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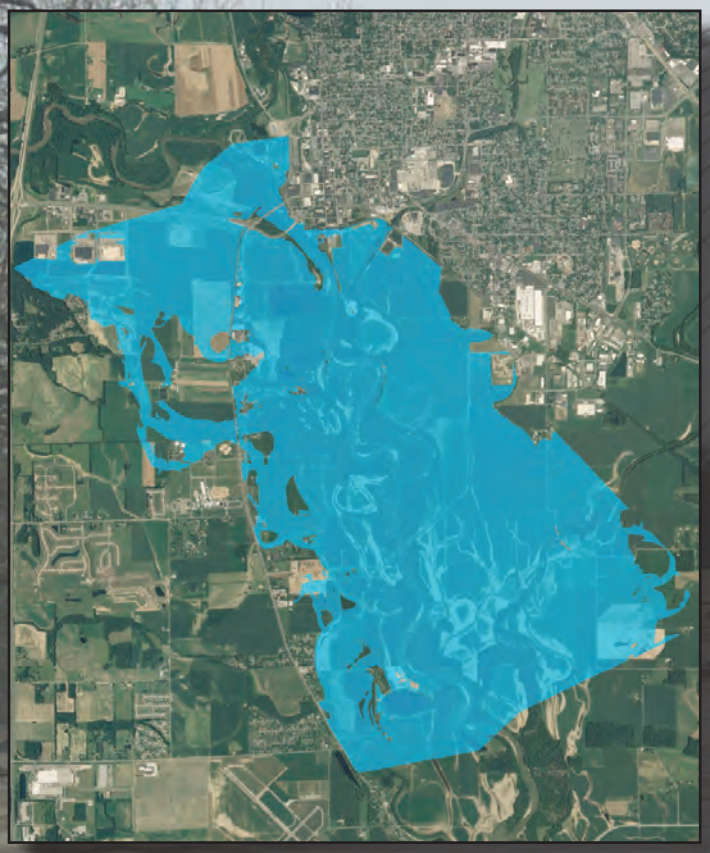
Flood-Inundation Maps for the East Fork White River at Columbus, Indiana



Pamphlet to accompany
Scientific Investigations Map 3255

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

Cover: Background photo is Eastbound Highway 46 arch bridge over East Fork White River in Columbus, Indiana, (by Hieu Nguyen, USGS, January, 2005). Inset image shows flood inundation at stage of 19.00 feet and elevation of 621.7 feet.

Flood-Inundation Maps for the East Fork White River at Columbus, Indiana

By Pamela J. Lombard

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

U.S. Department of the Interior
SALLY JEWELL, Secretary

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

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Acknowledgments

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1. Gage height of 5.00 and an elevation of 607.7 feet
2. Gage height of 6.00 and an elevation of 608.7 feet
3. Gage height of 7.00 and an elevation of 609.7 feet
4. Gage height of 8.00 and an elevation of 610.7 feet
5. Gage height of 9.00 and an elevation of 611.7 feet
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13. Gage height of 17.00 and an elevation of 619.7 feet
14. Gage height of 18.00 and an elevation of 620.7 feet
15. Gage height of 19.00 and an elevation of 621.7 feet

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.0929	square meter (m^2)
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 the 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 at Columbus, Indiana

By Pamela J. Lombard

Abstract

Digital flood-inundation maps for a 5.4-mile reach of the East Fork White River at Columbus, Indiana, from where the Flatrock and Driftwood Rivers combine to make up East Fork White River to just upstream of the confluence of Clifty Creek with the East Fork White River, 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 of flooding corresponding to selected water levels (stages) at USGS streamgage 03364000, East Fork White River at Columbus, Indiana. Current conditions at the USGS streamgage may be obtained on the Internet from the USGS National Water Information System (*http://waterdata.usgs.gov/in/nwis/uv/?site_no=03364000&agency_cd=USGS&amp*). The National Weather Service (NWS) forecasts flood hydrographs for the East Fork White River at Columbus, Indiana at their Advanced Hydrologic Prediction Service (AHPS) flood warning system website (*http://water.weather.gov/ahps/)*, that may be used in conjunction with the maps developed in this study to show predicted areas of flood inundation.

In this study, flood profiles were computed for the stream reach by means of a one-dimensional step-backwater model. The hydraulic model was calibrated by using the most current stage-discharge relation at USGS streamgage 03364000, East Fork White River at Columbus, Indiana. The calibrated hydraulic model was then used to determine 15 water-surface profiles for flood stages at 1-foot (ft) intervals referenced to the streamgage datum and ranging from bankfull to approximately the highest recorded water level at the streamgage. The simulated water-surface profiles were then combined with a geographic information system digital elevation model (derived from Light Detection and Ranging (LiDAR) data), having a 0.37-ft vertical accuracy and a 1.02 ft horizontal 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 at Columbus, Indiana, and forecasted stream stages from the NWS will provide emergency management personnel and residents with information that is critical for flood response activities such as evacuations and road closures as well as for post-flood recovery efforts.

Introduction

The East Fork White River flows south from where it begins at the confluence of the Flatrock and Driftwood Rivers west of the City of Columbus in Bartholomew County, Indiana, through Bartholomew County and then southwest through Lawrence, Jackson, and Martin Counties. It then heads west as it enters Davies County and forms the southern border of Davies County until it joins the White River north of Petersburg, Indiana.

The peak discharge from the highest stage of 17.9 feet (ft) recorded at the East Fork White River at Columbus streamgage occurred in March 1913 and was estimated to be 100,000 cubic feet per second (ft^3/s). The 1913 peak flow estimate was before the period of continuous record at the streamgage location. The measured peak discharges (and stages) for other large flows including the 1937, 1963, 2005, and 2008 floods were 51,000 ft^3/s (15.1 ft), 52,300 ft^3/s (16.23 ft), 57,300 ft^3/s (17.05 ft), and 68,100 ft^3/s (18.61 ft), respectively.

Prior to this study, Columbus officials relied on several information sources (all of which are available on the Internet) to make decisions on how to best alert the public and mitigate flood damages. One source is the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for City of Columbus (Federal Emergency Management Agency, 1996) and the preliminary FIS for Bartholomew County (Federal Emergency Management Agency, written commun., 2012). A second source is U.S. Geological Survey (USGS) streamgage 03364000. East Fork White River at Columbus, Indiana, from which current and historical water levels (stage) can be obtained. A third source is the National Weather Service's (NWS) forecast of peak stage at USGS streamgage 03364000, East Fork White River at Columbus, Indiana, through their Advanced Hydrologic Prediction Service (AHPS) Web site. Although USGS current stage and NWS forecast stage 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 or property owners typically lack information related to how deep the water is at locations other than near USGS streamgage 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 at Columbus, Indiana. The maps and other useful flood information are available on the USGS Flood Inundation Mapping Science Web site. Internet users can select estimated inundation maps that correspond to (1) current stages at the USGS streamgage, (2) NWS forecasted peak stage, or (3) other desired stream stages.

The scope of the study was limited to a 5.4-mile reach of the East Fork White River at Columbus (fig. 1). To develop flood-inundation maps, a hydraulic model of the East Fork White River reach was built that provided water-surface profiles for various flood stages.

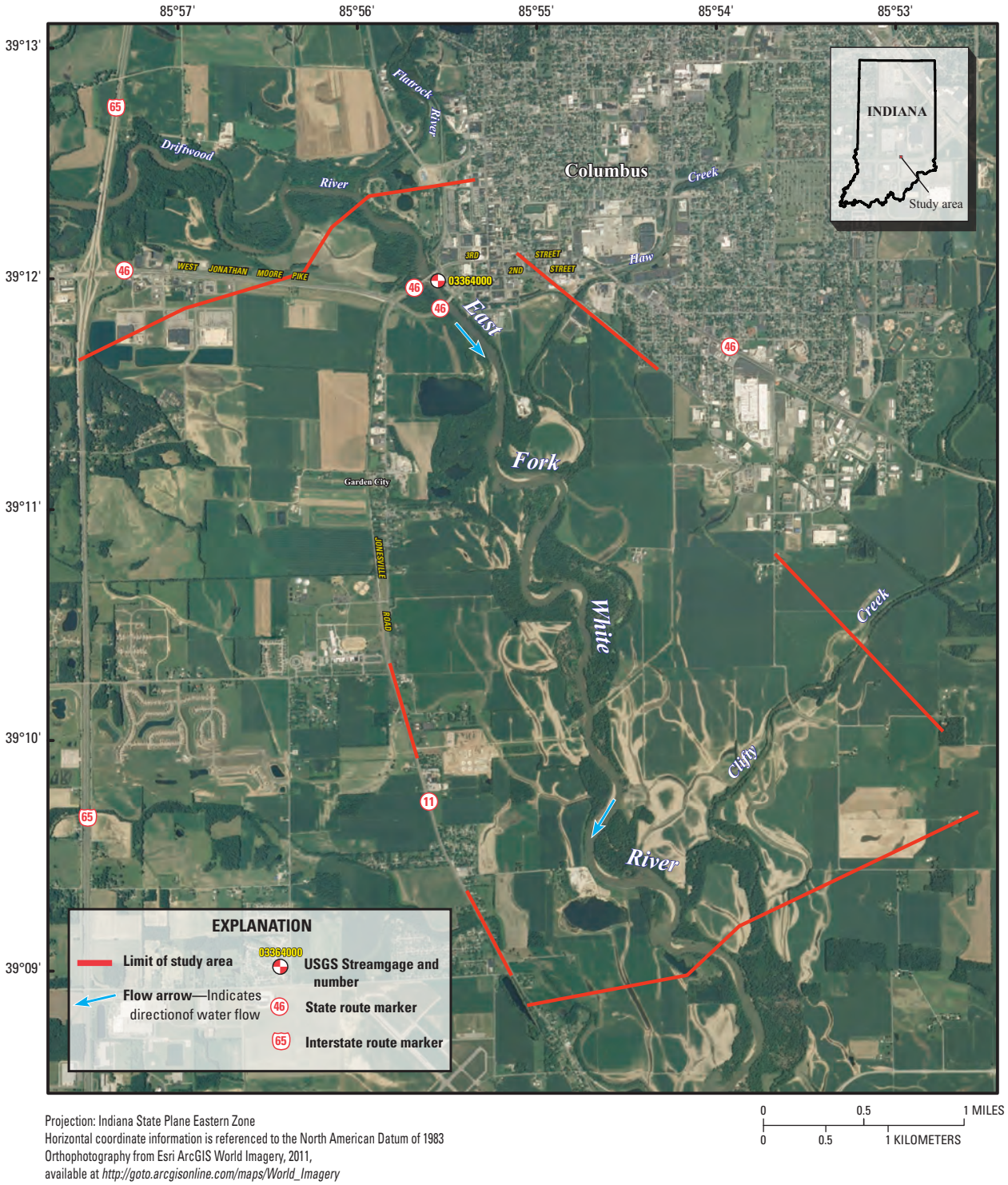
Methods used are generally cited from previously published reports. If techniques varied significantly from previously documented methods owing to local hydrologic conditions or available data, they are described in detail in this report. Maps were produced for water levels referenced to the water-surface elevation (stage) at East Fork White River at Columbus and range from approximately bankfull to the maximum observed water level at the streamgage.

Table 1. U.S. Geological Survey streamgage and miscellaneous site information for the study area, East Fork White River at Columbus, Indiana.

[mi^2, square mile; ft, foot; NAVD 88, North American Vertical Datum of 1988; °, degrees; ', minutes; ", seconds]

Station name	Station number	Drainage area (mi^2)	Latitude	Longitude	Period of record	Maximum recorded flood elevation at gage (ft above NAVD 88) and date
East Fork White River at Columbus	03364000	1,707	39°12'00"	85°55'32"	1948 to 2012	621.33, June 8, 2008.[1]

[1]Current streamgage datum is 602.72 ft above NAVD 88. Conversion from NAVD 88 to National Geodetic Vertical Datum of 1929 is +0.4 ft at this location.



Projection: Indiana State Plane Eastern Zone
Horizontal coordinate information is referenced to the North American Datum of 1983
Orthophotography from Esri ArcGIS World Imagery, 2011,
available at *http://goto.arcgisonline.com/maps/World_Imagery*

Figure 1. Location of study reach for the East Fork White River at Columbus, Indiana, and location of U.S. Geological Survey streamgage and National Weather Service forecast site.

Study Area Description

The City of Columbus is located in central Bartholomew County and is surrounded by unincorporated areas of Bartholomew County. The estimated population of Columbus, according to the 2010 U.S. Census, was 45,578 (U.S. Census Bureau, 2011). The Flatrock River and the East Fork White River border the City of Columbus on the west. The Driftwood River, from the northwest, and the Flatrock River, from the north-northeast, converge and form the East Fork White River near the southwest corner of the city. Haw Creek flows through the City of Columbus and joins the East Fork White River approximately 2 miles (mi) south of the confluence of the Driftwood and Flatrock Rivers. Clifty Creek flows in a southwesterly direction along the extreme eastern part of the city and discharges into the East Fork White River approximately 4 mi downstream from its junction with Haw Creek, and just downstream of the studied reach. Most of the residential properties and the larger part of the business section of the city are located on high ground, but there are commercial and some industrial establishments on the flood plains of the Driftwood and Flatrock Rivers. Development along the flood plains of Clifty Creek and the Flatrock River is partially residential. The flood plains of the Driftwood River and the East Fork White River are primarily agricultural, except for an industrial site along Interstate Highway 65. The Haw Creek flood plain is primarily clear, with a little development consisting of a mixture of industrial, residential, and commercial development.

The drainage area of the East Fork White River is 1,707 square miles (mi^2) at the Columbus streamgage. The basin terrain is generally flat. The study reach is approximately 5.4 mi long and has an average top-of-bank channel width of 240 ft and an average channel slope of 0.0004. The main channel within the study reach has two road crossings and 1 railroad crossing.

Previous Studies

The current FIS for the City of Columbus (Federal Emergency Management Agency, 1996) was completed by the U.S. Army Corps of Engineers for FEMA in 1996. That study provided information on the 10-, 2-, 1-, and 0.2-percent annual exceedance probability water-surface profiles and discharges. Hydrologic and hydraulic information from the 1996 publication will be incorporated into the Bartholomew County publication by FEMA (Federal Emergency Management Agency, 2012, written commun.) (table 2).

Constructing Water-Surface Profiles

The water-surface profiles used to produce the 15 flood-inundation maps in this study were computed 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 steady-state (gradually varied) or unsteady-state flow computation options. The HEC–RAS analysis for this study was done by using the steady-state flow computation option.

Hydrologic and Steady-Flow Data

The study area hydrologic network consists of one USGS streamgage (fig. 1; table 1), which has been in operation since 1948. This gage has a continuous record of measured water level (stage) and computed streamflow. All water-surface elevations are referenced to North American Vertical Datum of 1988 (NAVD 88). Conversion from NAVD 88 to National Geodetic Vertical Datum of 1929 is approximately 0.4 ft at this location. The streamgage is equipped with satellite radio transmitters that allow data to be transmitted routinely on the Internet within 2 hours of collection.

Steady-flow data consisted of flow regime, boundary conditions (normal depth slope was set to 0.0003), and peak discharge information. The steady-flow data for the study reach were obtained from field measurements and stage-discharge rating calculations made by USGS personnel at the East Fork White River at Columbus streamgage.

Topographic and Bathymetric Data

Channel cross sections were developed from USGS field surveys that were conducted in September 2011. Detailed channel depths below the water surface were collected by using hydroacoustic instrumentation, while differential Global Positioning System (DGPS) instrumentation was used to determine horizontal position. Cross-section elevation data were obtained from a digital elevation model (DEM) that was derived from Light Detection and Ranging (LiDAR) data that

Table 2. Estimates of annual exceedance probability peak discharges on the East Fork White River at Columbus, Indiana, station number 03364000 (from Federal Emergency Management Agency, 1996).

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

Annual exceedance probability (percent)	Discharge estimate (ft^3/s)
10	47,000
2	69,000
1	79,000
0.2	105,000

were collected as part of this project during April 2010, by Aero-Metric, Inc., Sheboygan, Wisconsin. Post-processing of these data was completed by Aero-Metric, Inc., on July 14, 2010 (Aero-Metric, Inc., 2010). The original LiDAR data have horizontal accuracy of 1.02 ft (31 centimeters) with horizontal resolution of 3.9 ft (1.2 meters) and vertical accuracy of 0.37 ft at a 95-percent confidence level for the "open terrain" land-cover category (root mean squared error of 0.19 ft (5.8 centimeters)). Although a finer resolution of the DEM was possible given the accuracy of the LiDAR data, the final DEM had a grid-cell size of 10 square feet (ft^2) in order to decrease the geographic information system (GIS) processing time.

Three bridges in Columbus have the potential to affect water-surface elevations during high water along the East Fork White River in the studied reach. To properly account for these features in the model, bridge geometry was taken from a previous HEC-2 step-backwater model (Federal Emergency Management Agency, 1996) and from bridge plans received from Indiana Department of Transportation (IN DOT) (Teresa Hammons, Indiana Department of Transportation, written commun., 2012). All three bridges were verified as current structures with pictures and elevation checks from the DEM and field observations. 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 were used to select initial (pre-calibration) Manning's roughness coefficients ("*n*" values) for energy (friction) loss calculations. Manning's *n* values were determined to be 0.045–0.05 for the main channel, and 0.087 for the overbank areas. It was determined that roughness coefficients varied with stage for this reach of the East Fork White River. Values were increased by a factor of 1.29 or decreased by a factor of 0.81 depending on the flow, and generally increased with increasing flow. Although typically roughness coefficients decrease with increasing flow, the increases could be owing to increased vegetation in the overbanks.

Model Calibration and Performance

The hydraulic model was calibrated to the most current stage-discharge relation at USGS streamgage 03364000, East Fork White River at Columbus, Indiana. Model calibration was accomplished by adjusting Manning's *n* values 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 specified flows were equal to or less than 0.1 ft. 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 15 stages at 1-ft intervals between 5 and 19 ft as referenced to USGS streamgage 03364000, East Fork White River at Columbus, Indiana. Discharges corresponding to the various stages were obtained from the most current stage-discharge relation at the East Fork White River gage, which is in the upper end of the 5.4 mi reach. Although Haw Creek enters East Fork White River within the study reach, its drainage area is only 3.2 percent of the East Fork White River drainage area; thus, it was considered negligible in terms of additional flow during a flood. Discharges for each profile were held constant throughout the reach (table 3). Clifty Creek enters East Fork White River downstream of the studied reach and thus was not included in the model or mapping.

Table 3. Stages (elevations referenced to streamgage datum and to NAVD 88) with corresponding discharge estimates at the streamgage at East Fork White River at Columbus, Indiana, for simulated water-surface profiles.

[NAVD 88, North American Vertical Datum of 1988; ft^3/s, cubic foot per second]

Stage (feet above gage datum)	Elevation (feet, NAVD 88)	Discharge (ft^3/s)
5	607.7	10,160
6	608.7	11,460
7	609.7	13,030
8	610.7	14,600
9	611.7	16,800
10	612.7	20,480
11	613.7	24,540
12	614.7	28,980
13	615.7	33,810
14	616.7	39,020
15	617.7	44,620
16	618.7	50,620
17	619.7	57,000
18	620.7	63,800
19	621.7	71,000

Inundation Mapping

Flood-inundation maps were created for the reach surrounding USGS streamgage 03364000, which is currently (2012), an NWS flood-forecast point. The maps were created in a GIS by combining the water-surface profiles and DEM data. The DEM data were derived from LiDAR data that had a horizontal accuracy of 1.02 ft and a vertical accuracy of 0.37 ft. 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 by 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 throughout the reach. The resulting inundation maps have a vertical accuracy of about 1 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, Indiana, Flood-Inundation Maps on the Internet

A USGS Flood Inundation Mapping Science World Wide Web portal has been established by the USGS to provide estimated flood-inundation information to the public (see *http://water.usgs.gov/osw/flood_inundation/*). The maps and data from this study showing the extent of inundated areas can be downloaded in two electronic file formats from that portal: (1) GIS shapefile format, and (2) Portable Document Format (PDF). Users can print out formatted maps quickly or create a customized map using available GIS data layers. In addition, downloadable GIS raster files showing the depth of flooded areas are available at the web portal. All PDF maps show aerial photography beneath the flood layers. Each stream reach displayed on the Web site contains links to NWISWeb graphs of the current stage and stream-flow at USGS streamgage 03364000, East Fork White River at Columbus, Ind., to which the inundation maps are referenced. A link also is provided to the NWS Advanced Hydrologic Prediction Service (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.

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.

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 03364000, East Fork White River at Columbus, Indiana. 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, bridges, and other hydraulic structures existing as of September, 2011. 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 owing to 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 (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

A series of estimated flood-inundation maps were developed in cooperation with the Indiana Department of Transportation for a 5.4-mile reach of the East Fork White River Columbus, Indiana, from the confluence of the Flatrock and Driftwood Rivers to just upstream of the confluence of Clifty Creek. These maps, available at a U.S. Geological Survey (USGS) Web portal (*http://water.usgs.gov/osw/flood_inundation/*). These maps, in conjunction with the real-time stage data from USGS streamgage 03364000, East Fork White River at Columbus, Indiana, and National Weather Service 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 5 and 19 feet at the East Fork White River streamgage. GIS Shapefiles showing the extent of the inundated area, and GIS raster files showing the depth of the inundated areas are also available for download at the USGS web portal.

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