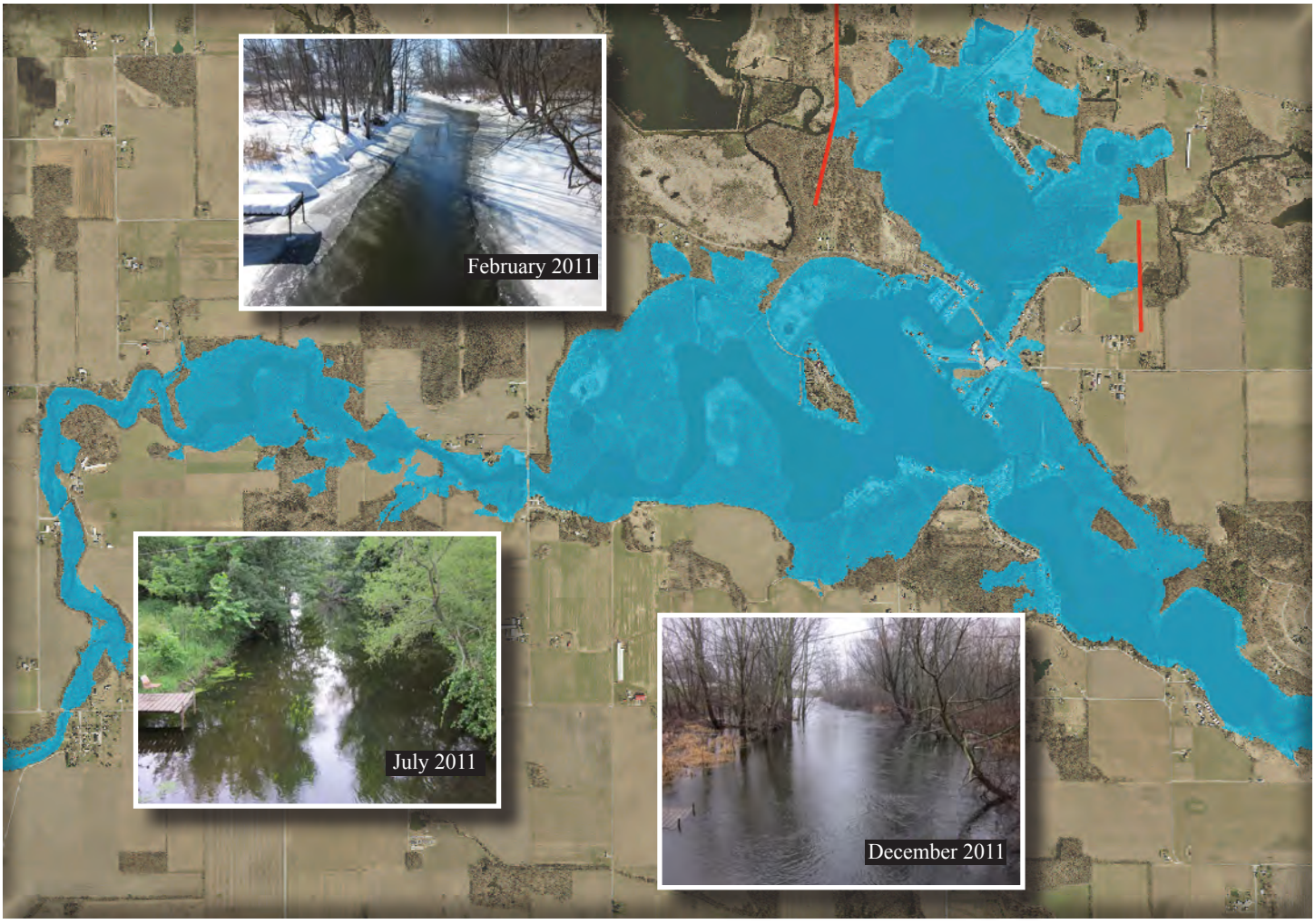
USGS
science for a changing world

Prepared in cooperation with the U.S. Army Corps of Engineers, Detroit District

Flood-Inundation Maps for the North Branch Elkhart River at Cosperville, Indiana



Scientific Investigations Report 2014–5128

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

Cover:
Background: An example of a flood-inundation map along the North Branch Elkhart River and West Lakes Chain area.
Photos: Images of North Branch Elkhart River at Cosperville, Indiana. Photos were taken looking downstream from 900 North Road bridge (by Edward G. Dobrowolski, USGS, at various times in 2011).

Flood-Inundation Maps for the North Branch Elkhart River at Cosperville, Indiana

By Moon H. Kim and Esther M. Johnson

Prepared in cooperation with the U.S. Army Corps of Engineers, Detroit District

Scientific Investigations Report 2014–5128

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, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

Suggested citation:
Kim, M.H., and Johnson, E.M., 2014, Flood-inundation maps for the North Branch Elkhart River at Cosperville, Indiana: U.S. Geological Survey Scientific Investigations Report 2014–5128, 9 p., *http://dx.doi.org/10.3133/sir20145128.*

ISSN 2328-0328
http://dx.doi.org/10.3133/sir20145128

Contents

Acknowledgments iv
Abstract 1
Introduction 1
    Purpose and Scope 3
    Study Area Description 3
    Previous Studies 3
Creation of Flood-Inundation-Map Library 3
    Computation of Water-Surface Profiles 4
        Hydrologic Data 4
        Topographic and Bathymetric Data 4
        Hydraulic Structures 4
        Energy-Loss Factors 5
        Hydraulic Model 5
        Development of Water-Surface Profiles 5
    Development of Flood-Inundation Maps 6
        Flood-Inundation Map Delivery 8
        Disclaimer for Flood-Inundation Maps 8
        Uncertainties and Limitations Regarding Use of Flood-Inundation Maps 8
Summary 8
References Cited 9

Figures

1. Map showing location of study reach for the North Branch Elkhart River and location of USGS streamgage 04100222 2
2. Map showing example of a flood-inundation map for the North Branch Elkhart River at Cosperville, Indiana, corresponding to a stage of 8.00 feet and an elevation of 887.68 feet (NAVD 88) at USGS streamgage 04100222 7

Tables

1. USGS streamgage information for study basin, North Branch Elkhart River at Cosperville, Indiana 4
2. Comparison of water-surface elevations at USGS streamgage 04100222, North Branch Elkhart River at Cosperville, Indiana, with water-surface elevations output from the hydraulic model 5
3. Comparison of hydraulic-model output and preliminary high-water-mark elevations from the flood of March 1982 for the North Branch Elkhart River at Cosperville, Indiana 5
4. Stages and corresponding discharge estimates for selected locations within the study reach for simulated water-surface profiles, North Branch Elkhart River at Cosperville, Indiana 6

Conversion Factors

Inch/Pound 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)
	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 authors wish to thank the many local, State, and Federal agencies that have cooperated in the funding for the operation and maintenance of the streamgage used for this study, especially the Indiana Department of Natural Resources. Special thanks are given to Noble County, Indiana, for their cooperation in this study and to the National Weather Service for their continued support of the USGS flood-inundation mapping program.

Flood-Inundation Maps for the North Branch Elkhart River at Cosperville, Indiana

By Moon H. Kim[1] and Esther M. Johnson[2]

Abstract

Digital flood-inundation maps for a reach of the North Branch Elkhart River at Cosperville, Indiana (Ind.), were created by the U.S. Geological Survey (USGS) in cooperation with the U.S. Army Corps of Engineers, Detroit District. The inundation maps, which can be accessed through the USGS Flood Inundation Mapping Science Web site at *http://water.usgs.gov/osw/flood_inundation/,* depict estimates of the areal extent and depth of flooding corresponding to selected water levels (stages) at USGS streamgage 04100222, North Branch Elkhart River at Cosperville, 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=04100222*. 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 places that are often colocated with USGS streamgages, including the North Branch Elkhart River at Cosperville, 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 inundation.

For this study, flood profiles were computed for the North Branch Elkhart River reach by means of a one-dimensional step-backwater model. The hydraulic model was calibrated by using the most current stage-discharge relations at USGS streamgage 04100222, North Branch Elkhart River at Cosperville, Ind., and preliminary high-water marks from the flood of March 1982. The calibrated hydraulic model was then used to determine four 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 simulated water-surface profiles were then combined 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 04100222, North Branch Elkhart River at Cosperville, 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 post-flood recovery efforts.

Introduction

The town of Cosperville, Indiana (Ind.), where a USGS streamgage is located, is a relatively small community. This community and residents along West Lakes Chain (upstream from Cosperville, Ind.; fig. 1), which is a series of lakes connected by North Branch Elkhart River, have experienced severe flooding numerous times, most recently in 2008 and 2009. Flood plains along the river are less developed and composed mostly of agricultural areas.

Prior to this study, officials from Cosperville, Ind., and Noble County and residents of West Lakes Chain relied on several information sources to make decisions on how to best alert the public and mitigate flood damages. One source of information is the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for Noble County (FEMA, 1979). A second source is USGS streamgage 04100222, North Branch Elkhart River at Cosperville, Ind., (*http://waterdata.usgs.gov/in/nwis/current/?type=flow*) from which current and historical water levels (stage) can be obtained. A third source is the NWS's forecast of peak stage through the Advanced Hydrologic Prediction Service (AHPS) Web site (*http://water.weather.gov/ahps/*).

Although the USGS stream stage and the NWS AHPS flood forecast information are particularly useful for residents in the immediate vicinity of a streamgage, it is generally of limited use to residents farther upstream or downstream because the water-surface elevation is not constant along the entire stream channel. 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

[1] U.S. Geological Survey.

[2] U.S. Army Corps of Engineers, Detroit District.

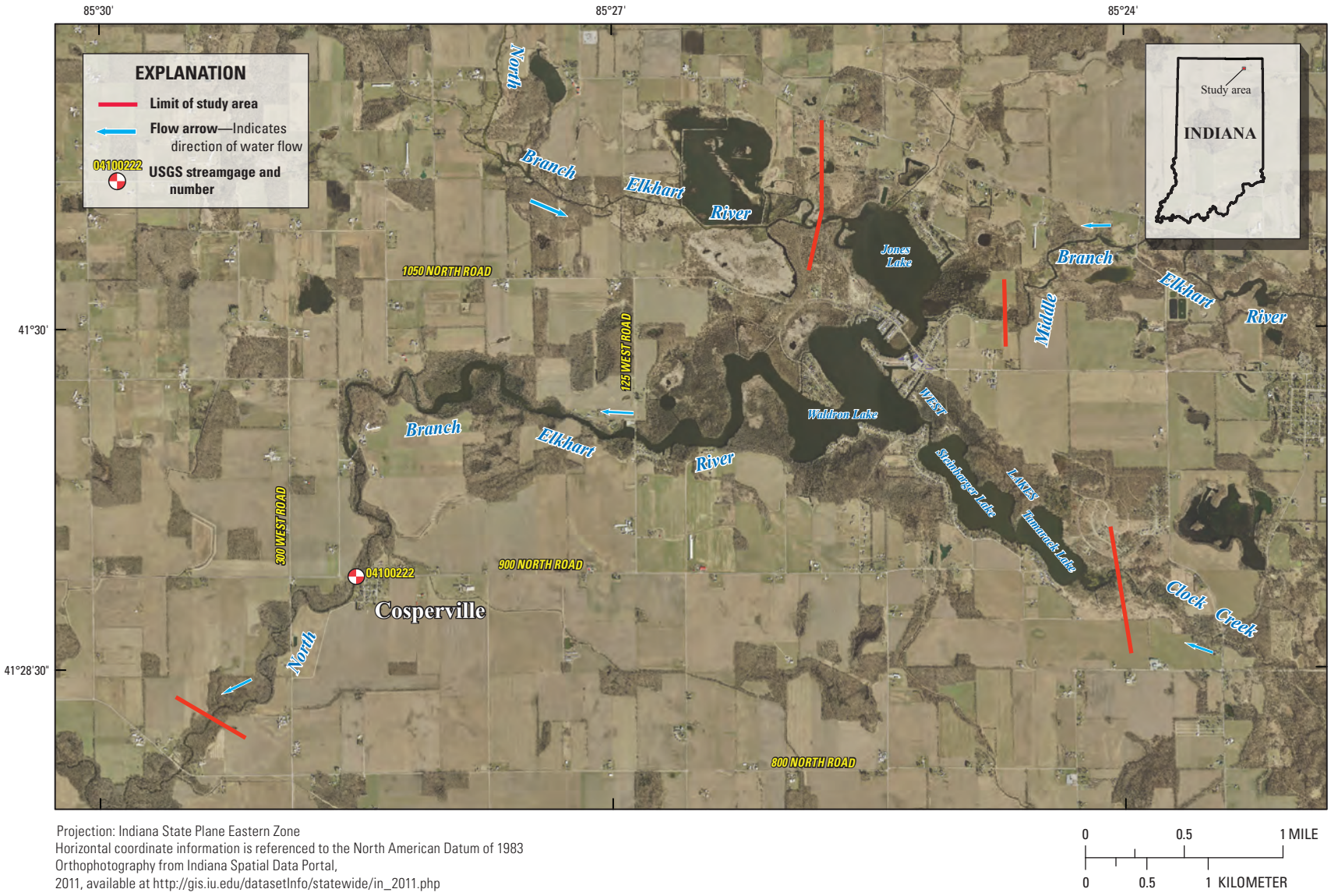


Figure 1. Location of study reach for the North Branch Elkhart River and location of USGS streamgage 04100222.

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. For this study, the USGS, in cooperation with the U.S. Army Corps of Engineers (USACE), Detroit District, conducted a project to produce a library of flood-inundation maps for the North Branch Elkhart River at Cosperville, Ind., and for the area of West Lakes Chain community.

Purpose and Scope

The purpose of this report is to describe the development of a series of estimated flood-inundation maps for the North Branch Elkhart River at Cosperville, 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 04100222 and the NWS AHPS forecast peak stage.

The scope of the study for hydraulic modeling was limited to the North Branch Elkhart River reach extending about 4.8 miles (mi) upstream of USGS streamgage 04100222 at the 900 North Road Bridge and about 1.0 mi downstream of the streamgage (fig. 1). Additional GIS techniques were used to extend the flood-inundation mapping area to include the West Lakes Chain community. The maps cover a range in stage from 5 to 8 feet (ft), gage datum. The 5-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 8-ft stage is approximately the highest recorded water level at the streamgage.

Study Area Description

The drainage area of the North Branch Elkhart River is about 133 square miles (mi^2) at the upstream end of the modeled reach, which is near the outlet of the Waldron Lake; 142 mi^2 at USGS streamgage 04100222, North Branch Elkhart River at Cosperville, Ind.; and about 144 mi^2 at the downstream extent of the study reach (USGS, 2013a). The headwaters originate in Noble County, and the stream flows generally in a westerly direction. There are no significant tributaries to the North Branch Elkhart River as it flows through the modeled reach. The study reach for the modeling is approximately 5.8 mi long and has an average top-of-bank channel width of about 200 ft and an average channel slope of about 1.1 feet per mile. The flood-inundation mapping area also includes the West Lakes Chain area, which comprises Waldron, Steinbarger, Tamarak, and Jones Lakes (Indiana Silver Jackets, 2010). Most of the land contiguous to the study reach is either agricultural or natural area with a few residences. In the identified North Branch Elkhart River/West Lakes Chain area of concern, 303 structures currently are within the area of the 1-percent annual exceedance probability (100-year) flood plain. Of those 303 structures (primarily residential), 121 (36 percent) are within areas also included in 50-percent annual exceedance probability (2-year) flood plain. Many of these structures were built prior to the adoption of local flood plain ordinances (Indiana Silver Jackets, 2010). Within the modeled reach, four major road crossings lie within the main channel or the adjacent flood plain.

Previous Studies

The current effective FIS for Noble County was published in 1979. A preliminary FIS document and an interim Digital Flood Insurance Rate Map (DFIRM) were obtained from the Indiana Department of Natural Resources Web site (*http://www.in.gov/dnr/water/6665.htm*). A Special Flood Hazards Area map from the interim DFIRM was used for comparison to the maps created in this study. An estimate of the peak discharge for the 1.0- and 0.2-percent annual exceedance probability flood (1,060 ft^3/s and 1,270 ft^3/s, respectively) near the Cosperville streamgage (300 West Road) on the North Branch Elkhart River was obtained from the FIS (FEMA, 1979).

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 04100222, (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 (USACE, 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 (USACE, 2009) and a GIS computer program called ArcGIS (ESRI, 2013), and (6) development of a Web interface that links to USGS real-time streamgage information and NWS AHPS forecast peak stage to facilitate the display of user-selected flood-inundation maps

on the Internet. Most of the tasks listed above were conducted and managed by the USACE including the development of the hydraulic model. The USGS provided support and guidance in collection of the hydraulic data, in development of flood-inundation GIS layers, and in development of the Web interface mentioned above. Both the USACE and the USGS provided quality-control reviews of hydraulic model and its related datasets and resulting flood-inundation maps. Methods used are generally cited from previously published reports. If techniques varied significantly from previously documented methods in response to local hydrologic conditions or availability of data, they are described in detail in this report. Four maps were produced for water levels referenced to the stage at USGS streamgage 04100222, North Branch Elkhart River at Cosperville, Ind., and range from approximately bankfull to the highest stage on the current stage-discharge rating curve.

Computation of Water-Surface Profiles

The water-surface profiles used to produce the four flood-inundation maps in this study were simulated by using HEC–RAS, version 4.0 (USACE, 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 (table. 1), which has been in operation since 1971. Water level (stage) is measured continuously at this site, and continuous records of streamflow are computed. All water-surface elevations are referenced to the North American Vertical Datum of 1988 (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. Preliminary high-water marks were documented after the flood that occurred in March 1982 (Indiana Department of Natural Resources, Division of Water, written commun., 2012) and also were used for model calibration.

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 field measurements of streamflow at USGS streamgage 04100222, North Branch Elkhart River at Cosperville, Ind. All computations were based on discharge values with known stages from actual streamflow measurements or stage-discharge relations.

Topographic and Bathymetric Data

Thirty-one channel cross sections were developed from American Survey and Engineering surveys that were conducted in 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. A total of 32 synthetic cross sections were generated by use of the DEM. In-channel data for all synthetic cross sections were estimated by combining 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 North Branch Elkhart River at Cosperville, Ind. (Noble 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 4.9 ft and vertical accuracy of 0.98 ft at a 95-percent confidence level based on a root mean squared error of 0.49 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, roadway embankments, levees, and dams) in and along the North Branch Elkhart 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

Table 1. USGS streamgage information for study basin, North Branch Elkhart River at Cosperville, 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)
North Branch Elkhart River at Cosperville, Indiana	04100222	142	41°28′54″	85°28′32″	879.68	October 1971 to present	887.80; March 23,1982.

dimensions for four bridges and an inline structure (Waldron Lake outlet control structure) were measured and surveyed in the field concurrently with the stream-channel surveys (Indiana Silver Jackets, 2010).

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 1979 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 observed water-surface elevations at the streamgage and elsewhere along the study reach were minimized. The final Manning's *n* values were set as 0.048 for the main channel and ranged from 0.05 to 0.1 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. 15.1) at USGS streamgage 04100222, North Branch Elkhart River at Cosperville, Ind., and preliminary high-water marks from the flood of March 1982 (Indiana Department of Natural Resources, Division of Water, written commun., 2012). The estimated peak discharge for the 1982 flood was 919 ft^3/s at an estimated stage of about 8.12 ft at the streamgage. 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 04100222 were less than or equal to about 0.11 ft (table 2). Differences between measured and simulated water levels for models calibrated to preliminary high-water marks in the study reach from the flood of 1982 were less than or equal to about 0.83 ft (table 3). An additional comparison was made to flood profiles from the FIS (FEMA, 1979) for the North Branch Elkhart 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 four stages at 1-ft intervals between 5 ft and 8 ft as referenced to USGS streamgage 04100222, North Branch Elkhart River at Cosperville, Ind. These stages correspond to elevations of 884.68 ft and 887.68 ft, NAVD 88, respectively. Discharges corresponding to the various stages were obtained from the most current stage-discharge relation (rating no. 15.1) at the North Branch Elkhart River streamgage.

Discharges for all profiles were selected with the assumption that there are no significant tributary inflows within the 5.8-mi modeled reach. The discharges were estimated to be uniform and steady throughout the modeled reach. However,

Table 2. Comparison of water-surface elevations at USGS streamgage 04100222, North Branch Elkhart River at Cosperville, Indiana, with 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)	Modeled water-surface elevation (ft, NAVD 88)	Elevation difference (ft)
5.00	884.68	884.78	0.10
6.00	885.68	885.75	0.07
7.00	886.68	886.71	0.03
8.00	887.68	887.57	-0.11

Table 3. Comparison of hydraulic-model output and preliminary high-water-mark elevations from the flood of March 1982 for the North Branch Elkhart River at Cosperville, Indiana.

[HWM, high-water mark; ft, feet; NAVD 88, North American Vertical Datum of 1988]

Location description	Preliminary observed HWM (ft, NAVD 88)	Modeled water-surface elevation (ft, NAVD 88)	Elevation difference (ft)
300 West Road	886.60	886.05	-0.55
900 North Road (USGS streamgage)	887.82	887.40	-0.42
Waldron Lake Outlet	889.82	888.99	-0.83
125 West Road	889.85	889.18	-0.67

because the difference in drainage area between the location at the streamgage and at the upstream extent of the modeled reach was greater than 5 percent, two change of flow locations in the hydraulic model were included: one at the Cosperville streamgage (900 North Road bridge) and one at the upstream extent of the modeled area near 125 West Road Bridge. Discharge at the upstream extent of the model was estimated by, first, calculating cubic feet per second per square mile (CFSM) that corresponded to the measured discharges at USGS streamgage 04100222, then multiplying this CFSM value by drainage area at the upstream extent of the model (table 4). 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.

Development of Flood-Inundation Maps

Flood-inundation maps were created for a reach of the North Branch Elkhart River at Cosperville, Ind. The maps were created in a GIS by combining the water-surface profiles and DEM data (an example is shown on fig. 2). The DEM data for Cosperville, Ind. (Noble 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 (USACE, 2009). HEC–GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS using a graphical user interface (ESRI, 2013). 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.

Additional GIS techniques were used to extend the flood-inundation mapping area to include the West Lakes Chain area. Because the upstream extent of the modeled area ends at the confluence of the North Branch Elkhart River and Waldron Lake, flood-extent polygons and depth grids for all profile stages were extended to include the West Lakes Chain area by, first, determining the modeled water-surface elevation at the upstream extent of model for each profile stage, then applying GIS techniques to subtract DEM elevations. This technique of extending flood-inundation polygons and depth grids was possible because the water-surface elevation at each modeled (steady-state) profile stage was assumed to remain constant throughout the West Lakes Chain area.

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.”

Table 4. Stages and corresponding discharge estimates for selected locations within the study reach for simulated water-surface profiles, North Branch Elkhart River at Cosperville, Indiana.

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

Location	Drainage area (mi^2)	Stage, in feet above streamgage datum			
		5.00	6.00	7.00	8.00
		Discharge (ft^3/s)			
At the outlet of Waldron Lake	133	237	389	630	937
USGS streamgage 04100222	142	251	413	668	994

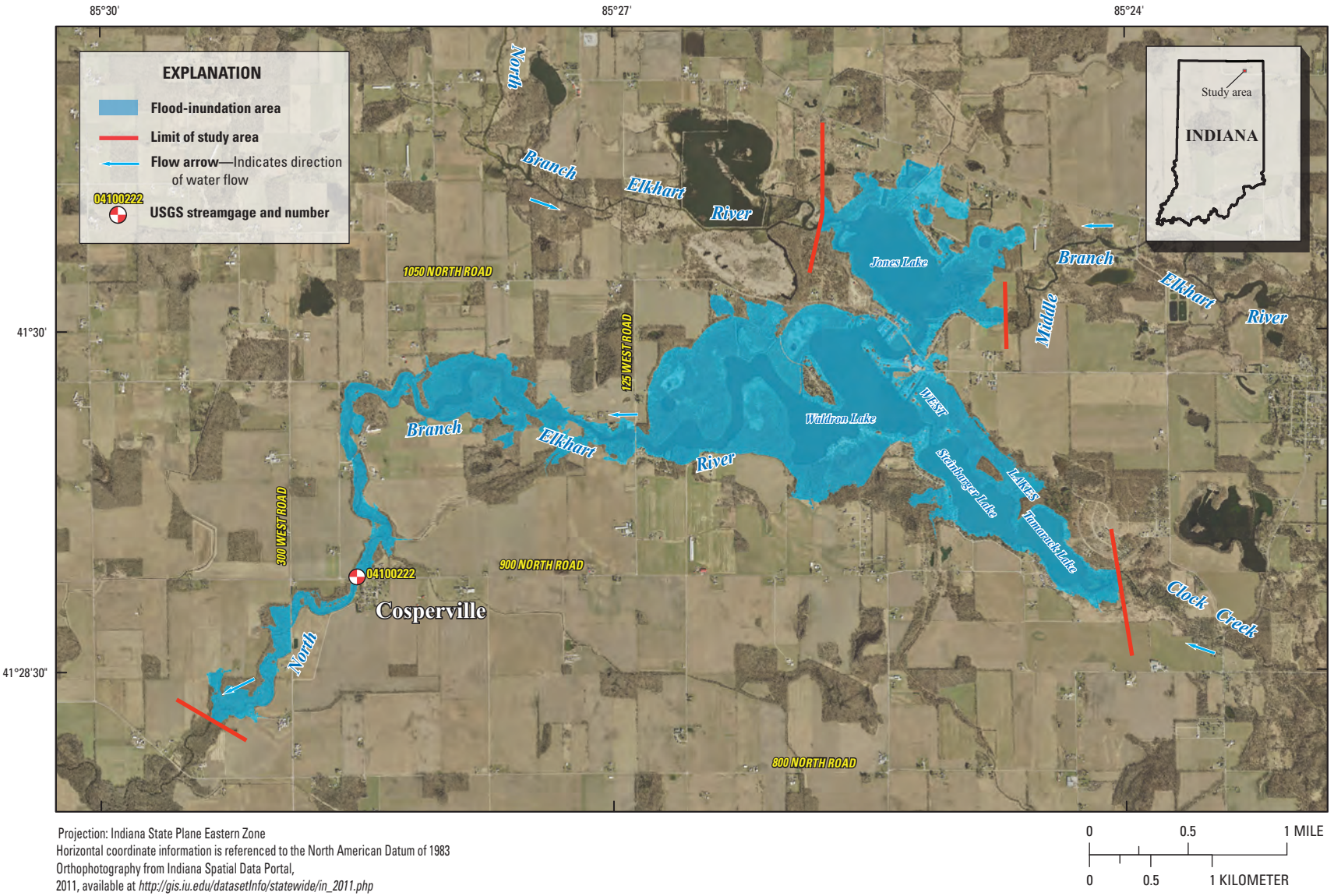


Figure 2. Example of a flood-inundation map for the North Branch Elkhart River at Cosperville, Indiana, corresponding to a stage of 8.00 feet and an elevation of 887.68 feet (NAVD 88) at USGS streamgage 04100222.

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 04100222, North Branch Elkhart River at Cosperville, Ind. The current study documentation is available online at the USGS Publications Warehouse (*http://dx.doi.org/10.3133/sir20145128*). Also, a Flood Inundation Mapping Science Web site has been established to provide a portal for USGS flood-inundation study information to the public at *http://water.usgs.gov/osw/flood_inundation/*. That Web portal has a link (*http://wim.usgs.gov/FIMI/FloodInundationMapper.html*) to 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 North Branch Elkhart River at Cosperville, 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 04100222 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. 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 (Bales and Wagner, 2009). 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, dam, levee, or other hydraulic structures existing as of November 2013. 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 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

Estimated flood-inundation maps were developed in cooperation with U.S. Army Corps of Engineers, Detroit District for the North Branch Elkhart River at Cosperville, Ind., from about 4.8 mi upstream of USGS streamgage 04100222 at the 900 North Road bridge to about 1.0 mi downstream of the streamgage. Additional GIS techniques were used to extend the flood-inundation mapping area to include the West Lakes Chain community.

The maps were developed by using the U.S. Army Corps of Engineers' HEC–RAS and HEC–GeoRAS programs and ESRI's ArcGIS program to compute water-surface profiles and to delineate estimated flood-inundation areas for selected

stream stages. The simulated water-surface profiles were then combined with a geographic information system (GIS) 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 5 ft and 8 ft at the North Branch Elkhart River at Cosperville 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 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. These maps, in conjunction with the real-time stage data from the USGS streamgage 04100222 and NWS AHPS flood-stage forecasts, 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., and Wagner, C.R., 2009, Sources of uncertainty in flood inundation maps: Journal of Flood Risk Management, 2, p. 139–147.

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, 2013, ArcGIS, accessed November 4, 2013, at *http://www.esri.com/software/arcgis/*.

Federal Emergency Management Agency (FEMA), 1979, Flood insurance study for Noble County, Indiana: Washington D.C., Flood Insurance Study Number 180183V000, 149 p.

Federal Geographic Data Committee, 1998, Geospatial positioning accuracy standards, part 3—National standard for spatial data accuracy: 25 p., available at *http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3*.

Indiana Silver Jackets, 2010, North Branch Elkhart River West Lakes Task Team Report: available at *http://www.nfrmp.us/state/docs/Indiana/IndianaReport/IndianaReport.cfm*.

U.S. Army Corps of Engineers (USACE), Hydrologic Engineering Center, 2009, HEC–GeoRAS, GIS tools for support of HEC–RAS using ArcGIS, user's manual [variously paged]: Available at *http://www.hec.usace.army.mil/software/hec-ras/hec-georas_downloads.html*.

U.S. Army Corps of Engineers (USACE), Hydrologic Engineering Center, 2010, HEC–RAS river analysis system—Hydraulic reference manual, version 4.1 [variously paged]: Available at *http://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS_4.1_Reference_Manual.pdf*.

U.S. Geological Survey (USGS), 2013a, StreamStats for Indiana streams: Available at *http://streamstats.usgs.gov/indiana.html*.

U.S. Geological Survey (USGS), 2013b, USGS Flood Inundation Mapping Science: U.S. Geological Survey, accessed November 10, 2013, 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 pl.

ISSN 2328-0328 (online)
http://dx.doi.org/10.3133/sir20145128