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Flood-Inundation Maps for the Tippecanoe River near Delphi, Indiana

Pamphlet to accompany
Scientific Investigations Map 3243

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

Cover:

Inset image: View of downstream, left bank from USGS streamgage 03332605, Tippecanoe River below Oakdale Dam, Indiana. (Photo taken by Chad Menke on March 12, 2009.)

Background image: View of USGS streamgage 03333050, Tippecanoe River near Delphi, Indiana. (Photo taken by Brad T. Reinking on January, 14, 2008.)

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U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
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[Sheets and additional materials are available online at *http://pubs.usgs.gov/sim/3243/*.]

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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 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.

Flood-Inundation Maps for the Tippecanoe River near Delphi, Indiana

By Chad D. Menke, Aubrey R. Bunch, and Moon H. Kim

Abstract

Digital flood-inundation maps for an 11-mile reach of the Tippecanoe River that extends from County Road W725N to State Road 18 below Oakdale Dam, Indiana (Ind.), were created by the U.S. Geological Survey (USGS) in cooperation with the Indiana Department of Transportation. The inundation maps, which can be accessed through the USGS Flood Inundation Mapping Science Web site at *http://water.usgs.gov/osw/flood_inundation/*, depict estimates of the areal extent of flooding corresponding to selected water levels (stages) at USGS streamgage 03333050, Tippecanoe River near Delphi, Ind. Current conditions at the USGS streamgages in Indiana may be obtained online at *http://waterdata.usgs.gov/in/nwis/current/?type=flow*. In addition, the information has been provided to the National Weather Service (NWS) for incorporation into their Advanced Hydrologic Prediction Service (AHPS) flood warning system (*http://water.weather.gov/ahps/*). The NWS forecasts flood hydrographs at many places that are often co-located at USGS streamgages. That forecasted peak-stage information, also available on the Internet, may be used in conjunction with the maps developed in this study to show predicted areas of flood inundation.

In this study, water-surface profiles were simulated for the stream reach by means of a hydraulic one-dimensional step-backwater model. The model was calibrated by using the most current stage-discharge relation at USGS streamgage 03333050, Tippecanoe River near Delphi, Ind., and USGS streamgage 03332605, Tippecanoe River below Oakdale Dam, Ind. The hydraulic model was then used to simulate 13 water-surface profiles for flood stages at 1-foot 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) in order to delineate the area flooded at each water level. A flood-inundation map was generated for each water-surface profile stage (13 maps in all) so that, for any given flood stage, users will be able to view the estimated area of inundation.

The availability of these maps, along with current stage from USGS streamgages and forecasted stream stages from the NWS, provides emergency management personnel and residents with information that is critical for flood response activities such as evacuations and road closures, as well as for post-flood recovery efforts.

Introduction

The study area affected by flooding is a rural area northwest of Delphi, Indiana (Ind.), populated with riverside homes, cottages, and camps. In January 2008, a record flood occurred on the Tippecanoe River in the study area and resulted in evacuations and damage to more than 400 homes. A second flood of nearly equal severity occurred a month later, in February, causing further damage to many residences in the study area (Scott E. Morlock, U.S. Geological Survey, written commun., November 2012).

Prior to this study, local officials relied on several information sources (many of which are available on the Internet) to make decisions on how to best alert the public and mitigate flood damages. One source is the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for Carroll County, dated 1989 (Federal Emergency Management Agency, 1989). A second source of information is data from two USGS streamgages, 03333050 Tippecanoe River near Delphi, Ind., and 03332605, Tippecanoe River below Oakdale Dam, Ind., from which current or historical water levels (stage) can be obtained at *http://waterdata.usgs.gov/in/nwis/current/?type=flow*. A third source is the National Weather Service's forecast of peak stage at the USGS streamgages through the AHPS site at *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 the depth of water at locations other than near USGS streamgage or NWS flood-forecast points.

Purpose and Scope

The purpose of this report is to describe the development of a series of estimated flood-inundation maps for the Tippecanoe River near Delphi, Ind., and to provide maps and other useful flood information on the USGS Flood Inundation Mapping Science Web site at *http://water.usgs.gov/osw/flood_inundation/* and the NWS Advanced Hydrologic Prediction Service Web site *at http:/water.weather.gov/ahps/*. 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 the Tippecanoe River between USGS streamgage 03333050, Tippecanoe River near Delphi, Ind., at State Route 18 and USGS streamgage 03332605, Tippecanoe River below Oakdale Dam, Ind. (fig. 1). Tasks specific to development of the maps were (1) collection of topographic data and geometric data (for structures and (or) bridges) throughout the study reach, (2) determination of energy-loss factors (roughness coefficients) in the stream channel and flood plain, and 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 Geographic Information System (GIS), and (5) 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 on the Internet.

Methods used generally are cited from previously published reports (for example, Bales and others, 2007; and Whitehead and Ostheimer, 2009). If techniques varied significantly from previously documented methods due to local hydrologic conditions or available data, they are described in detail in this report. Maps were produced for water levels referenced to the water-surface elevation (stage) at USGS streamgage 03333050 Tippecanoe River near Delphi, Ind., and ranging from approximately bankfull to the approximate maximum observed water level at the streamgage.

Study Area Description

The Tippecanoe River flows through the study area in the western part of Carroll County, in north-central Indiana. The drainage area ranges from 1,790 mi^2 at USGS streamgage 03332605, Tippecanoe River below Oakdale Dam, Ind., to 1,869 mi^2 at USGS streamgage 03333050, Tippecanoe River near Delphi, Ind. The headwaters originate from Tippecanoe Lake in Kosciusko County in north-central Indiana, and the stream flows generally southward. One major tributary to the Tippecanoe River (Big Creek) joins the main stem midway through the study reach. The study reach is approximately 11 mi long; average top-of-bank channel width is about 280 ft, and an average channel slope is 2.6 ft/mi. The basin contiguous to the study reach is classified as rural and is populated with riverside homes, summer cottages, and recreational camps. The main channel within the study reach has two major road crossings that lie within the channel or the adjacent flood plain.

Previous Studies

The current FIS for Carroll County was completed by the U.S. Geological Survey in 1986 (Federal Emergency Management Agency, 1989). This study provided information on the 1.0-percent annual exceedance probability water-surface profiles and associated flood-plain maps for the Tippecanoe River. Estimates of the peak discharges for the 1.0-percent annual exceedance probability flood were documented for the Tippecanoe River at Oakdale Dam and at the Carroll County boundary with discharges of 25,500 ft^3/s and 27,500 ft^3/s, respectively (Federal Emergency Management Agency, 1989); the estimated drainage areas for the above locations were determined to be 1,790 mi^2 and 1,892 mi^2 respectively using Indiana StreamStats (*http://water.usgs.gov/osw/streamstats/indiana.html,* accessed July 18, 2012).

Constructing Water-Surface Profiles

The water-surface profiles used to produce the 13 flood-inundation maps in this study were computed by using HEC-RAS, version 4.1.0 (U.S. Army Corps of Engineers, 2010). HEC-RAS is a one-dimensional step-backwater model for simulation of water-surface profiles with steady-state (gradually varied) or unsteady-state flow computation options. The HEC-RAS analysis for this study was done by using the steady-state flow computation option.

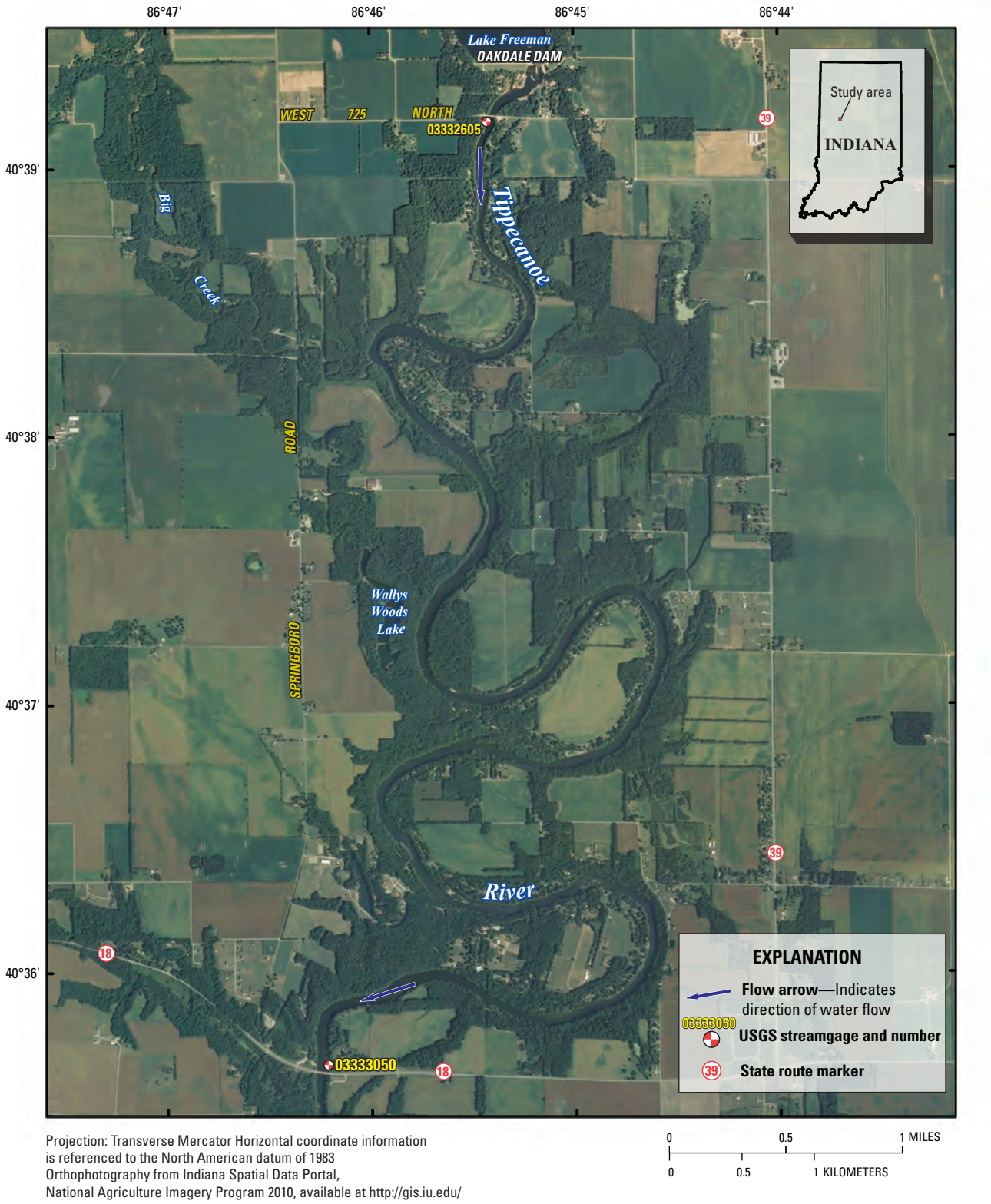

Figure 1. Location of study reach for the Tippecanoe River and location of USGS streamgage sites.

Hydrologic and Steady-Flow Data

The study area hydrologic network consists of two streamgages (fig. 1; table 1). Both gages were in operation prior to this study. Water level (stage) is measured continuously at each of the sites, and continuous records of streamflow are computed at both sites. All water-surface elevations are referenced to the North American Vertical Datum of 1988 (NAVD 88). The gages are equipped with satellite radio transmitters that allow data to be transmitted routinely on the Internet within an hour of collection. USGS streamgage 03333050, Tippecanoe River near Delphi, Ind., is also equipped with a recording tipping-bucket rain gage. Flow data can be accessed at *http://waterdata.usgs.gov/in/nwis/current/?type=flow* by selecting the appropriate streamgage number.

Steady-flow data consisted of flow regime, boundary conditions (either known water-surface elevation associated with a discharge measurement, normal depth, or streamgage rating-curve value), and peak-discharge information. The steady-flow data for the study reach were obtained from previous studies and field measurements of streamflow at USGS streamgage 03333050, Tippecanoe River near Delphi, Ind. At gaged sites, all computations based on discharge values with known stages from actual streamflow measurements or stage-discharge relations were used.

Topographic/Bathymetric Data

Channel cross sections were developed from USGS field surveys that were conducted in November and December 2011; these cross sections provide detailed channel-elevation data below the water surface and were collected by using hydroacoustic instrumentation to measure depth and Differential Global Positioning System (DGPS) instrumentation to determine horizontal position. Light Detection and Ranging (LiDAR) data, collected in 2010 for Carroll County (David S. Nail, U.S. Geological Survey, written commun., October 2010), was 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.

Various manmade structures (bridges, culverts, roadway embankments, and levees) in and along the 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, bridge geometry was surveyed for the two bridges in the model. Both bridges were verified as current structures with pictures and elevation checks from digital-elevation model and field observations. A detailed description of the methods used to acquire and process the topographic and bathymetric data can be found in Bales and others (2007).

Energy-Loss Factors

Field observations and high-resolution aerial photographs were used to select initial (pre-calibration) Manning's roughness coefficients ("*n*" values) for energy-loss (friction-loss) calculations. The final Manning's *n* values used were 0.04 for the main channel and 0.06 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 USGS streamgages 03333050, Tippecanoe River near Delphi, Ind., and 0332605, Tippecanoe River below Oakdale Dam, Ind. The model calibration was accomplished by adjusting Manning's *n* values and, in some cases, changing the channel cross section 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 at USGS streamgage 03333050, Tippecanoe River near Delphi, Ind., were within 0.09 ft (table 2). Differences between measured and simulated water levels for specified flows at USGS streamgage 03332605, Tippecanoe River at Oakdale Dam, Ind., were within 0.36 ft (table 3). 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).

Table 1. USGS streamgage information for selected sites near Delphi, Indiana.

[mi^2, square miles; NAD 83, North American Datum of 1983; NAVD 88, North American Vertical Datum of 1988; ft, feet]

Streamgage name	Streamgage number	Drainage area (mi^2)	Latitude	Longitude	Period of record	Maximum flood elevation (ft above NAVD 88 and date).
Tippecanoe River near Delphi, Indiana	03333050	1,869	40º35′38″	86º46′12″	July 1939 to present	552.49 ft, Jan. 8, 2008.
Tippecanoe River at Oakdale Dam, Indiana	03332605	1,790	40º39′12″	86º 45′24″	Dec. 2008 to present	578.53 ft, March 11, 2009.

Table 2. Comparison of hydraulic-model output and measured stages at USGS streamgage 03333050, Tippecanoe River near Delphi, Indiana.

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

Stage (ft)	Measured water-surface elevation (ft, NAVD 88)	Modeled water-surface elevation (ft, NAVD 88)	Elevation difference (ft)
6.00	540.66	540.75	-0.09
7.00	541.66	541.69	-0.03
8.00	542.66	542.58	0.08
9.00	543.66	543.58	0.08
10.00	544.66	544.71	-0.05
11.00	545.66	545.67	-0.01
12.00	546.66	546.66	0.00
13.00	547.66	547.62	0.04
14.00	548.66	548.61	0.05
15.00	549.66	549.69	-0.03
16.00	550.66	550.67	-0.01
17.00	551.66	551.65	0.01
18.00	552.66	552.62	0.04

Table 3. Comparison of hydraulic-model output and measured stages at USGS streamgage 03332605, Tippecanoe River below Oakdale Dam, Indiana

[ft, feet; NAVD 88, North American Vertical Datum of 1988; modeled water-surface elevations of 580.07 ft, 581.32 ft, and 582.55 ft could not be compared because the rating was not extended to these elevations]

Stage (ft)	Measured water-surface elevation (ft, NAVD 88)	Modeled water-surface elevation (ft, NAVD 88)	Elevation difference (ft)
9.13	568.94	568.85	0.09
10.31	570.12	570.10	0.02
11.41	571.22	571.27	-0.05
12.59	572.4	572.38	0.02
13.72	573.53	573.51	0.02
14.48	574.29	574.58	-0.29
15.44	575.25	575.59	-0.34
16.78	576.59	576.58	0.01
17.52	577.33	577.54	-0.21
18.63	578.44	578.80	-0.36

Development of Water-Surface Profiles

Profiles were developed for a total of 13 stages at 1-ft intervals between 6.00 ft and 18.00 ft as referenced to USGS streamgage 03333050, Tippecanoe River near Delphi, Ind. Discharges corresponding to the various stages were obtained from the most current stage-discharge relation (rating no. 5.0) at this same streamgage.

Models on the Tippecanoe River were calibrated to produce the selected profile elevations at USGS streamgage 03333050 (table 4). Discharge at USGS streamgage 03332605, Tippecanoe River below Oakdale Dam, Ind., was determined by calculating cubic feet per second per square mile (CFSM) that corresponded to the measured discharges at USGS streamgage 03333050, Tippecanoe River near Delphi, Ind. The CFSM is defined as the average number of cubic feet of water per second flowing from each square mile of area drained by a stream, assuming that the runoff is distributed uniformly in time and area.

The contributing drainage area to the river at the mouth of Big Creek accounts for the increase in discharge from the estimated discharge upstream at USGS streamgage 03332605 and measured discharge downstream at USGS streamgage 03333050. Drainage areas were calculated by using a Web-based GIS application called StreamStats (Ries and others), which can be accessed at *http://water.usgs.gov/osw/streamstats/indiana.html*.

Inundation Mapping

Flood-inundation maps were created for USGS streamgage 03333050, Tippecanoe River near Delphi, Ind., which is also an NWS flood-forecast point. 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 LiDAR data with 1.02-ft horizontal accuracy and a vertical accuracy of 0.37 ft (David S. Nail, U.S. Geological Survey, written commun., October 2010). The initial resolution of the DEM with 3.9-ft cell size was later resampled to 10- by 10-ft cell size in order to reduce the 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 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.

Table 4. Discharge estimates for corresponding stages at selected locations along the Tippecanoe River near Delphi, Indiana, for simulated water-surface profiles.

[Numbers in parentheses reference NAVD 88; mi^2, square miles; ft^3/s, cubic feet per second]

Location	Drainage area (mi^2)	Stage, in feet above gage datum												
		6.00 (540.66)	7.00 (541.66)	8.00 (542.66)	9.00 (543.66)	10.00 (544.66)	11.00 (545.66)	12.00 (546.66)	13.00 (547.66)	14.00 (548.66)	15.00 (549.66)	16.00 (550.66)	17.00 (551.66)	18.00 (552.66)
		Discharge (ft^3/s)												
USGS streamgage 03333050	1,869	5,350	6,960	8,663	10,450	12,440	14,520	16,690	18,940	21,380	25,020	29,160	33,640	38,460
At mouth of Big Creek confluence	1,860	5,324	6,926	8,621	10,400	12,380	14,450	16,610	18,849	21,277	24,900	29,020	33,478	38,275
USGS streamgage 03332605	1,790	5,124	6,666	8,297	10,008	11,914	13,906	15,985	18,139	20,476	23,962	27,927	32,218	36,834
Sheet no.		1	2	3	4	5	6	7	8	9	10	11	12	13

Tippecanoe River, Indiana, Flood-Inundation Maps on the Internet

A USGS Flood Inundation Mapping Science World Wide Web portal has been established by the USGS to provide estimated flood-inundation information to the public (see *http://water.usgs.gov/osw/flood_inundation/*). The maps and data from this study showing the extent of inundated areas can be downloaded in three electronic file formats from that portal: (1) GIS shapefile format, (2) Keyhole Markup Language (KML) file format, and (3) 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 and KML 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 streamflow at USGS streamgage 03333050, Tippecanoe River near Delphi, Ind., 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.

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 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 streamgages. The hydraulic model reflects the land-cover characteristics and any bridge, dam, levee, or other hydraulic structures existing as of December 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 from 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 digital elevation model 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 was developed in cooperation with the Indiana Department of Transportation for the Tippecanoe River in Indiana between State Road 18 and Oakdale Dam. These maps, available at a USGS Web portal, in conjunction with the real-time stage data from USGS streamgage 03333050, Tippecanoe River near Delphi, Ind., and National Weather Service flood-stage forecasts, will help to guide the general public in taking individual safety precautions and will provide local officials with a tool to efficiently manage emergency flood operations and flood mitigation efforts.

The maps were developed by using the U.S. Army Corps of Engineers' HEC-RAS and HEC-GeoRAS programs to compute water-surface profiles and to delineate estimated flood-inundation areas for selected stream stages. The maps show estimated flood-inundation areas overlaid on high-resolution, georeferenced aerial photographs of the study area for stream stages between 6.00 ft and 18.00 ft at USGS streamgage 03333050, Tippecanoe River near Delphi, Ind.

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