Prepared in cooperation with Indiana Office of Community and Rural Affairs

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




Pamphlet to accompany

Scientific Investigations Map 3251

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

Cover: Flood scenes in Spencer, Indiana, (Photographs by Chad Menke, USGS, June, 2008).

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KEN SALAZAR, Secretary

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

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Photo taken in Spencer, Indiana, by Chad Menke in June 2008.

Photos taken in Spencer, Indiana, by Chad Menke in June 2008.

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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 White River at Spencer, Indiana

By Elizabeth A. Nystrom

Abstract

Digital flood-inundation maps for a 5.3-mile reach of the White River at Spencer, 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 White River at Spencer, Indiana (sta. no. 03357000). 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/*. National Weather Service (NWS)-forecasted peak-stage information 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 model was calibrated by using the most current stage-discharge relation at the White River at Spencer, Indiana, streamgage and documented high-water marks from the flood of June 8, 2008. The hydraulic model was then used to compute 20 water-surface profiles for flood stages at 1-foot intervals referenced to the streamgage datum and ranging from the NWS action stage (9 feet) to the highest rated stage (28 feet) 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) in order to delineate the area flooded at each water level.

The availability of these maps along with Internet information regarding the current stage from the Spencer USGS streamgage 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 Town of Spencer is a small community with an estimated population of 2,217 (U.S. Bureau of the Census, 2010). The Town of Spencer has experienced severe flooding numerous times, most notably in 1913, 2005, and 2008. The greatest historical flood occurred on March 26, 1913, with an estimated stage of 28.5 ft and flow of 100,000 ft^3/s. Recent highs flows include the floods of January 7, 2005, and June 8, 2008, with stages of and 25.06 ft and 26.84, respectively. The majority of flood damages have occurred along the White River and several tributaries (including Meadowbrook Creek), which flow through the town. Flood plains within the town contain a mix of agricultural and residential areas.

Prior to this study, Town of Spencer 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 of information is the Indiana Department of Natural Resources (IDNR) Floodway Boundary Study for the Town of Spencer dated March 2002 (Indiana Department of Natural Resources, 2002). A second source is the USGS streamgage White River at Spencer, Indiana (Ind.) (sta. no. 03357000), from which current or historical water levels (stage) can be obtained. A third source is the NWS forecast of peak stage at the USGS streamgage through the Advanced Hydrologic Prediction Service (AHPS) site. The NWS does not routinely forecast stages at the Spencer streamgage; rather, forecasts are issued as needed during times of high flows. 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, Federal Emergency Management Agency (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 the 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 White River near Spencer, Ind. The maps and other useful flood information are available on the USGS Flood Inundation Mapping Science Web site and the NWS AHPS Web site. Internet users can select estimated inundation maps that correspond to (1) current stages at the USGS streamgage, (2) the NWS forecasted peak stage, or (3) other desired stream stages.

The scope of the study was limited to a 5.3 mi reach of the White River at Spencer (fig. 1), from 3.1 mi upstream to 2.2 mi downstream of the Main Street Bridge in Spencer. Maps were produced for water levels referenced to the stage at the streamgage White River at Spencer, Ind., ranging from the NWS action stage (9 ft) to the maximum rated stage (28 ft) at the streamgage. Tasks specific to development of the maps were (1) examination of current and historical stage and discharge data from the streamgage on the White River (table 1); (2) collection of topographic data and geometric data for two bridges in the study reach; (3) determination of energy-loss factors (roughness coefficients) in the stream channel and flood plain, and steady-flow data; (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 the U.S. Army Corps of Engineer's HEC–GeoRas computer program (U.S. Army Corps of Engineers, 2009) and a Geographic Information System (GIS), and (6) preparation of the maps as shapefile polygons that depict the areal extent of flood inundation and as depth grids that provide the depth of flood water for display on the USGS Flood Inundation Mapper web site that links to USGS real-time streamgage information and(or) NWS forecasted peak stage to facilitate the display of user-selected flood-inundation maps on the Internet.

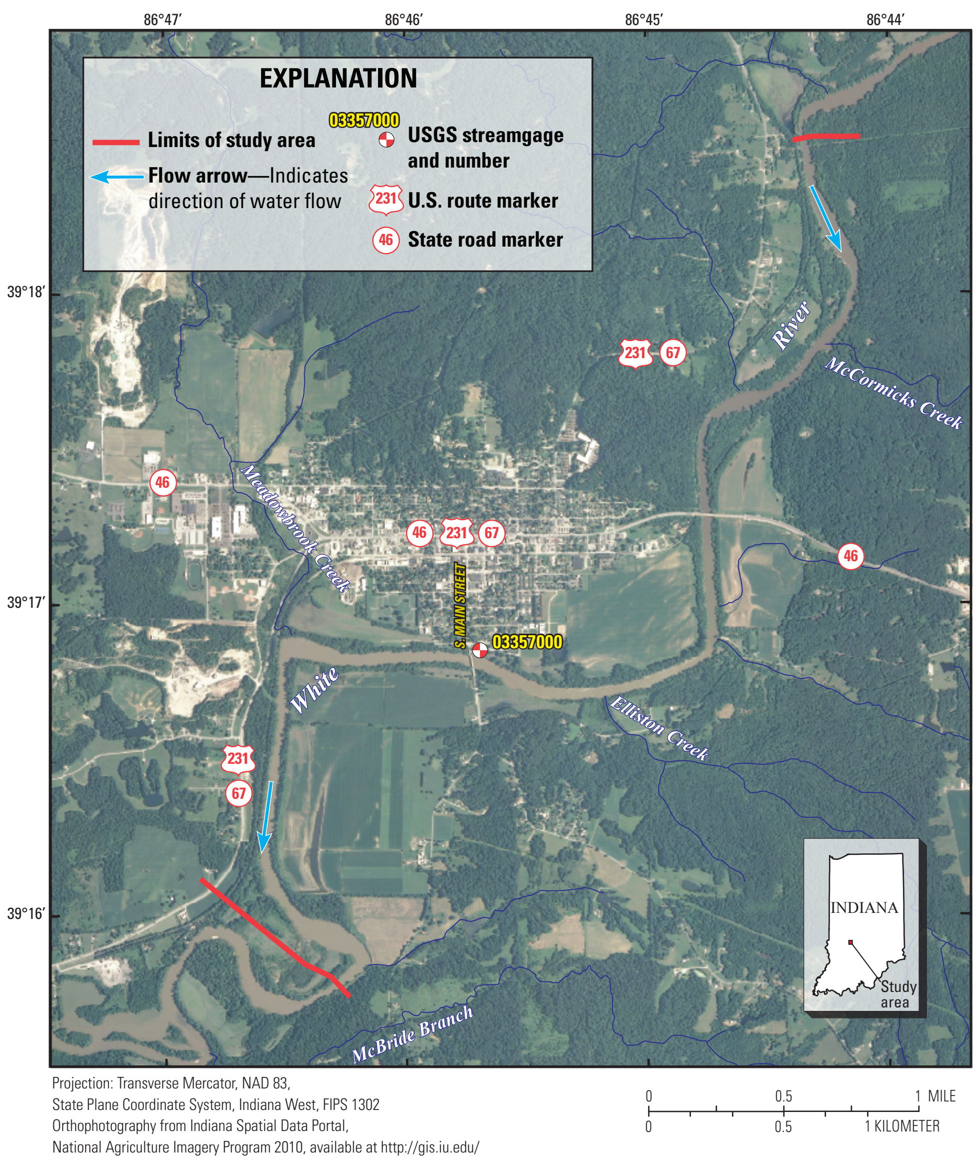

Figure 1. Location of study reach for the White River at Spencer, Indiana, and location of U.S. Geological Survey streamgage and National Weather Service forecast site.

Table 1. U.S. Geological Survey streamgage information for the study reach, White River at Spencer, Indiana.

Station name	Station number	Drainage area (mi²)	Latitude	Longitude	Period of record	Maximum recorded stage at gage (ft) and date
White River at Spencer, Ind.	03357000	2,988	39°16′52″	86°45′44″	July 1925 to September 1971 (discharge) October 1987 to current year (stage only)	26.84, June 8, 2008[1]

[1] A historic peak of 28.5 ft occurred in 1913 prior to installation of the gage. During 1925 to 1971, the period of record for discharge, the peak recorded flow was 59,400 ft^3/s at a stage of 23.2 ft; floods in 2005 and 2008 exceeded this stage but are outside of the period of record for discharge.

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.

Study Area Description

The White River is in southwest Indiana in Owen County, in the Mitchell Plateau section of the Southern Hills and Lowlands Region (Gray, 2000). The drainage area at the White River at Spencer, Ind., streamgage is 2,988 mi^2; the drainage area at the downstream extent of the study reach is less than 1 percent larger than at the upstream extent of the study reach. The headwaters originate in Randolf County, and the stream flows generally southwestward through the city of Indianapolis before approaching the town of Spencer. Several minor tributaries to the White River join the main stem as it flows through Spencer, including Meadowbrook Creek, McCormicks Creek, and Elliston Creek. The basin terrain is generally flat to rolling. The study reach is approximately 5.3 mi long and extends from 3.1 river miles upstream of streamgage 03357000, located at the Main Street Bridge, to 2.2 river miles downstream of the bridge; it has an average top-of-bank channel width of about 320 ft and an average channel slope of 1.3 ft/mi. The land contiguous to the study reach is predominantly classified as agricultural and forested; a developed area encroaches on the northern flood plain near the gage. The main channel within the study reach has two road crossings—the State Road 46 and Main Street bridges.

Previous Studies

A preliminary flood insurance study (FIS) for Owen County (Federal Emergency Management Agency, 2012) was issued in April 2012. Hydrologic and hydraulic analyses for the FIS were completed by the IDNR and Morley and Associates on behalf of the IDNR. That study provided information on the 1.0- and 0.2-percent annual exceedance probability water-surface profiles and associated peak flows for the West Fork White River, herein referred to as "White River," and Meadowbrook Creek, which were studied by detailed methods, as well as other areas within Owen County, which were studied by approximate methods. Estimates of the peak discharges for the 1.0-percent annual exceedance probability flood along the White River from this FIS are shown in table 2 below.

Table 2. 1.0-percent annual exceedance probability peak-discharge estimates and drainage areas for selected locations in Spencer, Indiana (from Federal Emergency Management Agency, 2012)

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

Location	Drainage area (mi²)	Discharge estimate (ft³/s)
White River at Main Street	2,988	80,000
Meadowbrook Creek at confluence with White River (approx. 0.7 mile downstream of Main Street)	3.44	1,350

Constructing Water-Surface Profiles

The water-surface profiles used to produce the 20 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 gradually varied, steady-state 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 streamgage (fig. 1; table 1), which was installed in 1925. Historical discharge records are available for this site from July 1925 to September 1971. Water level (stage) has been measured at the site since October 1987; however, discharges are no longer computed. All water-surface elevations in this study are referenced to the North American Vertical Datum of 1988 (NAVD 88); the datum of the gage at White River at Spencer, Indiana is 525.63 ft NAVD 88 (526.04 ft as referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29)). The gage is equipped with a satellite radio transmitter that allows data to be transmitted routinely, and on the Internet within an hour of collection. Longitudinal water-surface profiles from high-water marks along the main channel from the State Road 46 bridge to the downstream limit of the study reach were documented after the flood of June 8, 2008 (Morlock and others, 2008).

Steady-state flow data consisted of flow regime, boundary condition, and peak-discharge information. Normal depth with a slope of 0.00035, which was estimated from LiDAR water-surface elevations through the downstream portion of the reach, was used as the downstream starting boundary condition. The steady-flow data for the study reach were obtained from the most current stage-discharge relation that has been developed for the USGS streamgage, White River at Spencer, Ind. The most recent stage-discharge rating, number 41.0, was created in June 2008; it is based on previous ratings, which were developed from measurements collected during and prior to 1971, when continuous discharge records were computed for the station. Since the station was inactivated in 1971, only five verification measurements have been made. The modeled flows coincide with target water-surface elevations at 1-ft increments of stage as referenced to the local datum at the White River streamgage.

Topographic/Bathymetric Data

Nineteen channel cross sections were surveyed within the study reach by USGS personnel during November 2011; these cross sections provided 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). Control for the USGS survey was established by tying the elevations of two reference marks into known elevations. The surveyed elevations were within 0.04 ft of their known elevations.

LiDAR data with horizontal accuracy of 1.02 ft and 3.9 ft cell size (resampled to 10.0 by 10.0 ft cell size), 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) were used to provide 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 were collected during April 2010 by Aero-Metric, Inc., Sheboygan, Wisconsin (Aero-Metric, Inc., 2010); postprocessing of these data was completed by Aero-Metric, Inc., during July 2010. Using a GIS, elevation data for 62 cross sections, spaced approximately 500 ft apart, were extracted from a LiDAR digital elevation model. In-channel bathymetry for cross sections that did not coincide with the surveyed channel cross sections was estimated by interpolation.

Various manmade drainage structures (bridges, culverts, roadway embankments, levees and dams) in and along a stream 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 two bridges—the Main Street and State Road 46 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 were used to select initial (pre-calibration) Manning’s roughness coefficients (“n” values) for energy-loss (friction-loss) calculations. The main channel of the White River near Spencer is generally meandering, but contains several sharp bends near town boundaries. The banks immediately along the channel are typically vegetated with trees and shrubs; overbank areas are forested or agricultural. It was determined that roughness coefficients varied with stage for this reach of the White River, and n values were adjusted for channel type/land cover categories by using groups of flood profiles representing ranges of stage. The final Manning’s n values used ranged from 0.027 to 0.048 for the main channel and 0.050 to 0.155 for the overbank areas modeled in this analysis.

Model Calibration and Performance

The hydraulic model was calibrated to the most current stage-discharge relation at the White River at Spencer, Ind. streamgage and to high-water marks from the flood of June 8, 2008. Model calibration was accomplished by adjusting Manning's n values within each group of profiles representing a range of stages 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 streamgage 03357000 were equal to or less than 0.3 ft (table 3).

Table 3. Stages (and water-surface elevations), with corresponding discharge estimates at the U.S. Geological Survey streamgage, White River at Spencer, Indiana, for selected simulated water-surface profiles.

[NAVD 88, North American Vertical Datum of 1988]

Stage, in feet above gage datum	Elevation, in feet above NAVD 88	Associated discharge value, in cubic feet per second	Sheet number	Simulated elevation, in feet above NAVD 88	Elevation difference, in feet
9	534.63	5,790	1	534.93	0.30
10	535.63	6,800	2	535.77	0.14
11	536.63	7,850	3	536.62	-0.01
12	537.63	8,960	4	537.40	-0.23
13	538.63	10,200	5	538.70	0.07
14	539.63	11,600	6	539.59	-0.04
15	540.63	13,100	7	540.49	-0.14
16	541.63	15,000	8	541.51	-0.12
17	542.63	17,400	9	542.61	-0.02
18	543.63	20,400	10	543.71	0.08
19	544.63	23,800	11	544.76	0.13
20	545.63	27,500	12	545.93	0.30
21	546.63	31,700	13	546.84	0.21
22	547.63	36,100	14	547.68	0.05
23	548.63	41,000	15	548.56	-0.07
24	549.63	46,300	16	549.45	-0.18
25	550.63	51,900	17	550.73	0.01
26	551.63	58,000	18	551.64	0.01
27	552.63	64,600	19	552.68	0.05
28	553.63	71,600	20	553.72	0.09

The estimated peak discharge for the June 8, 2008, flood was 63,500 ft3/s at a stage of 26.84 ft (elevation 552.47 ft, NAVD 88) at the gage. High-water marks were surveyed mainly between the State Road 46 and Main Street bridges. Differences between measured and simulated elevations of high-water marks were less than 0.8 ft (table 4). These 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).

Table 4. Comparison of hydraulic-model output and surveyed high-water-mark elevations from the flood of June 7–9, 2008, White River at Spencer, Indiana.

High-water mark field identification number[1]	High-water-mark elevation, in feet	Model water-surface elevation, in feet	Elevation difference, in feet
Gaged maximum stage	552.47	552.51	0.03
22	555.40	555.62	0.22
23	556.09	555.56	-0.53
24	555.90	555.55	-0.35
26	554.87	554.54	-0.33
27	554.56	554.35	-0.21
28	554.59	554.23	-0.36
29	553.96	553.94	-0.02
30	554.33	553.70	-0.63
31	553.60	553.30	-0.30
32	553.29	553.02	-0.27
33	552.55	552.14	-0.41
34	552.36	552.08	-0.28
35	552.30	552.07	-0.23
36	552.11	552.19	0.08
37	552.44	552.15	-0.29
39	553.69	552.92	-0.77
41	553.30	552.70	-0.60
43	551.71	551.83	0.12
44	551.50	551.76	0.26
45	551.67	551.76	0.09
46	551.80	551.73	-0.07
47	551.73	551.76	0.03
48	551.66	551.76	0.10
49	551.76	551.75	-0.01
50	551.26	551.75	0.49
51	551.23	551.75	0.52
52	548.62	548.62	0.00
53	548.38	548.49	0.11

[1]Indiana Department of Natural Resources high-water marks for the flood of June 2008, collected June 17, 2008.

Development of Water-Surface Profiles

Profiles were developed for a total of 20 stages at 1-ft intervals between 9 ft and 28 ft as referenced to the White River at Spencer, Ind. (sta. no. 03357000). Discharges corresponding to the various stages were obtained from the most current stage-discharge relation (rating no. 41.0) at the Spencer gage. Discharges for all profiles (table 3) were selected with the assumption that within the 5.3-mi study reach there were no significant inflows; therefore, the discharges (as listed in table 3) were held constant throughout the study reach for a given profile.

Inundation Mapping

Flood-inundation maps were created for the White River at Spencer, Ind., USGS site, which has been designated as an NWS flood-forecast point (as of 2012). The maps were created in a GIS by combining the water-surface profiles and digital elevation model (DEM) data. The DEM data were derived from 3.9-ft horizontal resolution LiDAR data with a vertical accuracy of 0.37 ft, obtained from Aero-Metric, Inc. (Aero-Metric, Inc., 2010). The original LiDAR data were resampled to a 10- by 10-ft cell size to reduce GIS processing time. 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 (Whitehead and Ostheimer, 2009). 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 1 ft. The maps show estimated flood-inundated areas overlaid on high-resolution, geo-referenced aerial photographs of the study area for each of the water-surface profiles that were generated by the hydraulic model.

White River at Spencer, Indiana, Flood-Inundation Maps on the Internet

The flood-inundation maps and current study documentation are available online at the U.S. Geological Survey Publications Warehouse (*http://pubs.usgs.gov/sim/2013/3251)*. Also, a Flood Inundation Mapping Science website 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. In the latter link, each stream reach displayed contains further links to NWISWeb graphs of the current stage and streamflow at USGS streamgage 03357000, 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. Roadways and 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. However, 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) in the vicinity of 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.

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 and streamflows at the USGS streamgage on the White River at Spencer (03357000). 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 November 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 due 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. Additional uncertainties and limitations pertinent to this study may be 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

A series of estimated flood-inundation maps for a 5.3-mi reach of the White River at Spencer, Ind., were developed in cooperation with the Indiana Office of Community and Rural Affairs for the White River at Spencer. These maps, available at a USGS Web portal, in conjunction with the real-time stage data from the USGS streamgage at White River at Spencer, Ind. (sta. no. 03357000), 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 at 1-ft intervals referenced to the streamgage datum and ranging from the NWS action stage (9 ft) to the highest rated stage (28 ft). A HEC-RAS hydraulic model was calibrated by using the most current stage-discharge relation at the White River at Spencer streamgage and documented high-water marks from the flood of June 8, 2008. The simulated water-surface profiles were then combined with a geographic information system digital elevation model (derived from LiDAR data) to delineate the area flooded at each water level. The maps show estimated (shaded) flood-inundation areas overlaid on high-resolution, georeferenced aerial photographs of the study area. Interactive use of the maps 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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