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Flood-Inundation Maps for the Wabash River at Terre Haute, Indiana

Pamphlet to accompany

Scientific Investigations Map 3232

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

Cover:
Photo shows south (downstream) side of Eastbound Highway 150 bridge over Wabash River at Terre Haute, Indiana while streamflow measurements were being collected (photo was taken by Eric Looper, USGS, April, 2013). Image shows flood inundation at stage of 30.00 feet and elevation of 475.4 feet.

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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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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).

Elevation, as used in this report, refers to distance above the vertical datum.

Acknowledgments

The author wishes to thank the Indiana Department of Transportation and the U.S. Army Corps of Engineers, Louisville District for cooperating in the operation and maintenance of the Wabash River at Terre Haute, Indiana, streamgage used for this study, and the Indiana Department of Transportation for providing bridge plans. In addition, thanks are given to the National Weather Service for their continued support of the U.S. Geological Survey flood-inundation mapping initiative.

Flood-Inundation Maps for the Wabash River at Terre Haute, Indiana

By Pamela J. Lombard

Abstract

Digital flood-inundation maps for a 6.3-mi reach of the Wabash River from 0.1 mi downstream of the Interstate 70 bridge to 1.1 miles upstream of the Route 63 bridge, Terre Haute, Indiana, 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 select water levels (stages) at the USGS streamgage Wabash River at Terre Haute (station number 03341500). 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=03341500&agency_cd=USGS&amp*). In addition, the same data are provided to the National Weather Service (NWS) for incorporation into their Advanced Hydrologic Prediction Service (AHPS) flood warning system (*http:/water.weather.gov/ahps/*). Within this system, the NWS forecasts flood hydrographs for the Wabash River at Terre Haute 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 model was calibrated using the most current stage-discharge relation at the Wabash River at the Terre Haute streamgage. The hydraulic model was then used to compute 22 water-surface profiles for flood stages at 1-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) to delineate the area flooded at each water level.

The availability of these maps along with Internet information regarding the current stage from the USGS streamgage and forecasted stream stages from the NWS can 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 Wabash River flows south with the city of Terre Haute, Indiana, on its eastern bank and the town of West Terre Haute on its western floodplain. The city of Terre Haute is an urban community in Vigo County with an estimated population of 60,800 (U.S. Census Bureau, 2010a). It has steep banks east of the Wabash River and elevations mostly greater than 490 NAVD88 so that it has not been severely affected by floodwaters from the Wabash River except at the northwest corner of the city around Maple Avenue. The much smaller town of West Terre Haute, on the western bank, had a population of 2,240 in 2010 (U.S. Census Bureau, 2010b). West Terre Haute is at elevations as low as 461 NAVD88 and traditionally has undergone more severe flooding than Terre Haute prior to the construction of the West Terre Haute levee in the early 1970s. West Terre Haute is surrounded by the West Terre Haute levee on the eastern and southern sides of the town and by a railroad bed on the northern side of the town. The West Terre Haute levee was in the process of being recertified by the Federal Emergency Management Agency (FEMA) at the time of this study (2012). There is another levee at the northeastern end of the study that protects the area around Maple Avenue in the northwest corner of Terre Haute. Taylorville (also known prior to 1960 by the variant name of Dresser) is a small, unincorporated town between West Terre Haute and the Wabash River which can be severely affected by flooding from the Wabash River. Taylorville is partially protected by a levee built in the 1930s (known as the old levee or the Sugar Creek levee). The old levee is not certified or maintained by the State or Federal government.

The Wabash River had instances of severe flooding in 1913, 1943, 1950, 1958, 1959, and 2005. The maximum recorded flow at the Wabash River at Terre Haute streamgage was 245,000 ft^3/s in 1913, which was associated with a stage of 31.2 ft as referenced to gage datum. The streamgage was moved and the gage datum was lowered in 1985, so a stage of 31.2 ft for the 1913 peak flow cannot be directly compared to stages presented in this report.

Officials of Terre Haute, West Terre Haute, and Taylorville have relied on three primary information sources (all of which are available on the Internet) to make decisions as to how best alert the public and mitigate flood damages. The first source is the FEMA Flood Insurance Study (FIS) for Vigo County dated February 18, 2011 (Federal Emergency Management Agency, 2011). A second source of information is the USGS streamgage Wabash River at Terre Haute (sta. no. 03341500), from which current or historical water levels (stage) can be obtained. A third source is the National Weather Service's forecast of peak stage at the USGS streamgage through the Advanced Hydrologic Prediction Service (AHPS) website (*http:/water.weather.gov/ahps/)*. 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 a USGS streamgage or NWS flood-forecast point.

Purpose and Scope

The purpose of this report is to describe the development of a series of estimated flood-inundation maps for the Wabash River near Terre Haute, Indiana. The scope of the study was limited to a 6.3-mi reach of the Wabash River from 0.1 mi downstream of the I–70 bridge to 1.1 mi upstream of the Route 63 bridge in Terre Haute (fig. 1). Twenty-two flood maps were created at 1-ft intervals between and including 9 ft and 30 ft as referenced to the Wabash River at Terre Haute streamgage (sta. no. 03341500) (table 1). Maps were produced for water levels referenced to the water-surface elevation (stage) at Wabash River at Terre Haute and ranging from approximately bankfull to the maximum observed water level at the streamgage.

Study Area Description

The Wabash River is 503 mi long and flows southwest from northwest Ohio across northern Indiana to southern Illinois, where it forms the Illinois-Indiana border before draining into the Ohio River. The city of Terre Haute is located in central Vigo County and is the county seat of government. The Wabash River forms the western boundary of the corporate limits of Terre Haute. The drainage area is 12, 263 mi^2 at the Terre Haute streamgage. The basin terrain is generally flat. The study reach is approximately 6.3 mi long, and has an average top-of-bank channel width of approximately 600 ft. The land contiguous to the study reach on the eastern side of the river is urban or developed, on the western side of the study reach it is primarily cropland with some forested areas. The main channel within the study reach has four road crossings and two railroad crossings. Route 40 is treated as two road crossings because its west and east bound lanes are 500 feet apart on the eastern bank. Although I–70 and Route 63 both have east and west bound lanes that are on separate bridges, they are treated as single structures because the bridges are only 40 feet apart.

Table 1. USGS streamgage information for study basin, Wabash River at Terre Haute, Indiana.

[mi^2, square miles; ft, feet; ° ′ ″, degrees minutes seconds; gage datum is 445.43 NAVD88]

Station name	Station number	Drainage area (mi^2)	Latitude	Longitude	Period of record
Wabash River at Terre Haute	03341500	12,263	39°28′33″	87°25′08″	November 1927 to September, 2011.

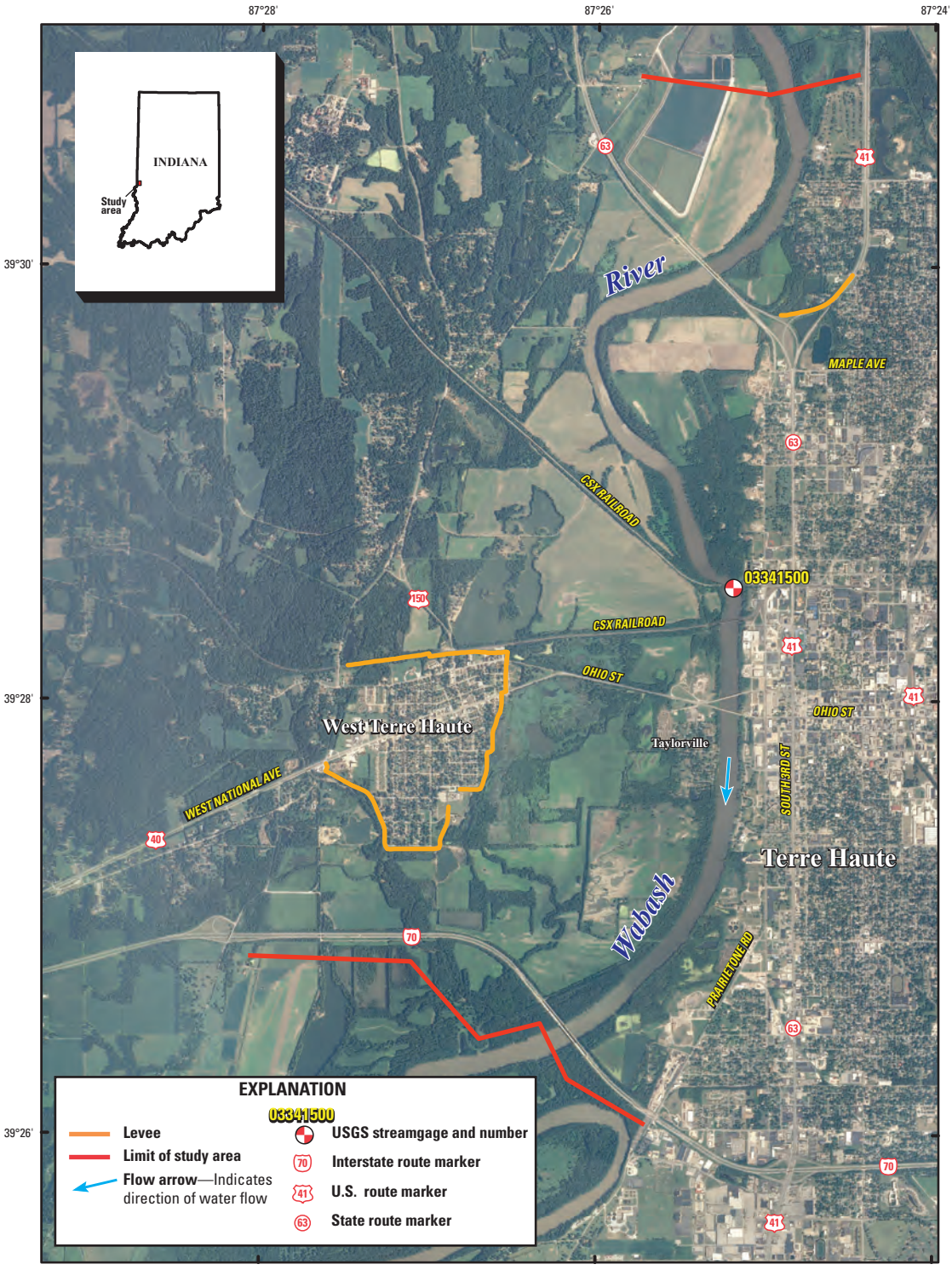

Figure 1. Location of study reach for the Wabash River at Terre Haute and location of USGS streamgage and National Weather Service forecast site.

Previous Studies

The current FIS for Vigo County (Federal Emergency Management Agency, 2011) was completed by United Consulting Engineers and Architects on behalf of the Indiana Department of Natural Resources in 2011. The study provided information on the 10-, 2-, 1- and 0.2-percent annual exceedance probability water-surface profiles and discharges for rivers and tributaries throughout Vigo County. Estimates of the peak discharges along the Wabash River at Terre Haute were completed by the USGS in 1981 and were incorporated into the county wide publication by FEMA (2011) (table 2).

Table 2. Estimates of annual exceedance probability peak-discharges on the Wabash River at Terre Haute, Indiana, streamgage number 03341500, (from Federal Emergency Management Agency, 2011).

Annual exceedance probability (percent)	Discharge estimate (ft^3/s)
10	98,500
2	136,500
1	151,000
0.2	188,500

Constructing Water-Surface Profiles

The water-surface profiles used to produce the 22 flood-inundation maps in this study were computed 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 using the steady-state flow computation option.

Tasks specific to development of the maps were (1) analyses of streamgaging data at the Wabash River at Terre Haute streamgage, (2) collection of topographic data and geometric data (for structures/bridges) throughout 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 using the U.S. Army Corps of Engineer's HEC–RAS computer program (U.S. Army Corps of Engineers, 2010), (5) production of estimated flood-inundation maps at various stream stages using the U.S. Army Corps of Engineer's HEC–GeoRas computer program (U.S. Army Corps of Engineers, 2009) (6) development of a Web interface that links to USGS real-time streamgage information and(or) NWS forecasted peak stage to facilitate the display of user-selected flood-inundation maps; available on the Internet at *http://wim.usgs.gov/FIMIdev/FloodInundationMapper.html*

Hydrologic and Steady Flow Data

The study area hydrologic network consists of one streamgage, Wabash River at Terre Haute (sta. no. 03341500) that has been operated by the USGS continuously since 1927, although the actual streamgage location was moved in 1985 (fig. 1; table 1). Water level (stage) is measured continuously and continuous records of streamflow are computed at this streamgage. Although datum of the streamgage is referenced to 445.78 feet above NGVD29, all water-surface elevations in this report have been converted so that they reference NAVD 88. The streamgage is equipped with a satellite radio transmitter that allows data to be transmitted routinely on the Internet within four hours of collection at url: *http://waterdata.usgs.gov/in/nwis/uv/?site_no=03341500&agency_cd=USGS&amp.*

Steady-flow data consisted of flow regime, boundary conditions (normal depth slope was set to 0.0002, the energy gradient slope in the model), and peak discharge information. The peak discharge data for the study reach were obtained from field measurements and the stage-discharge relation that was developed by the USGS at the Wabash River at Terre Haute streamgage.

Topographic and Bathymetric Data

Channel cross sections were developed from USGS field surveys that were carried out in September, 2011. Detailed channel depths below the water surface were collected using hydroacoustic instrumentation while differential Global Positioning System (DGPS) instrumentation determined 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 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. 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-ft^2 in order to decrease the GIS processing time. A detailed description of the methods used to acquire and process the topographic and bathymetric data can be found in Bales and others (2007).

Six bridges and two levees in Terre Haute and West Terre Haute have the potential to affect water-surface elevations during high water along the Wabash River. To properly account for these features in the model, bridge geometry was obtained from a previous USGS E431 step-backwater model

(Federal Emergency Management Agency, 2011); from bridge plans received from the Indiana Department of Transportation (IN DOT) (Teresa Hammons, written commun., 2012); and from railroad bridge plans from CSX Transportation Inc. (Rick Garro, written commun., 2012). All six bridges were verified as current structures with pictures and elevation checks from a digital-elevation model and field observations. The geometry data for the levee were acquired from the U.S. Army Corps of Engineers (ACE), Louisville District (Matthew Whelan, written commun., 2012) and the elevation data of the levee were included in the model to properly account for these structures.

Energy Loss Factors

Field observations were used to select initial (pre-calibration) Manning's roughness coefficients ("n" values) for energy (friction) loss calculations. Manning's roughness coefficients were determined to be 0.03 to 0.032 for the main channel, and 0.066 to 0.068 for the overbank areas. It was determined that roughness coefficients varied with stage for this reach of the Wabash River. Final values were increased up to 123 percent or decreased down 87 percent depending on the stage profile, and generally decreased with increasing stage as expected for large rivers. For the lower flows, final values increased with increased stage likely due to increased vegetation as the water started to come over the banks.

Model Calibration and Performance

The hydraulic model was calibrated to the most current stage-discharge relation at the Wabash River at Terre Haute streamgage. The estimated peak discharge for the March, 1913 flood was 245,000 ft^3/s at an estimated stage of about 31.2 ft at the streamgage. The measured peak discharges (and stages) for the 1943, 1958, 2005, and the 1950 floods were 189,000 ft^3/s (30.5 ft), 125,000 ft^3/s (29.53 ft), 123,000 ft^3/s (27.38 ft) and 122,000 ft^3/s (27.65 ft), respectively. Note that the streamgage location was changed and the streamgage datum was lowered 2.9 feet in 1985; so stages prior to 1985 cannot be compared directly to stages after 1985. In addition, starting in 1968, discharges are affected to an unknown degree by regulation from upstream reservoirs. 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 22 stages at 1-ft intervals between and including 9 ft (action stage) and 30 ft (flood of record) as referenced to the Wabash River at Terre Haute streamgage (sta. no. 03341500). Discharges corresponding to the various stages were obtained from the most current stage-discharge relation (rating no. 55.1) at the streamgage. The streamgage is near the midpoint of the 6-mi reach. There are no major tributaries; thus discharges for each profile were held constant throughout the reach (table 3).

Table 3. Stages (elevations referenced to streamgage datum and to NAVD88) with corresponding discharge estimates at the Wabash River at Terre Haute streamgage for simulated water-surface profiles.

Stage (feet above gage datum)	Elevation (feet, NAVD 88)	Discharge (ft^3/s)
9	454.4	15100
10	455.4	16900
11	456.4	18800
12	457.4	20900
13	458.4	23000
14	459.4	25200
15	460.4	28000
16	461.4	31000
17	462.4	34500
18	463.4	39000
19	464.4	44000
20	465.4	49000
21	466.4	55000
22	467.4	61400
23	468.4	70700
24	469.4	81000
25	470.4	92200
26	471.4	104000
27	472.4	118000
28	473.4	132000
29	474.4	148000
30	475.4	165000

Inundation Mapping

Flood-inundation maps were created for the 6.3-mi reach of the Wabash River centered on the USGS streamgage at Terre Haute, which is currently (as of 2012) a 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). The HEC–GeoRAS results, shapefile polygons and depth grids of the inundated areas, were modified to ensure a hydraulically reasonable transition of the flood boundaries between modeled cross sections relative to the digital-elevation model of the land surface. 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.

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 (*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 Wabash River at Terre Haute, Indiana (station number 03341500), to which the inundation maps are referenced (*http://waterdata.usgs.gov/in/nwis/uv/?site_no=03341500&agency_cd=USGS&amp*). 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 for 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 the Wabash at Terre Haute (03341500) streamgage. 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 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. Furthermore, a steady state model is not able to take timing into account. Flood inundation maps show areas that would be flooded at a given stage, but do not indicate how long it might take for the inundation to occur. If a given stage only occurs for a brief amount of time, the extent of the flooding may not be as extreme as the map indicates. 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 digital elevation model used to simulate the land surface.

If this series of flood-inundation maps will be used in conjunction with National Weather Service (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 22 estimated flood-inundation maps were developed in cooperation with the Indiana Department of Transportation for a 6.3-mi reach of the Wabash River from 0.1 mi downstream of the I–70 bridge to 1.1 mi upstream of the Route 63 bridge, at Terre Haute, Indiana. These maps, available at a publications url: *http://pubs.usgs.gov/sim/3232/* in conjunction with the real-time stage data from the USGS streamgage, Wabash River at Terre Haute (sta. no 03341500, *http://waterdata.usgs.gov/in/nwis/uv/?site_no=03341500&agency_cd=USGS&amp*), and the flood-stage forecasts by the National Weather Service, can help to guide the general public in taking individual safety precautions and can provide municipal officials with a tool to efficiently manage emergency flood operations and flood mitigation efforts. The maps and other useful flood information are available on the USGS Flood Inundation Mapping Science Web site (*http://water.usgs.gov/osw/flood_inundation/*) and the NWS AHPS website (*http:/water.weather.gov/ahps/*). 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.

Flood profiles were computed along the stream reach for selected stream stages by means of a one-dimensional step-backwater model using the U.S. Army Corps of Engineers' HEC–RAS program. The model was calibrated using the most current stage-discharge relation at the Wabash River at Terre Haute gage. Estimated flood-inundation areas were delineated using the U.S. Army Corps of Engineers' HEC–GeoRAS program. The maps show estimated flood-inundation areas overlaid on high-resolution, georeferenced, aerial photographs of the study area for stream stages between and including 9 ft and 30 ft at the Wabash River streamgage.

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