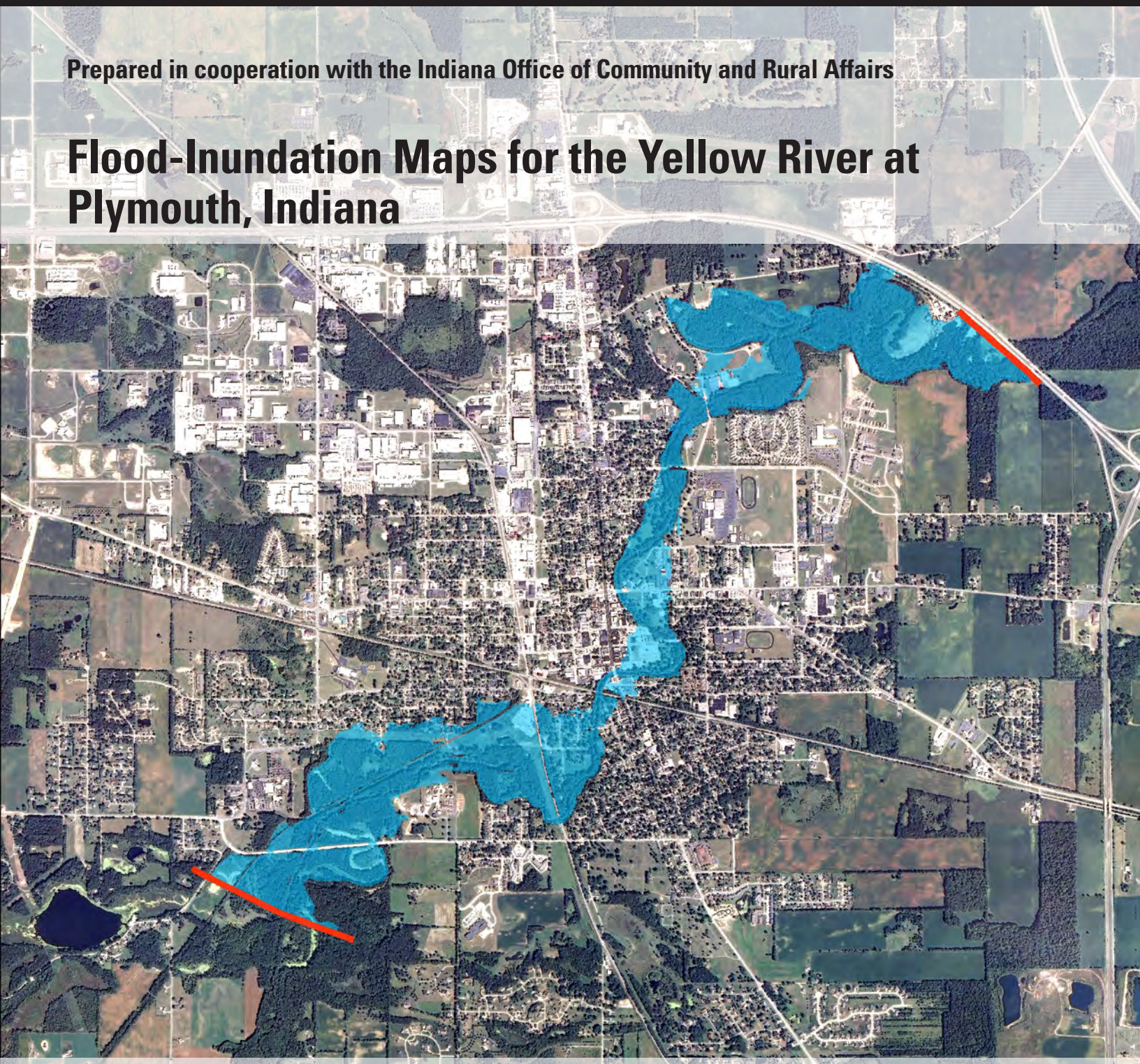
USGS
science for a changing world

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

Flood-Inundation Maps for the Yellow River at Plymouth, Indiana



Scientific Investigations Report 2016–5117

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

Cover. Example of a flood-inundation map for the Yellow River at Plymouth, Indiana.

Flood-Inundation Maps for the Yellow River at Plymouth, Indiana

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

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

Scientific Investigations Report 2016–5117

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

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

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

U.S. Geological Survey, Reston, Virginia: 2016

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit http://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit http://store.usgs.gov.

Suggested citation:
Menke, C.D., Bunch, A.R., and Kim, M.H., 2016, Flood-inundation maps for the Yellow River at Plymouth, Indiana: U.S. Geological Survey Scientific Investigations Report 2016–5117, 9 p., http://dx.doi.org/10.3133/sir20165117.

ISSN 2328-0328 (online)

Acknowledgments

The authors wish to thank the many local, State, and Federal agencies that have cooperated in the funding for the operation and maintenance of the gages. Special thanks are given to the National Weather Service for their continued support to the U.S. Geological Survey flood-inundation mapping program.

Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile ($[ft^3/s]/mi^2$)	0.01093	cubic meter per second per square kilometer ($[m^3/s]/km^2$)

Datum

Vertical coordinate information is referenced to (1) stage, the height above an arbitrary datum established at a streamgage, and (2) elevation, the height above the 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 Yellow River at Plymouth, Indiana

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

Abstract

Digital flood-inundation maps for a 4.9-mile reach of the Yellow River at Plymouth, Indiana (Ind.), were created by the U.S. Geological Survey (USGS) in cooperation with the Indiana Office of Community and Rural Affairs. The flood-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 05516500, Yellow River at Plymouth, Ind. 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/in/nwis/uv?site_no=05516500. In addition, 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 AHPS forecasts flood hydrographs at many sites that are often collocated with USGS streamgages, including the Yellow River at Plymouth, Ind. NWS AHPS-forecast peak-stage information may be used in conjunction with the maps developed in this study to show predicted areas of flood and forecasts of flood hydrographs at this site.

For this study, flood profiles were computed for the Yellow River reach by means of a one-dimensional step-backwater model. The hydraulic model was calibrated by using the current stage-discharge relations at the Yellow River streamgage, in combination with the flood-insurance study for Marshall County (issued in 2011). The calibrated hydraulic model was then used to determine eight water-surface profiles for flood stages at 1-foot intervals referenced to the streamgage datum and ranging from bankfull to the highest stage of the current stage-discharge rating curve. The 1-percent annual exceedance probability flood profile elevation (flood elevation with recurrence intervals within 100 years) is within the calibrated water-surface elevations for comparison. The simulated water-surface profiles were then used with a geographic information system (GIS) digital elevation model (DEM, derived from Light Detection and Ranging [lidar]) in order to delineate the area flooded at each water level.

The availability of these maps, along with Internet information regarding current stage from the USGS streamgage 05516500, Yellow River at Plymouth, Ind., and forecast stream stages from the NWS AHPS, 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 postflood recovery efforts.

Introduction

The city of Plymouth, in Marshall County, Indiana (Ind.), is an urban community with an estimated population of 10,033 (U.S. Census Bureau, 2010). The Yellow River, which flows southwestward through the city, has severely flooded numerous times in the past. The period of record began July 1948 at the U.S. Geological Survey streamgage 05516500, Yellow River at Plymouth, Ind. The largest recorded flood occurred when the river rose to 17.13 feet (ft) above the gage datum of 764.27 ft (North American Vertical Datum of 1988, NAVD 88) on October 12, 1954, with a discharge of 5,390 cubic feet per second (ft^3/s). The most recent flooding occurred in 2008, 2009, and 2013.

Prior to this study, emergency responders in Marshall County 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 flood insurance study (FIS) for Marshall County, which includes the city of Plymouth, dated November 16, 2011 (Federal Emergency Management Agency, 2011). A second source of information is the USGS streamgage 05516500, Yellow River at Plymouth (http://waterdata.usgs.gov/in/nwis/uv?site_no=05516500), from which current and historical water levels (stage) can be obtained. A third source of flood-related information is the National Weather Service (NWS) Advanced Hydrologic Prediction Service (AHPS), which displays the USGS stage data from the Plymouth streamgage (http://water.weather.gov/ahps/). The NWS does not routinely issue forecasts at the Yellow River streamgage at Plymouth, but it does so as needed during times of high-stage flows.

Although the current stage at a USGS streamgage is particularly useful for residents in the immediate vicinity of a streamgage, it is of limited use to residents farther upstream or downstream because the water-surface elevation is not constant along the entire stream reach. Knowledge of a water level at a streamgage is difficult to translate into depth and areal extent of flooding at points distant from the streamgage. One way to address these informational gaps is to produce a library of flood-inundation maps that are referenced to the stages recorded at the USGS streamgage. By referring to the appropriate map, emergency responders can discern the severity of flooding (depth of water and areal extent), identify roads that are or will soon be flooded, and make plans for notification or evacuation of residents in harm's way for some distance upstream and downstream from the streamgage. In addition, the capability to visualize the potential extent of flooding has been shown to motivate residents to take precautions and heed warnings that they previously might have disregarded. In 2014, the USGS, in cooperation with the Indiana Office of Community and Rural Affairs, conducted a project to produce a library of flood-inundation maps for the Yellow River at Plymouth, Ind.

Purpose and Scope

The purpose of this report is to describe the development of a series of estimated flood-inundation maps for the Yellow River at Plymouth, Ind. The maps and other 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 flood stages at USGS streamgage 05516500 and the NWS AHPS forecast peak stage.

The scope of the study for hydraulic modeling was limited to the Yellow River reach extending about 2.7 miles (mi) upstream from USGS streamgage 05516500 (table 1) at the State Highway Route 30 Bridge and about 2.2 mi downstream from the streamgage. The downstream study boundary ends 0.2 mi downstream from Glenn Overmyer Drive Bridge (fig. 1). The maps cover a range of stages from 11 to 18 feet (ft), gage datum. The 11-ft stage is approximately bankfull and is defined by the NWS as the "action stage" or that stage which, when reached by a rising stream, requires the NWS or a partner to take some type of mitigation action in preparation for possible significant hydrologic activity. The 18-ft stage is the highest rated stage at the streamgage.

Study Area Description

The drainage area of the Yellow River is about 274 square miles (mi^2) at the upstream end of the modeled reach; 294 mi^2 at USGS streamgage 05516500, Yellow River at Plymouth, Ind.; and still about 294 mi^2 at the downstream extent of the study reach (U.S. Geological Survey, 2013a). The headwaters originate in St. Joseph County, and the stream flows generally in a southwesterly direction. There is only one major tributary, Elmer Seltenright Ditch; approximately 0.5 mi upstream from Randolph Street, the tributary joins the Yellow River as it flows through the modeled reach.

The study reach for the modeling is approximately 4.9 mi long and has an average top-of-bank channel width of about 130 ft and an average channel slope of about 2.4 feet per mile. The flood-inundation mapping area includes the city of Plymouth. The main channel within the study reach is traversed by seven roadways and two railroads. The three walkway bridges in the study area were not modeled because they do not constrict natural flow. Most of the land contiguous to the study reach is either agricultural or natural area. The flood plain within the city of Plymouth is dominated by residential and commercial development.

Previous Studies

The current FIS for Marshall County (Federal Emergency Management Agency, 2011) is a compilation of earlier community FISs, including those for the city of Plymouth (Federal Emergency Management Agency, 1977) and the unincorporated areas of Marshall County (Federal Emergency Management Agency, 1983), as well as detailed studies of selected known flood-hazard areas. The current version (dated November 2011) was revised to include redelineation of effective flood hazard information, conversion of incorporated and unincorporated areas of Marshall County to a countywide format, and a correction to the NAVD 88 (Federal Emergency Management Agency, 2011). The 1980s hydraulic models for the Yellow River in Plymouth are the basis for the data presented in the current FIS. The FIS presents only an estimate of the peak discharge with 1-percent annual exceedance probability and its associated water-surface elevation in the flood profile for the USGS streamgage, Yellow River at Plymouth, just downstream from the Garro Street bridge. Peak discharge and surface-water elevation for the 1-percent annual exceedance probability are documented in table 2.

Table 1. U.S. Geological Survey streamgage information for the study reach, Yellow River at Plymouth, 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 (NAD 83)	Longitude (NAD 83)	Streamgage datum (ft, NAVD 88)	Period of record	Maximum flood elevation (ft, NAVD 88 and date)
Yellow River at Plymouth, Indiana	05516500	294	41°20′25″	86°18′16″	764.27	July 1948 to 2015	781.40 October 12, 1954

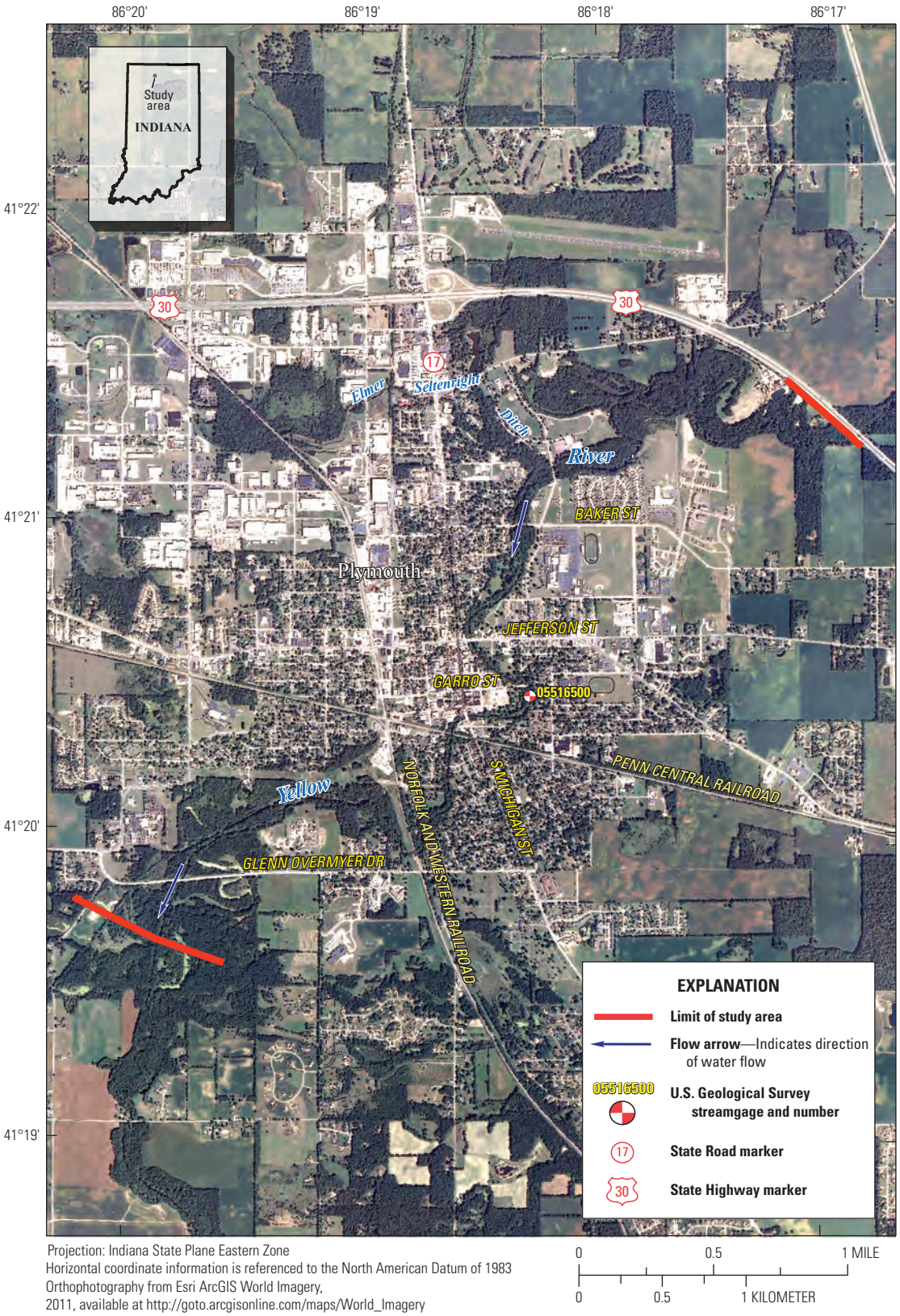


Figure 1. Location of study reach for the Yellow River at Plymouth, Indiana, and location of U.S. Geological Survey streamgage 05516500.

Table 2. Peak discharge for 1-percent annual exceedance probability for Yellow River at Plymouth, Indiana (streamgage 05516500).

[ft³/s, cubic feet per second; FEMA, Federal Emergency Management Agency; NAVD 88, North American Vertical Datum of 1988; USGS, U.S. Geological Survey]

Annual exceedance probability (percent)	Peak discharge[1] (ft³/s)	FEMA water-surface elevation[1] (feet, NAVD 88)	USGS water-surface elevation[2] (feet, NAVD 88)	Difference in elevation (feet)
1	3,800	780.50	779.53	-0.97

[1]Data from Federal Emergency Management Agency, 2011. Discharges from table 6; water-surface elevations from Flood-Profile Panel 9.

[2]Value from most recent stage-discharge relation (number 28, dated January 30, 2007) for the Yellow River at Plymouth, Indiana.

Creation of Flood-Inundation-Map Library

The USGS has standardized the procedures for creating flood-inundation maps for flood-prone communities (U.S. Geological Survey, 2013b) so that the process followed and products produced are similar regardless of which USGS office is responsible for the work. Tasks specific to construction of the maps were (1) compilation of flow data from streamgage 05516500, (2) collection of topographic data and geometric data (for structures/bridges) throughout the study reach, (3) estimation of energy-loss factors (roughness coefficients) in the stream channel and flood plain, (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 U.S. Army Corps of Engineers' HEC–GeoRAS computer program (U.S. Army Corps of Engineers, 2009) and a geographic information system (GIS), and (6) preparation of the maps, both as shapefile polygons that depict the areal extent of flood inundation and as depth grids that provide the depth of floodwaters, for display on a USGS flood-inundation mapping application.

Computation of Water-Surface Profiles

The water-surface profiles used to produce the eight flood-inundation maps in this study were simulated by using HEC–RAS, version 4.1 (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 completed with the steady-state flow computation option.

Hydrologic Data

The study area hydrologic network consists of one streamgage (fig. 1), which has been in operation since 1948. Water level (stage) is measured continuously at this site, and continuous records of discharge are computed using the stage-discharge relation. Stage-discharge rating no. 28.0 (dated February 1, 2007) was used for this study. All water-surface elevations are referenced to the NAVD 88. The streamgage is equipped with a satellite radio transmitter that allows data to be transmitted routinely on the Internet within an hour of collection.

Steady-flow data consisted of flow regime, boundary conditions (normal depth), and peak-discharge information. The steady-flow data for the model were obtained from the stage-discharge relation at USGS streamgage 05516500, Yellow River at Plymouth, Ind. All computations were based on rating 28.0, which in turn is based on values of known stages from actual streamflow measurements.

Topographic and Bathymetric Data

Thirty-six channel cross sections were developed from USGS surveys that were conducted in June 2012; 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. Real-Time Kinematic surveys were also done to establish channel bottom elevations. A total of 52 synthetic cross sections were generated by the use of the digital elevation model (DEM). In-channel data for all synthetic cross sections were estimated by combining Light Detection and Ranging (lidar) overbank data and bathymetric channel profiles.

Lidar data were used to obtain 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 for the Yellow River at Plymouth, Ind., (Marshall County LiDAR) were collected for the Indiana Statewide Imagery and LiDAR Program (http://gis.iu.edu/datasetInfo/statewide/in_2011.php) and processed by Wolpert, Inc., in 2012. The lidar data have horizontal resolution of 1.342 ft and vertical accuracy of 0.184 ft at a 95-percent confidence level, based on a root mean squared error of 1.96 ft for the "open terrain" land-cover category. A detailed description of the methods used to acquire and process the topographic and bathymetric data can be found in Bales and others (2007).

Hydraulic Structures

Various manmade drainage structures (bridges, culverts, and roadway embankments) in and along the Yellow River 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 seven bridges

were measured and surveyed in the field concurrently with the stream-channel surveys. Two bridges were modeled by importing existing geometry from the 1980s hydraulic model into the current model. Three pedestrian bridges are present but were not integrated into the model because they do not constrict flow.

Energy-Loss Factors

Hydraulic analyses require the estimation of energy losses that result from frictional resistance exerted by a channel on flow. Field observations, aerial photos, and the 2011 FIS report were used to select initial channel and flood-plain friction coefficients. These friction coefficients, commonly called Manning's roughness coefficients or Manning's *n* values, account for energy (friction) loss in the model (Arcement and Schneider, 1989). As part of the calibration process, the initial *n* values were varied by flow and adjusted until the differences between simulated and measured water-surface elevations at the streamgage and elsewhere along the study reach were minimized. The final Manning's *n* values were set as 0.045 for the main channel and 0.06 for the overbank areas modeled in this analysis.

Hydraulic Model

The HEC–RAS analysis for this study was done by using the steady-state flow computation option. Steady-state flow data consisted of flow regime, boundary conditions, and peak flows that produced water-surface elevations at the streamgage cross section that matched target water-surface elevations. These target elevations coincided with even 1-ft increments of stage, referenced to the local gage datum. Subcritical (tranquil) flow regime was assumed for the simulations. Normal depth was used as the reach's downstream boundary condition.

The hydraulic model was calibrated to the most current stage-discharge relation (USGS rating no. 28.0 created February 1, 2007) at USGS streamgage 05516500, Yellow River at Plymouth, Ind., and the historical FEMA FIS study for Marshall County, Ind., (issued 2011) documenting the 1-percent annual exceedance elevations along the profile reach at bridges also was used as a qualitative check for model calibration. Model calibration was accomplished by adjusting Manning's *n* values and, in some cases, changing the channel cross section or slope 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 05516500 were less than or equal to about 0.41 ft (table 3). Additional comparison was made to the flood profile from the FIS (Federal Emergency Management Agency, 2011) for the Yellow River to check the model-derived water-surface elevations. The results demonstrate that the model is capable of simulating reasonable 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

The calibrated hydraulic model was used to generate water-surface profiles for a total of eight stages at 1-ft intervals between 11 ft and 18 ft as referenced to USGS streamgage 05516500, Yellow River at Plymouth, Ind. These stages correspond to elevations of 775.27 ft and 782.27 ft, NAVD 88, respectively. Discharges corresponding to the various stages were obtained from the most current stage-discharge relation (rating no. 28.0 created February 1, 2007) at the Yellow River streamgage.

One major tributary, Elmer Seltenright Ditch, joins the Yellow River 0.5 mi upstream from Randolph Street within the 4.9-mi study reach. The streamgage-derived discharges were adjusted, as necessary, to account for tributary inflows. Discharge at the upstream extent of the model above the Elmer Seltenright Ditch was estimated by first calculating cubic feet

Table 3. Measured water-surface elevations at U.S. Geological Survey streamgage 05516500, Yellow River at Plymouth, Indiana, and estimated water-surface elevations output from the hydraulic model.

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

Stage (ft)	Measured water-surface elevation (ft, NAVD 88)	Estimated water-surface elevation (ft, NAVD 88)	Elevation difference (ft)
11.00	775.27	775.68	0.41
12.00	776.27	776.56	0.29
13.00	777.27	777.38	0.11
14.00	778.27	778.10	-0.17
15.00	779.27	778.98	-0.29
16.00	780.27	779.98	-0.29
17.00	781.27	781.02	-0.25
18.00	782.27	782.16	-0.11

per second per square mile ([ft³/s]/mi²) that corresponded to the measured discharges at USGS streamgage 05516500, then multiplying this [ft³/s]/mi² value by drainage area at the upstream extent of the model (table 4). The [ft³/s]/mi² 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 discharge downstream from Elmer Seltenright Ditch to the end of the study reach was taken from current stage-discharge relation at the USGS streamgage and corresponded to the target water-surface elevations.

Development of Flood-Inundation Maps

Flood-inundation maps were created for a reach of the Yellow River at Plymouth, Ind. The maps were created in a GIS by combining the water-surface profiles and DEM data (an example shown in fig. 2). The DEM data for Plymouth, Ind., (Marshall County LiDAR) were collected for the Indiana Statewide Imagery and LiDAR Program (http://gis.iu.edu/datasetInfo/statewide/in_2011.php). 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 using a graphical user interface (ESRI, 2014). 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 plus or minus 1.0 ft.

Any inundated areas that were detached from the main channel were examined to identify subsurface connections with the main river, such as through culverts under roadways. Where such connections were found, the mapped inundated areas were retained in their respective flood maps; otherwise, the erroneously delineated parts of the flood extent were deleted. The flood-inundation areas are overlaid on high-resolution, georeferenced aerial photographs of the study area. Bridge surfaces are displayed as inundated regardless of the actual water-surface elevation in relation to the lowest structural chord of the bridge or the bridge deck. Estimates of water depth can be obtained from the depth-grid data that are included with the presentation of the flood maps on an interactive USGS mapping application described in the following section "Flood-Inundation Map Delivery."

Flood-Inundation Map Delivery

The flood-inundation maps from this study depict estimates of the areal extent and depth of flooding corresponding to selected water levels (stages) at the USGS streamgage 05516500, Yellow River at Plymouth, Ind. The current study documentation is available online at the USGS Publications Warehouse (http://dx.doi.org/10.3133/sir20165117). Also, a Flood Inundation Mapping Science Web site has been established to provide a portal at http://water.usgs.gov/osw/flood_inundation/ to make USGS flood-inundation study information available to the public. That Web portal has a link (http://wim.usgs.gov/FIMI/FloodInundationMapper.html) to a mapping application that presents map libraries and provides detailed information on flood extents and depths for selected sites. The mapping application enables the production of customized flood-inundation maps from the map library for the Yellow River at Plymouth, Ind. At the map library site, each stream reach displayed contains further links to NWISWeb graphs of the current stage and streamflow at USGS streamgage 05516500 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 forecast peak stage. The NWS does not continuously forecast stage at this site but does so only as needed during times of high-stage flows. 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. Depending on the flood magnitude, roadways are shown as shaded (inundated and likely impassable) or not shaded (dry and passable) to facilitate emergency planning and use. Bridges are shaded—that is, shown as inundated—regardless of the flood magnitude. A shaded building should not be interpreted to mean that the structure is completely submerged, rather that bare earth surfaces in the vicinity of the building are inundated.

Table 4. Stages and corresponding discharge estimates for selected locations within the study reach, Yellow River at Plymouth, Indiana, (streamgage 05516500) for simulated water-surface profiles.

[mi², square miles; ft³/s, cubic feet per second]

Location	Drainage area (mi²)	Stage, in feet above streamgage datum							
		11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00
		Estimated discharge (ft³/s)							
Upstream from Elmer Seltenright Ditch mouth	274	1,760	2,120	2,490	2,880	3,380	4,030	4,730	5,500
Downstream from Elmer Seltenright Ditch mouth	294	1,890	2,270	2,670	3,090	3,630	4,320	5,080	5,900

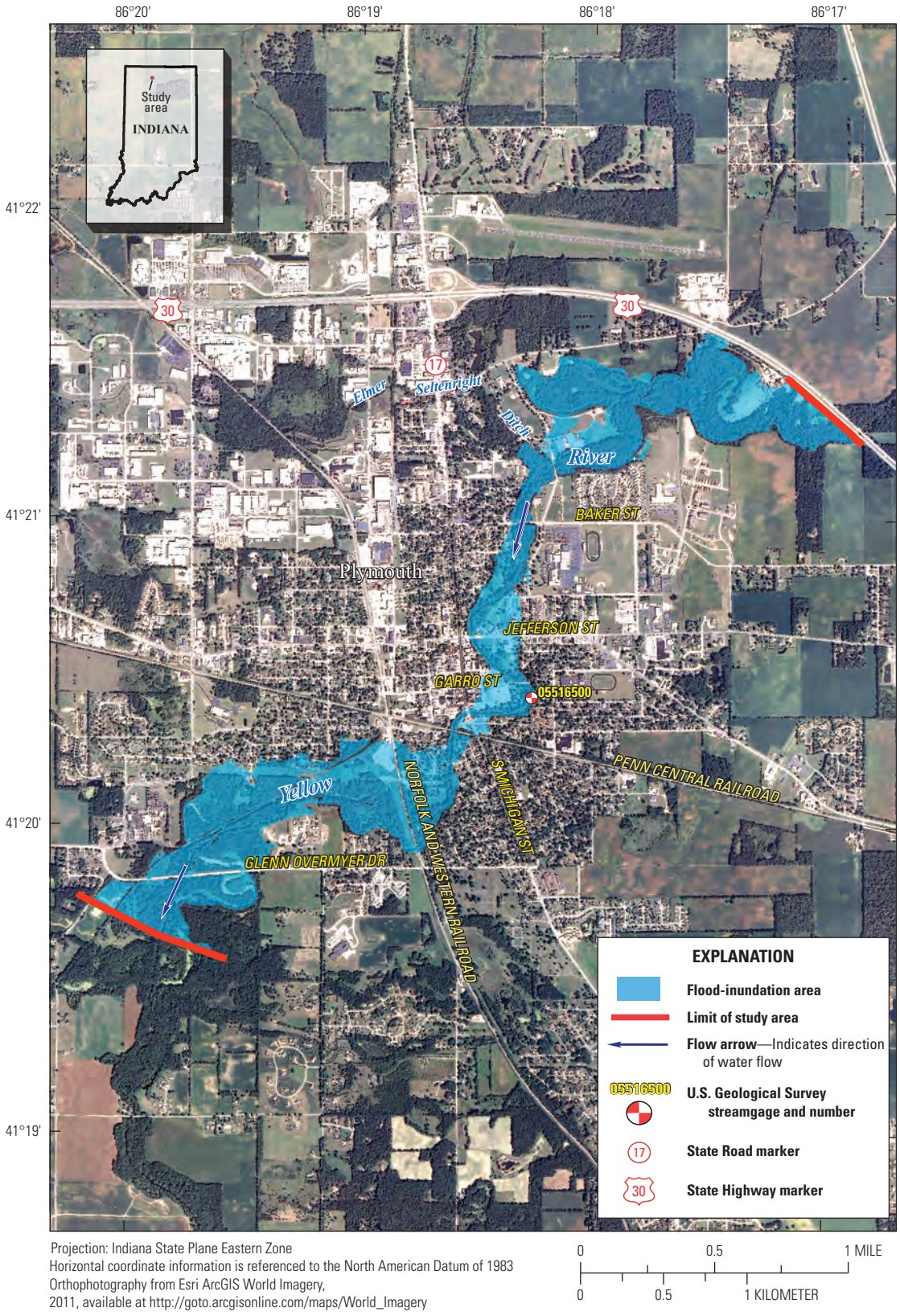


Figure 2. Example of a flood-inundation map for the Yellow River at Plymouth, Indiana, corresponding to a stage of 18.00 feet and an elevation of 782.27 feet (NAVD 88)at U.S. Geological Survey streamgage 05516500.

In these instances, the water depth (as indicated in the mapping application by holding the cursor over an inundated area) near the building would be an estimate of the water level inside the structure, unless flood-proofing measures had been implemented.

Disclaimer for Flood-Inundation Maps

The flood-inundation maps should not be used for navigation, regulatory, permitting, or other legal purposes. The USGS provides these maps "as-is" for a quick reference, emergency planning tool but assumes no legal liability or responsibility resulting from the use of this information.

Uncertainties and Limitations Regarding Use of Flood-Inundation Maps

Although the flood-inundation maps represent the boundaries of inundated areas with a distinct line, some uncertainty is associated with these maps. The flood boundaries shown were estimated on the basis of water stages and streamflows at selected USGS streamgages. Water-surface elevations along the stream reaches were estimated by steady-state hydraulic modeling, assuming unobstructed flow, and using streamflows and hydrologic conditions anticipated at the USGS streamgage(s). The hydraulic model reflects the land-cover characteristics and any bridge or other hydraulic structures existing as of March 2012. 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 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 (and water-surface elevation) for the stream at a given location (AHPS forecast point) throughout the forecast period (every 6 hours and 3–5 days out in many locations). For more information on AHPS forecasts, please see http://water.weather.gov/ahps/pcpn_and_river_forecasting.pdf.

Summary

Estimated flood-inundation maps were developed by the U.S. Geological Survey (USGS) in cooperation with the Indiana Office of Community and Rural Affairs for the Yellow River at Plymouth, Indiana, for the reach about 2.7 miles (mi) upstream from USGS streamgage 05516500 at the State Highway Route 30 Bridge to about 2.2 mi downstream from the streamgage. The downstream study boundary ends 0.2 mi downstream from Glenn Overmyer Drive Bridge.

The flood-inundation maps were developed by using the U.S. Army Corps of Engineers' HEC–RAS and HEC–GeoRAS programs to compute water-surface profiles and to delineate estimated flood-inundation areas and depths of flooding for selected stream stages. The HEC–RAS hydraulic model was calibrated to the current stage-discharge relation at the Yellow River streamgage (05516500). The model was used to compute eight water-surface profiles for flood stages at 1-foot (ft) intervals referenced to the streamgage datum and ranging from 11 ft, or near bankfull, to 18 ft, which is the highest stage of the stage-discharge rating. The simulated water-surface profiles were then combined with a geographic information system digital elevation model derived from light detection and ranging (lidar) data to delineate estimated flood-inundation areas as shapefile polygons and depth grids for each profile. These flood-inundation polygons were overlaid on high-resolution, georeferenced, aerial photographs of the study area. The maps show estimated (shaded) flood-inundation areas of the study area for stream stages between 11 ft and 18 ft at the Yellow River at Plymouth streamgage. The flood maps are available through a mapping application that can be accessed on the USGS Flood Inundation Mapping Science Web site (http://water.usgs.gov/osw/flood_inundation).

Interactive use of the maps on the USGS mapping application can give users a general indication of depth of water at any point by using the mouse cursor to click within the shaded areas. The mapping application enables the production of customized flood-inundation maps from the map library for the Yellow River at Plymouth, Ind. These maps, in conjunction with the real-time stage data from the USGS streamgage, Yellow River at Plymouth, Ind. (station number 05516500), and forecasted flood stage data from the National Weather Service Advanced Hydrologic Prediction Service will help to guide the general public in taking individual safety precautions and will provide emergency management personnel with a tool to efficiently manage emergency flood operations and postflood recovery efforts.

References Cited

Arcement, G.J., Jr., and Schneider, V.R., 1989, Guide for selecting Manning's roughness coefficients for natural channels and flood plains: U.S. Geological Survey Water-Supply Paper 2339, 38 p.

Bales, J.D., Wagner, C.R., Tighe, K.C., and Terziotti, Silvia, 2007, LiDAR-derived flood-inundation maps for real-time flood-mapping applications, Tar River Basin, North Carolina: U.S. Geological Survey Scientific Investigations Report 2007–5032, 42 p.

ESRI, 2014, ArcGIS, accessed January 10, 2014, at http://www.esri.com/software/arcgis/.

Federal Emergency Management Agency, 1983, Flood Insurance Study, Marshall County, Indiana, unincorporated areas: Washington, D.C.

Federal Emergency Management Agency, 1977, Flood Insurance Study, City of Plymouth, Marshall County, Indiana: Washington, D.C.

Federal Emergency Management Agency, 2011, Flood Insurance Study, Marshall County, Indiana, and incorporated areas: Washington, D.C., Flood Insurance Study Number 18099CV000A, 21 p.

U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2009, HEC–GeoRAS, GIS tools for support of HEC–RAS using ArcGIS, user's manual [variously paged], accessed January 10, 2014, at http://www.hec.usace.army.mil/software/hec-georas/downloads.aspx.

U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2010, HEC–RAS river analysis system—Hydraulic reference manual, version 4.1 [variously paged], accessed January 10, 2014, at http://www.hec.usace.army.mil/software/hec-ras/downloads.aspx.

U.S. Census Bureau, 2010, State population datasets—Population, population change and estimated components of population change: April 1, 2010 to July 1, 2006: U.S. Census Bureau.

U.S. Geological Survey, 2013a, StreamStats for Indiana streams, available at http://streamstats.usgs.gov/indiana.html.

U.S. Geological Survey, 2013b, USGS Flood Inundation Mapping Science: U.S. Geological Survey, accessed November 10, 2014, at http://water.usgs.gov/osw/flood_inundation.

Whitehead, M.T., and Ostheimer, C.J., 2009, Development of a flood-warning system and flood-inundation mapping for the Blanchard River in Findlay, Ohio: U.S. Geological Survey Scientific Investigations Report 2008–5234, 9 p., 11 pls.

Publishing support provided by the
U.S. Geological Survey Science Publishing Network,
West Trenton and Pembroke Publishing Service Centers

ISSN 2328-0328 (online)
http://dx.doi.org/10.3133/sir20165117