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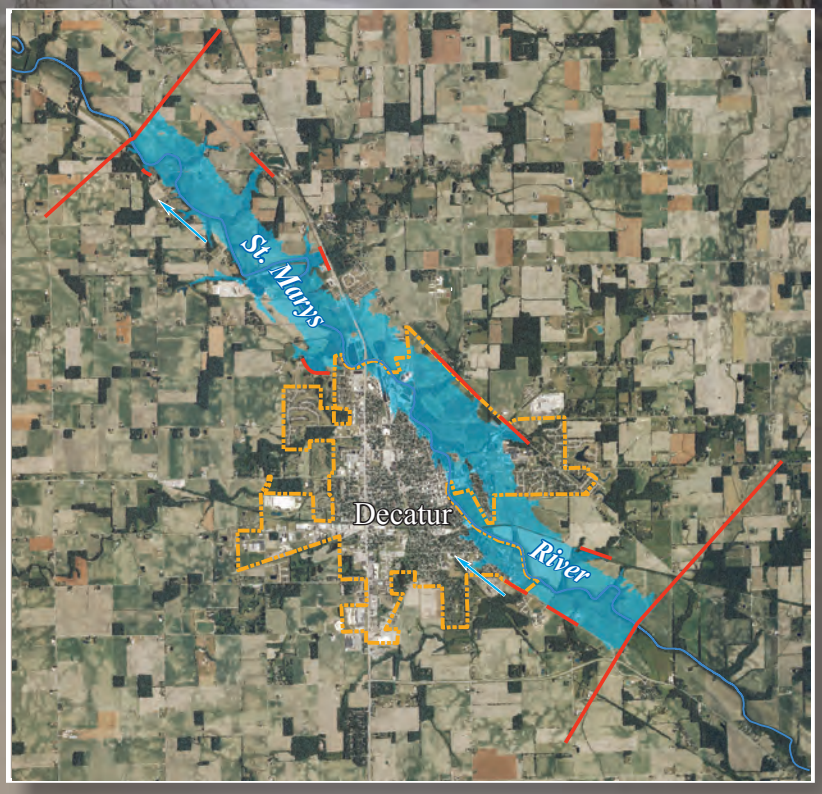
Flood-Inundation Maps for the St. Marys River at Decatur, Indiana



Scientific Investigations Report 2015–5099

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

Cover: St. Marys River at Decatur, Indiana, downstream from the U.S. Geological Survey streamgage (station number 04181500) (photo by Edward Dobrowolski, USGS, January 11, 2013). Inset image shows flood inundation at stage of 30.00 feet and elevation of 790.12 feet.

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By Kellan R. Strauch

Prepared in cooperation with the Indiana Office of Community and Rural Affairs

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SALLY JEWELL, Secretary

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

U.S. Geological Survey, Reston, Virginia: 2015

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Suggested citation:
Strauch, K.R., 2015, Flood-inundation maps for the St. Marys River at Decatur, Indiana: U.S. Geological Survey Scientific Investigations Report 2015–5099, 8 p., http://dx.doi.org/10.3133/sir20155099.

ISSN 2328-0328 (online)

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Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
foot (ft)	30.48	centimeter (cm)
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

The author would like to thank the many local, State, and Federal agencies that have cooperated in the funding for the operation and maintenance of the gages used for this study, especially the Indiana Department of Natural Resources. Special thanks are given to the City of Decatur, Indiana, and the Adams County staff for providing data and reviewing flood-inundation maps prior to publication, and to the National Weather Service for their continued support to the U.S. Geological Survey flood-inundation mapping initiative.

Flood-Inundation Maps for the St. Marys River at Decatur, Indiana

By Kellan R. Strauch

Abstract

Digital flood-inundation maps for an 8.9-mile reach of the St. Marys River at Decatur, Indiana, were developed 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 (http://water.usgs.gov/osw/flood_inundation/), depict estimates of the areal extent and depth of flooding corresponding to selected water levels (stages) of the St. Marys River at Decatur (USGS station number 04181500). The maps are useful for estimating near-real-time areas of inundation by referencing concurrent USGS streamgage information at http://waterdata.usgs.gov/. In addition, the streamgage information was provided to the National Weather Service (NWS) for incorporation into their Advanced Hydrologic Prediction Service flood warning system (http:/water.weather.gov/ahps/). NWS-forecasted peak-stage information may be used in conjunction with the maps developed during this study to show predicted areas of flood inundation.

During 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 stage-discharge relation for the streamgage at St. Marys River at Decatur. The hydraulic model was used to compute 18 water-surface profiles for flood stages varied at 1-foot (ft) intervals and ranging from approximately bankfull (13 ft above gage datum) to greater than the highest recorded water level at the streamgage. To delineate the area of flood inundation for each modeled water level, maps were constructed in a geographic information system by combining the simulated water-surface profiles with a digital-elevation model derived from light detection and ranging (lidar) data. Estimated flood-inundation boundaries along each simulated profile were developed using HEC–GeoRAS software.

The availability of these maps and associated Web mapping tools, along with the current river stage from USGS streamgages and forecasted flood stages from the NWS, provides emergency managers and residents with information that may be critical for flood-emergency planning and flood-response activities such as evacuations and road closures, as well as for post-flood recovery efforts.

Introduction

The City of Decatur, Indiana, is an urban community with an estimated population of 25,740 (U.S. Census Bureau, 2010). Peak streamflows (since 1932) and continuous stage measurements (since 1947) have been recorded at a U.S. Geological Survey (USGS) streamgage on the St. Marys River at Decatur (station number 04181500). The peak discharge of record, 15,000 cubic feet per second (ft^3/s) at a stage of 26.92 feet (ft; gage datum), occurred on July 9, 2003. The most recent flood event (stage above 17 ft) with USGS-approved flow data occurred on November 30, 2011, with a peak flow of 6,100 ft^3/s and a stage of 20.12 ft (U.S. Geological Survey, 2014).

Prior to this study, Decatur officials relied on several information sources, all of which are available on the Internet, to make decisions on how to best alert the public and mitigate flood damages. One source is the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for Adams County, which includes the city of Decatur and is dated September 29, 2010 (Federal Emergency Management Agency, 2010). A second source of information is the USGS streamgage, St. Marys River at Decatur (station number 04181500), from which current or historical water levels (stage) can be obtained. A third source is the National Weather Service (NWS) forecast of peak stage at the USGS gage through the NWS Advanced Hydrologic Prediction Service (AHPS) Web site. Although USGS current river stage and collocated NWS forecast stage information are particularly useful for residents in the immediate vicinity of a streamgage, they are of limited use to residents farther upstream or downstream because the water-surface elevation is not constant along the entire stream channel. Also, FEMA and State emergency-management-mitigation teams or property owners typically lack information related to how deep the water is at locations other than near USGS streamgages or NWS flood-forecast points. To enable local officials or residents to take appropriate precautions, make preparations, or efficiently manage flood-emergency operations and flood-mitigation efforts by using scientific maps of simulated water depth and inundated area(s) for a potential flood, the USGS, in cooperation with the

Indiana Office of Community and Rural Affairs, completed the herein-described flood-inundation study for an 8.9-mile (mi) reach of the St. Marys River at Decatur, Ind.

Purpose and Scope

The purpose of this report is to describe the development of a series of estimated flood-inundation maps for the St. Marys River at Decatur, Ind. 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 Web site (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 an 8.9-mi reach of the St. Marys River at Decatur, Ind., from 2.3 mi upstream of the Erie Railroad Bridge to 0.7 mi downstream of the county road W 900 N Bridge (fig. 1). Tasks specific to development of the maps were as follows:

1. collection of topographic data, cross sections, and geometric data (for structures/bridges) throughout the study reach,
2. estimation of energy-loss factors (roughness coefficients) in the stream channel and flood plain and compilation of steady-flow data,
3. 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),
4. estimation of the flood-inundation area at various stream stages by use of 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. preparation of the maps, both as polygon shapefiles that depict the areal extent of flood inundation and as depth grids that provide the depth of flood waters, as displayed on the USGS Flood Inundation Mapper Web site (http://wim.usgs.gov/FIMI/), which can be accessed through the USGS Flood Inundation Mapping Science Web site at http://water.usgs.gov/osw/flood_inundation/.

Methods used are generally cited from previously published USGS flood-inundation reports. If techniques varied significantly from previously documented methods because of local hydrologic conditions or availability of data, they are described in detail in this report. Maps were produced for water levels referenced to the stage at St. Marys River at Decatur, Ind., and ranged from approximately bankfull (13 ft above gage datum) to 30 ft, which is greater than the highest recorded water level at the streamgage.

Study-Area Description

The study reach of the St. Marys River is in Adams County in northeastern Indiana. The drainage area ranges from 592 square miles (mi^2) at the upstream limit of the study area to 678 mi^2 at the downstream extent of the study reach. The drainage area of the streamgage at St. Marys River at Decatur is 621 mi^2. The headwaters originate in western Ohio, and the stream flows generally to the northwest. The study reach is approximately 8.9 mi long and has an average top-of-bank channel width (of all cross sections) of about 146.5 ft and an average channel slope of 1.06 feet per mile (ft/mi). About 23 percent of the land contiguous to the study reach is classified as urban or developed, 9 percent as forest, and 60 percent as cropland (Homer and others, 2007). The main channel within the study reach has seven major road crossings that have the ability to affect the water-surface profiles.

Previous Studies

The current FIS for Adams County (Federal Emergency Management Agency, 2010), which includes all of Decatur, Ind., was completed in 2003. That study provided information on the 10- and 1.0-percent annual exceedance probability water-surface profiles and associated flood-plain maps for the St. Marys River.

Constructing Water-Surface Profiles

The water-surface profiles used to produce 18 flood-inundation maps for 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 used the steady-state flow computation option.

Hydrologic and Steady-Flow Data

The study-area hydrologic network consists of one streamgage (fig. 1; table 1). Water level (stage) is measured continuously at the site, and continuous records of streamflow are computed for the site. All water-surface elevations were referenced to the North American Vertical Datum of 1988 (NAVD 88). The gage is equipped with satellite radio transmitters that allow data to be transmitted routinely on the Internet within 1 hour of collection.

Steady-flow data consisted of flow regime, boundary conditions set to normal depth, and peak-discharge information. The steady-flow data for the study reach were obtained from USGS field measurements and gage-recorded data for streamflow of the St. Marys River at Decatur, Ind. At the gaged site,

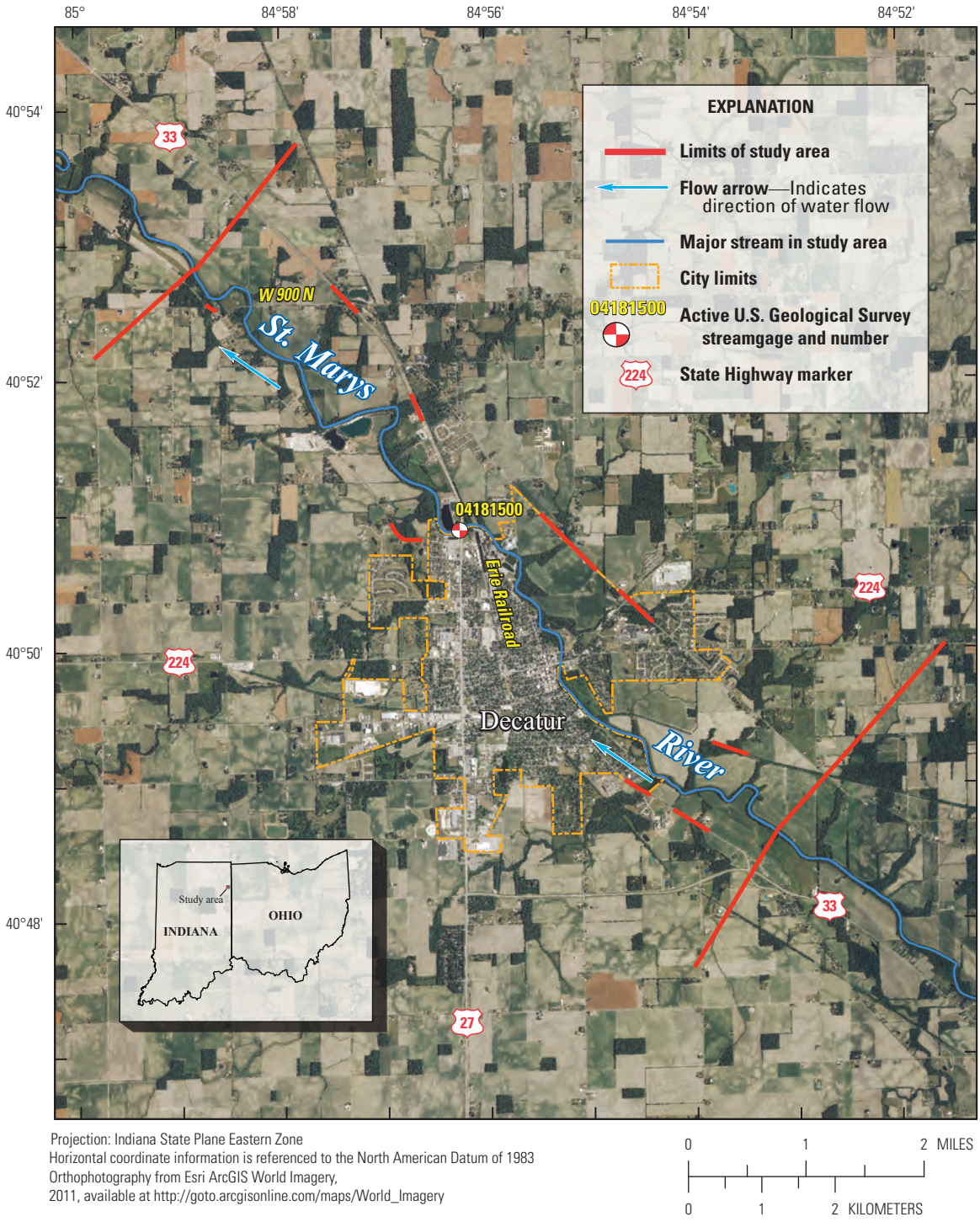

Figure 1. Location of study reach for the St. Marys River at Decatur, Indiana, and location of U.S. Geological Survey streamgage (station number 04181500).

all computations based on discharge values with known stages, from actual streamflow measurements or stage-discharge relations were used (U.S. Geological Survey, 2014). Normal depth was used as the downstream boundary condition of the reach. The slope required for calculation of normal depth was computed from the slope of the channel bottom of the four farthest downstream cross sections in the model.

Table 1. U.S. Geological Survey streamgage site information for the study area, St. Marys River at Decatur, Indiana.

[mi², square miles; °, degrees; ′, minutes; ″, seconds]

Station name	Station number	Drainage area (mi²)	Latitude	Longitude	Period of record	Maximum recorded flood stage at gage and date (feet)
St. Marys River at Decatur, Indiana	04181500	621	40°50′ 53.2″	84°56′ 15.9″	Apr. 1947 to current year	26.92 July 09, 2003.

Topographic/Bathymetric Data

Channel cross sections were developed from USGS field surveys that were conducted in November 2012. These cross sections include detailed channel-elevation data below the water surface that were collected using hydroacoustic instrumentation to measure depth and differential global positioning system (DGPS) instrumentation to determine horizontal position. All topographic data used in this study are referenced vertically to the NAVD 88 and horizontally to the North American Datum of 1983 (NAD 83). Cross-section elevation data for flood-plain areas were obtained from a light detection and ranging (lidar)-derived digital-elevation model (DEM). The lidar data were collected as part of a statewide project during 2011–13 by Woolpert, Inc., Geospatial Services, Dayton, Ohio. Lidar data for Adams County were collected January 31–December 13, 2012. The DEM was obtained from the Indiana Spatial Data Portal (Indiana University, 2013). The original lidar data have horizontal resolution of 4.9 ft (1.5 meters) and vertical accuracy of 0.98 ft (30 centimeters) at a 95percent confidence level based on a root mean squared error (RMSE) of 0.49 ft (15 centimeters) for the "open terrain" land-cover category. Although a finer horizontal resolution of the DEM was possible given the accuracy of the lidar data, the final DEM used for the flood-inundation analysis was resampled to a grid-cell size of 10-ft × 10-ft to decrease GIS processing time.

Various man-made drainage structures (bridges, culverts, roadway embankments, levees, and dams) in and along the stream affect or have the potential to affect water-surface elevations during floods. To properly account for these features in the model, bridge geometry was imported from a previous HEC-2 model (Federal Emergency Management Agency, 2010) for seven bridges. All seven bridges were verified as current (2014) structures with photographs and elevation checks from the DEM and field observations. A detailed description of the methods used to acquire and process the topographic and bathymetric data can be found in Bales and others (2007).

Energy-Loss Factors

Field observations and high-resolution aerial photographs were used to select initial (pre-calibration) Manning's roughness coefficients ("*n*" values) for energy-loss (friction-loss) calculations. An *n* value of 0.045 was selected for the wide, low-gradient main channel with sandy bed and tree-lined banks (Arcement and Schneider, 1989). The flood plains have mixed land uses but are dominated by agriculture. Forested areas cover wide swaths of land on both banks and flood plains adjacent to the river. Densely populated residential areas are west of the St. Marys River, but these areas are mostly on elevated ground above the flood plain. A composite *n* value (0.085) that was presumed to represent the diverse energy-loss factors of these land types was deemed appropriate to use for the initial estimate of the flood plain *n* value.

As part of the calibration process, the initial *n* values were varied by flow and adjusted until the differences between measured and simulated water-surface elevations at the streamgage were minimized. The final Manning's *n* values used ranged from 0.037 to 0.054 for the main channel and 0.076 to 0.156 for the overbank areas modeled in this analysis.

Model Calibration and Performance

The hydraulic model was calibrated to the most current USGS stage-discharge relation for the St. Marys River at Decatur, Ind. 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 measured or rated flows at USGS streamgage 04181500 were equal to or less than 0.01 ft (table 2). The results demonstrate that the model is capable of accurately simulating water levels over a wide range of flows. Details on techniques used in model development and calibration can be found in Bales and others (2007).

Table 2. Comparison of hydraulic-model measured and simulated water-surface elevations of the St. Marys River at Decatur, Indiana, streamgage (station number 04181500).

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

Stage (ft)[1]	Measured water-surface elevation (ft, NAVD 88)[1]	Simulated water-surface elevation (ft, NAVD 88)	Elevation difference (ft)
13.0	773.12	773.13	−0.01
14.0	774.12	774.13	−0.01
15.0	775.12	775.13	−0.01
16.0	776.12	776.13	−0.01
17.0	777.12	777.11	0.01
18.0	778.12	778.11	0.01
19.0	779.12	779.11	0.01
20.0	780.12	780.13	−0.01
21.0	781.12	781.11	0.01
22.0	782.12	782.12	0.00
23.0	783.12	783.11	0.01
24.0	784.12	784.13	−0.01
25.0	785.12	785.13	−0.01
26.0	786.12	786.12	0.00
27.0	787.12	787.11	0.01
28.0	788.12	788.11	0.01
29.0	789.12	789.11	0.01
30.0	790.12	790.11	0.01

[1] Values derived from rating curve number 33 at U.S. Geological Survey gaging station 04181500.

Development of Water-Surface Profiles

Water-surface profiles were developed for a total of 18 stages at 1-ft intervals from 13 to 30 ft as referenced to the USGS streamgage 04181500, St. Marys River at Decatur, Ind. Discharges corresponding to the various stages were obtained from the most current stage-discharge relation (rating number 33) at this same streamgage. No major tributaries join the St. Marys River within the 8.9-mi study reach; therefore, the discharges (as listed in table 3) were held constant throughout the study reach for a given profile.

Table 3. Stages (and water-surface elevations) with corresponding discharge estimates of the St. Marys River at Decatur, Indiana, for simulated water-surface profiles.

[mi², square miles; ft, feet; ft³/s, cubic feet per second; stage, in feet above gage datum, corresponds to water-surface elevation, in feet above the North American Vertical Datum of 1988; USGS, U.S. Geological Survey]

Location	Drainage area (mi²)	Stage (ft)								
		13 (773.12)	14 (774.12)	15 (775.12)	16 (776.12)	17 (777.12)	18 (778.12)	19 (779.12)	20 (780.12)	21 (781.12)
		Discharge (ft³/s)								
USGS streamgage 04181500	621	1,948	2,289	2,655	3,056	3,568	4,266	5,100	5,986	6,973

Location	Drainage area (mi²)	Stage (ft)								
		22 (782.12)	23 (783.12)	24 (784.12)	25 (785.12)	26 (786.12)	27 (787.12)	28 (788.12)	29 (789.12)	30 (790.12)
		Discharge (ft³/s)								
USGS streamgage 04181500	621	8,059	9,249	10,550	11,960	13,480	15,130	16,900	18,800	20,820

Inundation Mapping

Flood-inundation maps were produced for the 18 water-surface profiles simulated for the St. Marys River in this study. The maps were created in a GIS by combining the water-surface profiles and DEM data. Estimated flood-inundation boundaries along each simulated profile were developed using HEC–GeoRAS software (U.S. Army Corps of Engineers, 2009). HEC–GeoRAS is a set of procedures, tools, and utilities that facilitates processing geospatial data in ArcGIS (ESRI, Redlands, Calif.) by providing 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 boundaries between modeled cross sections relative to the contour data for the land surface (Whitehead and Ostheimer, 2009). The resultant maps were compiled to show estimated flood-inundated areas overlaid onto high-resolution, georeferenced aerial orthophotographs of the study area for each of the water-surface profiles that were simulated by the hydraulic model.

Flood-Inundation Maps on the Internet for St. Marys River, Indiana

The flood-inundation study documentation is available online at the USGS Publications Warehouse (http://pubs.usgs.gov/sir/2015/5099). Also, a Flood Inundation Mapping Science Web site has been established (http://water.usgs.gov/osw/flood_inundation/) to provide a portal for USGS flood-inundation study information released to the public. That Web portal has a link (http://wimcloud.usgs.gov/apps/FIM/FloodInundationMapper.html) to interactive online-map libraries that can be downloaded in several commonly used electronic-file formats. At the map library site, each stream reach displayed contains further links to USGS National Water Information System (NWIS)-Web graphs of the current stage and streamflow at USGS streamgage 04181500, 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 a 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 made efficiently. Roadways were closely reviewed and are shown as shaded (inundated and likely impassable) or not shaded (dry and passable) to facilitate emergency planning and use. Bridges are shaded—that is, shown as inundated—regardless of the flood magnitude. However, buildings that are shaded do not reflect inundation; but rather, the shading denotes 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) adjacent to the building of interest exceeds that building's height, the structure can be considered fully submerged. The flood map corresponding to the highest simulated water-surface profile, for a stage of 30 ft, is presented as figure 2.

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 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(s). The hydraulic model reflects the land-cover characteristics and any bridge, dam, levee, or other hydraulic structures existing as of February 2014. 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, 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 fore- cast period (every 6 hours and 3 to 5 days in the future for many locations). For more information on AHPS forecasts, please see http://water.weather.gov/ahps/pcpn_and_river_forecasting.pdf.

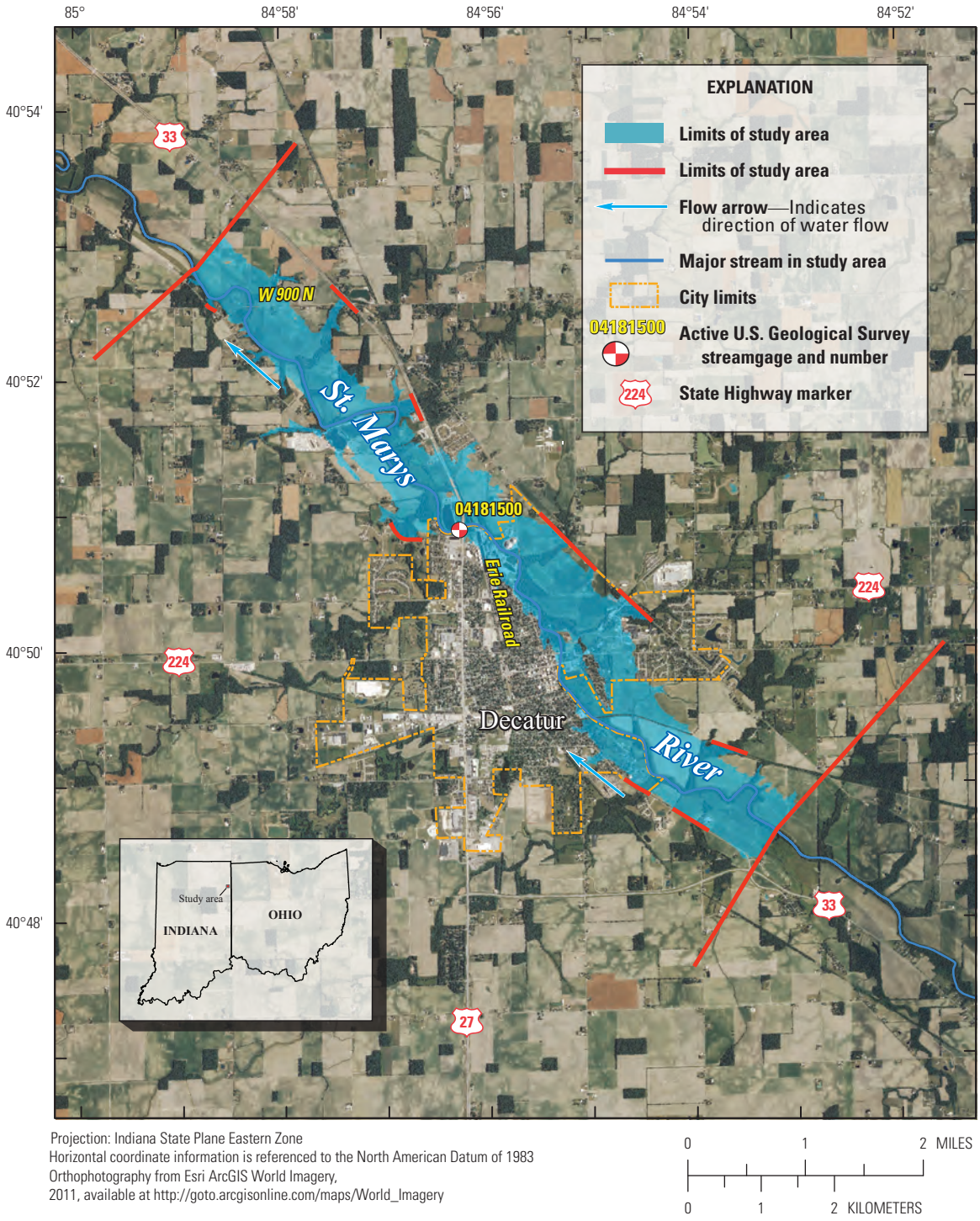

Figure 2. Flood-inundation map for the St. Marys River at Decatur, Indiana, corresponding to a stage of 30 feet at the U.S. Geological Survey streamgage (station number 04181500).

Summary

Estimated flood-inundation maps were developed in cooperation with the Indiana Office of Community and Rural Affairs for an 8.9-mile (mi) reach of the St. Marys River at Decatur, Indiana, from 2.3 mi upstream of the Erie Railroad Bridge to 0.7 mi downstream of the county road W 900 N Bridge. These maps, in conjunction with the real-time stage data from the U.S. Geological Survey (USGS) streamgage, St. Marys River at Decatur, Ind. (station number 04181500), and National Weather Service flood-stage forecasts, will help to guide the general public in taking individual safety precautions and will provide city officials with a tool to efficiently manage emergency flood operations and flood-mitigation efforts.

The maps were developed by using the U.S. Army Corps of Engineers' HEC─RAS and HEC─GeoRAS programs to compute water-surface profiles and to delineate estimated flood-inundation areas for selected stream stages. The maps show estimated (shaded) flood-inundation areas overlaid on high-resolution, georeferenced aerial photographs of the study area for stream stages from 13 to 30 feet at USGS streamgage 04181500, St. Marys River at Decatur, Ind. 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 this 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.

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ISSN 2328-0328 (online)
http://dx.doi.org/10.3133/sir20155099