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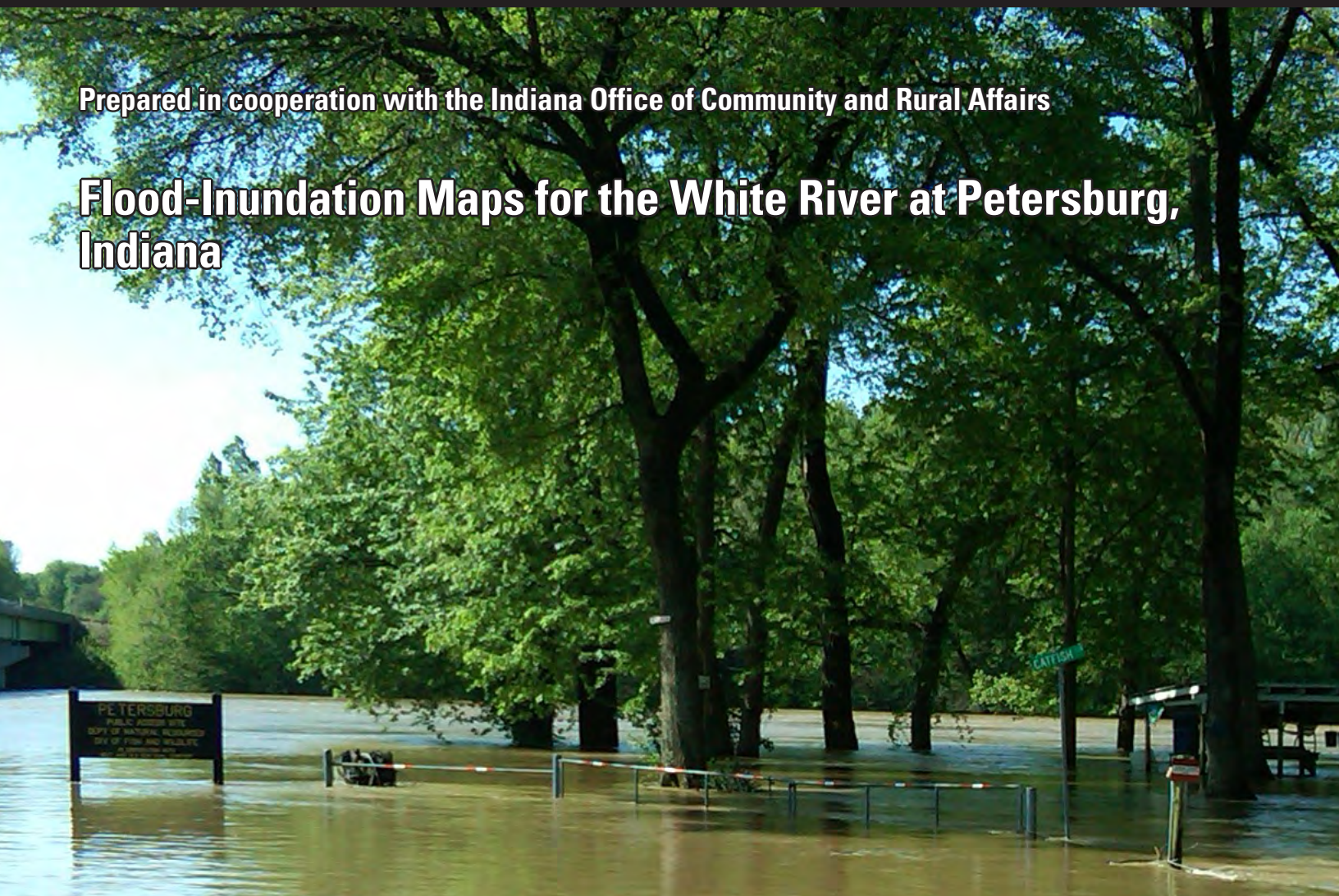
Flood-Inundation Maps for the White River at Petersburg, Indiana



Scientific Investigations Report 2015–5107

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

Front cover: Boat ramp on White River at Petersburg, Indiana, April 28, 2011. Photo by Larry Myers, U.S. Geological Survey.

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

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

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Conversion Factors

Inch/Pound 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)

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).

Acknowledgments

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Flood-Inundation Maps for the White River at Petersburg, Indiana

By Kathleen K. Fowler

Abstract

Digital flood-inundation maps for a 7.7-mile reach of the White River at Petersburg, Indiana, were created by the U.S. Geological Survey (USGS), in cooperation with the Indiana Office of Community and Rural Affairs. 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 the USGS streamgage at White River at Petersburg, Ind. (03374000). Near-real-time stages at this streamgage may be obtained from the USGS National Water Information System at http://waterdata.usgs.gov/ or the National Weather Service (NWS) Advanced Hydrologic Prediction Service at http:/water.weather.gov/ahps/, which also forecasts flood hydrographs at this site (PTRI3).

Flood profiles were computed for the White River at Petersburg 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 most current stage-discharge relations at the White River at Petersburg, Ind., and the White River above Petersburg, Ind. (03373890), gages. The calibrated hydraulic model was then used to compute 18 water-surface profiles for flood stages at approximately 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 digital elevation model 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 White River at Petersburg, Ind., and forecasted stream stages from the NWS 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 city of Petersburg, Indiana, is a community in Pike County, with an estimated population of 2,383 (U.S. Census Bureau, 2010). Petersburg and the surrounding area have experienced flooding numerous times, most recently in 2005, 2008, and 2011. The majority of flood damages in the Petersburg area have occurred along the White River, which flows on the north side of the town (Federal Emergency Management Agency, 1984). During flood events, some evacuations are necessary in low areas in the northeast part of the city and some local roads are impassable. Another potential problem from flooding is the halting of rail traffic to the power-generating plant northeast of the city and flooding in parts of the plant property. In addition, agricultural lands surrounding the city have potential for flooding as embankments are overtopped. Flood plains along the river are moderately developed and contain a mix of residential, commercial, and agricultural areas.

Prior to this study, emergency responders in Petersburg relied on several information sources 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 Knox County (Federal Emergency Management Agency, 1984). White River forms the boundary between Knox County and Pike County, in which Petersburg is located. A second source of information is the U.S. Geological Survey (USGS) streamgage, White River at Petersburg, Ind. (03374000), from which current (U.S. Geological Survey, 2014a) and historical (U.S. Geological Survey, 2014b) water levels (stage) and discharges can be obtained. A third source is the National Weather Service (NWS) Advanced Hydrologic Prediction Service (AHPS) Web site http://water.weather.gov/ahps2/hydrograph/ptri3, which issues forecasts of stage at the USGS streamgage (National Weather Service, 2014a).

Although the current stage at a USGS streamgage 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 reach. 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 previously might have disregarded. In 2013–14, the USGS, in cooperation with the Indiana Office of Community and Rural Affairs, conducted a project to produce a library of flood-inundation maps for the White River at Petersburg.

Purpose and Scope

This report describes the development of a series of estimated flood-inundation maps for the White River at Petersburg, 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 streamgage 03374000 and (2) the NWS forecasted stages at the NWS site PTRI3. The scope of the study was limited to the White River reach extending 3.7 miles (mi) upstream and 4.0 mi downstream from streamgage 03374000 at the State Highway 61 bridge (fig. 1).

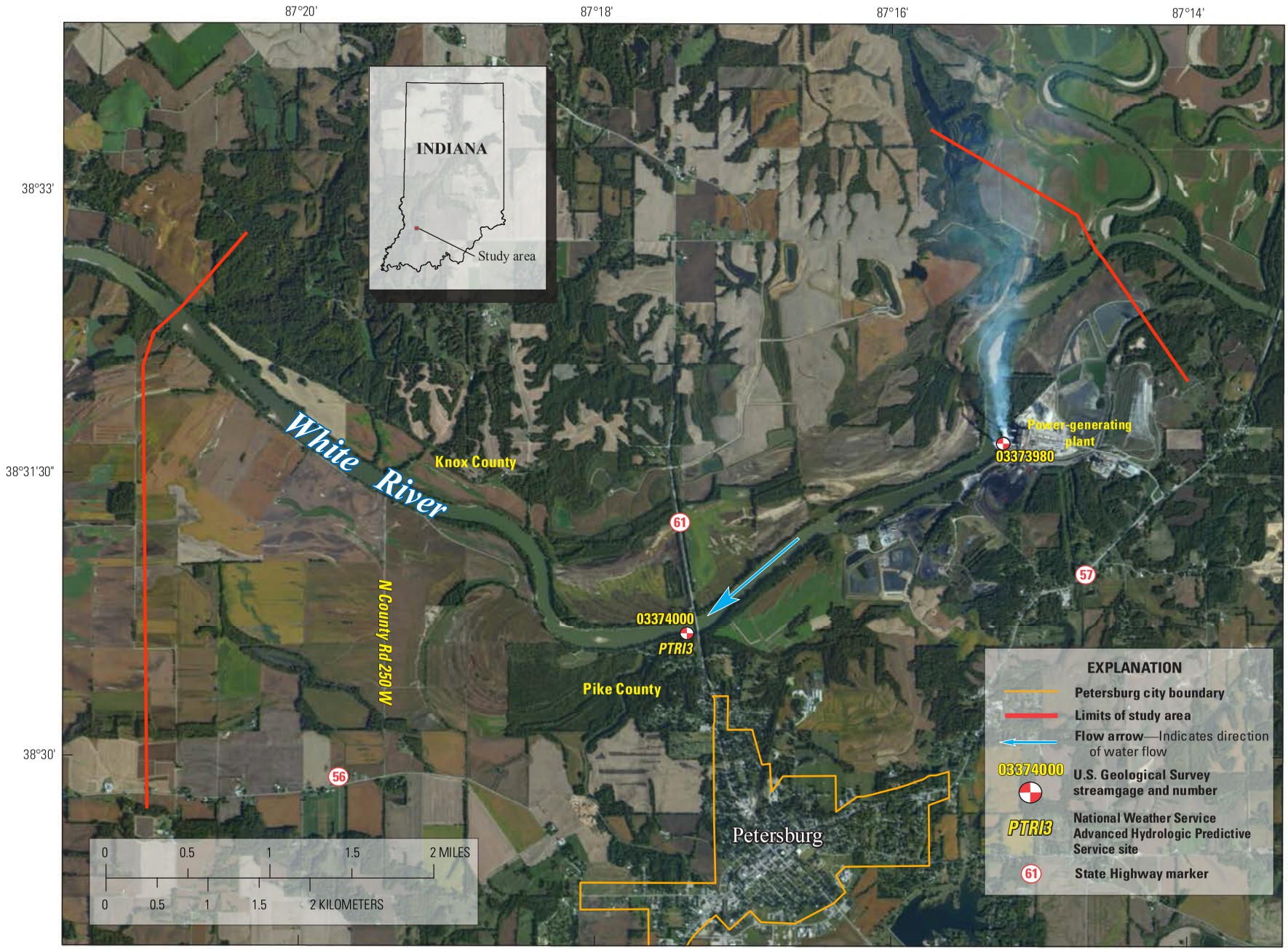
The flood-inundation maps were produced for flood levels referenced to the stage recorded at streamgage 03374000 (table 1); the streamgage is on the downstream side of the State Highway 61 bridge. The maps cover a range in stage from 12 to 29 feet (ft). The 12-ft stage is approximately bankfull and is defined by National Weather Service (2014b) 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 major flood stage, as determined by the NWS, is 26 ft. The 29-ft stage is the highest stage on the most recent stage-discharge rating curve (updated August 5, 2008). During a recent flood at Petersburg, June 12, 2008, the stage was 26.96 ft, the highest recorded stage since 1937 (U.S. Geological Survey, 2014c).

Table 1. U.S. Geological Survey (USGS) streamgage information for the White River at Petersburg, Indiana (station number 03374000), and the White River above Petersburg, Indiana (station number 03373980).

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

Streamgage name	Streamgage number	Drainage area (mi^2)	Latitude (NAD 83)	Longitude (NAD 83)	Period of record	Datum of gage (NAVD 88)	Maximum recorded flood elevation (NAVD 88) and date	Maximum discharge, in ft^3/s, and date	Maximum peak discharge, outside period of record in ft^3/s, and date
White River at Petersburg, Indiana	03374000	11,125	38°30′39″	87°17′22″	October 1927 to present	399.38 ft	430.96 ft on January 22, 1937 (corresponds to a gage height of 31.58 ft)	183,000 January 22, 1937	235,000 March 29, 1913.
White River above Petersburg, Indiana	03373980	11,123	38°31′42″	87°15′14″	October 1976 to present	400.70 ft	428.99 ft on June 12, 2008 (corresponds to a gage height of 28.29 ft)[1]	135,000 June 12, 2008[1].	

[1]Although daily flows above 1,500 ft^3/s and annual peak flows are not published by the USGS, stages are continuously recorded, and a stage-discharge relation has been developed for this site. The period of record (since 1976) was identified from the stage data, and a discharge was assigned to this stage.



Projection: Indiana State Plane Western 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. Locations of the study reach for the White River at Petersburg, Indiana; U.S. Geological Survey streamgages; and National Weather Service forecast site.

Study Area Description

The White River near the city of Petersburg is in southwest Indiana in the Wabash Lowland physiographic section of the Southern Hills and Lowlands Region (Gray, 2000). The drainage area is 11,118 square miles ($mi^{2)}$ at the upstream end of the study reach; 11,125 mi^2 at streamgage 03374000); and 11,146 mi^2 at the downstream end of the study reach (U.S. Geological Survey, 2014a, 2014d). The headwaters originate in Randolph County, Ind. (not shown), and the stream flows generally southwestward. As the river passes the northern edge of the city, it is flowing to the southwest. There are no significant tributaries to the White River as it flows through the study reach. Generally, the area has extensive floodplains flanked by broad terraces underlain by outwash sand. The study reach is approximately 7.7 mi long, has an average top-of-bank channel width of about 459 ft, and an average channel slope of 0.00014 (0.7 feet per mile [ft/mi]). Most of the land contiguous to the study reach is either in agricultural use or forested with a small portion that is residentially developed.

The population of Petersburg has declined in recent years from 2,570 in 2000 to 2,383 in 2010 (U.S. Census Bureau, 2010). The main channel and adjacent flood plain within the study reach has one major road crossing, State Highway 61. A railroad spur enters the study area from the northeast, skirts the power-generating facility, and then runs along the south side of the river for about 0.5 mi before veering to the south and into Petersburg. This railroad, a small part of the power-generating facility, and local roads close to the river are vulnerable to flooding during the highest flows.

Previous Studies

The most recent FIS that provides information for the streamgage at White River at Petersburg is the FIS for Knox County (Federal Emergency Management Agency, 1984). This study investigated the existence and severity of flood hazards in the unincorporated areas of Knox County including the White River, which forms the boundary between Knox and Pike Counties. The FIS presents estimates of the peak discharges with 10-, 2-, 1-, and 0.2-percent annual exceedance probabilities and their associated water-surface elevations for the White River at Petersburg (03374000) (river mile 45.7).

The Indiana Department of Natural Resources (IDNR) has produced Digital Flood Insurance Rate Maps (DFIRM), which include the study area in Pike County (Indiana Department of Natural Resources, 2004). These maps outline the special flood hazard areas around Petersburg. In addition, IDNR, the USGS, the Natural Resources Conservation Service, and the U.S. Army Corps of Engineers have agreed to the discharge-frequency values for sites along many rivers in Indiana; the values are termed coordinated discharges and assure consistency among the State and Federal agencies that undertake streamflow studies (Indiana Department of Natural Resources, 2014). The coordinated discharges for the White River at Petersburg were obtained from StreamStats for Indiana Streams (U.S. Geological Survey, 2014d) and are listed in table 2.

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 (U.S. Geological Survey, 2014e). Tasks specific to development of the flood maps for Petersburg, Ind., were (1) collection of topographic and bathymetric data for selected cross sections and geometric data for the State Highway 61 bridge; (2) estimation of energy-loss factors (roughness coefficients) in the stream channel and flood plain and determination of steady-flow data; (3) computation of water-surface profiles using the U.S. Army Corps of Engineers' HEC–RAS computer program (U.S. Army Corps of Engineers, 2010); (4) production of estimated flood-inundation maps at various stream stages using the U.S. Army Corps of Engineers' HEC–GeoRAS computer program (U.S. Army Corps of Engineers, 2009) and a GIS; and (5) 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.

Table 2. Coordinated discharges for selected annual exceedance probabilities for the White River at Petersburg, Indiana.

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

Location on White River	Drainage area (mi^2)	Coordinated discharges (ft^3/s) for indicated annual exceedance probabilities (in percent)[1]		
		10	2	1
At USGS streamgage number 03374000	11,125	115,000	164,000	186,000

[1]Data from USGS StreamStats (U.S. Geological Survey, 2014d).

Computation of Water-Surface Profiles

The water-surface profiles used to produce the 18 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 Data

The study area hydrologic network consists of two streamgages 03374000 and 03373980 (fig. 1; table 1). Streamgage 03374000 has been in operation since October 1927 and is collocated with the NWS AHPS site PTRI3. 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 (NWIS; U.S. Geological Survey, 2014b). 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 399.38 ft. Streamgage 03373980 has been in operation since October 1976 and is located 300 ft upstream of the intake structure of the power-generating facility and 2.3 mi upstream from streamgage 03374000. Only discharges less than 1,500 cubic feet per second (ft^3/s) are published for this site; however, instantaneous stages are presented in NWIS (U.S. Geological Survey, 2014b). Stage data from this streamgage are referenced to a local datum but can be converted to water-surface elevations referenced to NAVD 88 by adding 400.70 ft. 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 boundary conditions (normal depth) and peak-discharge information. The peak flows used in the model simulations (table 3) were taken from the current stage-discharge relation (USGS rating no. 40, effective August 5, 2008) for streamgage 03374000 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 White River within the 7.7-mi study reach; therefore, the gage-derived discharges were not adjusted for tributary inflows but were held constant throughout the study reach for a given profile (table 3).

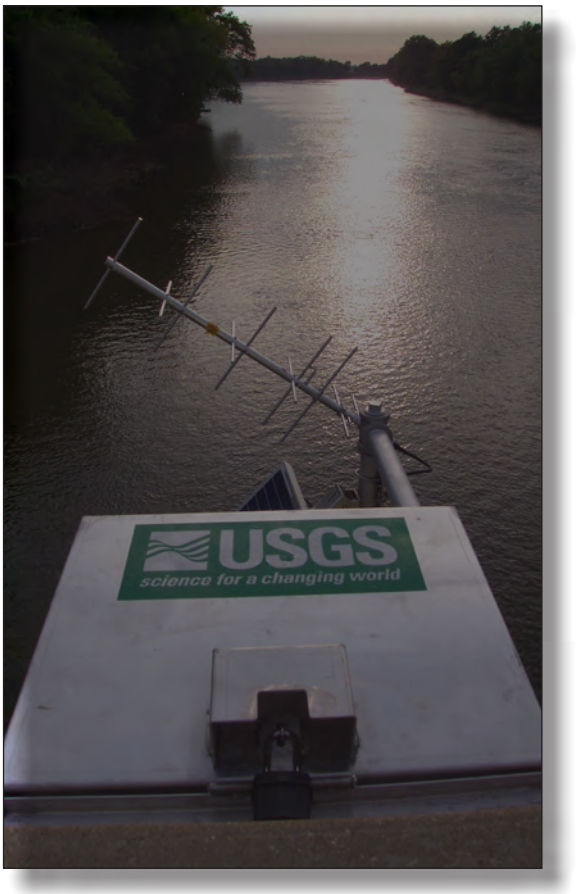


Photo by Bradley Reinking, U.S. Geological Survey

Table 3. Estimated discharges for corresponding stages and water-surface elevations at U.S. Geological Survey (USGS) streamgage 03374000 used in the hydraulic model of the White River at Petersburg, Indiana.

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

Stage (ft)	Water-surface elevation (ft, NAVD 88)	Estimated discharge at USGS streamgage number 03374000 (ft^3/s)
12	411.38	19,000
13	412.38	21,200
14	413.38	23,500
15	414.38	26,000
16	415.38	28,500
17	416.38	31,600
18	417.38	35,100
19	418.38	38,700
20	419.38	43,000
21	420.38	49,000
22	421.38	56,000
23	422.38	64,700
24	423.38	77,100
25	424.38	94,700
26	425.38	115,000
27	426.38	135,000
28	427.38	161,000
29	428.38	193,000

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 (NAD 83). Cross-section elevation data were obtained from a digital elevation model (DEM) that was derived from light detection and ranging (lidar) data that were collected as part of a statewide project during 2011–13 by Woolpert, Inc., Geospatial Services, Dayton, Ohio (Woolpert, Inc., 2011). The lidar data for Knox and Pike Counties were collected in 2013. The DEM was obtained from the Indiana Spatial Data Portal (Indiana University, 2013). The original lidar data have horizontal resolution of 4.9 ft and vertical accuracy of 0.98 ft at a 95-percent confidence level based on a root mean squared error of 0.49 ft for the "open terrain" land-cover category. By these criteria, the lidar data support production of 2-ft contours (Dewberry, 2012); the final DEM, which was resampled to a grid-cell size of 10 ft by 10 ft to decrease the GIS processing time, has a vertical accuracy of plus or minus 1 ft. By using HEC–GeoRAS (a set of procedures, tools, and utilities for processing geospatial data in ArcGIS), elevation data were extracted from the DEM for 71 cross sections. These data subsequently were input to the HEC–RAS model.

Because lidar data cannot provide ground elevations below a stream's water surface, channel cross sections were surveyed by USGS field crews during March 2013. Cross-sectional depths were measured by using hydroacoustic instrumentation at 24 locations. A differential global positioning system (DGPS) with real-time kinematic (RTK) 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, 2014), 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 that were spaced approximately 500 ft apart. The mesh elevations were subsequently added to the DEM data of the 47 synthetic cross sections before the data were exported to HEC–RAS. Instructions for the bathymetry mesh tool are presented by Merwade (2011).

Hydraulic Structures

There is one road (State Highway 61) crossing that has the potential to affect water-surface elevations during floods along the stream. Bridge-geometry data were obtained from field surveys conducted by USGS personnel in March 2013 for the main bridge over the channel and the overflow bridge in the flood plain.

Energy-Loss Factors

Hydraulic analyses require the estimation of energy losses that result from frictional resistance exerted by a channel on flow. These energy losses are quantified by the Manning's roughness coefficient (*n*-value) (Arcement and Schneider, 1989). Initial (pre-calibration) *n*-values were selected on the basis of field observations and high-resolution aerial photographs. An *n*-value of 0.03 was selected for the main channel because it is natural, fairly clean and straight, and low gradient. An *n*-value of 0.08 was used for the overbank areas, which are dominated by agricultural fields and forest in the rural sections of the study reach, a small residential area to the north of Petersburg, and a power-generating facility to the northeast.

The initial *n*-values were adjusted as part of the calibration process, which involved minimizing the differences between simulated and observed water-surface elevations at the two streamgages in the study reach. Roughness-coefficient adjustment factors were varied by flow and adjusted until the simulated water-surface elevations approximated the target water-surface elevations. The actual *n*-values were computed by multiplying the initial *n*-value by each of the roughness-coefficient adjustment factors. Main channel *n*-values downstream of the bridge ranged from 0.022 to 0.034, and overbank values ranged from 0.038 to 0.059. Upstream from the bridge, the main channel *n*-values ranged from 0.020 to 0.029, and overbank values ranged from 0.035 to 0.050.

Hydraulic Model

The HEC–RAS analysis for this study was done by using the steady-state flow computation option. Steady-state flow data consisted of flow regime, boundary conditions, and peak flows that produced water-surface elevations at the streamgage cross sections that matched target water-surface elevations within 0.29 ft of the current rating for streamgage 03374000. These target elevations coincided with even 1-ft increments of stage, referenced to the local streamgage datum. Subcritical (tranquil) flow regime was assumed for the simulations. Normal depth based on an estimated average channel slope of 0.00014 from data obtained from a USGS field crew in 2013, was used as the downstream boundary condition of the reach. The peak flows that were used in the model were discussed in the "Hydrologic Data" section.

The hydraulic model was calibrated to the most current stage-discharge relations at streamgage 03374000 (rating no. 40, August 5, 2008), and streamgage 03373890 (rating no. 9, January 1, 2006). 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 18 simulated flows at streamgage 03374000 were equal to or less than 0.29 ft (table 4). Differences between target and

Table 4. Calibration of hydraulic model to target water-surface elevations at the U.S. Geological Survey streamgage on the White River at Petersburg, Indiana (station number 03374000).

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

Stage of water-surface profile (ft)	Target water-surface elevation (ft, NAVD 88)	Modeled water-surface elevation (ft, NAVD 88)	Elevation difference (ft)
12.00	411.38	411.61	0.23
13.00	412.38	412.47	0.09
14.00	413.38	413.35	–0.03
15.00	414.38	414.28	–0.10
16.00	415.38	415.20	–0.18
17.00	416.38	416.31	–0.07
18.00	417.38	417.48	0.10
19.00	418.38	418.59	0.21
20.00	419.38	419.58	0.20
21.00	420.38	420.43	0.05
22.00	421.38	421.78	0.40
23.00	422.38	422.53	0.15
24.00	423.38	423.59	0.21
25.00	424.38	424.26	–0.12
26.00	425.38	425.23	–0.15
27.00	426.38	426.09	–0.29
28.00	427.38	427.14	–0.24

Photo by Paul Baker, U.S. Geological Survey

modeled water-surface elevations for the 16 simulated flows at streamgage 03373980 were equal to or less than 0.47 ft (table 5).The results demonstrate that the model is capable of simulating accurate water levels over a wide range of flows in the basin.

Development of Water-Surface Profiles

The calibrated hydraulic model was used to generate water-surface profiles corresponding to flows for a total of 18 stages at 1-ft intervals from 12 ft to 29 ft as referenced to streamgage 03374000. Calibration of the model also was aided by comparison with the streamgage rating at 03373890 near the upstream end of the study reach. Emphasis was placed on the calibration to the downstream gage (03374000) since its rating extends to the highest discharge used in the model (193,000 ft^3/s). The rating table for the upstream gage (03373890) extends to 156,000 ft^3/s, but is used primarily by the power-generating plant for low-flow periods.

Development of Flood-Inundation Maps

Flood-inundation maps were created for a reach of the White River at Petersburg, Ind. The maps were created in a GIS by combining the 18 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 and therefore have an estimated vertical accuracy of 2 ft (that is, plus or minus 1 ft). Estimated flood-inundation boundaries for each simulated profile were developed with HEC–GeoRAS software (U.S. Army Corps

Table 5. Calibration of hydraulic model to water-surface elevations at the U.S. Geological Survey (USGS) streamgage on the White River above Petersburg, Indiana (station number 03373980).

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

Stage of water-surface profile[1] (ft)	Target water-surface elevation (ft, NAVD 88)	Modeled water-surface elevation (ft, NAVD 88)	Elevation difference[2] (ft)
12	412.53	412.93	0.40
13	413.60	413.85	0.25
14	414.67	414.79	0.12
15	415.70	415.79	0.09
16	416.60	416.76	0.16
17	417.73	417.84	0.11
18	418.76	418.92	0.16
19	419.66	419.90	0.24
20	420.51	420.77	0.26
21	421.54	421.59	0.05
22	422.37	422.84	0.47
23	423.34	423.69	0.35
24	424.60	424.73	0.13
25	426.12	426.32	0.20
26	427.67	427.60	-0.07
27	428.99	428.77	-0.22

[1]Stages are referenced to USGS streamgage 03374000, 2.3 miles downstream.

[2]Elevations are applicable to flows listed in table 3.

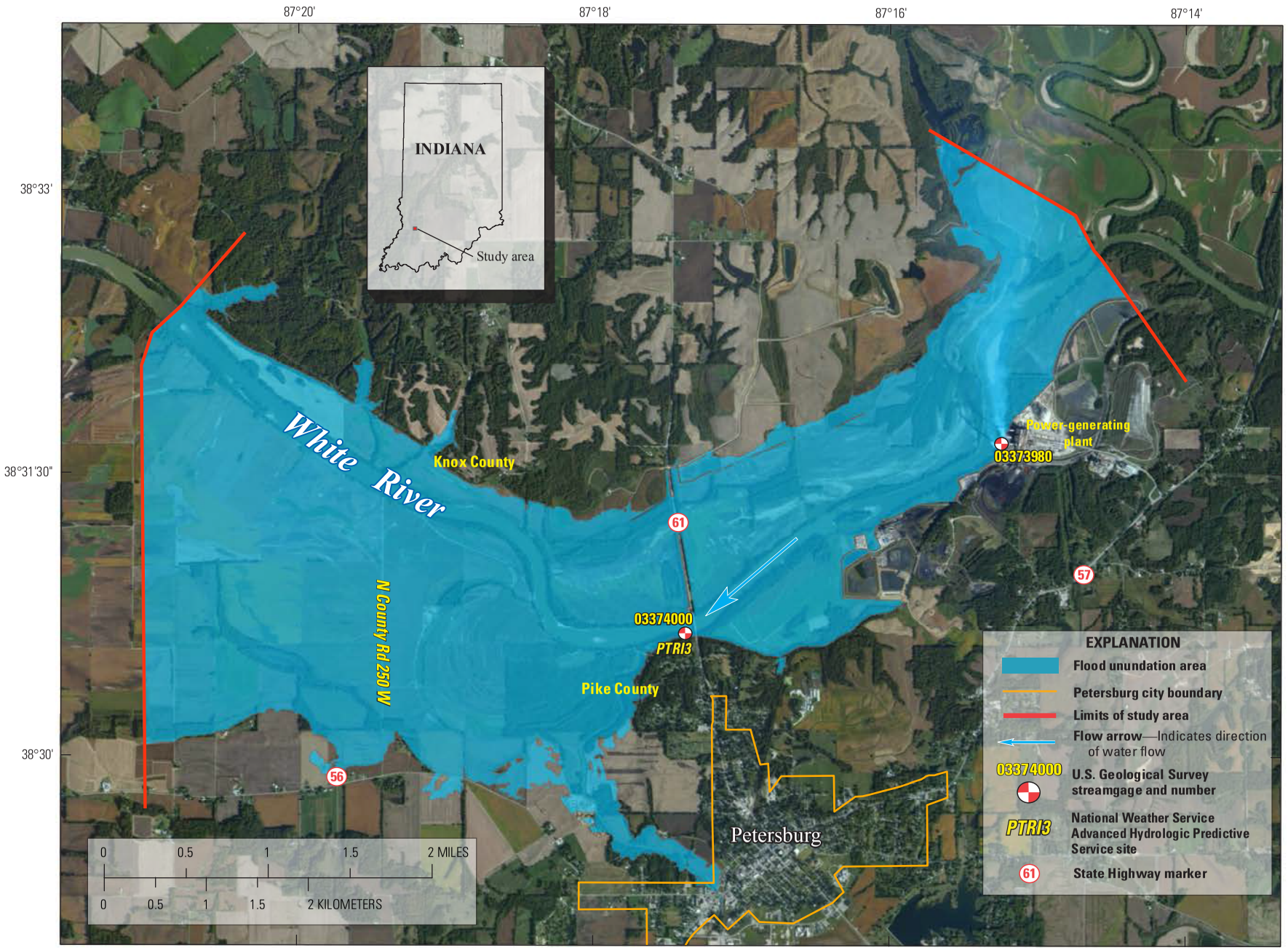
of Engineers, 2009), which allows the preparation of geometric data for import into HEC–RAS and processes simulation results exported from HEC–RAS (U.S. Army Corps of Engineers, 2010). Shapefile polygons and depth grids of the inundated areas for each profile were modified, as required, in the ArcMap application of ArcGIS to ensure a hydraulically reasonable transition of the flood boundaries between modeled cross sections.

Any inundated areas that were detached from the main channel were examined to identify subsurface connections with the main river, such as through culverts under roadways. Where such connections existed, the mapped inundated areas were retained in their respective flood maps; otherwise, the erroneously delineated parts of the flood extent were deleted. The flood-inundation areas are overlaid on high-resolution, geo-referenced, aerial photographs of the study area. Bridge surfaces are displayed as inundated regardless of the actual water-surface elevation in relation to the lowest structural chord of the bridge or the bridge deck.

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. The flood-inundation map corresponding to the highest simulated water-surface profile, a stage of 29 ft, is presented in figure 2.

Flood-Inundation Map Delivery

The current study documentation is available online at the USGS Publications Warehouse (http://pubs.er.usgs.gov/publication/sir20155107). Also, a Flood Inundation Mapping Science Web site (U.S. Geological Survey, 2014d) has been established to make USGS flood-inundation study information available to the public; that site links to a mapping application that presents map libraries and provides detailed information on flood extents and depths for modeled sites. The mapping application enables the production of customized flood-inundation maps from the map library for White River at Petersburg, Ind. A link on this Web site connects to the USGS NWIS (U.S. Geological Survey, 2014a), which presents the current stage and streamflow at USGS streamgage 03374000 to which the flood-inundation maps are referenced. A second link connects to the NWS AHPS site (National Weather Service, 2014a) so that the user can obtain applicable information on forecasted peak flows. 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 on the flood magnitude, roadways 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 indicate that the structure is completely submerged, rather that bare earth surfaces in the vicinity of the building are inundated.



Projection: Indiana State Plane Western 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 2. Flood-inundation map for the White River at Petersburg, Indiana, corresponding to a stage of 29.0 feet at the U.S. Geological Survey streamgage (station number 03374000).

In these instances, the water depth (as indicated in the mapping application by holding 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. The flood boundaries shown were estimated on the basis of water stages and streamflows at selected USGS streamgages. Water-surface elevations along the stream reaches 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 March 2013. 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 in the future in many locations). For more information on AHPS forecasts, please refer to http://water.weather.gov/ahps/forecasts.php.

Photo by Bradley Reinking, U.S. Geological Survey

Summary

A series of 18 digital flood-inundation maps were developed in cooperation with the Indiana Office of Community and Rural Affairs for the White River at Petersburg, Indiana, from 3.7 miles (mi) upstream to 4.0 mi downstream from U.S. Geological Survey (USGS) streamgage 03374000 at the State Highway 61 bridge. The flood-inundation 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 and depths of flooding for selected stream stages. The HEC–RAS hydraulic model was calibrated to the current stage-discharge relations at the White River streamgages at or near Petersburg (03374000 and 03373980). The model was used to compute 18 water-surface profiles for flood stages at 1-foot (ft) intervals referenced to the streamgage datum and ranging from 12 ft, or near bankfull, to 29 ft, which is the highest stage of the stage-discharge rating. The simulated water-surface profiles were then combined with a geographic information system digital elevation model derived from light detection and ranging (lidar) 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, geo-referenced, aerial photographs of the study area. The flood maps are available through a mapping application that can be accessed on the USGS Flood Inundation Mapping Science Web site (http://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 White River at Petersburg, Ind. These maps, in conjunction with the real-time stage data from the USGS streamgage, White River at Petersburg, Ind. (station number 03374000), and forecasted flood stage data from the National Weather Service Advanced Hydrologic Prediction Service 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 post-flood recovery efforts.

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