 hours and 3 to 5 days out in many locations). For more information on AHPS forecasts, please refer to https://water.weather.gov/ahps/forecasts.php. Additional uncertainties and limitations pertinent to this study may be described elsewhere in this report.

Summary

A series of 26 digital flood-inundation maps were developed in cooperation with the Kentucky Silver Jackets and the U.S. Army Corps of Engineers Louisville District for the North Fork Kentucky River at Hazard, Kentucky, extending 3.7 miles upstream and 3.4 miles downstream from U.S. Geological Survey (USGS) streamgage 03277500. The flood-inundation maps were developed by using the U.S. Army Corps of Engineer's HEC–RAS, HEC–GeoRAS, and RAS Mapper programs to compute water-surface profiles and to delineate estimated flood-inundation areas and depths of flooding for selected stream stages. The HEC–RAS hydraulic model was calibrated to the current stage-discharge relation (USGS, rating no. 24.0) at the North Fork Kentucky River streamgage at Hazard. The model was used to compute 26 water-surface profiles for flood stages at 1-foot (ft) intervals referenced to the streamgage datum and ranging from approximately bankfull (14 ft) to the highest even-foot increment stage (39 ft) of the current stage-discharge rating curve. The simulated water-surface profiles were then combined with a geographic information system digital elevation model derived from light detection and ranging data to delineate estimated flood-inundation areas as shapefile polygons and depth grids for each profile. These flood-inundation polygons were overlaid on high-resolution, georeferenced aerial photographs of the study area. The flood maps show estimated (shaded) flood-inundation areas of the study area for stream stages from 14 ft to 39 ft at the North Fork Kentucky River at Hazard streamgage. The flood maps are available through a mapping application that can be accessed on the USGS Flood Inundation Mapping Science website (https://water.usgs.gov/osw/flood_inundation).

Interactive use of the maps on the USGS mapping application can give users a general indication of depth of water at any point by using the mouse cursor to click within the shaded areas. The mapping application enables the production of customized flood-inundation maps from the map library for the North Fork Kentucky River at Hazard, Kentucky. These maps, in conjunction with the near-real-time stage data from the USGS streamgage 03277500 and National Weather Service Advanced Hydrologic Prediction Service flood-stage forecasts, will help to guide the general public in taking individual safety precautions and will provide emergency management personnel with a tool to efficiently manage emergency flood operations and postflood recovery efforts.

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