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Flood-Inundation Maps for the East Fork White River near Bedford, Indiana

Pamphlet to accompany

Scientific Investigations Map 3274

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

Cover: Panoramic photo and bridge shots of East Fork White River, Indiana. (Photo by Jeff Salas and Chad Menke)

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By Kathleen K. Fowler

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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2. 21.00 feet and an elevation of 494.20 feet
3. 22.00 feet and an elevation of 495.20 feet
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Conversion Factors

Inch/Pound to SI

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)

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 North American Vertical Datum of 1988 (NAVD 88).

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

Flood-Inundation Maps for the East Fork White River near Bedford, Indiana

By Kathleen K. Fowler

Abstract

Digital flood-inundation maps for an 11.8-mile reach of the East Fork White River near Bedford, Indiana (Ind.) were created by the U.S. Geological Survey (USGS) in cooperation with the Indiana Department of Transportation. The inundation maps, which can be accessed through the USGS Flood Inundation Mapping Science Web site at *http://water.usgs.gov/osw/flood_inundation/,* depict estimates of the areal extent and depth of flooding corresponding to selected water levels (stages) at USGS streamgage 03371500, East Fork White River near Bedford, Ind. Current conditions for estimating near-real-time areas of inundation using USGS streamgage information may be obtained on the Internet at *http://waterdata.usgs.gov/in/nwis/uv?site_no=03371500*. In addition, information has been provided to the National Weather Service (NWS) for incorporation into their Advanced Hydrologic Prediction Service (AHPS) flood warning system (*http://water.weather.gov/ahps/*). The NWS forecasts flood hydrographs at many places that are often colocated with USGS streamgages, including the East Fork White River near Bedford, Ind. NWS-forecasted peak-stage information may be used in conjunction with the maps developed in this study to show predicted areas of flood inundation.

For this study, flood profiles were computed for the East Fork White River reach by means of a one-dimensional step-backwater model. The hydraulic model was calibrated by using the most current stage-discharge relations at USGS streamgage 03371500, East Fork White River near Bedford, Ind., and documented high-water marks from the flood of June 2008. The calibrated hydraulic model was then used to determine 20 water-surface profiles for flood stages at 1-foot intervals referenced to the streamgage datum and ranging from bankfull to the highest stage of the current stage-discharge rating curve. The simulated water-surface profiles were then combined with a geographic information system (GIS) digital elevation model (DEM, derived from Light Detection and Ranging (LiDAR) data having a 0.593-foot vertical accuracy) in order to delineate the area flooded at each water level.

The availability of these maps, along with Internet information regarding current stage from the USGS streamgage near Bedford, Ind., and forecasted stream stages from the NWS, 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 Bedford, Ind. is a community with an estimated population of 13,413 (U.S. Census Bureau, 2010). Bedford has experienced severe flooding numerous times, most recently in 2008. Areas most affected by the flooding are along Leatherwood Creek and the East Fork White River, which flows south of the town. Flood plains along the river are moderately developed and contain a mix of residential, commercial, and agricultural areas.

Prior to this study, Bedford officials relied on several information sources to make decisions on how to best alert the public and mitigate flood damages. One source of information is the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for Lawrence County completed in 2004 (Federal Emergency Management Agency, 2010). A second source is USGS streamgage 03371500, East Fork White River near Bedford, Ind., from which current and historical water levels (stage) can be obtained. A third source is the NWS's forecast of peak stage through the AHPS Web site. Two NWS sites are within the study reach. One, BEDI3 East Fork White River at Rivervale, is colocated with the USGS gage 03371500 at the Buddha Road bridge. The other, NWS site BFRI3 East Fork White River at the Bedford Boat Club, is located approximately 10.7 miles downstream of USGS streamgage 03371500. Although USGS stream stage and NWS flood forecast information is particularly useful for residents in the immediate vicinity of a streamgage, it is of limited use to residents farther upstream or downstream because the water-surface elevation is not constant along the entire stream channel. Also, FEMA and State emergency management mitigation teams and property owners typically lack information related to water elevation at locations other than near USGS streamgages or NWS flood-forecast points.

Purpose and Scope

The purpose of this report is to describe the development of a series of estimated flood-inundation maps for the East Fork White River near Bedford, Ind. The maps and other flood information are available on the USGS Flood Inundation Mapping Science Web site and the NWS Advanced Hydrologic Prediction Service Web site. Internet users can select estimated inundation maps that correspond to (1) flood stages at USGS streamgage 03371500 and (2) the NWS forecasted peak stage.

The scope of the study was limited to the East Fork White River reach extending 1.1 mi upstream of USGS streamgage 03371500 at the Buddha Road bridge and 10.7 mi downstream of the streamgage (fig. 1). Tasks specific to construction of the maps were (1) compilation of flow data from streamgage 03371500, (2) collection of topographic data and geometric data (for structures/bridges) throughout the study reach, (3) estimation of energy-loss factors (roughness coefficients) in the stream channel and flood plain, (4) computation of water-surface profiles by use of the U.S. Army Corps of Engineers' HEC–RAS computer program (U.S. Army Corps of Engineers, 2010), (5) production of estimated flood-inundation maps at various stream stages by use of the U.S. Army Corps of Engineers' HEC–GeoRas computer program (U.S. Army Corps of Engineers, 2009) and a GIS, and (6) development of a Web interface that links to USGS real-time streamgage information and NWS forecasted peak stage to facilitate the display of user-selected flood-inundation maps on the Internet.

Methods used are generally cited from previously published reports. If techniques varied significantly from previously documented methods due to local hydrologic conditions or available data, they are described in detail in this report. Twenty maps were produced for water levels referenced to the stage at USGS streamgage 03371500, East Fork White River near Bedford, Ind., and ranging from approximately bankfull to the highest stage on the current stage-discharge rating curve.

Study Area Description

The East Fork White River near the city of Bedford is in south central Indiana in the Mitchell Plateau physiographic section of the Southern Hills and Lowlands Region (Gray, 2000). The drainage area is 3,858 mi^2 at the upstream end of the study reach, 3,861 mi^2 at USGS streamgage 03371500, East Fork White River near Bedford, and 4,055 mi^2, at the downstream extent of the study reach. The headwaters originate in Henry County and the stream flows generally southward before turning a more westerly direction about 18 mi southeast of Bedford. There are no significant tributaries to the East Fork White River as it flows through the study reach. The basin terrain is generally a rolling clay-covered upland of low relief and large areas of karst, entrenched by major valleys (Gray, 2000). The study reach is approximately 11.8 mi long and has an average top-of-bank channel width of about 320 ft and an average channel slope of 0.0002 (1.2 ft/mi). Most of the land contiguous to the study reach is either agricultural or natural areas with much smaller portions having residential development. The population of Bedford has declined in recent years from 13,858 in 2000 to 13,413 in 2010 (U.S. Census Bureau, 2010). The main channel within the study reach has two major road crossings and one railroad crossing that lie within the channel or the adjacent flood plain.

Previous Studies

The current FIS for Lawrence County (Federal Emergency Management Agency, 2010) was completed by Christopher B. Burke Engineering, Ltd., in 2004. The study used approximate methods to determine flood hazards for 39 of the county's streams. The East Fork White River was one of the streams studied by approximate methods, and the resultant Special Flood Hazards Area map was used for comparison to the maps created in this study. An estimate of the peak discharge for the 1.0-percent annual exceedance probability flood at the Bedford gage on the East Fork White River was obtained from USGS StreamStats for Indiana (U.S. Geological Survey, 2012) and is listed in table 1.

Table 1. 1.0-percent annual exceedance probability peak-discharge estimate and drainage area for USGS streamgage 03371500, East Fork White River near Bedford, Indiana.

[mi^2, square miles; ft^3/s, cubic feet per second]

Discharge estimate (ft^3/s)	Drainage area (mi^2)
108,000*	3,861

* From USGS StreamStats for Indiana (U.S. Geological Survey, 2012).

Constructing Water-Surface Profiles

The water-surface profiles used to produce the 20 flood-inundation maps in this study were simulated by using HEC–RAS, version 4.1.0 (U.S. Army Corps of Engineers, 2010). 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.

Hydrologic and Steady-Flow Data

The study area hydrologic network consists of one streamgage (fig. 1; table 2), which has been in operation since 1939. Water level (stage) is measured continuously at this site, and continuous records of streamflow are computed. All water-surface elevations are referenced to the North American

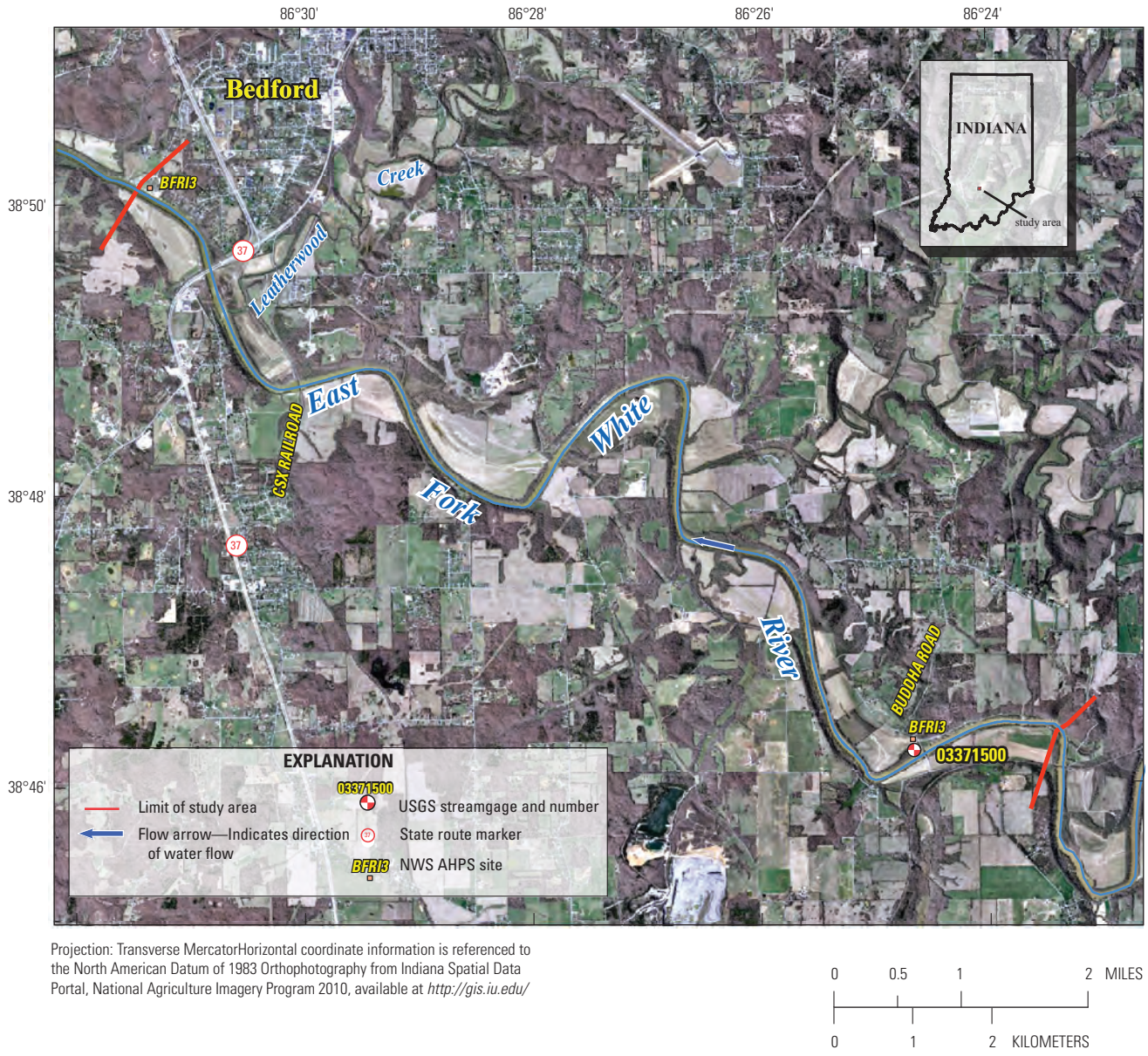

Figure 1. Location of study reach for the East Fork White River, location of USGS streamgage 03371500, and National Weather Service forecast sites BEDI3 and BFRI3.

Vertical Datum of 1988 (NAVD 88). The gage is equipped with a satellite radio transmitter that allows data to be transmitted routinely on the Internet within an hour of collection. High-water marks were documented after the flood that occurred in 2008 and also were used for model calibration.

Steady-flow data consisted of flow regime, boundary conditions (normal depth), and peak-discharge information. The steady-flow data for the model were obtained from field measurements of streamflow at USGS streamgage 03371500, East Fork White River near Bedford, Ind. All computations were based on discharge values with known stages from actual streamflow measurements or stage-discharge relations.

Topographic/Bathymetric Data

Forty-two channel cross sections were developed from USGS field surveys that were conducted in August 2012; these cross sections provide detailed channel-elevation data below the water surface and were collected by using hydroacoustic instrumentation to measure depth and Differential Global Positioning System (DGPS) instrumentation to determine horizontal position. A total of 37 synthetic cross sections were generated by use of the DEM. In-channel data for all synthetic cross sections were estimated by use of a bathymetry mesh tool using interpolation from cross-sectional data surveyed in the field (Merwade and others, 2008).

Table 2. USGS streamgage and miscellaneous site information for study basin, East Fork White River near Bedford, Indiana.

[mi², square miles; ft, feet; NAD 83, North American Datum of 1983; NAVD 88, North American Vertical Datum of 1988]

Streamgage name	Streamgage number	Drainage area (mi²)	Latitude (NAD 83)	Longitude (NAD 83)	Period of record	Datum of gage (ft NAVD 88)	Maximum recorded flood elevation (ft NAVD 88) and date
East Fork White River near Bedford, Indiana	03371500	3,861	38°46'13"	86°24'35"	May 1939 to present	473.20	511.04 on January 9, 2005[1]

[1] Corresponds to a stage of 37.84 ft.

LiDAR data were used to obtain digital elevation data for the portions of the cross sections that were above the water surface at the time of the surveys. The LiDAR data for the East Fork White River near Bedford (Lawrence County LiDAR) were collected for the Indiana Statewide Imagery and LiDAR Program and processed by Woolpert, Inc., of Dayton, Ohio, in 2011 (Woolpert, Inc., 2011). The original LiDAR data have horizontal resolution of 4.9 ft (1.5 meters). The vertical accuracy is 0.593 ft (18.074 centimeters) at a 95-percent confidence level. By these criteria, the LiDAR data support production of 2-ft contours (Dewberry, 2012). Although a finer resolution of the DEM was possible given the accuracy of the LiDAR data, the DEM data were resampled to a grid-cell size of 10 ft by 10 ft to decrease the GIS processing time. This resulted in a vertical accuracy of plus or minus 1 ft.

Various manmade drainage structures (bridges, culverts, roadway embankments, levees, and dams) in and along the East Fork White 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 three bridges were measured and surveyed in the field concurrently with the stream-channel surveys. A detailed description of the methods used to acquire and process the topographic and bathymetric data can be found in Bales and others (2007).

Energy-Loss Factors

Field observations and high-resolution aerial photographs obtained from the Indiana Spatial Data Portal, National Agricultural Imagery Program 2010 (*http://gis.iu.edu/*) were used to select initial channel and flood-plain friction coefficients. These friction coefficients, commonly called Manning's roughness coefficients or Manning's *n* values, account for energy (friction) loss in the model (Arcement and Schneider, 1989). The final Manning's *n* values ranged from 0.035 to 0.037 for the main channel and 0.09 to 0.13 for the overbank areas modeled in this analysis.

Model Calibration and Performance

The hydraulic model was calibrated to the most current stage-discharge relation (USGS rating no. 25, July 25, 2008) at USGS streamgage 03371500, East Fork White River near Bedford, Ind., and high-water marks from the flood of 2008. The estimated peak discharge for the 2008 flood was 68,700 ft³/s at an estimated stage of about 34.66 ft at the gage. Model calibration was accomplished by adjusting Manning's *n* values and, in some cases, changing the channel cross section or slope until the results of the hydraulic computations closely agreed with the known flood discharge and stage values. Differences between measured and simulated water levels for measured or rated flows at USGS gaging station 03371500 were less than or equal to 0.17 ft (table 3). Differences between measured and simulated water levels for models calibrated to high-water marks in the study reach from the flood of 2008 were less than or equal to 0.80 ft (table 4). An additional comparison was made to the Indiana Department of Natural Resources' graph of flood profiles for the East Fork White River (Basin 21) to verify the beginning slope of the model (Suzie Delay, Indiana Department of Natural Resources, written commun., 2012). The results demonstrate that the model is capable of simulating accurate water levels over a wide range of flows in the basin. Details on techniques used in model development and calibration can be found in Bales and others (2007).

Development of Water-Surface Profiles

Profiles were developed for a total of 20 stages at 1-ft intervals between 20 ft and 39 ft as referenced to USGS streamgage 03371500, East Fork White River near Bedford, Ind. Discharges corresponding to the various stages were obtained from the most current stage-discharge relation (rating no. 25, July 25, 2008) at the East Fork White River gage. All bridge surfaces were displayed as inundated regardless of the actual water-surface elevation in relation to the lowest structural chord of the bridge or the bridge deck.

Table 3. Comparison of water-surface elevations at USGS streamgage 03371500, East Fork White River near Bedford, Indiana, with water-surface elevations output from the hydraulic model.

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

Stage (ft)	Water-surface elevation from stage-discharge rating (ft, NAVD 88)	Modeled water-surface elevation (ft, NAVD 88)	Elevation difference (ft)
20.00	493.20	493.15	-0.05
21.00	494.20	494.04	-0.16
22.00	495.20	495.07	-0.13
23.00	496.20	496.16	-0.04
24.00	497.20	497.30	0.10
25.00	498.20	498.22	0.02
26.00	499.20	499.24	0.04
27.00	500.20	500.14	-0.06
28.00	501.20	501.14	-0.06
29.00	502.20	502.03	-0.17
30.00	503.20	503.09	-0.11
31.00	504.20	504.15	-0.05
32.00	505.20	505.32	0.12
33.00	506.20	506.34	0.14
34.00	507.20	507.08	-0.12
35.00	508.20	508.22	0.02
36.00	509.20	509.14	-0.06
37.00	510.20	510.35	0.15
38.00	511.20	511.14	-0.06
39.00	512.20	512.08	-0.12

Discharges for all profiles (table 5) were selected with the assumption that within the 11.8-mi study reach there are no significant tributary or groundwater inflows. The discharges were estimated to be uniform and steady throughout the study reach.

Inundation Mapping

Flood-inundation maps were created for a reach of the East Fork White River near Bedford, Ind. The maps were created in a GIS by combining the water-surface profiles and DEM data. The DEM data for Bedford (Lawrence County LiDAR) were collected for the Indiana Statewide Imagery and LiDAR Program. Estimated flood-inundation boundaries for each simulated profile were developed with HEC–GeoRAS software (U.S. Army Corps of Engineers, 2009). HEC–GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS using a graphical user interface. The interface allows the preparation of geometric data for import into HEC–RAS and processes simulation results exported from HEC–RAS (U.S. Army Corps of Engineers, 2010). USGS personnel then modified the HEC–GeoRAS results to ensure a hydraulically reasonable transition of the boundary between modeled cross sections relative to the contour data for the land surface (Whitehead and Ostheimer, 2009).

The resulting inundation maps have a vertical accuracy of about plus or minus 1.0 ft. The maps show estimated flood-inundated areas overlaid on high-resolution, georeferenced aerial photographs of the study area for each of the water-surface profiles that were generated by the hydraulic model.

East Fork White River near Bedford, Indiana, Flood-Inundation Maps on the Internet

The flood-inundation maps and current study documentation are available online at the USGS Publications Warehouse (*http://pubs.usgs.gov/sim/3274*). Also, a Flood Inundation Mapping Science Web site has been established to provide a portal for USGS flood-inundation study information to the public at *http://water.usgs.gov/osw/flood_inundation/*. That Web portal has a link (*http://wim.usgs.gov/FIMI/FloodInundationMapper.html*) to interactive online map libraries that can be downloaded in several commonly used electronic file formats. At the map library site, each stream reach displayed contains further links to NWISWeb graphs of the current stage and streamflow at USGS streamgage 03371500 to which the inundation maps are referenced. A link also is provided to the NWS AHPS site (*http://water.weather.gov/ahps/*) so that the user can obtain applicable information on forecasted peak stage. The estimated flood-inundation maps are displayed in sufficient detail to note the extent of flooding with respect to individual structures so that preparations for flooding and decisions for emergency response can be performed efficiently. All bridges are displayed as inundated (shaded) regardless of the flood magnitude. Buildings that are shaded do not reflect inundation but denote that bare earth surfaces in the vicinity of the buildings are inundated. When the water depth (as indicated in the Web mapping application by holding the cursor over an inundated area) adjacent to the building of interest exceeds that building's height, the structure can be considered fully submerged.

Disclaimer for Flood-Inundation Maps

Inundated areas shown 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.

Table 4. Comparison of hydraulic-model output and surveyed high-water-mark elevations from the flood of June 2008 for the East Fork White River near Bedford, Indiana.

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

Location	High-water mark field identification number[1]	High-water mark elevation (ft, NAVD 88)	Model water-surface elevation (ft, NAVD 88)	Elevation difference (ft)
Downstream side of State Route 37 bridge	143.46	499.41	498.99	-0.42
Downstream side of State Route 37 bridge	143.48	499.11	498.99	-0.12
Upstream side of State Route 37 bridge	143.56	500.01	499.21	-0.80
Downstream side of Buddha Road bridge	153.25	507.61	507.81	0.20
Upstream side of Buddha Road bridge	153.29	507.81	507.92	0.11

[1]Indiana Department of Natural Resources high-water marks for the flood of June 10, 2008 (location in river miles).

Table 5. Stages, water-surface elevations, and corresponding discharge estimates for USGS streamgage 03371500, East Fork White River near Bedford, Indiana, for simulated water-surface profiles.

[ft^3/s, cubic feet per second; NAVD 88, North American Vertical Datum of 1988; sheet numbers correspond to the separate flood-inundation maps available online at *http://pubs.usgs.gov/sim/3274/*]

Sheet number									
1	2	3	4	5	6	7	8	9	10
Stage, in feet above gage datum (elevation, in feet above NAVD 88) associated with the indicated discharge value									
20.0 (493.20)	21.0 (494.20)	22.0 (495.20)	23.0 (496.20)	24.0 (497.20)	25.0 (498.20)	26.0 (499.20)	27.0 (500.20)	28.0 (501.20)	29.0 (502.20)
Discharge (ft^3/s)									
17,070	18,420	20,040	21,810	24,200	26,850	29,850	33,030	36,420	40,000
Sheet number									
11	12	13	14	15	16	17	18	19	20
Stage, in feet above gage datum (elevation, in feet above NAVD 88) associated with the indicated discharge value									
30.0 (503.20)	31.0 (504.20)	32.0 (505.20)	33.0 (506.20)	34.0 (507.20)	35.0 (508.20)	36.0 (509.20)	37.0 (510.20)	38.0 (511.20)	39.0 (512.20)
Discharge (ft^3/s)									
44,150	48,560	53,240	58,200	64,390	71,020	78,100	85,640	93,590	102,000

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. The flood boundaries shown were estimated based on water stages (water-surface elevations) and streamflows at USGS streamgage at 03371500, East Fork White River near Bedford, Ind. Water-surface elevations along the stream reaches were estimated by steady-state hydraulic modeling, assuming unobstructed flow, and using discharges 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 August 2012. Unique meteorological factors (timing and distribution of precipitation) may cause actual discharges along the modeled reach to vary from those assumed during a flood and lead to deviations in the water-surface elevations and inundation boundaries shown. Additional areas may be flooded due to unanticipated conditions such as changes in the streambed elevation or roughness, backwater into 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. Additional uncertainties and limitations pertinent to this study are described elsewhere in this report.

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 see *http://water.weather.gov/ahps/pcpn_and_river_forecasting.pdf*.

Summary

Estimated flood-inundation maps were developed in cooperation with the Indiana Department of Transportation for the East Fork White River near Bedford from 1.1 mi upstream of USGS streamgage 03371500 at the Buddha Road bridge to10.7 mi downstream of the streamgage. These maps, in conjunction with the real-time stage data from the USGS streamgage at East Fork White River near Bedford (sta. no. 03371500) and NWS flood-stage forecasts, will help to guide the general public in taking individual safety precautions and will provide city officials with a tool to efficiently manage emergency flood operations and flood mitigation efforts.

The maps were developed by using the U.S. Army Corps of Engineers' HEC–RAS and HEC–GeoRAS programs to compute water-surface profiles and to delineate estimated flood-inundation areas for selected stream stages. The maps show estimated (shaded) flood-inundation areas overlaid on high-resolution, georeferenced aerial photographs of the study area for stream stages between 20 ft and 39 ft at the East Fork White River streamgage. The maps are available at a USGS Web portal at *http://pubs.usgs.gov/sim/3274/*. Interactive use of the maps by using the mouse cursor to click within the shaded areas can give users a general indication of depth of water at any point.

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